Study and construction of structural elements in low cost and sustainable concrete with fiber-reinforced networks.

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Abstract
ENG

The interest in environmental conservation has experienced a significant increase in recent years, making it urgent and necessary to address this issue in the field of architecture and construction. As architects, we must feel responsible for what we build and the potential economic and environmental impact we generate with every project we undertake. Within this context, the research for this thesis has been developed, focusing on the environmental and economic aspects of using a particular material and considering the processes involved in its extraction, transportation, production, and assembly.

The research goal is to achieve a low-cost, lightweight product with reduced environmental impact, easy transportation, and assembly using simple yet functional procedures. Specifically, the study concentrates on the type of structural reinforcement used in the design of roof beams, with particular attention to its application. The material under consideration is fiberglass mesh, commonly used as reinforcement for masonry, but in this case, exploited for reinforced concrete beams. The research work aims to demonstrate the feasibility of these construction elements as competitive and reliable solutions, offering a new and efficient approach.

From this perspective, the research is still relatively unexplored and represents an interesting innovation in the field, opening up intriguing possibilities for future applications in the construction industry. The lightweight nature and ease of assembly, coupled with the low cost required for their production, make these elements worthy of in-depth investigation, with ample room for improvement and a greater focus on refining aspects over time. Consequently, this research paves the way for construction practices that are easy to implement and economically advantageous.

Abstract

ITA

L'interesse per la salvaguardia dell'ambiente ha registrato, negli ultimi anni, un aumento significativo, rendendo impellente e necessaria una risposta che coinvolge in maniera determinante anche il campo dell'architettura e con essa, delle costruzioni. In quanto architetti dobbiamo sentirci responsabili di quello che costruiamo e del possibile impatto economico, quanto ambientale, che generiamo ogni qualvolta che progettiamo qualcosa.

All'interno di questo contesto si è sviluppata la ricerca della seguente tesi, che prende in considerazione gli aspetti ambientali ed economici dell'utilizzo di un materiale, coinvolgendo i processi che comprendono la sua estrazione, il trasporto, la produzione e il suo assemblaggio. L'obiettivo di ricerca è quello di ottenere un prodotto a basso costo, leggero, con un impatto ambientale ridotto e che prevede un trasporto facile e un assemblaggio fatto di semplici ma funzionali procedimenti.

Nello specifico, lo studio si concentra sul tipo di rinforzo strutturale usato nella progettazione di travi per coperture, con particolare attenzione al suo utilizzo. Il materiale in questione è una rete in fibra di vetro, comunemente impiegata come rinforzo per le murature, caratteristica in questo caso sfruttata per le travi in calcestruzzo armato. Il lavoro svolto si propone di dimostrare la fattibilità di questi elementi da costruzione con il fine di essere competitivi e affidabili, offrendo una soluzione nuova ed efficiente.

Da questo punto di vista, la ricerca è ancora poco approfondita e rappresenta una novità interessante in questo settore, aprendo prospettive interessanti per possibili applicazioni future nel campo delle costruzioni. La leggerezza e la facilità di assemblaggio, unita al basso costo necessario per la loro realizzazione, li rendono sicuramente meritevoli di un approfondimento dettagliato, con un'ampia possibilità di miglioramento e una maggiore attenzione a quegli aspetti che possono essere ancora perfezionati nel tempo. Di conseguenza, questa ricerca apre la strada a pratiche costruttive di facile realizzazione ed economicamente vantaggiose.

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01 Introduction

In the last 50 years, the production and use of cement-based concrete materials have remained almost the same.

Even though the global usage of these materials is widespread every year, two major drawbacks still limit the use of cement-based materials. These include the nature of the concrete placement, which affects features such as quality control, cost, and the speed of production, and the low tensile strength of the brittle material, which can bring it to cracking. The low tensile strength limits the functioning of these materials in areas where tensile stresses are the dominant forces. Given the challenges our society faces in providing sustainable shelters and civil infrastructure systems with improved seismic resistance, durability, and increased service life, we must demand materials with better performance than what is conventional. The enormous investment in the infrastructure systems must be underwritten with innovations that address improved properties in terms of carbon footprint, life cycle cost, durability, corrosion resistance, strength, ductility, and stiffness[1] and to sustain such an enormous growth this demand must be balanced against environmental aspects. In particular one of the most discussed topic nowdays is the sustainability of structures and infrastructures. From this point of view the necessity of usage of feasible production and life cycle maintenance costs in the construction field are always growing.

Among all building materials, concrete is the most common used material in construction and it has been experienced an exponential growth for years of infrastructure and consequently the growth in demand for concrete has now led to an annual consumption that has passed 30 billion tons per year[2], an enormous number that consequently causes an important and worrying environmental impact on the world.

In general, in construction, the classic structural concrete system is made of concrete with steel as reinforcement.

In civil engineering, steel-reinforced concrete is the most important composite material that is used for structural applications. The combination of the high compressive strength of the concrete and the high tensile strength of the steel reinforcement leads to an appropriate load-carrying capacity for many applications in the building industry.

After years of tradition, a lot of research on the topic of composite materials has begun to develop, and in particular, for about 15 years, there is a very active research activity aimed to develop new composite materials, with the hope of discovering something new and functional to bring new opportunities to construction material's field[3].

One opportunity and the main topic of this thesis is textile-reinforced concrete (TRC) that is reinforced using technical textiles made of yarns/strands[4]. The development of TRC is based on the fundamentals of fiber-reinforced concrete (FRC) with short filaments. being of continuous interest since the 1930s. Similar to ordinary reinforced concrete (RC) the filaments are aligned in the direction of the tensile stresses, which leads to an increase in their effectiveness.

This rather newly developed composite material, TRC, is made of a multi-axial fabric used in combination with an organic or inorganic binder able to hold in place the fabric's structural reinforcement.

The fabric is a manufactured planar textile structure made of fibers and/or yarns assembled to give the structure sufficient strength and other properties required for its intended use. Several hundred up to thousands of single filaments, mainly made of alkali-resistant (AR) glass, carbon or aramid, are collected in strands in order to create continuous yarns suitable for knitting or weaving into a form of textile fabric[5].

The use of TRC allows the design of very thin-structured concrete elements[6] with a high strength in compression as well as in tension that provides a considerable load-bearing capacity.

Profile thickness can be achieved with textile reinforcement as well as high quality homogenous surfaces.

Then, in this worldwide context, this thesis's study is trying to give alternatives to the classic method used to make beams in construction, intending to study structural elements of low-cost and sustainable, trying to limit the strong impact of materials and production of them on the today's world.

General

Traditional roof beam method

01.1

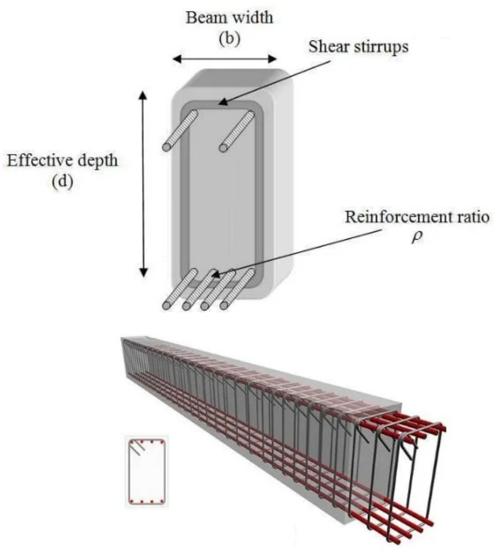
A roof beam is a type of roofing structure that can be built with different techniques. One of these, and maybe the most adopted one, is with concrete and steel as primary construction materials.

This method is considered a traditional one and is a common practice of construction industry, since it has been used for many years and is still widely used today, in particular due to its strength and durability.

The combination of steel and concrete in roofing systems works by utilizing the unique properties of each material. Concrete is an excellent material for roofing systems because it is strong, durable, and fire-resistant. However, concrete has low tensile strength, which means that it cannot withstand stretching or bending forces. Steel, on the other hand, has high tensile strength, which means that it can resist these types of forces. By using steel reinforcements, such as steel bars or mesh, the concrete roofing system can withstand a greater amount of force and remain stable over time.

The traditional method for constructing a concrete roof with steel reinforcements involves several steps. First, the steel reinforcements are placed into a pre-determined pattern **[fig. 1, fig. 2]** within the formwork, which is a temporary structure that holds the concrete in place until it sets. Next, the concrete mixture is poured into the formwork, covering the steel reinforcements.

[fig. 1]



[fig. 2] **[fig. 3]**

The concrete is allowed to cure and harden, creating a solid roof structure **[fig. 3]**.

While the combination of steel and concrete is an effective method for constructing roofing systems, it does have a significant environmental footprint.

The environmental impact begins with the creation of both

materials. Steel production is energy-intensive and requires the use of natural resources such as iron ore, coal, and limestone. Concrete production also requires the use of natural resources, including sand, gravel, and minerals for cement. The production process for cement, a key ingredient in concrete, is particularly carbon-intensive, accounting for up to 8% of global greenhouse gas emissions[7].

In addition to the environmental impact of creating these materials, there are also environmental concerns associated with their storage and transportation. Both steel and concrete are heavy materials that require significant energy to transport. In fact, the transportation of these materials can result in greenhouse gas emissions from the use of fossil fuels.

Another traditional method for constructing a roof can be with wooden roof beams.

This traditional method has been widely used in the construction industry for centuries. Wooden beams offer several advantages and have a long-standing history of reliability and strength. The process begins with the careful selection of appropriate wood species for the beams, such as oak, pine, cedar, or Douglas fir. The wood is then cut and shaped to the required dimensions, using techniques, like milling, to achieve the desired cross-sectional shape.

Traditional wooden roof beams often incorporate various joinery techniques, such as mortise and tenon joints, dovetail joints, and lap joints, to ensure structural stability and support.

These joints provide strong connections between the beams and other structural elements. Once the beams are prepared, they are installed horizontally across the building's framework to provide support for the roof structure.

Nails, screws, or traditional wooden pegs are used to secure the beams in place **[fig. 4, fig. 5]**.

[fig. 4]

[fig. 5]

To enhance durability and aesthetic appeal, wooden beams can be treated or finished. Protective coatings like varnish or paint are applied to protect the wood from moisture, UV rays, and insect infestation. Regular maintenance is required to ensure the longevity of wooden roof beams. This includes inspections for signs of decay, insect damage, or structural weakness.

Depending on the wood species and environmental conditions, the beams may need to be treated with preservatives or sealants to protect against rot and deterioration.

In this traditional context for constructing roof beams, there are advantages to considering fiberglass roof beams as an alternative on the market. Specifically, fiberglass beams are studied to find a way to be competitive with wooden beams: fiberglass beams are lightweight, allowing for easier handling and installation and they also have a smaller thickness compared to wood beams, providing potential space-saving benefits. Fiberglass beams are durable, resistant to rotting, and require less maintenance over time.

When deciding between traditional wooden beams and fiberglass beams, builders and architects should carefully evaluate the specific project requirements. While wood beams offer a natural beauty and traditional charm, fiberglass beams can provide cost-effective and efficient roofing solutions, particularly in terms of weight, thickness, durability, and maintenance requirements. By considering these factors, builders should consider the choice of fiberglass net reinforced beam as an opportunity of finding a new, different, but efficient solution available on the market.

Objectives

Differences respect to traditional beams

01.2

As already introduced before, the main objective is to try to follow a path that could bring something new and efficient, at the same time, with the goal of being competitive and environmentally effective.

The idea is to give the market a competitor of traditional beams, like traditional wooden beams or concrete beams with steel reinforcement.

One such innovation able to do this is the development of textile-reinforced concrete (TRC), consisting of technical textiles made of yarns/strands that provide structural reinforcement for the material. TRC is a relatively new material developed based on the fundamentals of fiber-reinforced concrete (FRC) with short filaments, which has been of interest since the 1930s. The multi-axial fabric used in TRC, combined with an organic or inorganic binder, provides the necessary structural reinforcement for the material. Then this type of composite material can be an effective system for load transfer:

- The matrix is the host whose mechanical properties will be enhanced by the inclusion fiber reinforcing;
- The matrix acts to transfer actions, protect the fibers, and resist certain type of loads that the fibers cannot, such as compression;
- The fibers act to enhance the mechanical properties of the material through high moduli and strength;
- The performance of the fibers is enhanced by their protection in a matrix that distributes forces along its lengths;

- Acting together proves an effective system for load transfer of various kinds, but for fiber-reinforced polymers, their behavior in tension is most important.

Also, the use of TRC allows for the design of very thin-structured concrete elements with high strength in compression and tension, providing a considerable load-bearing capacity with reducing weight and saving materials.

TRC has several advantages, such as the ability to create high-quality homogenous surfaces and thin-structured concrete elements with a broad range of design options. This leads to a new application of concrete as a building material. The investigation in this sense is about studying the feasibility of reinforced concrete structural elements in which the reinforcement is replaced by a fiberglass mesh (slightly prestressed).

Now to analyze why this choice can be competitive on the market, let's consider some important aspects and characteristics of fiberglass reinforced beams in comparison with ordinary steel reinforced concrete and timber beams.

In the construction industry, the choice of roof beams plays a vital role in ensuring structural integrity and cost-effectiveness. While traditional timber and r.c. beams have been widely used, the emergence of fiberglass roof beams presents a compelling alternative that addresses the limitations of these conventional materials. This section aims to explore how fiberglass beams can compete with wood and steel beams, highlighting their advantages and market competitiveness.

One of the primary advantages of fiberglass roof beams is their lightweight nature. Unlike heavy wood and r.c. beams, fiberglass beams

are significantly lighter, resulting in easier transportation, handling, and installation. This characteristic not only reduces labor and equipment costs but also minimizes the structural load on the building, potentially leading to additional cost savings.

Furthermore, fiberglass beams may offer a significant advantage in terms of thickness. While wood beams often require substantial thickness to provide adequate strength, fiberglass beams can achieve comparable strength while being considerably thinner, and also thanks to the facts that their shapes can be more easily designed for efficiency. This reduced thickness not only allows for more efficient use of space within the building but also contributes to cost savings by reducing material requirements and simplifying construction processes[8].

Durability is another key aspect where fiberglass beams may excel. Unlike wood, which is susceptible to rot, decay, and insect damage, and unlike r.c. which is susceptible of steel corrosion, fiberglass beams exhibit exceptional resistance to these issues. This enhanced durability may ensures a longer lifespan for the roof beams, reducing maintenance and replacement costs over time. Additionally, fiberglass is non-combustible, providing an added level of fire resistance and improving overall building safety.

Versatility may also be a significant advantage of fiberglass beams. They can be manufactured in various shapes and sizes, allowing for customized designs to suit specific architectural requirements. This flexibility in design opens a wide range of possibilities for architects and builders, enabling the creation of unique and aesthetically pleasant structures.

From a cost-effectiveness perspective, fiberglass beams offer an attractive alternative. While wood beams require ongoing maintenance, including treatments for preservation and protection against pests, fiberglass beams are virtually maintenance-free. This significantly reduces long-term costs associated with maintenance and repairs, making fiberglass beams a financially viable choice over the lifespan of a building.

Moreover, fiberglass beams have a smaller carbon footprint compared to r.c. beams, making them a more environmentally friendly option. The production of r.c. beams involves high energy consumption and carbon emissions, whereas fiberglass production is relatively energy-efficient and generates fewer greenhouse gases.

In summary, fiberglass roof beams provide a competitive alternative to traditional wood and r.c. beams. Their lightweight nature, reduced thickness, durability, versatility, and cost-effectiveness, in perspective, may make them highly appealing in the market. By embracing fiberglass beams, builders can achieve significant cost savings, improved space utilization, enhanced durability, and aesthetic versatility. For all these reasons, the sustainability and eco-friendliness of fiberglass beams could contribute to a greener future, aligning with the increasing demand for environmentally conscious construction practices.

In conclusion, the use of fiberglass beams could offers substantial benefits and positions them as strong competitors to wood and r.c. beams. Their characteristics in terms of weight, thickness, durability, versatility, and cost-effectiveness make them an attractive choice for builders and architects seeking to optimize their projects. By adopting fiberglass beams, construction projects can achieve greater efficiency, reduced costs, and sustainable building practices, ensuring

competitiveness in the market while promoting a more sustainable and environmentally friendly future.

In this view of sustainability, the thesis is proposed as a study not only from the point of view of the structural characteristics of the element in question but also from the point of view of its environmental impact and ease of use, trying to minimize the cost as much as possible. A theme that will be touched upon in it will also be that of the possibility of being able to self-construct the beam element, following well-defined instructions. All this leads to a vision of specific applications, such as in certain climatic zones and in need of innovative and low-cost technologies, capable of being useful in an emergency or difficult context, as well as useful, as mentioned above, to limit costs and environmental impact, in the search for a less polluted future, but in the same way efficient and able to meet human needs.

Research

02

Before getting to the practical act of the project, significant research work was done in order to understand what information was available concerning this topic, and whether there were experiments available to consult and from which to analyze the idea of this thesis.

This extensive research went into different techniques and experiments that had as their main theme the use of fiber reinforcement.

All the articles read and studied provided insights and useful information for the development of the project, as it is well known that this field has not yet finished its exploration, and every little bit of information was useful to better understand the functioning and opportunities of this material.

Construction is a complex and constantly evolving field that requires extensive research to ensure that the structures built are not only safe and durable but also meet the needs of their intended users. Research is particularly crucial when it comes to developing new technologies and materials, such as fiberglass reinforcement for concrete beams.

Fiber reinforcement for concrete beams is a relatively new field, and as such, there is still much to learn about its properties, performance, and potential applications. This is where research comes in. By conducting comprehensive research, scientists and engineers can gain a deeper understanding of the material and its capabilities, as well as identify any potential issues or limitations.

One of the main benefits of research in the construction field is that it can help to drive innovation and progress. By investing in research, companies and individuals can develop new technologies and materials that can improve the quality and durability of the structures they build. This not only benefits the construction industry but also society as a whole, as it can lead to the development of more sustainable and environmentally friendly buildings.

Research can also help to improve the safety of construction projects. By testing new materials and technologies in a controlled environment, researchers can identify any potential hazards or safety issues before they become a problem in real-world situations. This can help to prevent accidents and ensure that the structures built are safe and reliable.

In the case of fiber reinforcement for concrete beams, research is particularly important because it is a relatively new material that is not yet widely used in the construction industry. By conducting research on its properties and performance, it is possible to identify its strengths and weaknesses and determine its suitability for different types of construction projects. This can help to guide the development and adoption of this material in the industry.

Furthermore, research can help to identify new opportunities and applications for fiber reinforcement for concrete beams. By studying the material's properties and performance, researchers may discover new ways to use it in construction projects, potentially leading to new design possibilities and improved building performance.

In conclusion, research is an essential component of the construction industry, particularly in the development of new

technologies and materials like fiberglass reinforcement for concrete beams.

By investing in research, companies and individuals can improve the quality, safety, and sustainability of the structures they build, while also driving innovation and progress in the industry.

The benefits of research in construction are clear, and we must continue to support and invest in this field to ensure a brighter and safer future for everyone.

FRC systems

02.1

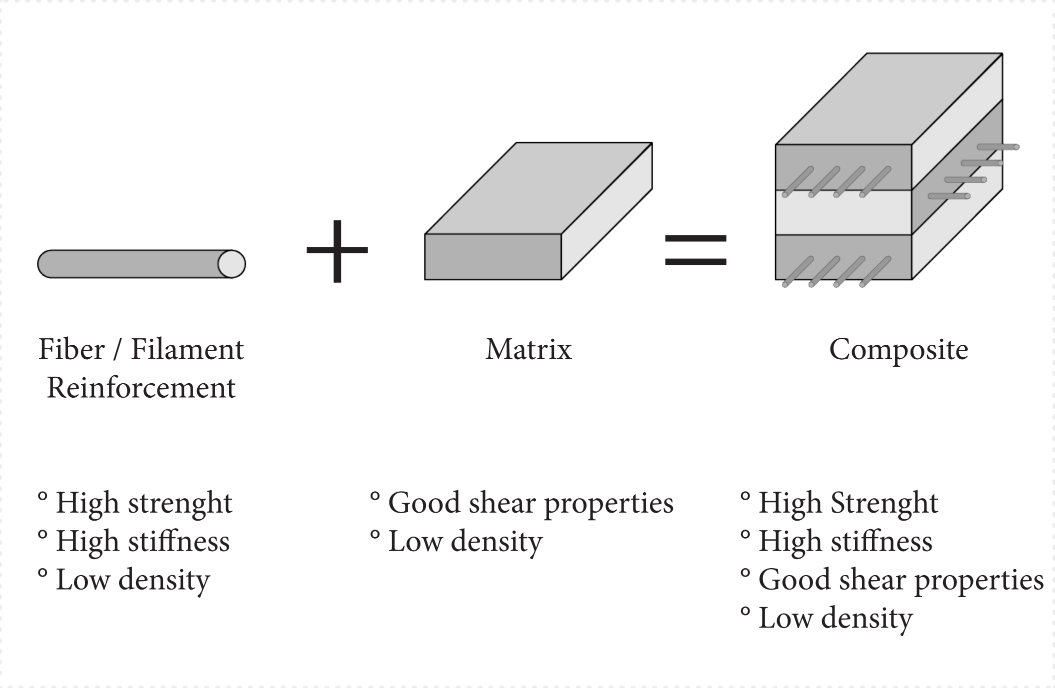
The development of fiber-reinforced concrete (FRC) has a long history, dating back more than 100 years alongside the rise of concrete and reinforced concrete.

Cement-based materials have proven to be cost-effective for residential buildings, but improving their damage tolerance and ductility has been a challenge. In terms of strength-to-weight ratio, cement composites rival steel and demonstrate the highest performance among building materials.

They are noncombustible, rot-resistant, and do not warp, split, crack, or creep. Cement composites also exhibit excellent dimensional stability and can be designed accordingly. Furthermore, they are impervious to termites, fungi, and other organisms. The manufacturing process of precast cement-based products ensures consistent material quality, meeting strict standards. The availability of a skilled labor pool adds to the advantages of working with precast cement-based products.

In this context, Fiber reinforced concrete (FRC) is gaining increasing interest. It is part of that categories called composites, which are materials consisting of multiple phases deliberately engineered to optimize specific properties.

This definition aptly applies to composites reinforced with fibers, whiskers, or platelets, where a matrix phase is reinforced by fibrous elements[9] **[fig. 6]**.



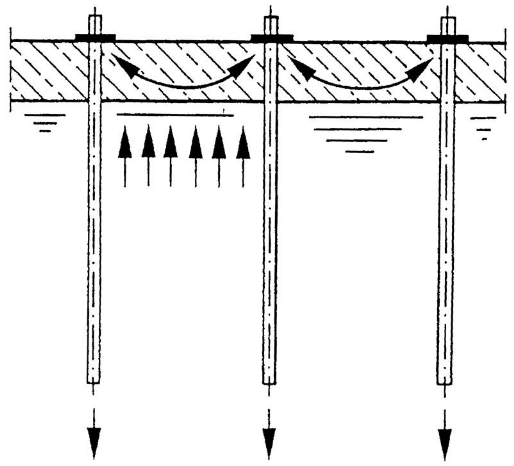
[fig. 6]

Steel FRC is already extensively utilized as the main reinforcement in bending structures. Examples include the square slabs in the Heathrow Airport car park in London **[fig. 7]** and the foundation slab of Potsdamer Platz in Berlin **[fig. 8]**.

One of the primary advantages of using composites is the ability to carry design loads with smaller sections, resulting in reduced weight, service loads, deflection criteria, and improved resistance to wind and earthquake loads.

FRC then, offers a potential solution to mitigate the heavy weight and environmental impact of steel-reinforced concrete, having the ability of carry design loads with smaller sections. Fibers, such as glass, carbon, or polymeric materials, can be incorporated into the concrete

[fig. 7]



[fig. 8]

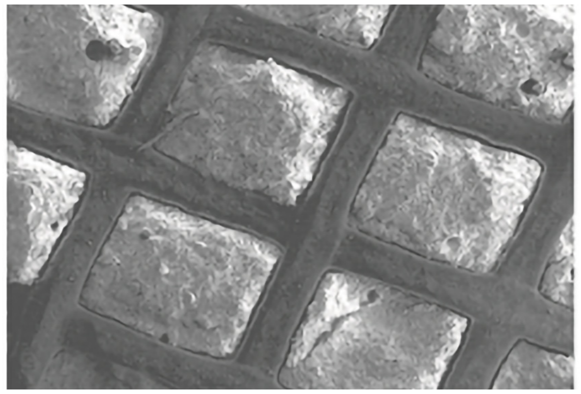
mixture to enhance its mechanical properties, including tensile strength, crack resistance, and impact resistance. This reinforcement mechanism reduces the reliance on steel reinforcement and allows for the use of lighter and more sustainable materials.

Thin-section FRC cladding panels have gained popularity in the construction industry[10] due to their lower production, transportation, and installation costs compared to conventional precast concrete. This has led to significant cost savings, which is one of the main focuses of this thesis.

Another reason for using FRC components is due to their cost-effectiveness in production, transportation, and installation compared to conventional precast concrete. Over the past four decades, the need to replace asbestos cement-based products has led to the development of new types of cementitious materials, matrix systems, reinforcing materials, and manufacturing techniques. Hybrid reinforcement, taking advantage of the inherent differences in fiber properties, becomes a design variable in FRC composite design. These materials find application in various areas such as building exteriors and interiors, roofing products, floor underlayment, water and wastewater pipes, cast-in-place forms, rebar-free applications, and retrofit projects.

By incorporating strong fibers into the brittle cementitious matrix, the ductility of the composite is enhanced. FRC applications typically involve low fiber volume fractions, resulting in a moderate increase in tensile or flexural strength. The matrix's ultimate strain capacity is lower than that of the fibers, causing the matrix to fail before the fibers reach their full capacity. The fibers act as bridges across cracks, contributing to energy dissipation through debonding and pullout mechanisms **[fig. 9]**.

Overall, the continuous development of cement composites and the increasing use of FRC highlights the benefits and potential of these materials in construction. Their performance, cost-effectiveness, durability, and versatility position them as a competitive alternative in the industry.

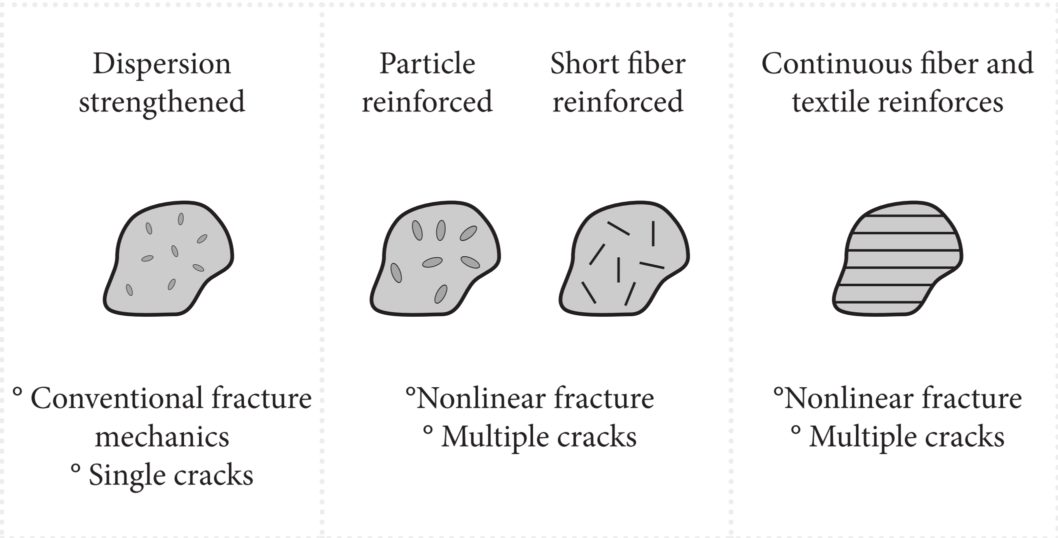


[fig. 9]

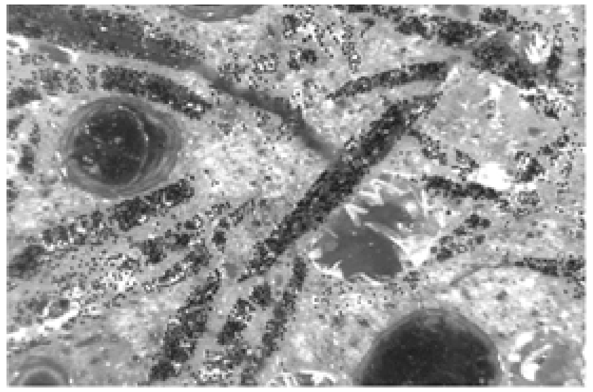
By leveraging the advantages of FRC, construction projects can achieve efficient and sustainable outcomes.

In particular, in order to introduce the next section, it has to be sad that FRC can be divided into different categories according to the type of fiber we are talking about. In fact, as shown in the figure below, it can be possible to have two macro different way to insert fiber into a matrix. The fibers can be randomly dispersed or woven in a precise way, and the dispersed one can also be made in different ways, dispersion strengthened, particle reinforced, or short fiber reinforced[11] **[fig. 10]**.

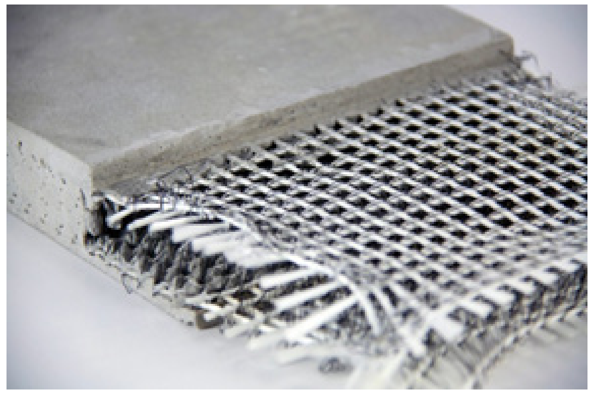
For the purpose of this thesis, the choice the choice fell on textile reinforced fibers, and consequently on the use of fiber reinforced composites, for different reasons that are shown in the following paragraph.



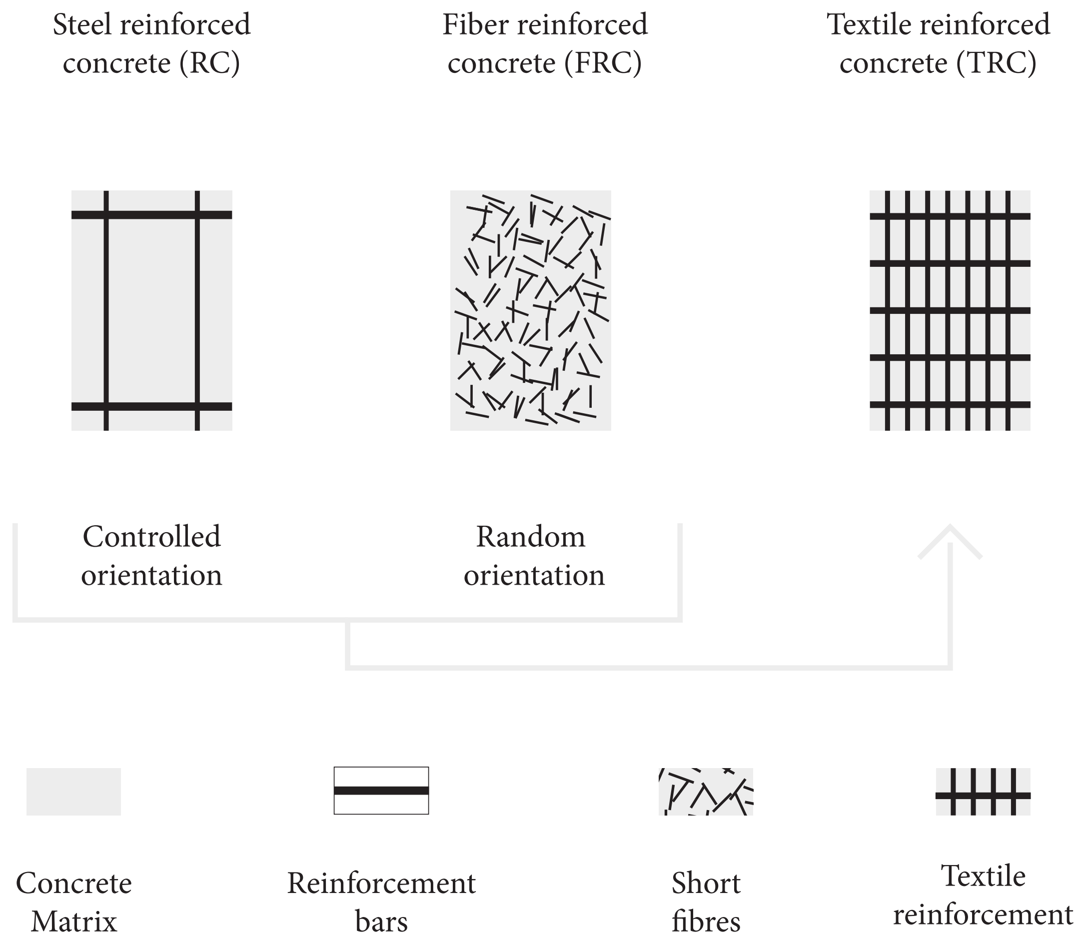
[fig. 10]



[fig. 11]



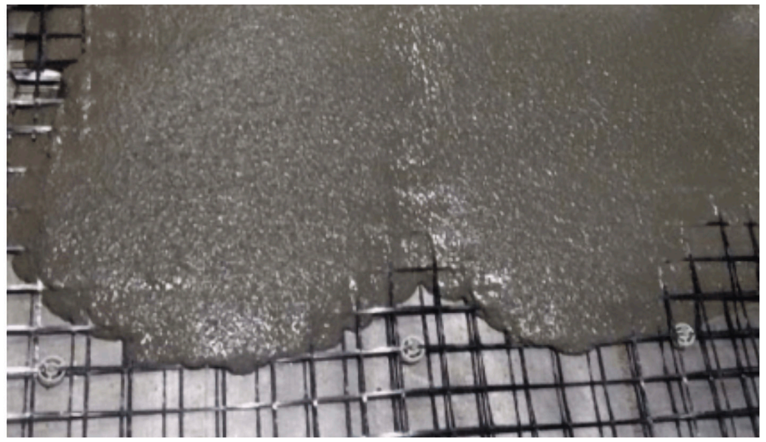
[fig. 12]



[fig. 13]

TRC 02.1.1

Textile reinforced composites (TRC) is a composite material that combines fine grained concrete matrix with textile fabrics[12]. The matrix material provides structural integrity, while the textile reinforcement allows for a controlled and ductile tensile response of the composite **[fig. 14]**.



[fig. 14]

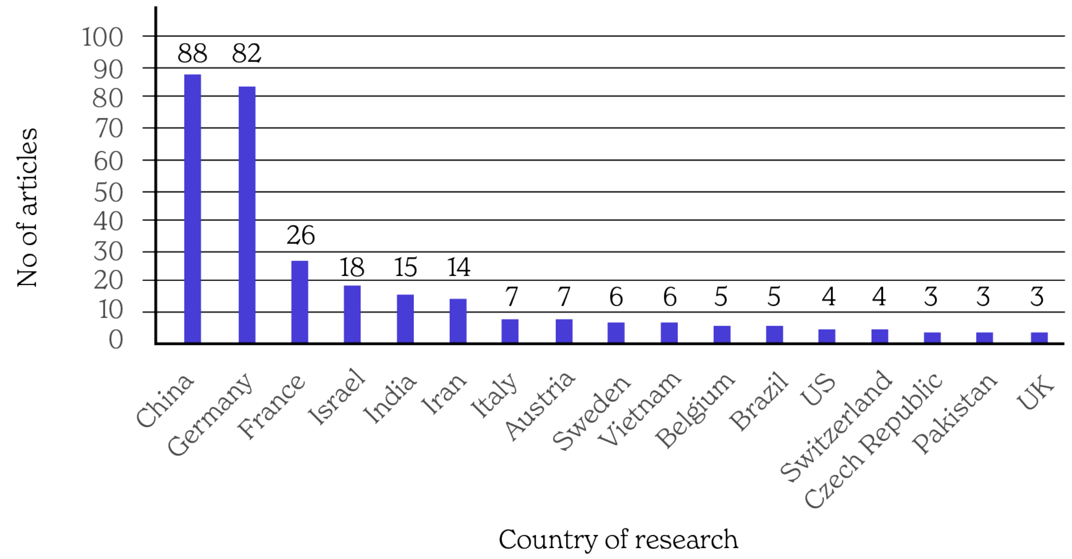
The choice of TRC is determined by specific characteristic of the fibers: unidirectional laminated composites excel in plane but exhibit weak interlaminar properties due to the lack of reinforcement in the thickness direction, leading to poor damage tolerance under interlaminar stresses. To mitigate this issue and reduce orthotropy, textiles like plain weave fabrics are employed as reinforcements, offering balanced ply properties and improved interlaminar characteristics. In textile-reinforced composites, fibers are shaped into textile forms. Despite reduced stiffness and strength in the in-plane directions, fabrics are advantageous due to cost-effective manufacturing processes. Hence, understanding the mechanical behavior of such composites is crucial to unlocking their full potential.

The use of TRCs in concrete systems is a relatively new area of research, and they have gained significant interest due to their potential for use as reinforcing material in concrete structures, which is the focus of this thesis. This is clearly visible from the graph below **[fig. 15]** where is shown the distribution of TRC publications in relation to countries. The two leading countries for this research are China and Germany, which represent approximately 60% of the total publications, with a focus of using sustainable materials and technology. Germany specially is the most advanced country in terms of using TRC as a reinforcement material (e.g., application as sandwich facades, shells, bridges, etc.).

However, many countries are still in the early stages of adopting TRC technology, then this research could offer some interesting insights into their possible application[13].

TRCs, in fact, offer a wide range of benefits such as improved crack resistance, high durability, and maintained costs, as well as present a wide array of fiber and matrix combinations along with various manufacturing techniques.

The analysis and design of materials can be integrated with the manufacturing process, providing flexibility compared to other engineering materials that are produced first and then shaped. In fact, recently there has been a growing exploration of mesh or continuous reinforcement in construction due to its inherent flexibility and its



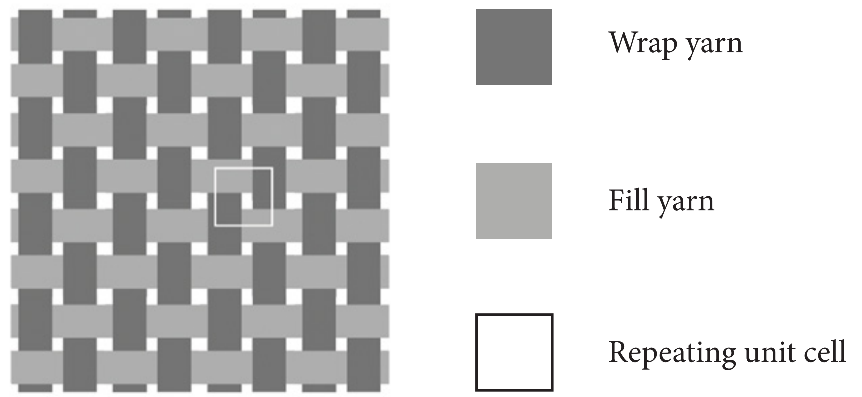
[fig. 15]

capacity to be easily fabricated into intricate shapes.

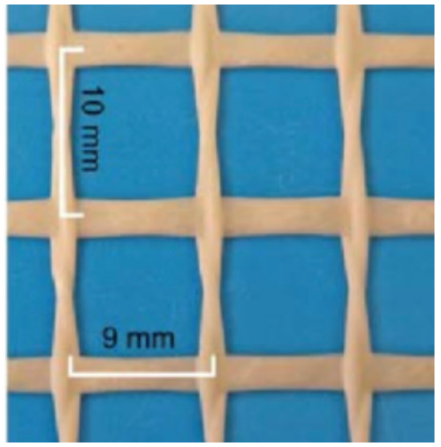
The textile fabrics used in TRC consist of filament yarns, which are interconnected using stitching yarn **[fig. 16, fig. 17, fig. 18]**. Yarn is a collection of intertwined fibers used for sewing, weaving, or knitting. A single filament of yarn typically has a diameter ranging from 5 to 30 m, and when thousands of filaments are combined, it is referred to as roving. However, a significant challenge with using textiles directly as reinforcement in concrete is their poor bonding characteristics. To address this issue, three manufacturing techniques have been developed: cabled, friction-spun, and commingled yarns.

Fabric, on the other hand, is created by combining multiple yarns and can be classified into woven, nonwoven, and knitted varieties based on the manufacturing process. Woven fabrics are produced by interlacing sets of yarns perpendicularly.

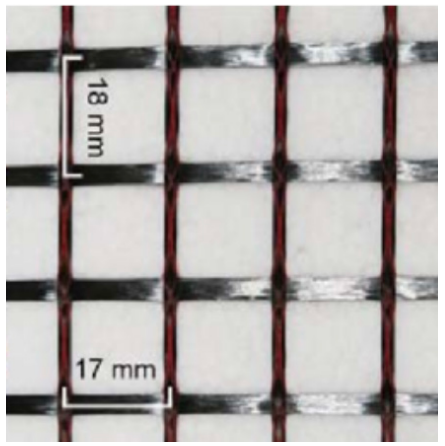
The yarns running along the length of the fabric are called warp



[fig. 16]



[fig. 17]



[fig. 18]

yarns, while the ones on the other side are known as weft yarns. In construction applications, leno-type fabrics are commonly used, where two sets of warp yarns are twisted around the weft yarn, forming a grid-like structure.

Textile fabrics are often woven in the form of a mesh, with specific mesh sizes in the warp and weft directions. In fact, utilizing textiles with rovings aligned along the principal stress direction of the composite proves to be more efficient than employing an equivalent amount of

fiber material in the form of randomly distributed short fibers[14].

in this regard, this type of woven net is exactly what was used for this research.

Another very important interesting feature of TRCs is their ability to distribute stress evenly throughout the concrete structure. This is due to the nature of the textile reinforcement, which provides a continuous network of fibers within the concrete matrix. Additionally, TRCs can be tailored to meet specific design requirements, as the textile reinforcement can be oriented in any direction and can be designed to have varying levels of stiffness and strength.

The complexity of TRCs' mechanical properties must be appreciated, as compared with the more traditional continuous fiber reinforcement of laminated composites. In TRCs, woven, braided, knitted, or stitched textiles are used as reinforcements, and several textile techniques can be combined for certain applications.

Additionally, TRCs offer improved control over fiber orientation and dispersion, resulting in more predictable and consistent mechanical properties.

This contrasts to traditional methods that involve blending fibers directly into the concrete mix, which can lead to challenges in fiber dispersion and orientation. By using textile fabrics, the issues associated with fiber dispersion and orientation are minimized, resulting in improved mechanical properties of the composite material[15].

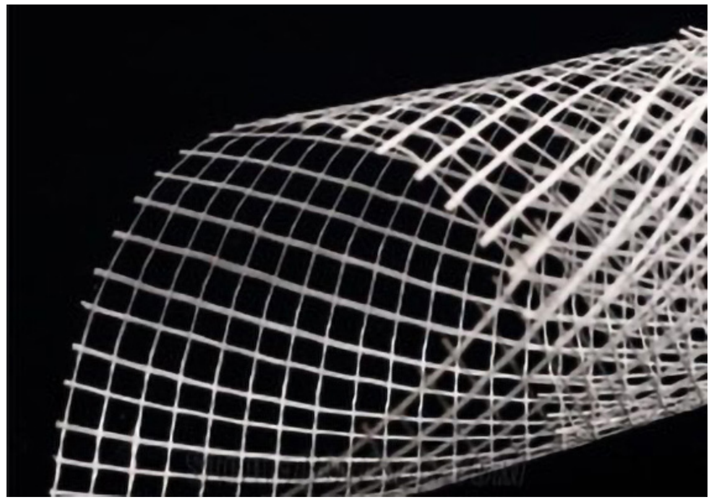
Overall, the use of TRCs in concrete systems has the potential to make something important and new at the same time in construction industry, by offering high performance and cost savings.

The versatility of textile reinforced composites is showcased in demanding applications like ventilated façade panels, repair and strengthening projects, as well as load-bearing structures such as shell constructions, sandwich panels, and pedestrian bridges, demonstrating the effectiveness of the material in achieving lightweight yet robust solutions for various structural needs[16].

In particular, this thesis project aims to explore the use of TRCs as reinforcement for concrete structural elements, with a focus on optimizing mechanical properties and exploring potential applications in the construction field. With continued research and development, TRCs are poised to become an interesting material for use in a wide range of applications, from strengthening existing structures to creating innovative new ones.

Textile reinforcement in concrete commonly utilizes three main materials: carbon, AR glass, and basalt[17].

The chosen material for this work's research is AR glass, and in particular is used a fiberglass-reinforced network **[fig. 19]** with the main goal of obtaining low cost and sustainable specimens.



[fig. 19]

Fiber glass

02.2

Fiberglass is a composite material that is made from glass fibers and resin. It is widely used in various industries due to its good strength, durability, and flexibility.

The specific type of fiberglass used for these concrete applications is known as Alkali Resistant fiberglass (AR). It is available in the form of continuous strands or rovings, as well as pre-chopped strands that can be either loose or bonded into mats for hand layup **[fig. 20]**.

[fig. 20]

Fiberglass is made by weaving glass fibers together to create a fabric-like material. This material is then coated with resin to give it added strength and durability. The resin used in fiberglass can be either a thermoset or a thermoplastic. Thermoset resins are cured by heat, while thermoplastic resins are melted and then cooled to form a solid.

As we mentioned before, thanks to the ability of being molded into various shapes, it can be used for many different solutions, like boats, cars, airplanes, and buildings, that is the category to which we are referring.

AR glass typically contains over 16% zirconia by mass. The primary raw materials, such as silica sand, clay, and limestone, undergo melting at temperatures up to 1350°C. The molten material is then drawn off a spinning nozzle at speeds ranging from 25 to 150 m/s, resulting in fiber diameters between 9 and 27 micrometers[18] **[fig. 21, fig. 22]**.

[fig. 21]

[fig. 22]

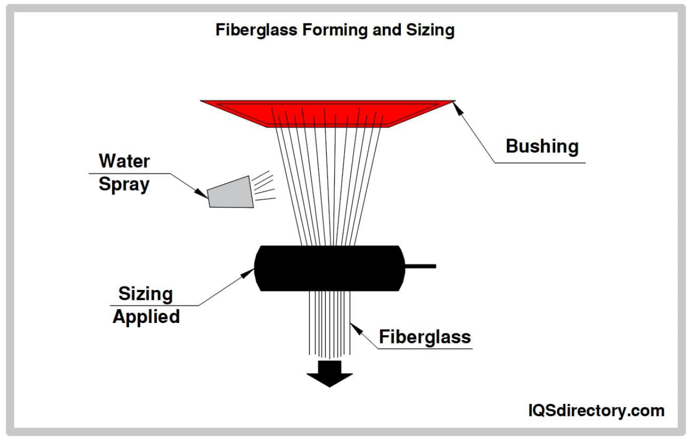
This type of fiberglass is specifically designed to resist to alkaline environment of cement and concrete structures, that is fundamental when concrete and fiberglass come into contact, since alkalis in the concrete can cause deterioration of the fibers, leading to reduced strength and durability of the composite material.

This capability of resistance of AR fiberglass is a type of fiberglass is made by adding special chemical coatings to the glass fibers during

the manufacturing process. These coatings enhance the durability and strength of the fiberglass, making it resistant to the harsh alkaline environment found in concrete structures.

In particular, subsequently, a coating material called sizing, comprising organic polymers dispersed in water, is applied to the filaments **[fig. 23, fig. 24].**

[fig. 23]



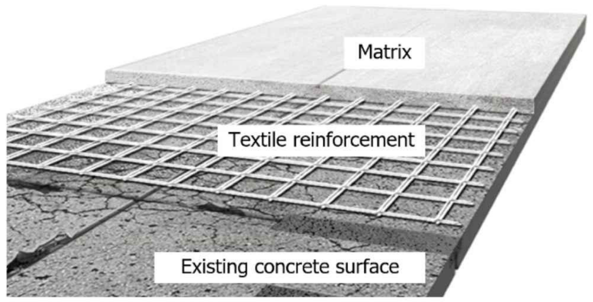
[fig. 24]

The sizing, which constitutes approximately 0.5-1.5% of the fiber mass, plays a crucial role in protecting and enhancing the properties of the yarn, as well as promoting its adhesion to the matrix material. Yarn production involves combining approximately 400 to 6600 filaments to form a yarn structure.

The nature and quality of the sizing agent are particularly important and represent the exclusive know-how of the manufacturer. In fact, the quality of the fiber is determined by the quality of the sizing agent. The sizing, in addition to characterizing the color of the net with pigment, allows the workability (weaving) of the fiber, the maintenance of its characteristics during application (compatibility with resins), maintaining the cohesion of the filaments that make up the fabric and optimizing resistance[19].

The subsequent production of the net is carried out starting from a direct roving, from a yarn or from cut filaments and is further covered with a coating called coating, which can be composed of bitumen or polyester, vinyl ester, epoxy resins, etc. The function of this second coating is to improve the material's protection and resistance to aging or decay.

This fiberglass network, that has been chosen for this thesis, is typically used to reinforce plasters **[fig. 25, fig. 26]** and is made up of a grid of woven glass fibers, which are coated with a layer of special resin

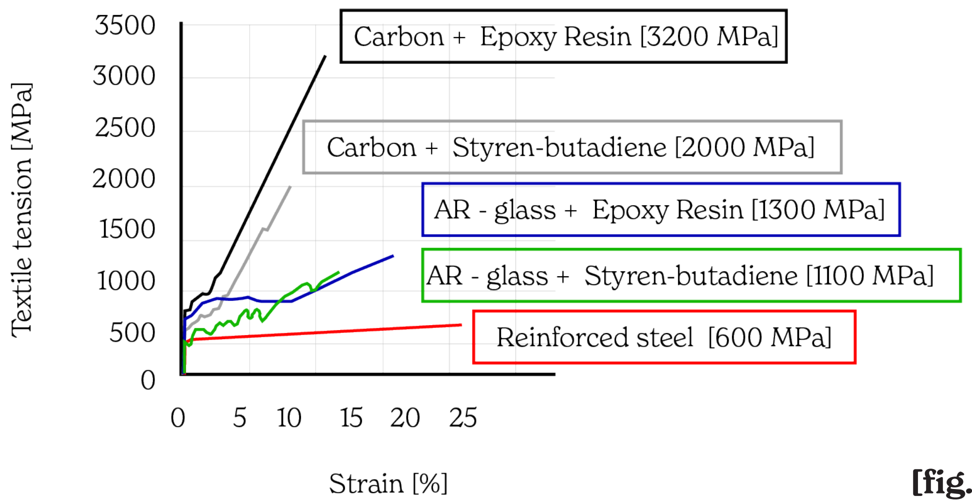


[fig. 25]

[fig. 26]

to improve their bonding strength.

In particular, the network in question is coated with an alkali resistant resin called SBR glue, or Styrene Butadiene Rubber (SBR), which is one of the most widely used synthetic rubber in adhesives and is an effective synthetic bonding solution for a variety of applications. Various combinations of fibers and coatings are employed in textile reinforced composites, each offering different characteristics. Table in **[fig. 27]** provides a comprehensive comparison of different textiles and coatings when subjected to tensile stress, enabling a thorough



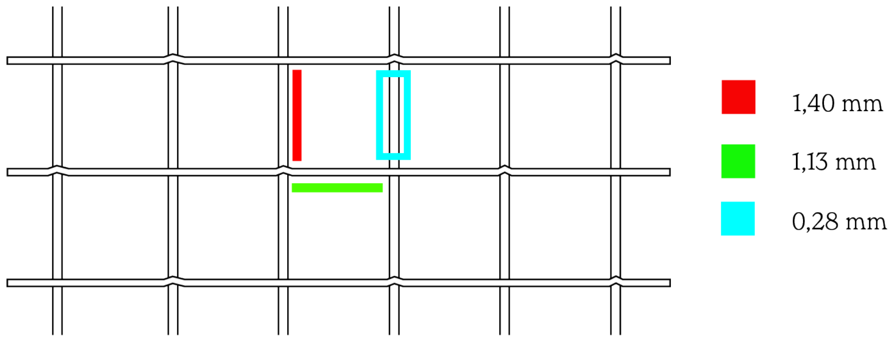
[fig. 27]

evaluation of their performance[20].

As the figure 28 shows, the selected network consists of intersecting longitudinal and transverse bars.

The bars are made of rectangular shape, possessing smooth top and bottom surfaces and rough fibrous side surfaces. The lateral-bar-spacing and transverse-bar- spacing are equal and both bars are equivalent in material and strength properties **[fig. 28]**.

This material is readily available in the store and combined with the low price makes it a choice in line with the guidelines that this experimentation aims to follow.



[fig. 28

Characteristics and specifics

As already sad before, use of TRCs in concrete systems has the potential to make something important and new at the same time in construction industry, by offering high performance and cost savings. The use of fiberglass with concrete generates a composite material called glass fiber reinforced concrete (GFRC) that have been widely used in the past and their properties studied extensively worldwide. GFRC may be thought of as a thin-section concrete, with a typical thickness of 10 to 15 mm, that is a range in which it has decided to be as important purpose of this thesis.

The proximity of fibers in the composite structure enhances its strength at the microlevel by effectively bridging micro-cracks before they reach critical sizes. Glass fibers, in particular, offer advantages over for example steel fibers due to their smaller diameter, resulting in better and more uniform dispersion within the material. The high surface area and compact size of glass fiber bundles further contribute to their superior distribution capabilities and potential for crack bridging compared to steel fibers, such as also a random distribution of fibers can also facilitate efficiently the loads transfer.

GFRC-based products have a wide range of applications, including cladding panels, small enclosures, noise barriers, drain channels, formwork, and architectural details. Typically, GFRC is a factory-produced material with a fiber content ranging from 2% to 5% by weight, depending on the specific application and production method.

The matrix composition consists of ordinary or rapid setting Portland cement, dry-graded sand, optional acrylic polymer in emulsion form for curing, superplasticizer, and water. Additional materials like metakaolin, fly ash, and silica fume may be added as partial cement replacements to enhance long-term properties[21].

The mechanical properties of GFRC composites are influenced by various factors, such as the amount of fibers, water-cement ratio, density, sand content, fiber orientation, fiber length, and the presence of polymers if utilized. These characteristics will be thoroughly investigated and discussed in the following chapters.

Chemical reaction concrete – fiberglass

The interaction between cement and fiberglass fibers in concrete is typically characterized by chemical reactions that contribute to the overall properties and performance of the material. These reactions involve the alkaline environment of the cement interacting with the surface of the fiberglass fibers. Alkalis in the cement react with the fibers, forming a thin gel-like layer that helps anchor the fibers within the concrete matrix and improves their adhesion and tensile strength. Additionally, the alkaline cement can contribute to the formation of calcium silicate hydrate (C-S-H) gel, enhancing the mechanical properties of the concrete.

However, in specific experiments where a particular type of fiberglass was used in a cement mixture composed of thin sand, cement, and water without any additives, minimal reactions between the fiberglass and cement can be observed.

Mortar

02.3

Mortar plays a crucial role in the construction of concrete beams, providing the necessary strength and durability to the structure. It is a mixture of cement, sand, and water that acts as the bonding agent between the various components, ensuring their cohesion and structural integrity.

In this thesis, the mortar is not specifically developed as focus and could represent a possible step forward for future research on this topic, aiming to obtain a better mixture with also the use of possible sustainable additives.

The selection of the matrix material in textile reinforced composites is crucial to ensure physical and chemical compatibility with the reinforcement. When considering the binding material, key factors to consider include its strength, which should align with the intended application, the ability to establish a strong bond between the reinforcement and cement matrix, workability during fabrication and setting, geometric stability, the production process, as well as minimal shrinkage and creep.

Usually, the cement matrix for TRC comprises binders, fine-grained aggregates, and a low water-to-binder ratio.

Commonly, the binder content for textile reinforced composites (TRC) ranges between 40% and 50%, accompanied by a water-to-binder ratio varying from 0.29 to 0.40 (Enhancing the binder content leads to improved bonding between the mortar and reinforcement)[22].

The water-to-cement ratio chosen for this research is carefully selected at 0.4 to strike a balance between moisture content and the optimal hydration of cement particles. This meticulous choice ensures that the matrix is both physically and chemically compatible with the textile reinforcement.

Alongside the water-to-cement ratio, the mortar mixture incorporates sand, which is combined with the cement in precise quantities. The sand not only adds strength to the mortar but also contributes to its overall integrity. The type and grading of the sand may vary depending on the specific requirements of the experiment and the desired outcomes.

To prepare the mortar, the cement and sand are thoroughly mixed together to achieve a homogeneous blend. Water is then added gradually while continuously mixing the mixture, until the desired consistency is obtained. This meticulous process ensures that the mortar is workable and can be easily applied during the construction of the concrete beams.

The chosen 0.4 water-to-cement ratio is a widely recognized guideline in the construction industry. It helps to balance the moisture content within the mortar, facilitating proper binding and setting of the cement. This, in turn, contributes to the overall strength and durability of the concrete beams.

Furthermore, it is important to mention that in this thesis, a specific type of cement called Colacem is utilized **[fig. 29]**. It is Portland lime cement, 32,5 R and 42,5 R, produced in Caravate , (VA) Italy. This type of cement combines Portland cement with hydrated lime, resulting

in a unique blend with enhanced properties.

The addition of hydrated lime to the Portland cement brings several advantages to the mortar. One notable benefit is improved workability. Portland lime cement offers increased plasticity and cohesiveness, making it easier to handle and manipulate during construction. This improved workability allows for better adhesion between masonry units and enhances the bond strength.

Another advantage is the enhanced resistance to cracking and shrinkage. The presence of hydrated lime helps mitigate the effects

[fig. 29]

of drying shrinkage, reducing the likelihood of cracking and resulting in a more durable and long-lasting structure. This characteristic is particularly beneficial in applications such as plastering, rendering, and stucco, where cracking is a common concern.

Moreover, Portland lime cement exhibits enhanced flexibility and elasticity, making it suitable for applications that require accommodating slight movements or vibrations. This property is advantageous in earthquake-prone areas or structures subjected to thermal expansion and contraction.

In addition to its functional properties, Portland lime cement also contributes to improved workmanship and aesthetics. It allows for finer jointing and smoother finishes, enhancing the overall appearance of the finished structure. The added lime content can also facilitate better color matching and blending with surrounding materials[23].

The right combination with th correct amount of water, ensures that the mortar possesses the desired workability, strength, and durability characteristics necessary for the construction and testing of the concrete beams.

By investigating and evaluating the performance of the concrete beams using this specific mortar composition, valuable insights will be gained regarding their behavior and properties under the defined experimental conditions. The meticulous selection and utilization of the mortar contribute to the rigor and accuracy of the research findings.

In our extensive series of trials, various quantities of the mortar components were employed, which will be detailed in the subsequent chapters dedicated to each specific combination tested. However, it is important to note that a consistent water-to-cement ratio of 0.4 was maintained throughout all the experiments.

In the following chapters, we will delve into the specific combinations explored, highlighting the quantities employed and their influence on the performance and properties of the concrete beams. The rigorous examination of these diverse formulations will provide

valuable insights into the behavior and characteristics of the resulting structures.

By meticulously controlling the water-to-cement ratio at 0.4, we maintained a consistent parameter that allowed us to focus on the effects of other variables within the experimental framework. This standardized approach enhances the credibility and reliability of our findings, contributing to a comprehensive understanding of the relationship between mortar composition and the performance of concrete beams.

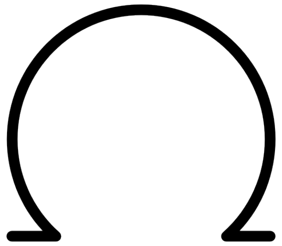
The shape 02.4

Roofing beams are critical structural components that require careful consideration in their design. Factors such as load capacity, structural integrity, and also aesthetic appeal are essential when someone is called to choose a roofing beam.

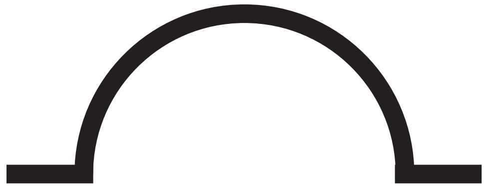
In the previous studies about this research, the previous idea was about making C shape beams, since the C shape has many potential application and easy way of assembling in construction field. So, the idea of the shape is closely related to the idea of projecting the specimen in a real scale in which is needed to obtain a as easy as possible way of assembling a structure and being competitive in construction field.

Instead for the purpose of this thesis it was decided to change this previous shape with someone different and the choice went to a shape that could offers several benefits for roofing beams and at the same time being architecturally appreciated, the arch. In particular the idea after a lot of trials, led to an omega shape. **[fig. 30, fig. 31]**. Then after various studies, for a stability purpose it was decided that was better to add also two lateral wings. This choice also was done in order to imagine a series of beam together as a roof floor, then to how they could be coupled in order to minimize the loads to be supported.

The omega shape beam revealed a correct choice for supporting heavy loads, such as the weight of a roof. Its curved design distributes weight evenly, which reduces the amount of stress and strain on any one part of the beam and make possible to resist bending and deflection.



[fig. 30]



[fig. 31]

This feature means that the weight is evenly distributed across the entire structure, preventing any section of the beam from becoming overloaded.

The two lateral supports also offer several benefits, like helping to distribute any horizontal stresses, reducing the risk of failure or collapse. This is particularly important in the case of a semicircular beam that has to bear the weight of the roof. The lateral supports ensure that the beam remains in place, even in the face of strong horizontal forces.

Aside from its structural benefits, an arch shape beam also offers aesthetic appeal. The curved shape of the arch can add an element of style to the design of the roof, creating a sense of openness and spaciousness. The arch shape also offers a visually pleasing contrast to the more common rectangular shapes of beams.

Then, the choice of a that one we can call shell roof system for a building has been influenced by various factors, such as architectural

design, structural performance, and cost-effectiveness. The shell roof system works by using a curved surface to resist loads, such as wind and snow, which are applied on the perimetrical walls. This one is exactly the idea of how can be applied in construction filed this thesis's idea.

The effectiveness of the shell roof system also depends on the material used for its construction and reinforcement. In this regard, the lightweight arch-shaped fiberglass beam can be a promising choice for roofing beams. Also, the fiberglass beam offers several structural benefits, such as even weight distribution and resistance to bending and deflection, while also being lightweight and easy to transport. This last point in particular, will have a special mention in the following chapters, as a focus on how simple an installation process can be made to the maximum possibilities.

Then, Fiberglass has emerged as a promising material for reinforcing shell roof systems, with fiberglass nets exhibiting significant potential in enhancing the structural capabilities of such roofs[24].

In this context, the proposed thesis aims to investigate the use of fiberglass net as reinforcement in concrete shell roof systems, focusing on the use of this idea in emergency or poor context scenarios as focus, then going through other two possible application that will be mentioned at the corresponding chapter.

Overall, the thesis will explore the use of fiberglass as a cost-effective and sustainable alternative to traditional reinforcement materials in shell roof systems, with the aim of contributing to the development of innovative solutions for building structures in emergency or low-resource settings.

03 Self construction

The ability to design a beam in emergency or low-resource contexts is a crucial factor in ensuring that essential infrastructure can be quickly and efficiently built. This is particularly true in situations where access to materials or skilled labour is limited, and also construction time is essential.

In the context of addressing this scenario, the thesis aims to provide a solution to the problem by developing a self-building beam utilizing simple and accessible materials and techniques.

As mentioned in the previous chapter, the beams have fiberglass net as reinforcement material and this choice can be considered particularly suitable for self-construction in specific contexts, such as emergency contexts, as well as in temporary constructions.

Fiberglass net is a lightweight and durable material that can be easily transported to the construction site, even in difficult terrain. Additionally, it is relatively easy to work with thanks to its elasticity and ability to be modelled in a wide variety of shapes, making it an ideal material for self-building projects.

The process of self-constructing for this particular type of beam involves a series of steps that can be easily followed by an individuals or groups of people requiring too much complexity. The procedure was designed to be as simple and smooth as possible through different steps including the preparation of the reinforcement material, the assembly of the formwork, the mixing and pouring of concrete, and the curing process. By providing clear and detailed instructions for each step of the process, anyone can quickly learn and master the techniques necessary to construct the beam.

Self-construction of a reinforced fiberglass net beam offers several benefits over traditional construction method. Firstly, it can be significantly cheaper than hiring skilled labourers or purchasing pre-made beams. This can be especially important in low-resource settings where funds are limited or in other specific situations, where, as already mentioned before, one of the main goals is of maintaining as low as possible the construction and production costs.

Additionally, the process of self-construction can save time, as there is no need to wait for pre-made beams to be delivered or for skilled workers to become available.

Another advantage of self-construction is the ability to tailor the beam to specific design requirements. This means that individuals or groups can create beams that are customized to fit the needs of a particular project, rather than relying on pre-made beams that may not be suitable.

Despite its advantages, self-construction of fiberglass beams does require specific instruction that will be provided in this research paper, to be sure of every single step and to reach the expected result. Therefore, it is important to provide clear instructions and training materials to ensure that anyone can carry out the process safely and effectively. Additionally, ongoing support and guidance may be required to address any issues or problems that could arise during the self-construction process. In this sense, specific guidelines will be provided with a specific separate paper.

Then, the ability to self-build a net fiberglass reinforced beam offers a practical and cost-effective solution for emergency, low-resource contexts, or temporary buildings. Also, the use of accessible materials and simple techniques means that anyone with little or no prior construction experience can quickly learn and master the necessary skills, trying to open more possibilities of construction techniques available on the market.

Goals

03.1

After this first part about the theoretical part of this thesis's research, it's time to go deeper into the practical phase.

After a deep study on the research topic, and analyzing a lot of articles and papers, an intense phase of laboratory work started.

As already mentioned before, to satisfy one of the main purposes, just recycled wood was used to maintain costs as low as possible, maintaining at the same time as high as possible the effectiveness of the results.

Every step was designed to obtain an easy procedure for the installation of all the parts of the project, then tried to make all the combinations and the whole functionality of the design process as simple as possible. In this way it could be possible to share the ideas, and to make the application possible also in other contexts.

All the steps are also available in a separate brochure only dedicated to the steps to be taken to reach the desired level of quality in the self-construction.

Saving costs efficiently should be an important path to follow in the construction filed in the actual worldwide context, where pollution and waste threaten to put us in a worrisome situation.

Timber frame

03.2

Previous research work enabled the use of the timber frame structure, which played a vital role.

However, modifications were necessary to satisfy the needs of the new project. The original idea was to create a C-shaped beam specimen, using a timber frame in a vertical direction. However, for this thesis, a horizontal direction of the formwork was needed, so small supporting timber frames were created to facilitate the turning of the timber frame into a horizontal position. This enabled the project to work on a plane, horizontally.

Creating an arch-shaped cross-section beam required the creation of a formwork, useful for allowing the beam profile to come off at the end of the casting and curing phase.

The idea of maintaining the previous timber structure, brought the design process to start with the creation of a wooden basement, constructed with wood laths, screwed in the same direction to create a sort of warping that could support all the pieces used to create the formwork on it. In particular, the basement is a chipboard wooden piece with dimensions of 120 cm x 80 cm and was put on the series of laths, to obtain a horizontal plane to work on.

The timber frame played two main roles: the first one is that of sustaining the formwork, as just sad, while the second one is about enabling the fiberglass net to be prestressed. This last role is the most important one cause the pretension of the net is one of the most delicate processes in the procedure. Then, to make it possible a steel pipe was inserted between the lateral wooden sides of the structure where there was left an appropriate space and at the end linked to both extremities.

The pipe was allowed to rotate to enable the fiberglass mesh to rotate and be prestressed. One of the pipes had a rotational pivot that allowed the net to be stretched by hand. This pivot, as we will see in the next chapters, will be substituted more effectively during the improvements processes. The idea of pretension is about letting two layers of mesh pass around one tube and back to the tube on the other side, achieving a satisfying pre-tension when stretched from just one side.

Maintaining the same tension in every part of the mesh during pre-tensioning was crucial to guarantee the same resistance in every part of the specimen, that’s why the positioning and the dimensions of the net played a very important role in this particular process as we subsequently will see.

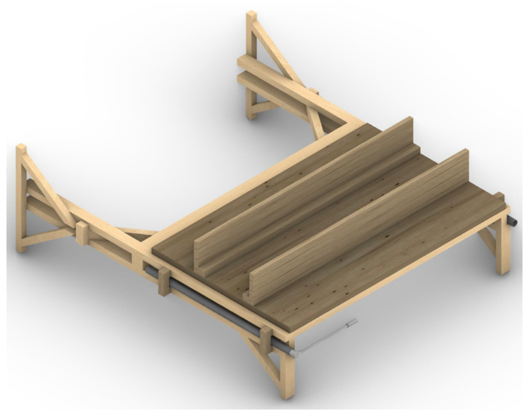
Timber frame shape was critical in ensuring that the wood pieces did not cut or demage any part of the net mesh during the pretension due to the contact with the frame structure. To avoid this, polished parts were inserted at the corners that were the most dangerous for the net, especially where the net turning cames in contact with the timber structure. To reach a satisfying result, a simple plastic layer was used to cover the contacting part of the wooden side. This guaranteed the integrity of the net without uneven tension.

However, there is a very important note to be made, beacuse the wooden structure used for this research was, as mentioned, taken from a previous idea.

It is not necessary to build a wooden structure like the one shown here **[fig. 32]**, but the form may be different, provided the elements are retained, which turns out to be essential for the successful construction of the specimen.

The structure must have on both sides two circular tubes well attached to it so that the net can be pretensioned, and provide support for the base and the formwork that will be placed on it. The shape then can be different, as long as the dimensions of the formwork are adhered to satisfactorily achieve the production process.

This concept, in particular, will be given with special attention in the brochure **[fig. 33]** devoted to the construction phases of the specimen.



[fig. 32]

[fig. 33]

Formwork

03.3

The timber structure is not the only component that was built following the ruole of semplicity. The formwork, which is essential in shaping the concrete to the desired form, was also constructed to be as simple as possible. Following this principle, only five pieces of wood were used to create it.

The first piece is the basement previously mentioned. The timber frame was used to create the basement, which was placed on top of the previously constructed row of laths. Then, two wooden laths were then screwed onto the panel, creating two rails that were specifically designed to allow the mortar to slide within them while maintaining a straight direction. These rails have dimensions of 3 cm x 4 cm x 120 cm and were used to create the two side wings of the omega shape.

Two additional wooden panels of 15 cm x 120 cm were screwed onto the side wings, serving as vertical restraints to the entire formwork **[fig. 34].**

[fig. 34]

These panels also and especially, allowed a specifically created trowel, shaped to the negative form of the beam, to slide the mortar precisely and uniformly, ensuring that the concrete would be spread evenly and to the desired thickness along the entire length of the beam. In this way, any excess portions of material could then be easily removed.

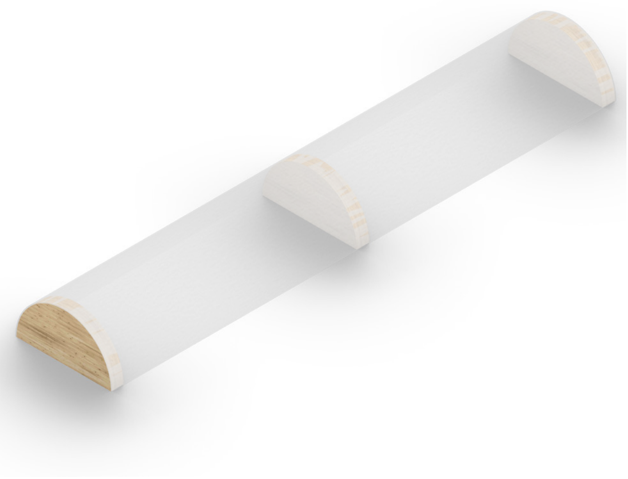
In addition to being simple, the use of wood also allowed the formwork to be built inexpensively. By prioritizing cost-effective solutions, we were able to keep the project within a low budget while still achieving the desired outcome.

Another element, which can be called the heart of the beam design, is then placed at the center of this wooden structure just described. We are talking about the body of the element, that made it possible to obtain the desired shape of the beam by casting mortar directly on it, which will then be removed like a mold. We are talking about the same material that has always been used so far, wood. The body **[fig. 35]** of the beam is formed by two semicircles with a diameter of 15 cm at the ends, and one in the middle to act as reinforcement. These semicircular pieces of wood were cut in two halves, from a circular piece of wood bought from a retailer.

A cardboard 1.5 cm thick and long as the length of the specimen, 80 cm, covers the semicircular shapes to create an effective body shape. The cardboard is first rolled up so that it can already take a semi-cylindrical shape and then fastened to the thickness of each semicircle with thumbtacks. In this way, the shape of the body lends itself being of the desired configuration.

Once assembled the body, being formed from cardboard, could

cause deterioration once in contact with mortar. For this reason, it was chosen to cover the body with simple adhesive tape, so that it is as much as possible insulated from possible moisture penetration.



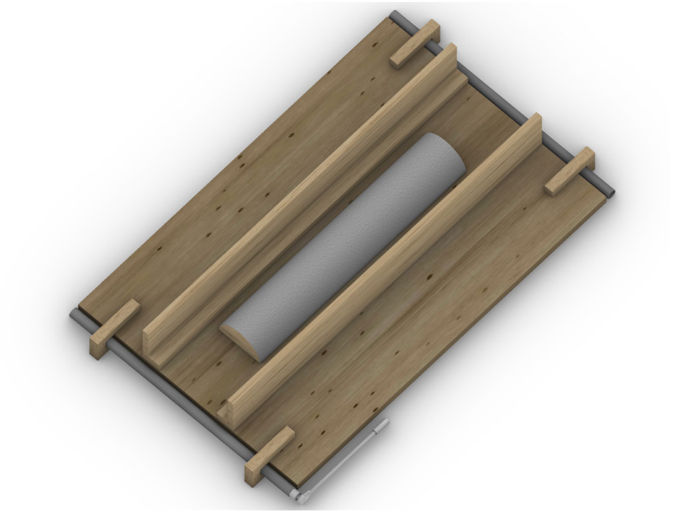
[fig. 35]

The body, in the end, proves to be very lightweight and easy to handle, while also being durable. It is placed precisely in the center of the formwork, leaving the two sides free to serve as tracks for the omega wings.

Once secured in position to avoid misalignments, the body is ready to be used to create the specimen. Several prototypes of the specimen body were created from the beginning to be quickly produced, yet resistant and efficient, and above all, disposable. This means that once a body is damaged, another one can be quickly available within minutes to proceed with the creation of another beam specimen. These speeds up the repeated production of these elements.

However, it is worth noting the surprising strength of these bodies, as they were not immediately replaced after the corresponding specimen was made, but rather, once the profile of the specimen was removed, the body was found to still be in excellent condition, capable of withstanding multiple attempts before deteriorating completely and requiring replacement.

The deteriorated part, moreover, only concerns the cardboard, while the wooden semi-circumferences can be reused for the creation of another body.



[fig. 36]

Installation procedure

03.3.1

Prestressed net

This step is one of the most important ones, because the pre-tensioning of the fiberglass net is very important to guarantee a good result in terms of strength and resistance, and then it requires specific precise instructions that must be followed to obtain a satisfying result.

During the experimentation, two different techniques were employed for tensioning the net, each utilizing a distinct approach.

This is why this research's work can be considered still ongoing and it is always improvable, aiming to achieve more and more satisfactory results by making the necessary modifications where needed.

So, the big difference in the two techniques entailed the utilization of two different types of metal pipes, and in particular in the way in which the net was prestressed.

Before going through this topic, it must be said that a very important instruction is that in every single specimen the fiberglass net was prestressed in a precise direction. The direction was chosen based on specific functional criteria: the net is pulled inwards towards the structure and then rotated towards the body, as the tension created allows it to adapt much better to the shape of the body while maintaining a qualitatively valid tension.

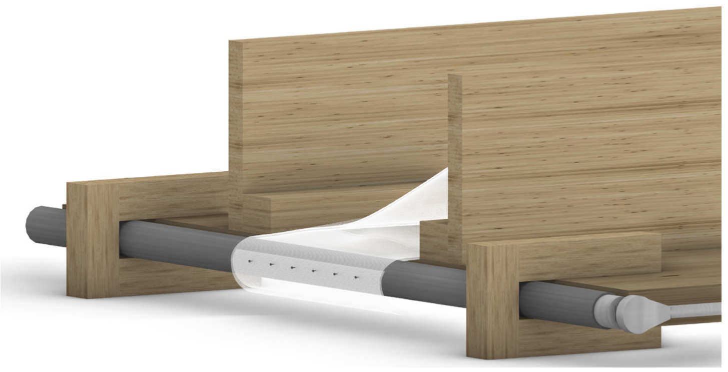
It was observed that pulling it in the opposite direction caused the net to bulge, resulting in inconsistent tension and imperfect adherence to the omega shape that the beam was supposed to assume.

In the first method, the torque wrench was integrated into a hole at the end of the pipe, enabling manual tensioning of the network. To achieve tension, the net needed to be fixed to the pipe. As the pipe initiated its rotational movement, the net would rotate synchronously, progressively increasing the tension. The net was secured using a series of screws within the pipe, facilitating the attachment of the net's meshes to the screws.

This mechanism ensured that the net was pulled taut as soon as the pipe commenced its rotation.

Once the net was tensioned, the knob was left under tension by fastening it with a string to the structure. This allowed sufficient time for the concrete to bond with the net that maintain its tension throughout the required period.

The second method employed a similar approach for net attachment. Specifically, a series of bolts were welded together, providing anchor points for the net **[fig. 37]**.



[fig. 37]

At the end of the pipe, a nut was welded, accommodating the insertion of a torque wrench. This enabled precise measurement of the applied tension, eliminating the need for manual adjustment.

The torque wrench **[fig. 38]**ensured accurate control of the tension, providing specific data for the experiment.

The torque wrench played a pivotal role in the experiment, offering several advantages.

[fig. 38]

Firstly, it allowed for a more precise and controlled tensioning of the net, ensuring consistent and accurate measurements. This enhanced the reliability of the experiment's results and increased the reproducibility of the findings. Furthermore, the torque wrench eliminated the need for manual intervention to maintain tension, reducing the risk of human error and providing a more stable and controlled condition for the concrete to bond with the net.

The introduction of the torque wrench and the improved method of net tensioning greatly facilitated the production process.

Researchers could now accurately calculate the applied tension and rely on the consistent and uniform tensioning of the net. This enhanced the reliability and accuracy of the experiment's outcomes, making it an invaluable tool in the laboratory.

In summary, the installation procedure for the network underwent multiple modifications during the laboratory experiment.

The utilization of two different techniques, each employing different metal pipes, that allows for effective tensioning of the net.

The integration of a torque wrench provided precise control over the applied tension, eliminating the need for manual adjustment and significantly enhancing the experiment's reliability and accuracy.

These advancements contributed to a more controlled and successful laboratory environment, ensuring the integrity of the experiment's findings.

Beam

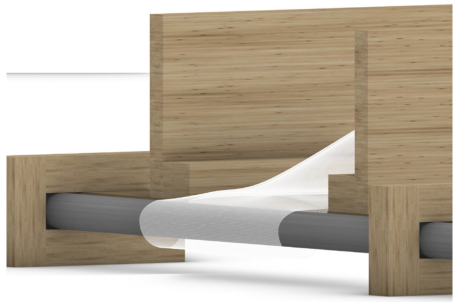
Once all the necessary components for constructing the beam have been described, it is time to delve into the actual production process through which all the test specimens were created during the work of this thesis.

As previously mentioned, the first step involved wrapping the entire formwork with a protective plastic sheet to shield it from potential moisture damage. Once this was done, the body of the beam was positioned precisely at the center of the formwork and secured simply with adhesive tape to maintain its shape. At this stage of the procedure, the fiberglass mesh was introduced.

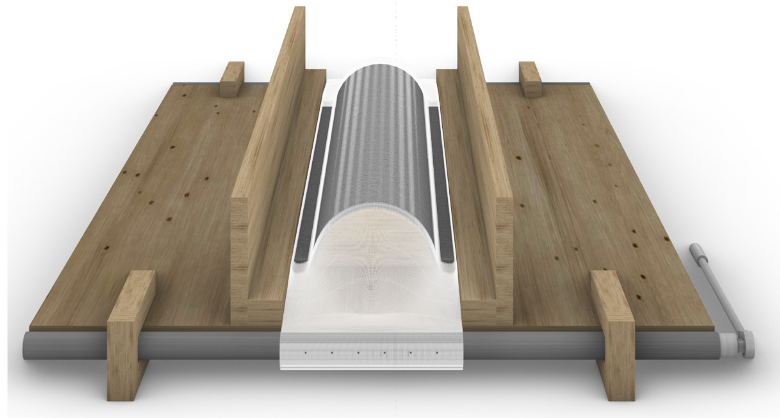
The mesh was cut to precise dimensions of 350 cm x 35 cm. The first half of the mesh was inserted into the tube without a torque wrench **[fig. 39]**, passing through the entire length of the beam until reaching the other tube on the opposite side of the structure. The second half followed the same path, passing over the first layer. This way, a double layer of mesh was positioned above the body and centered within the formwork **[fig. 40]**.

Once the correct position of the mesh was achieved, its mesh links were hooked onto the bolts welded in series on the tube.

Ensuring that the mesh was securely attached to the tube and resistant to an initial rotational test, tensioning of the mesh began in the direction of the formwork body using the torque wrench. Once the desired pre-tension was achieved, the wrench was left in position.



[fig. 39]



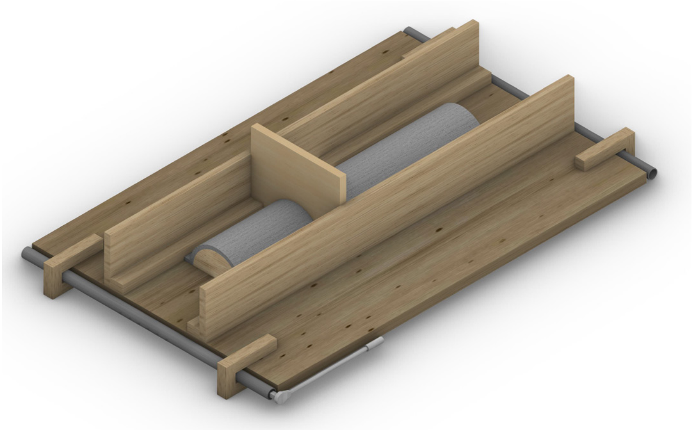
[fig. 40]

An initial problem that was encountered was the risk of the mesh tearing when it came into contact with the wooden ends of the structure, as it was held taut. The solution adopted proved to be simple and effective: two wooden cubes with rounded corners were screwed onto the ends of the structure and covered with plexiglass to make the surface as non-cutting as possible. This also allowed for greater tension in the mesh.

At this point in the procedure, the concrete mixture was prepared, as previously mentioned, consisting of 2 kg of fine sand, 2 kg of cement, and 0.8 kg of water. Once the correct mix was obtained, it was spread onto the body of the formwork, over the tensioned mesh. This moment is likely to be the most delicate phase of the process as it is crucial to ensure that the mortar fully penetrates the mesh.

After the first layer of mortar is applied to the body, a new component comes into play: the trowel **[fig. 41]**. The trowel is passed along the entire length of the body to provide material equality throughout the specimen, eliminating excess concrete and achieving the desired thickness in every part of the specimen **[fig. 42]**.

[fig. 41]



[fig. 42]

At this point, the procedure is completed, and the concrete is left to dry for the necessary time. Once dry, the specimen is ready to be removed and tested. As a first step, the excess mesh is cut off, allowing it to be detached from the wooden structure and providing the possibility for subsequent testing.

The body and the specimen are then removed from their previous position, and the specimen is detached from the underlying body by applying the necessary force for separation.

The body is then placed back into the formwork, ready for a new test. Once the specimen is tagged, it is set aside and left to dry completely before being tested

The upcoming chapter will showcase a series of tests conducted using various techniques. This iterative process involves performing different trials until a satisfactory result is achieved. Throughout the chapter, it will become evident that these techniques encompass distinct procedures, including different methods for applying stress to the fiberglass net and spreading the mortar.

04

Introduction to Mechanical Behavior

Textile Reinforced Concrete (TRC) is a unique construction material that exhibits distinct behavior under tensile stress, which can be evaluated through various tests. Understanding the mechanical properties and performance of TRC is crucial for informed design decisions and ensuring its structural integrity.

The testing procedure involves dividing the TRC specimen into three zones: loading, transition, and testing. Linear Variable Differential Transformers (LVDTs) are strategically placed at the center of the specimen to precisely measure tensile strain within a specified gauge length. These LVDTs remain fixed while the specimen is subjected to a gradually increasing load until it reaches failure.

To assess the tensile strength and obtain the stress-strain curve, it is recommended to employ standardized test methods. These methods provide valuable insights into the mechanical behavior of TRC, particularly during different stages of tensile loading. The stress-strain curve of TRC in tension undergoes three distinct states: initial, crack propagation, and ultimate failure.

A probabilistic approach has been developed to understand the microscopic tensile behavior of TRC, considering different levels of analysis such as filaments, crack bridges, and direct tensile tests. By integrating these levels into a unified model, the tensile response and bond behavior of TRC can be evaluated based on stress distributions within the material. This comprehensive approach provides insights into the intricate mechanics of TRC and enables a more accurate assessment of its performance.

Additionally, the compression test and flexure test are commonly used to characterize TRC's properties. These tests provide information on maximum stress, modulus of elasticity, and the entire stress-strain response. Understanding the post-peak behavior and localized deformation within a narrow zone is essential for evaluating the specimen's ductility, energy absorption capacity, and related parameters.

TRC is widely used in tension members, while failures in bending can occur in applications such as shells and facades. The flexural behavior of TRC can be analyzed through a three-stage stress-strain curve, considering the formation and propagation of microcracks and crack opening. Test setups like three-point and four-point loadings are employed to assess the flexural strength of TRC elements.

Researchers have investigated parameters such as the type and number of textile layers and pre-stressing techniques to enhance the bending capacity of TRC. The selection of an omega-shaped beam configuration with a double layer of fiberglass in the middle, sandwiched between concrete layers, offers enhanced structural performance and load-carrying capabilities. This unique shape is expected to efficiently distribute and transmit applied loads, resist buckling, and maintain integrity.

In this chapter, the focus is on exploring the mechanical, structural, and technical characteristics of TRC derived from standard mechanical

tests. These tests provide valuable insights into the macrostructure of the specimen, such as strength, stiffness, and ductility. By analyzing the specimen's overall response, interactions of internal phases within the material can be understood, enabling accurate modeling.

The stress-strain curve plays a fundamental role in understanding the behavior of the specimen, as it reveals the relationship between stress and strain. The interpretation of the stress-strain curve is complex, considering factors such as specimen size, geometry, test control mode, and loading setup. However, analyzing the post-peak response provides valuable insights into the specimen's ductility and energy absorption capacity.

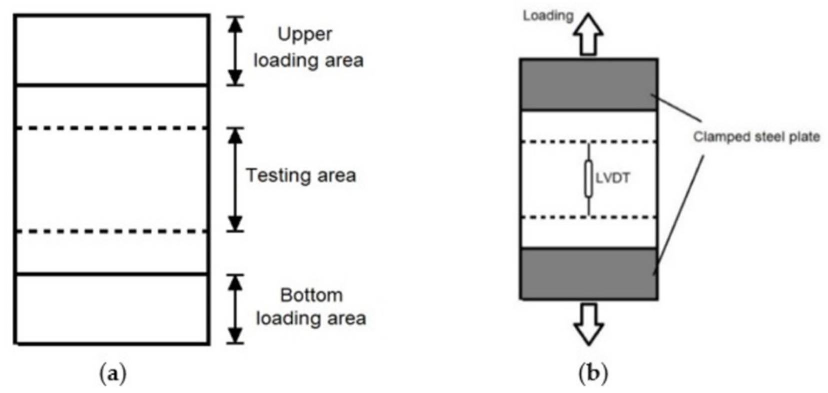
The omega-shaped beam demonstrates remarkable mechanical, structural, and technical characteristics, making it a promising choice for various construction applications. Its ability to handle compression and flexural stresses efficiently, coupled with unique load distribution properties, positions it as an alternative to traditional beam designs. By understanding the stressed areas, leveraging structural advantages, and implementing sound technical considerations, the omega-shaped beam can provide a reliable and durable solution in diverse construction scenarios.

Tensile behavior of TRC 04.1

Textile Reinforced Concrete (TRC) exhibits distinct behavior under tensile stress, which can be evaluated through various tests.

For the testing procedure, the specimen is divided into three zones, which are called loading, transition, and testing. LVDTs, known as Linear Variable Differential Transformers, are strategically positioned at the center of the specimen to precisely measure tensile strain within a specified gauge length. These LVDTs remain fixed in place while the load is steadily applied to the specimen until it reaches the point of failure **[fig. 43]**.

To assess the stress-strain curve and design TRC elements, it is recommended to employ a standardized test method for determining the tensile strength.

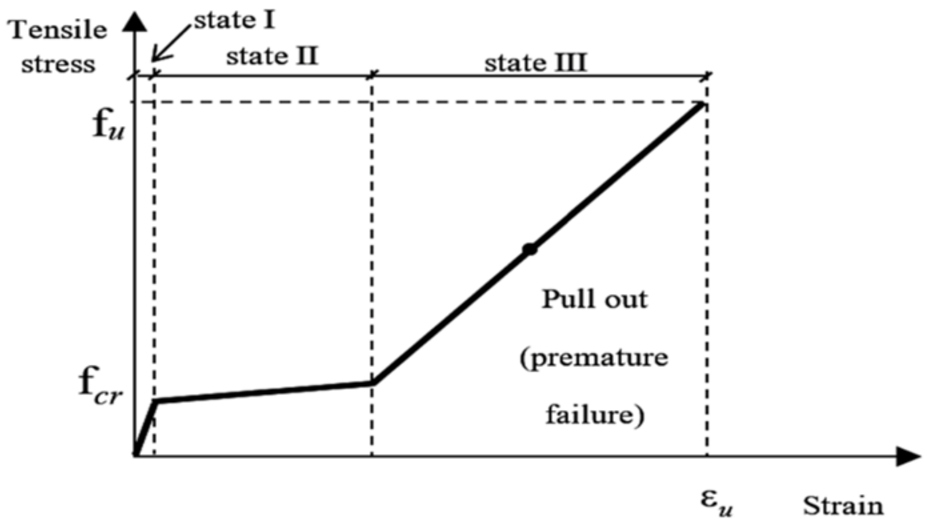


[fig. 43]

This method serves as a valuable tool in understanding the mechanical behavior of TRC and enables informed design decisions.

The stress-strain curve of TRC in for a tensile behavior undergoes into three states **[fig. 44]**. In the initial state, the TRC specimen exhibits properties similar to reinforced concrete without any visible cracking, and the stress-strain curve follows a linear trend.

As the loading continues, the sample transitions into the second state (II), characterized by the formation of multiple cracks within the material. It is during this stage that the stiffness of the TRC decreases due to the presence of these cracks. Finally, upon reaching the ultimate load, the sample enters the third state (III), where brittle tensile failure occurs in the textile-reinforced concrete.



[fig. 44]

Then, it can be noticed that the first crack load is identified as the point where the deformation response deviates from linearity (fcr),

signifying the onset of cracking. Subsequently, as the load decreases, the crack continues to open while the remaining portion of the specimen undergoes elastic unloading. This behavior brings the focus to crack openings or tensile displacements.

A probabilistic approach was developed to provide an understanding of the tensile behavior of TRC at the microscopic level. This approach considers three distinct levels of analysis: the filament, crack bridge, and direct tensile tests. By integrating these levels into a unified model, it becomes possible to evaluate the tensile response and bond behavior of TRC based on the stress distributions within the material. This comprehensive approach offers valuable insights into the intricate mechanics of TRC and enables a more accurate assessment of its performance under tensile loading[25].

By understanding the behavior of TRC under tensile stress and analyzing the stress-strain curve, we can establish expectations for the specific omega-shaped specimen. Although the shape may differ, these theoretical foundations provide valuable insights into the anticipated performance and response of our TRC specimen during the upcoming tests.

Compression test 04.2

The compression test is a commonly used method for characterizing concrete, typically providing information on maximum stress (strength) and modulus of elasticity.

However, by extending the test into the post-peak regime, the entire stress-strain response can be determined. Standard ASTM tests are conducted under load or actuator displacement control conditions. Once the maximum load is reached, the specimen's resistance to increasing load levels diminishes. If the testing machine is unable to redistribute energy away from the specimen, sudden shattering can occur due to the stored strain energy.

However, if the testing system has sufficient stiffness to release less energy than consumed by the specimen during deformation, stability can be maintained during unloading.

The configuration for obtaining a stable post-peak response depends on the material's behavioral class and brittleness. Various options are available for controlled variables, such as load, stroke, axial displacement, transverse and circumferential displacement, or combinations thereof.

Load control is not suitable after the peak load, as it does not allow for load reduction. To obtain the post-peak response, an extensometer can be employed, encircling the specimen to measure circumferential displacement as the control variable.

A specialized ring-like fixture with linear variable differential transducers (LVDTs) measures axial strain over the majority of the specimen's length.

A chain with rollers can also support the extensometer for measuring circumferential dilatation and transverse strain.

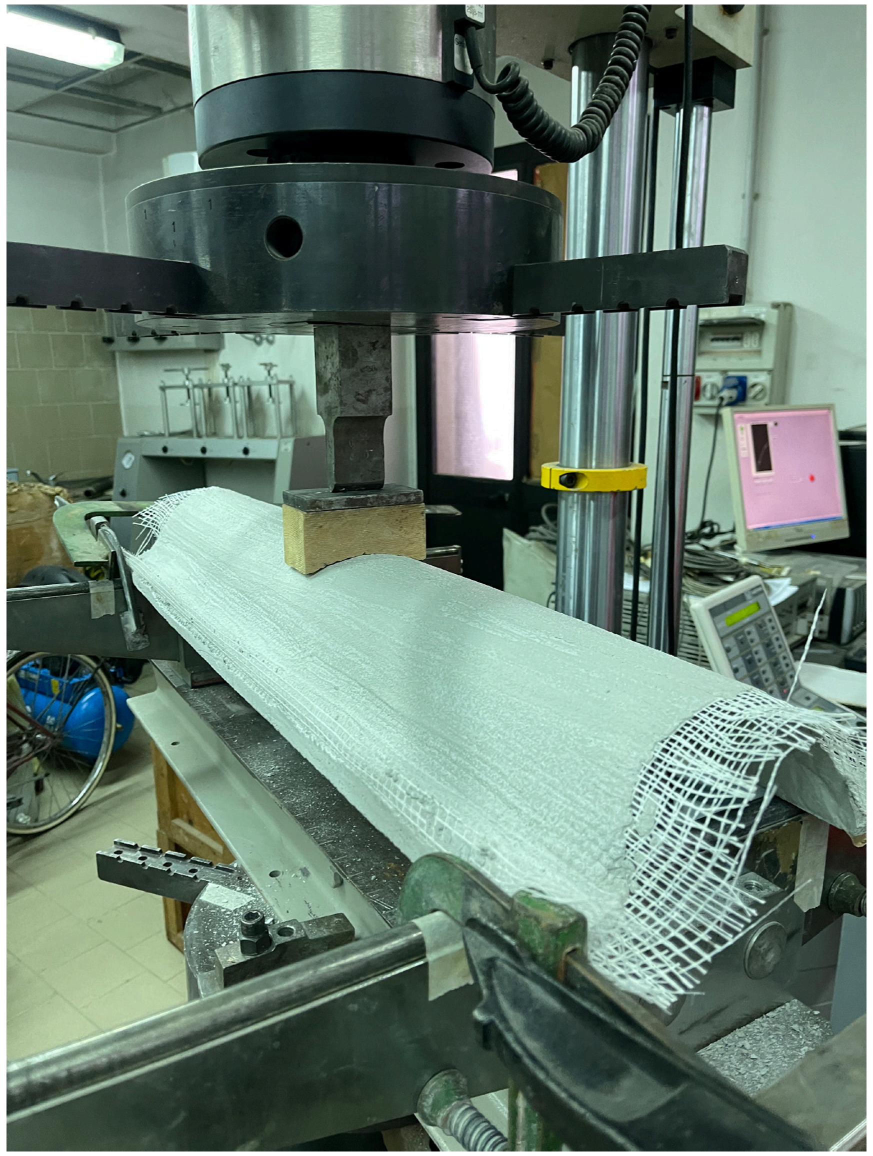
The test begins with load control and is then transferred to the extensometer, which controls the test before reaching the peak load, during the peak load, and through the post-peak response until completion.

Two modes of behavior can be observed: under normal conditions, axial strain increases with circumferential displacement, while under a snap-back condition, axial displacement decreases as circumferential strain increases. These modes are influenced by the fact that post-peak deformation is localized within a narrow zone undergoing progressive damage and cracking.

The displacement response is dominated by the energy released during unloading in the bulk of the specimen.

Interpreting the stress-strain curve in the post-peak region is challenging, as it represents an average displacement in both elastic and inelastic zones and is influenced by specimen geometry and loading setup. Additionally, post-peak deformation is localized and progressive within a narrow zone.

Hence, the stress-strain curve beyond the peak is a combination of structural and material responses[26].



[fig. 45]

Flexure test

04.3

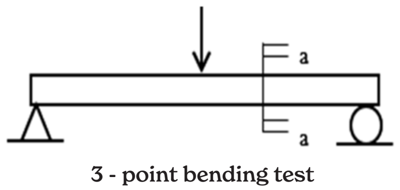
TRC finds widespread use in tension members, while it has been observed that failures in bending can occur in applications such as shells and facades. Extensive literature reviews have focused on determining the flexural strength of TRC elements using test setups similar to those employed for conventional structural panels, slabs, and beams.

It should be noted that due to the relatively thinner nature of TRC, it exhibits a lower capacity to sustain flexural loads. Therefore, it is crucial to carefully observe and monitor the failure mechanism during testing, analyzing the behavior of the specimens.

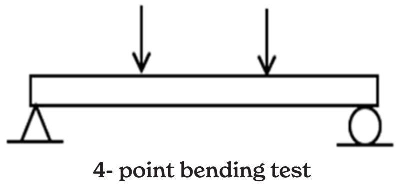
The flexural behavior of Textile-Reinforced Concrete (TRC) can be analyzed through a three-stage stress-strain curve. Initially, TRC exhibits linearly elastic behavior in flexural tests. Under applied loads, tensile stress fields can lead to the formation and propagation of microcracks, typically following the flexural stress distribution along the depth of the beam. As deformation localizes at the main crack, the response transitions to the second stage dominated by crack propagation.

The load progressively increases until reaching the maximum load, while the crack continues to open and the remaining portion of the specimen undergoes elastic unloading. Subsequently, TRC enters the third stage characterized by post-peak behavior. At this point, the crack remains open, and the specimen experiences post-peak deformation.

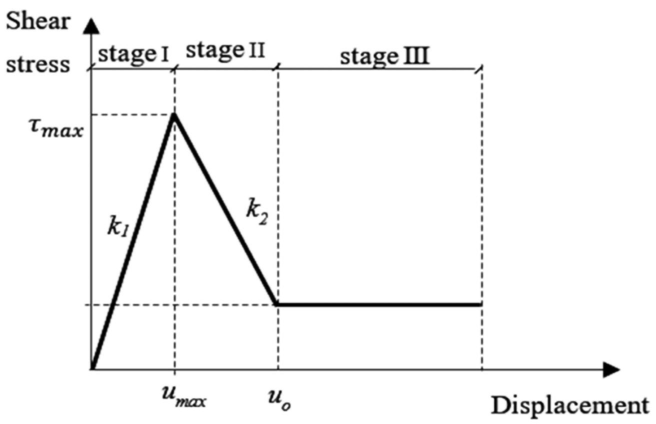
The stress-strain curve shows a decreasing trend, indicating a reduction in load-carrying capacity. Notably, the flexural behavior of TRC is often assessed using various test setups, such as three-point and four-point loadings on the specimens **[fig. 46, fig. 47]**.



[fig. 46]



[fig. 47]



[fig. 48]

Researchers have investigated parameters like the type and number of textile layers, which can affect the bending capacity of TRC. Furthermore, pre-stressing the textile has demonstrated a significant increase in the first-crack load capacity compared to conventional reinforcement placement methods. Specifically, it has been reported

that pre-stressing the textile can increase the first-crack load capacity by as much as 85% compared to conventional reinforcement placement methods[27] **[fig. 38]**. As a result, here is explained the reason why it was decided to prestress the fiberglass net used in this thesis.

Understanding these stages and behaviors provides valuable insights into the expected flexural performance of TRC, serving as a foundation for anticipating the behavior of the omega-shaped specimen under bending conditions.

Omega Shaped Beam 04.4

In this chapter, the focus is to explore the mechanical, structural, and technical characteristics derived from standard mechanical tests and it will be explained which could be the expected response of an omega-shaped beam.

These tests provide valuable information about the macrostructure of the specimen such as strength, stiffness, and ductility, and by analyzing the specimen's overall response under controlled conditions, we gain insights into the interaction of internal phases within the material.

By recording the characteristics of crack formation and the underlying mechanisms that enhance ductility in composites, accurate modeling can be undertaken. This is accomplished by employing techniques to identify the initial stages of failure during the application of load and by adapting and controlling the test accordingly.

What is fundamental to understand if the direction of the idea is the right one, is the so-called stress-strain curve. For material, the stress-strain curve gives the relationship between stress and strain.

This graph is generated from a gradual application of a load on the specimen, and measuring at the same time the deformation. From this output is possible to determine important properties of the specimen such as the one mentioned before.

The response to the given stress of the specimen is attributed to the gradual decrease of load-carrying capacity with an increase in the strain or widening of cracks in a tensile stress field.

Interpreting the stress-strain curve obtained from these tests is complex, as the post-peak response is influenced by factors such as specimen size, geometry, test control mode, and loading setup.

Additionally, the post-peak deformation is not homogenous but is localized within a narrow zone that undergoes progressive damage and cracking. However, analyzing the post-peak response provides valuable insights into the specimen's ductility, energy absorption capacity, and related parameters.

A series of tests, including the mechanical properties developed, that address tension, flexure, compression, in-plane shear, interlaminar shear, bond, and connection.

According to the purpose of this thesis, mechanical tests have to be carried out to not only have a structural result but also in order to have answers related to the different applications discussed in this research.

Of particular importance are the compression test and the flexure test, which need to be conducted to obtain both structural results and answers related to the various applications explored in this study. These tests play a significant role in evaluating the performance and behavior of the omega-shaped beam and provide valuable data for further analysis.

Omega Shaped Beam 04.4

[fig. 49]

04.5 Omega Shaped Beam Reactions

This innovative design incorporates a double layer of fiberglass in the middle, sandwiched between two layers of concrete—one in the bottom part and one in the upper part. We will explore how this unique shape reacts to compression and flexural stresses, identify the most stressed areas, and highlight the structural advantages offered by this configuration.

The selection of the shape has been studied and designed several times until we obtained a shape able to satisfy our preset parameters. Then, the omega shape comes out, because it has enhanced structural performances and important load-carrying capabilities, in particular, it can assume exceptional strength and load distribution properties.

So before getting into the results of the tests carried out on the built specimens, this chapter is reported what is expected to find from the conducted design process, trying to be aware of what could be expected from a specimen like the one presented in this thesis's work.

As was motioned before the stress-strain curve, in the next chapter will be possible to analyze and comment on all the test results of the different specimens created, but the expectation from our prototype is that an omega shape should be particularly adept at handling both compression and flexural stresses. The curvature of the beam allows it to efficiently distribute and transmit applied loads throughout its structure. Under compressive forces, the arch shape enables the beam to resist buckling and maintain its integrity. From what concern the lateral sides, they allow to couple of the beams in order to distribute the loading efficiently on the lateral self-bearing walls as we'll see in the application part. In particular, it is expected that the most stressed areas, in which there are higher stress concentrations, are the upper part of the arch and the two lateral bases. These areas are particularly prone to higher stress levels and they have been considered critical areas during design and reinforcement strategies in order to ensure the best current possible load-bearing capacity. Is clear that, in this sense, there are many opportunities to create variables in each specimen until a great result is reached.

The load-bearing capacity is also helped by the double layers of fiberglass in the center obviously, the significantly contribute to the beam0s capacity to withstand compression and in particular flexural stresses.

Also, an important characteristic that was already mentioned in the previous chapters is the theme of lightweight construction. Despite an important capacity for sustaining stresses, the omega-shaped beam maintains a lightweight construction. In fact, with the goal of being competitive as much as we could has been possible to build very thin sections, and this is an enormous benefit for several reasons, such as making easier the transport of the beams, the installation phase, as well as the possibility of saving a lot of material ensuring at the same time the right performance in the construction field.

All these considerations obviously, are taken into account starting from the idea that to ensure the feasibility of the whole process, a

precise formwork, an appropriate curing phase, and strict quality control measures are vital for achieving consistent and reliable results.

So, to conclude these considerations, it is possible to say that the omega-shaped beam demonstrates remarkable mechanical, structural, and technical characteristics that make it a compelling choice for various construction applications. Its ability to handle compression and flexural stresses efficiently, coupled with its unique load distribution properties, positions it as a promising alternative to traditional beam designs. By understanding the stressed areas, harnessing the structural advantages, and implementing sound technical considerations, the omega-shaped beam can provide a reliable and durable solution in diverse construction scenarios.

Tests

04.6

All the test carried out has been made with a punctual load applied on the middle span of the specimen. Considering the need of having a distributed load on a specimen that will be used as a beam in reality, a wooden piece of wood used to spread the load on the specimen. In this way a distributed load has been applied on all the tested specimens.

All the performed tests have been very useful in understanding the behavior of fiberglass net reinforced concrete beams under bending loads.

The observed failure mode and crack formation serve as valuable data for evaluating the structural performance of similar specimens and can inform future design considerations, such as reinforcement placement and load-bearing capacity calculations.

Specimen 1 | Description

The first specimen created has to be considered as a first trial done to take confidence with the procedure.

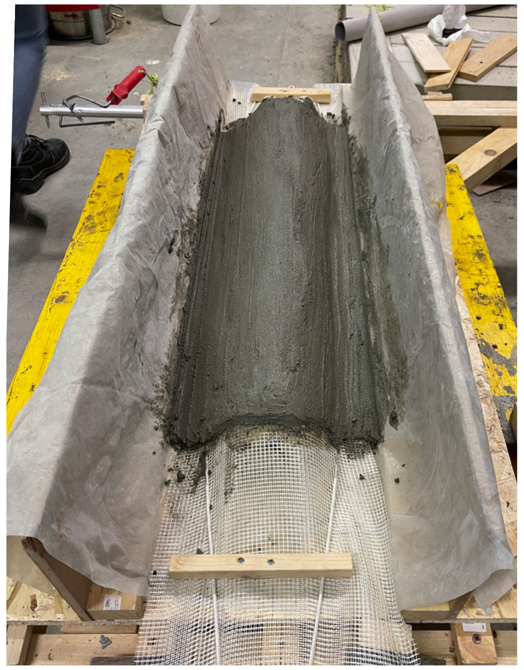
The net was pre-stressed with the first method described in this research, which means that this part of the procedure was made by hand, with two layers applied on the body of the formwork. Once the net was prestressed as we wanted, the tension was blocked with a string linked to the wooden structure. In this way, the same tension was maintained until the concrete was set.

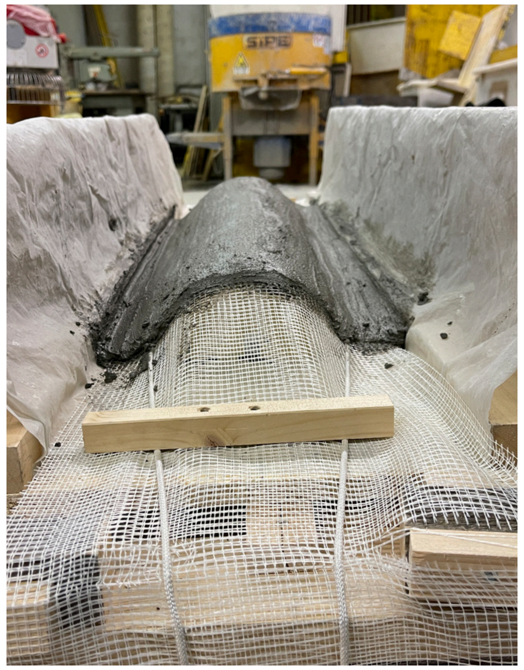
The mixer of the concrete was composed of 3,5 kg of cement, 3,5 kg of sand, and 1,5 kg of water. The spreading of the mortar was made by hand, trying to obtain the best possible result in terms of heterogeneity of the material. This specimen is the only one with these quantities because we notice at the end an excessive weight, which was 7,5 kg. Here there was a problem in terms of the shape of the specimen, cause was difficult to create the shape and stressing at the same time the net.

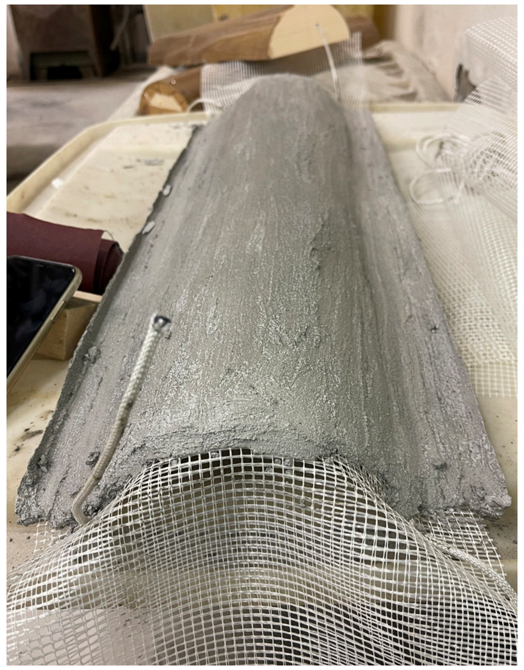
Despite the decision to use two elastic strings to try to maintain the low as much as possible the net, the result was not satisfactory. Was noticed that after the set phase that was not obtained a good shape as was expected. As can be noticed in the bottom picture, the angle between the curve and the two lateral bases of the specimen is not right.

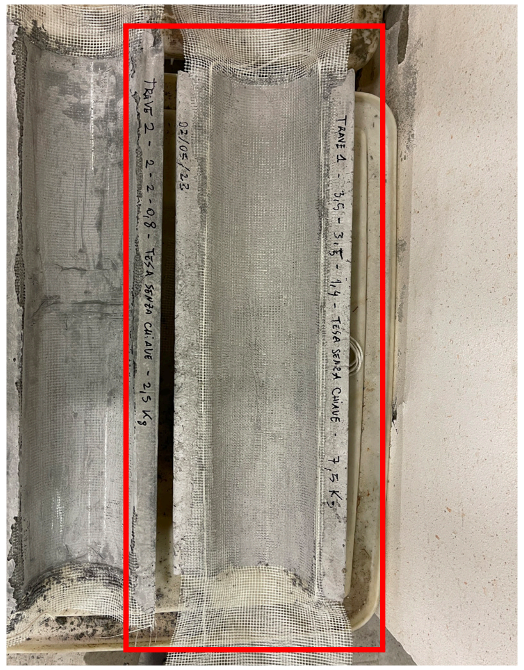
Since the goal, in term of weight and shape, it was decided after this first trial, to modify the quantities of the mixture.

This specimen has not been tested in order to maintain the integrity of the test average, as it is considered of approximate manufacture and excessively heavy.









Specimen 2 | Description

These are the first specimens with a different mixture. These two specimens are very similar in terms of results. From here on, all the other specimens will have the same mixture, composed of 2 kg of cement, 2 kg of sand, and 0,8 kg of water.

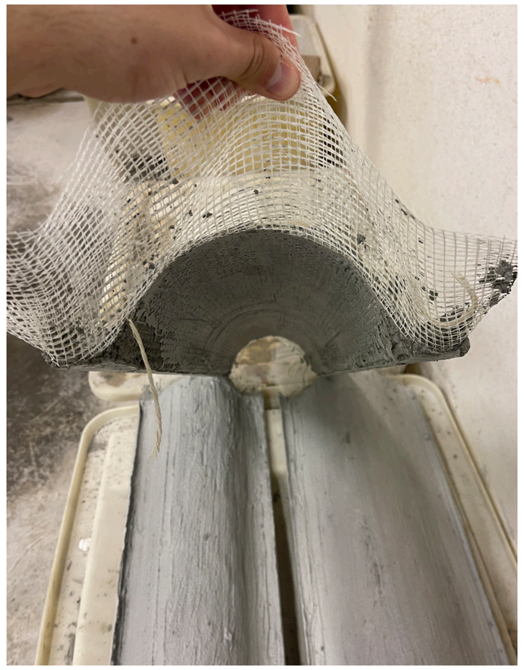
Thanks to these new quantities have been possible to obtain a lighter and thicker specimen. This brought an important change in terms of weight, going from 7,5 kg to 2,5 kg. A huge and surprising change that creates a very interesting output for being competitive in the market.

The net has been always pre-stressed by hand as in the first specimen created, and again always two layers have been applied to the body of the formwork.

To obtain a better shape than the previous one, in the second and third trials was decided to use a different type of string, thicker. This string has been linked to the base of the formwork and stressed as much as possible in order to create a 90 degrees angle between the arch and the lateral bases.

The spreading of the mortar was again made by hand and the picture here shows the visual result we obtained.

From the frontal view of the beam is evident the difference in terms of shaping that we obtain respect from the first specimen, reaching a better result, as in terms of shape, as in terms of weight was sad before.

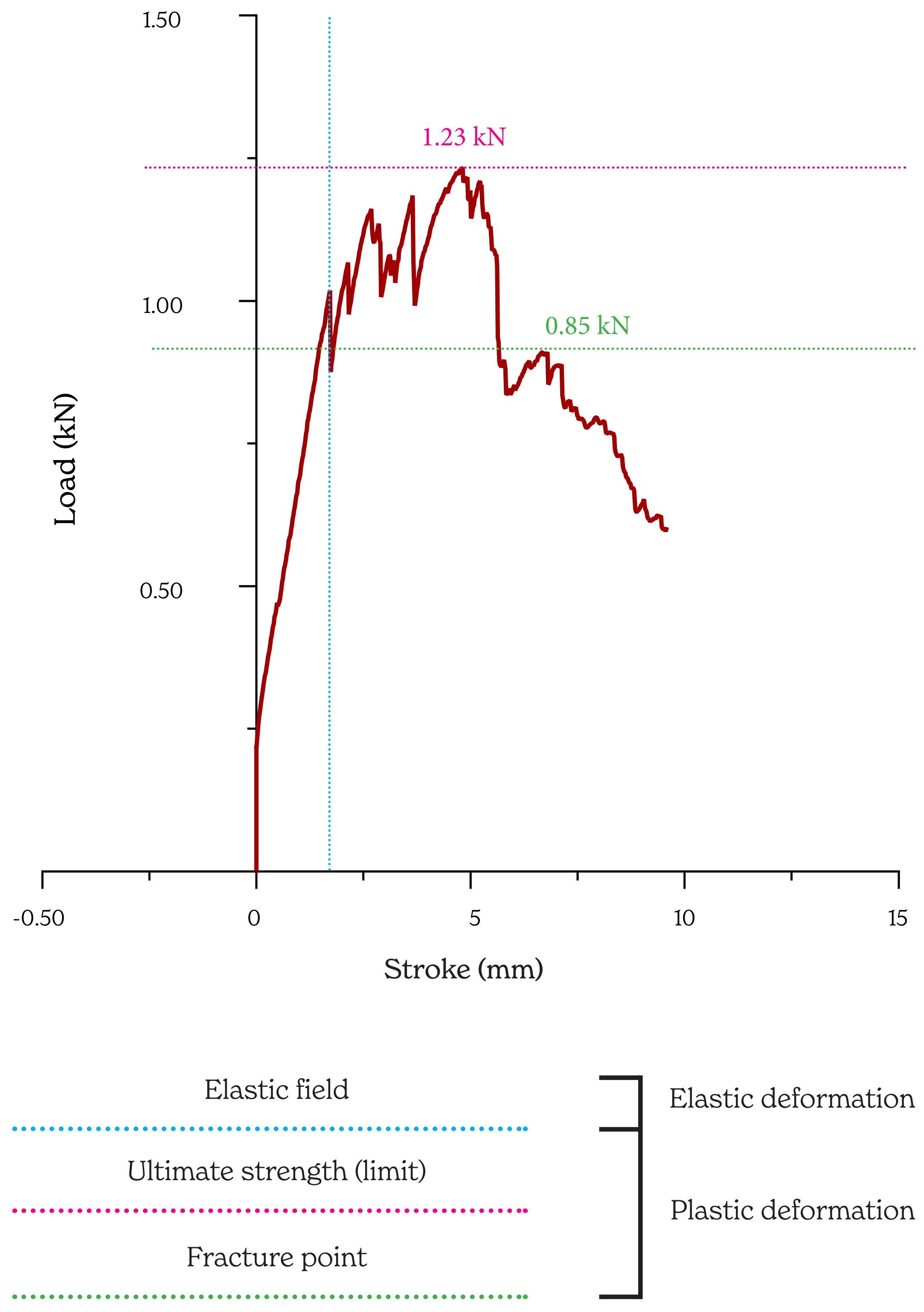


Specimen 2 | Test Results

The tests performed on this specimen showed bending failure after the maximum strength of 1.23 kN was reached, with a maximum beam deflection of about 5.2 mm at the breaking point. The speed at which the machinery acted by imparting a point load on the specimen was set to 35 um/sec.

As the load was applied, the specimen initially responded elastically, exhibiting linear behavior within the elastic field. However, entering in the plastic field, the specimen began to display flexural cracks on the wings. These cracks gradually propagated as the load intensified, eventually leading to a flexural failure on the wing in the vicinity of the loading point.

The visual evidence captured in the accompanying picture provides a clear depiction of the flexural cracks and the point of failure. The occurrence of cracks on the wings highlights the vulnerability of this area to bending stresses and indicates a potential stress concentration zone. Understanding the crack patterns and failure mechanisms is crucial for further analysis and improvement of reinforced concrete beam designs, as visible in the following specimens.

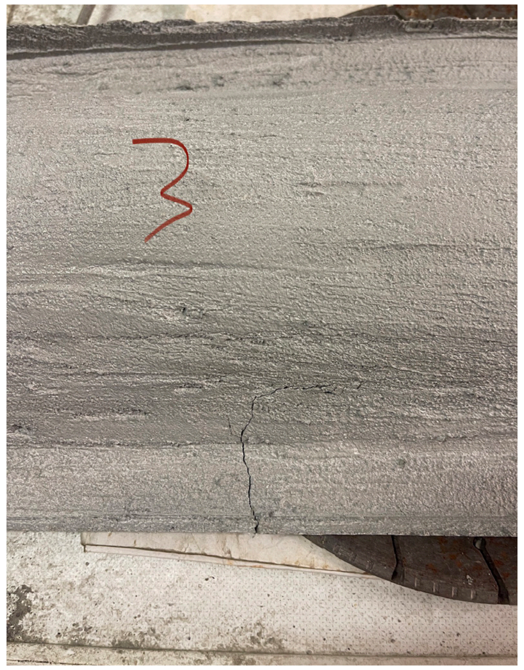


Specimen 3 | Description

In the case of this third specimen, it is worth noting that it was created using an identical mixture consisting of 2 kilograms of cement, 2 kilograms of sand, and 0.8 kilograms of water. Surprisingly, despite the same composition, this particular specimen exhibited a weight of 4 kilograms.

Furthermore, the construction process involved the customary method of manually applying tension to the double layer of fiberglass reinforcement. Once this step was completed, a layer of mortar was carefully spread over the fiberglass net. Although the thickness of the specimen was not entirely uniform, it was observed that its approximate measurement could be attributed to around 1 centimeter.

Regarding its shape, it is worth mentioning that this specimen represents the final instance where strings were utilized on both wings to maintain the desired shape. Interestingly, the outcome of this approach was rather favorable, as evidenced by the bottom picture.



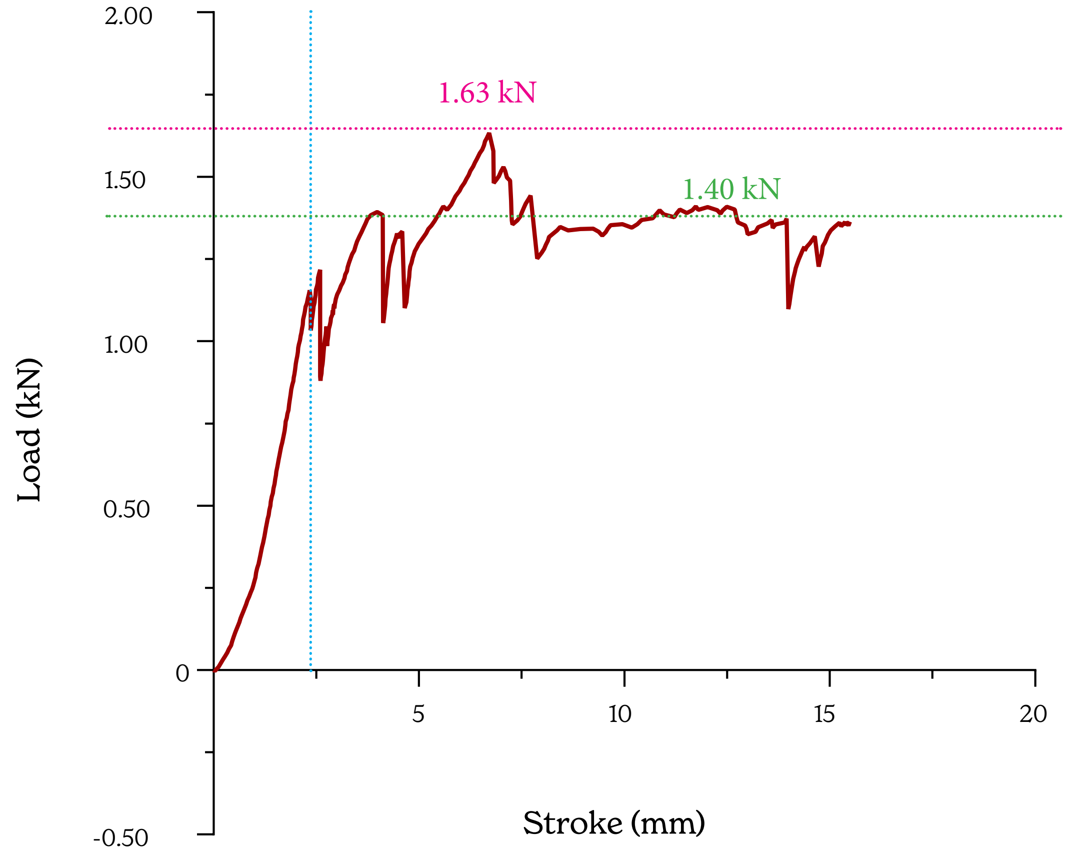
Specimen 3 | Test Results

The tests conducted on this particular specimen revealed that it experienced a failure due to bending after reaching its maximum strength of 1.63 kilonewtons (kN). The point at which the specimen broke exhibited a maximum deflection of approximately 6.7 millimeters. It is noteworthy that this time, the machinery applied a point load on the specimen at a speed of 20 micrometers per second (um/sec), which caused it to reach the breaking point more rapidly.

The failure occurred in the form of flexural failure primarily at the central part of the wing, extending towards the beginning of the connection where the wing and curvature meet. Additionally, a localized fracture was observed at the top of the curvature.

Observing the graph, it is evident that the values of kilonewtons during the plastic phase remained relatively consistent over time until the complete collapse of the section was reached.

Tests | 3 04.6



Elastic field

Ultimate strength (limit)

Fracture point

Elastic deformation

Plastic deformation

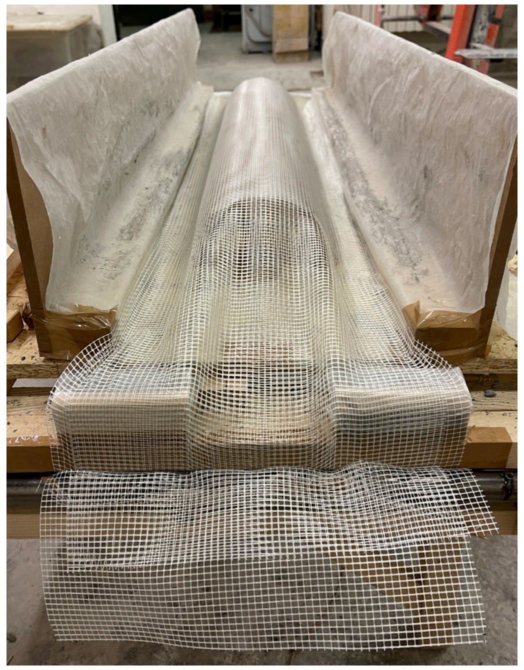
Specimen 4 | Description

This specimen had the same mixture of specimens 2 and 3, composed of 2 kg of cement, 2 kg of sand, and 0,8 kg of water.

There was here an important difference from the previous experiments, and it was that one of changing a little bit the dimension of the net. We chose to cut out a wider net for the length parameter because we were not completely satisfied with the shape, so in this way, we successfully reach a very precise angle between the arch and the two bases.

The procedure plans to stick the net inside the guides for the side bases, in this way it was noticed that the net stayed in the desired position, without the use of strings as before. From this specimen on, no more strings will be used to obtain the desired shape, but simply a wider net will be maintained for all subsequent tests as well.

As expected from net positioning, the specimen set with a more satisfied shape, but we missed still an important step, cause again the net was stressed by hand.

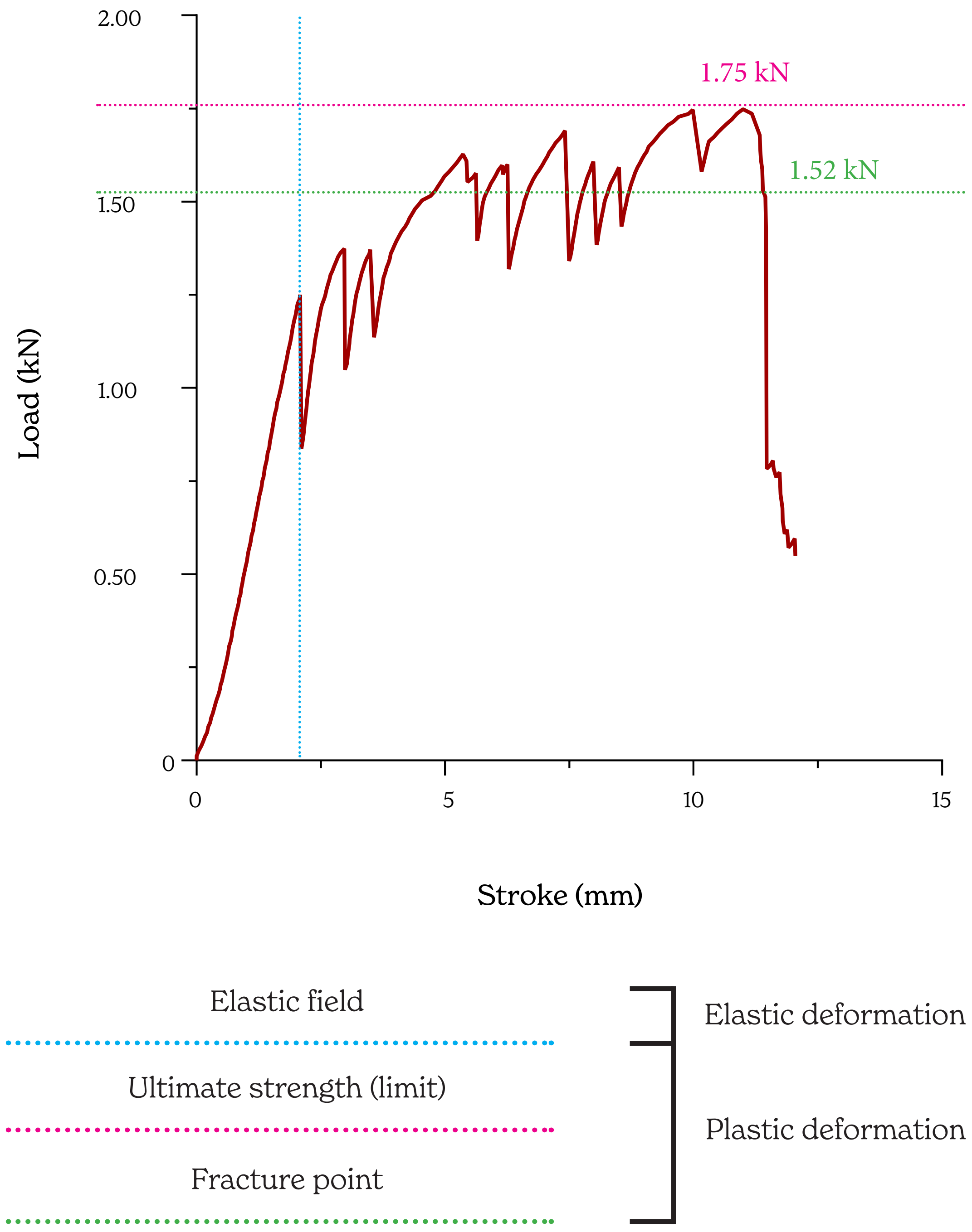


Specimen 4 | Test Results

On this specimen, the tests indicated flexural failure subsequent to reaching a maximum strength of 1.75 kN. The breaking point exhibited a maximum beam deflection of approximately 10 mm. The machinery applied a point load on the specimen at a speed of 25 um/sec this time.

Multiple cracks were clearly visible on both sides of the specimen's wings, gradually propagating towards the point of ultimate failure. These fractures consistently originated from the central region where the load was applied.

The collapse phase demonstrated rapid deterioration, with the load swiftly decreasing from approximately 1.70 kN to 0.7 kN, ultimately resulting in the complete failure of the specimen.



End first part

In these first trials was noticed that there was a problem with the penetration of the mortar inside the net. In particular as visible in the previous picture of the first four specimens, in the bottom part of the connection between the arch and the bases, the mortar was not completely penetrated inside the net, and the latter was clearly visible also after the set phase. So it was decided to change the stratigraphy of the composition of the specimen. Before stressing the net, a layer of mortar was applied directly to the body of the formwork.

The way in which it was applied has changed during the different trials as we'll see in the following specimens.

Specimen 5 | Description

This is the initial specimen that underwent stress testing using a torque wrench. Subsequently, the tube that allowed the net to rotate was replaced with another tube equipped with a welded nut, enabling the insertion of a key.

The weight recorded for this particular specimen surpasses that of the previous one, measuring 5.4 kg. It possesses a thickness of 1.5 cm, which corresponds logically to the increased weight.

Similar to the preceding specimen, this one also contains the same mixture, consisting of 2 kg of cement, 2 kg of sand, and 0.8 kg of water.

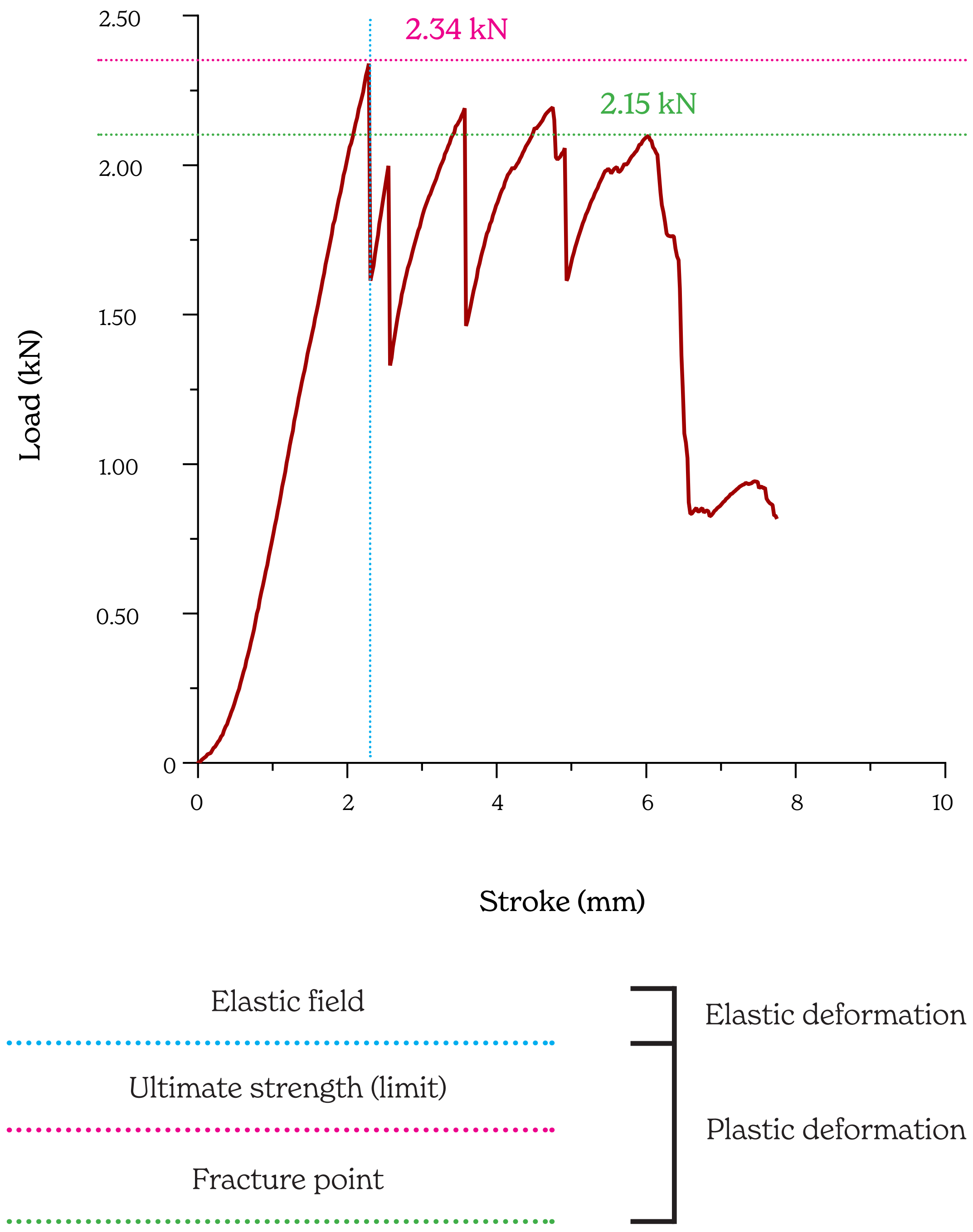
However, what distinguishes this specimen is the technique employed to apply the mortar onto the body. Following a preliminary spread of the mortar to even out the layer's thickness which, in this instance, happened to be quite thin, a net was positioned over the first layer. Subsequently, the net was subjected to tension using the torque wrench. Once this step was completed, the remaining mortar was spread over the body to create an additional layer.

Specimen 5 | Test Results

Conducting tests on this specimen revealed flexural failure after it reached its maximum strength of 2.34 kN. The breaking point exhibited a maximum beam deflection of about 2.3 mm. The machinery applied a point load on the specimen at a faster speed of 40 um/sec this time, reaching the breaking point more quickly.

The rupture of this specimen occurred due to several flexural cracks on both wings, covering a wider range compared to specimen number 4. Once again, these cracks were localized at the central part of the specimen.

The collapse phase, as depicted in the graph, was highly rapid. A prominent fracture can be observed in the photograph taken after the post-peak collapse.



Specimen 6 | Description

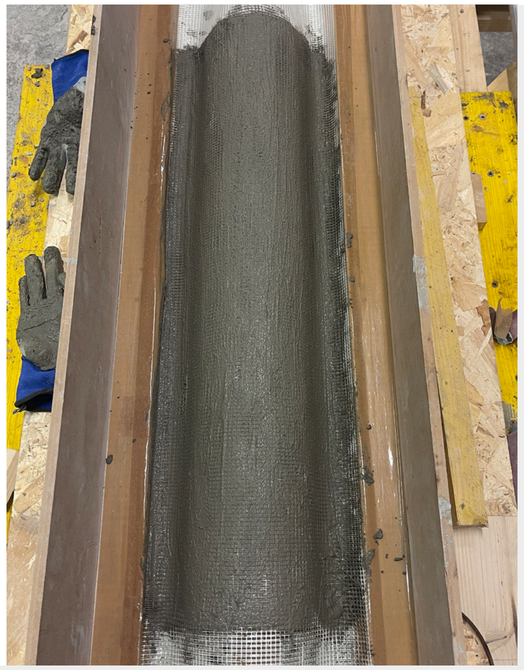
From here on, it was decided to put more mortar as a base layer, because it was noticed in the previous trial that there was a lack of mortar at the internal junction point between the two lateral bases and the arch.

This specimen again has the same mixture, composed of 2 kg of cement, 2 kg of sand, and 0,8 kg of water, with a registered weight for this specimen that is higher than the previous one and is 5.5 kg, with a thickness of 1 cm.

Then, it was decided to have a thicker first layer with the goal of letting the net penetrate inside the mortar in a better way. After the first layer of mortar, the net was prestressed with the torque wrench and then all the rest of the mortar was spread over the body.

The result was very satisfying, in fact after the setting phase the cement of these specimens resulted correctly drowned inside the net, which was not more visible on the surface of the omega profile. It was a step forward to reach a specimen that was as aesthetically functional as materially homogeneous, both externally and internally.

Also here, the trowel was efficiently useful to ensure the final result, with a smoothened spreading of the mortar along all the specimens. With the right pressure, maintaining it as much as possible the same, it is possible to reach a very interesting result in terms of homogeneity, maintaining in this case a constant thickness of 1.5 cm

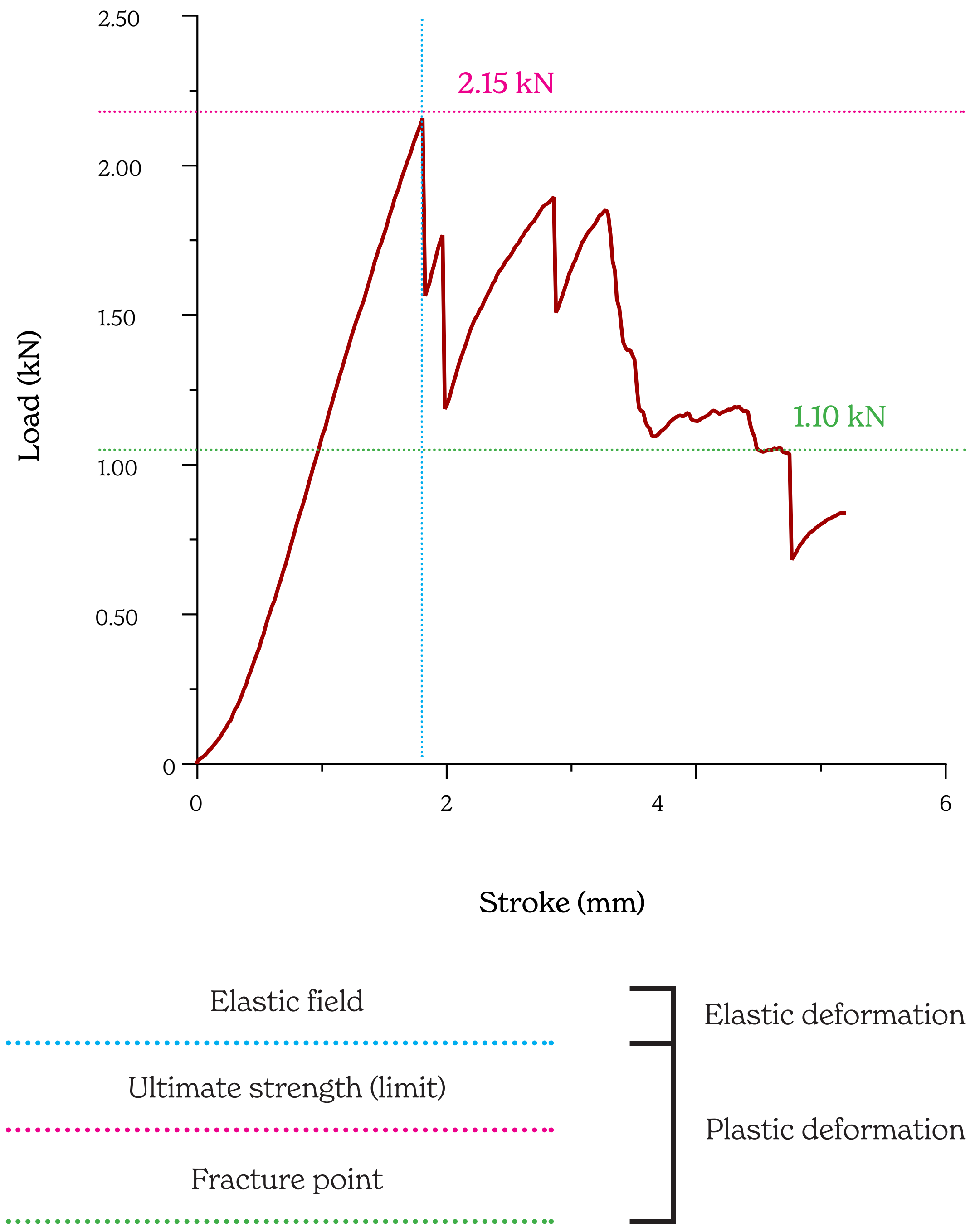


Specimen 6 | Test Results

The examination revealed that the specimen experienced flexural failure after reaching its maximum strength of 2.15 kilonewtons (kN). Notably, at the point of rupture, the maximum deflection of the beam was approximately 1.8 millimeters (mm). The machinery used to subject the specimen to a point load was programmed to act at a speed of 35 micrometers per second (um/sec).

As anticipated based on the similarities with specimen 5, it was expected that this specimen would also collapse after developing several cracks on its wings.

The collapse, however, did not occur suddenly; rather, it transpired gradually as wide-ranging cracks propagated throughout the structure until it reached its breaking point.

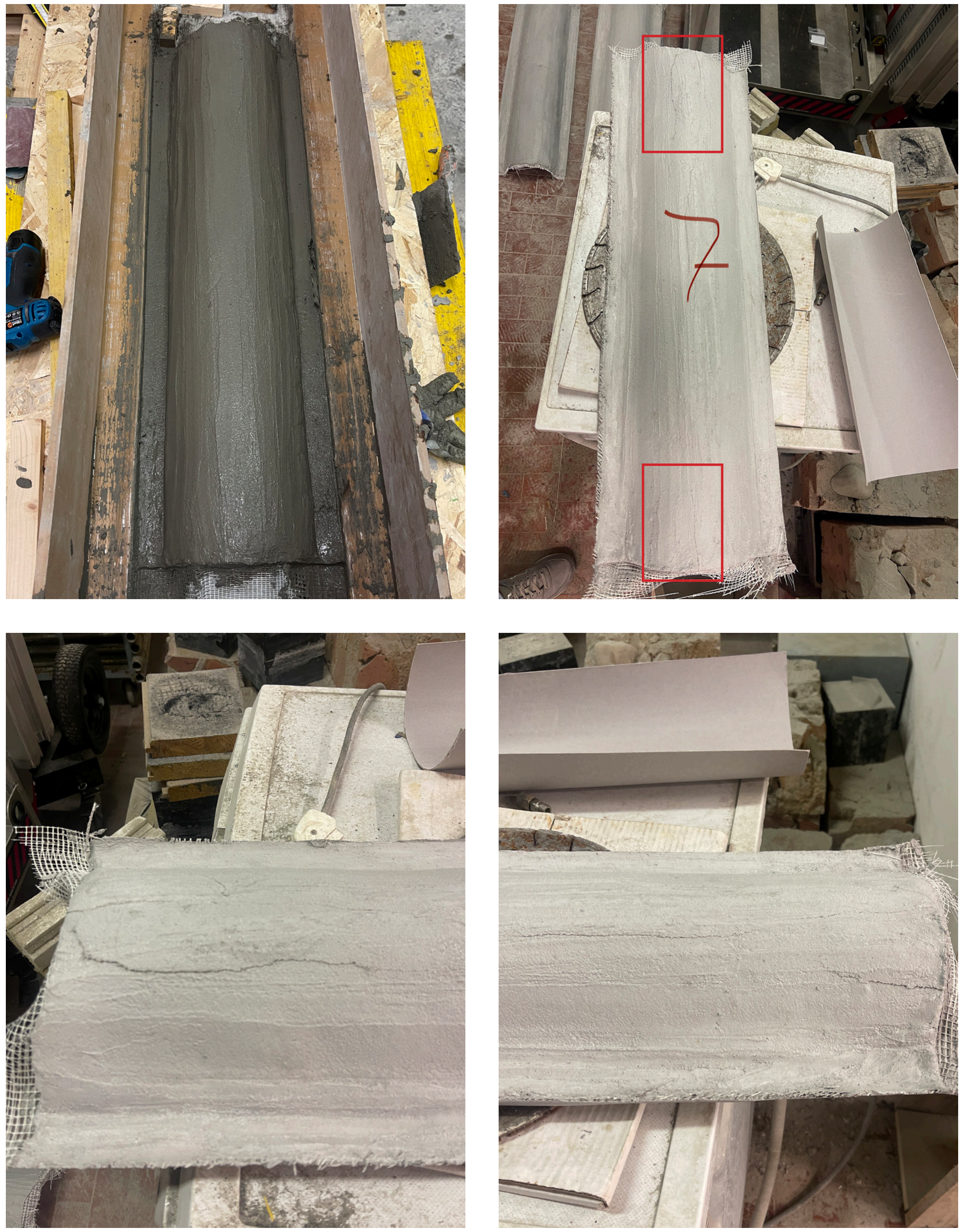


Specimen 7 | Description

The construction of this test specimen has the same characteristics as the two previous ones, except for its final weight (dry specimen), which is 3.9 kg, likely due to some leftover mortar on the walls of the bucket used during the preparation phase.

The proportions used to create the concrete are the same as those used for the previous specimens: 2 kg of sand, 2 kg of cement, and 0.8 kg of water.

The double layer of mesh, applied using the torque wrench, was placed after the application of the first layer of mortar and subsequently covered by another layer. Its average thickness is 1.2 cm.



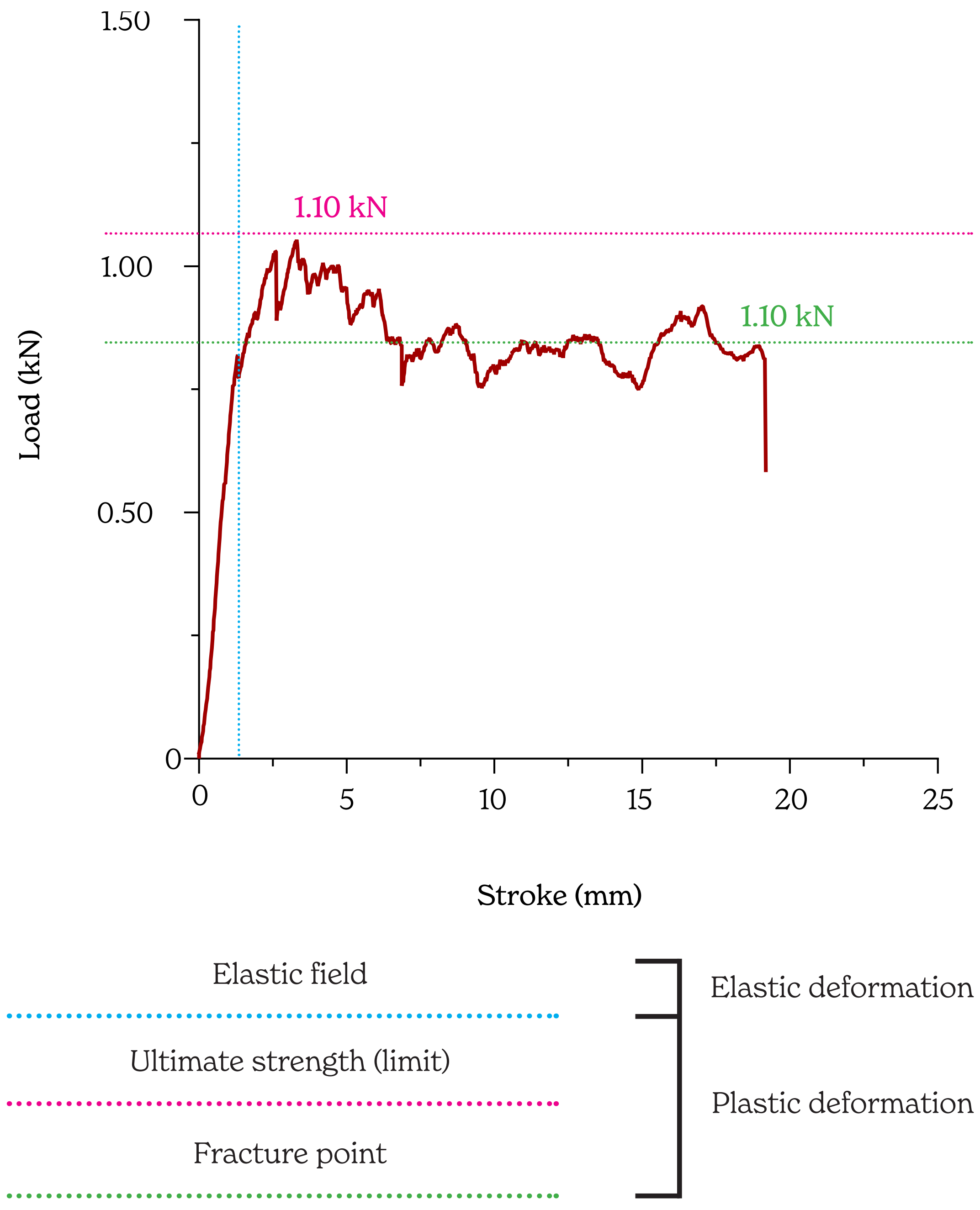
Specimen 7 | Test Results

In the case of the specimen subjected to a test with a maximum strength of 1.10 kN, it experienced flexural failure accompanied by a maximum beam deflection of approximately 3.60 mm. The machinery, operating at a speed of 35 um/sec, imposed a point load on the specimen.

During the plastic phase of this test, a longitudinal fracture occurred on both the interior and exterior parts of the curved section. These fractures were localized in specific areas, which can be observed in the figures provided.

Despite the section's lackluster performance, in terms of resistance, it exhibited satisfactory ductility. This can be observed from the graph, which demonstrates that the specimen remained sufficiently strong within the plastic range, without experiencing significant reductions in strength.

However, eventually, the specimen succumbed to collapse.



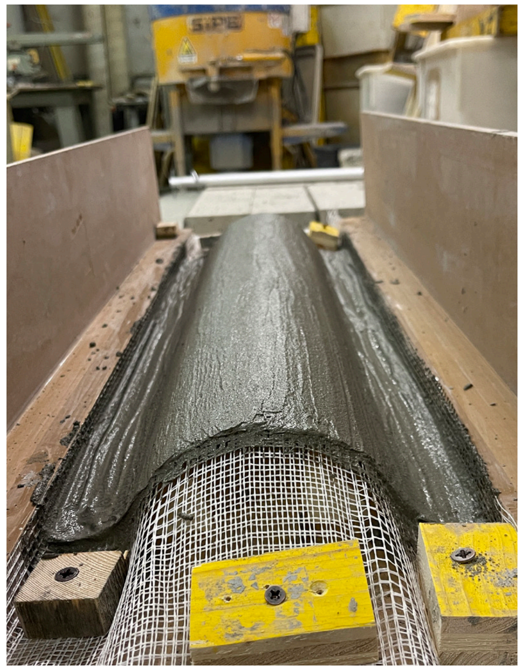
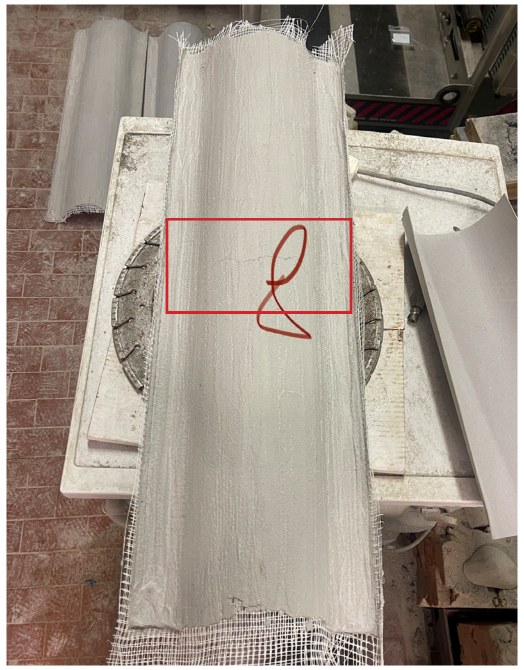
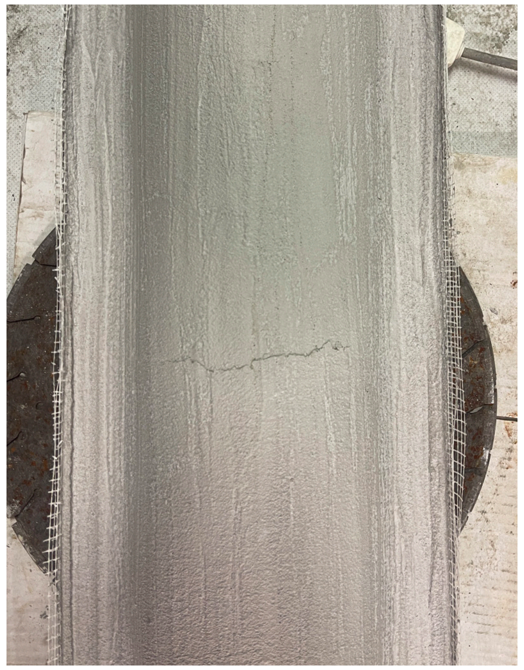
Specimen 8| Description

This specimen was test with the goal of reaching the limits of this research in terms of thickness of the specimen.

In fact, for this trial also the composition of the mixture was different, with 1 kg of cement, 1 kg of sand, and 0,4 kg of water, specifically half of the usual mixture was used. Doing that, a thickness of 0,5 mm was reached, obtaining a very thin section for this trial, with a registered weight is 3 kg.

Despite the small thickness of the section, the procedure for the stratigraphy of the specimen remained the same, with a double layer of fiberglass in the middle of two external layers of concrete.

The result was a specimen with wings however thick but with a really small curvature thickness, as mentioned before, and this resulted in a section that was really at the breaking point even before it was tested. Despite initial doubts, the section was still tested to find out its potential.

Specimen 8 | Test Results

The tests conducted on this specimen revealed flexural failure after reaching its maximum strength of 0.89 kN. The breaking point exhibited a maximum beam deflection of approximately 10.8 mm.

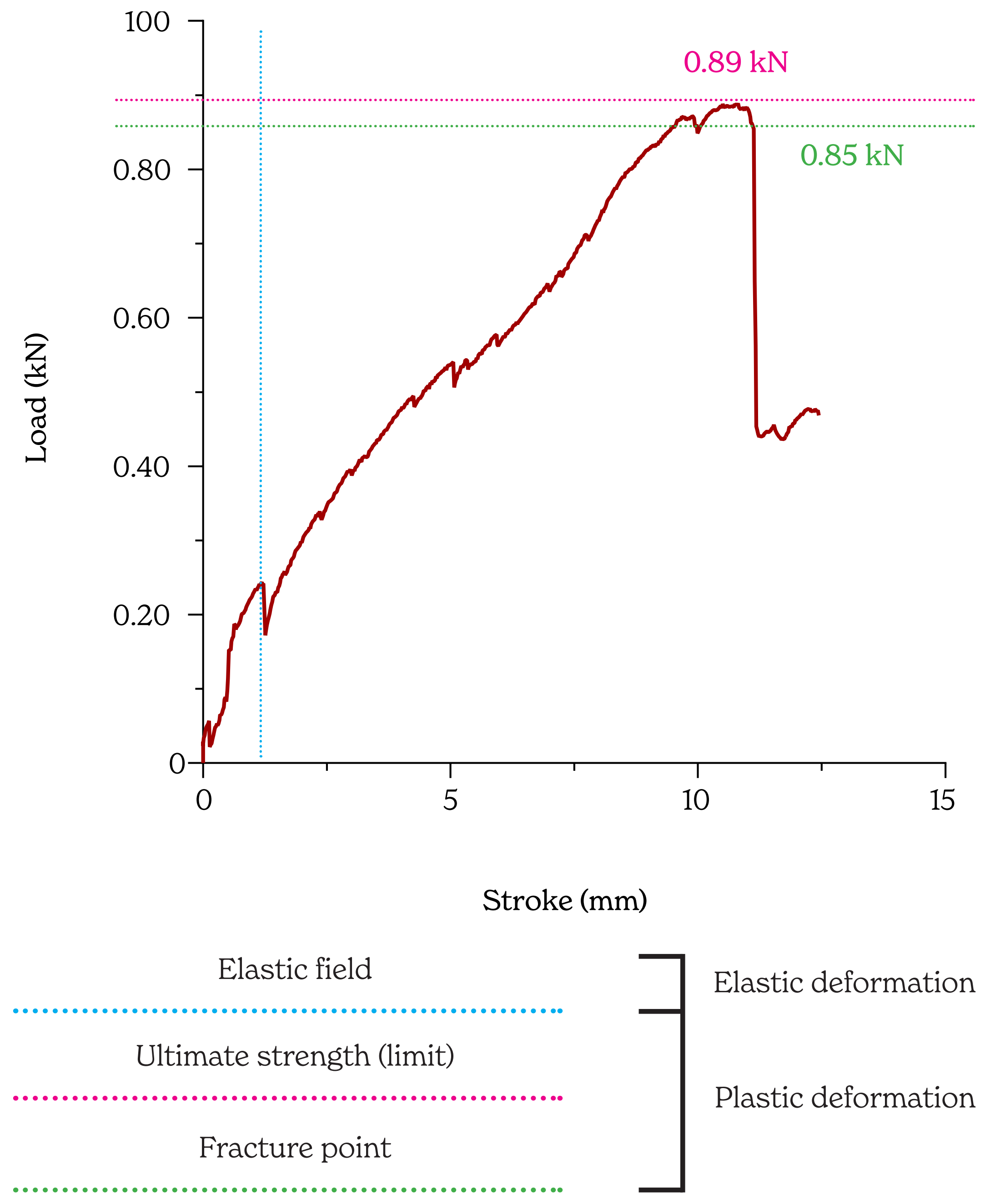
The machinery applied a point load on the specimen at a speed of 35 um/sec.

Since the section appeared to be weak and considering its intended application in the construction field, where these specimens are coupled to eliminate horizontal stresses, it was decided to test this specimen and all subsequent ones using two clamps. This configuration aimed to simulate the presence of two additional specimens juxtaposed on both sides.

In this case, the collapse of the specimen was caused by a localized crack precisely at the loading point.

The collapse was sudden, as evidenced by the graph. The specimen's excessively thin section likely influenced its rapid collapse. Consequently, the final numerical results were not as satisfying as expected.

However, the tests did serve the purpose of pushing the limits of this type of specimens to the extent possible, making the effort worthwhile.



Specimen 9 | Description

Here the new trial was one of working following in particular a structural criteria. Since it was expected to have some particular areas of the specimen that should be more stressed concerning others, it was decided to act reinforcing more the lateral sides.

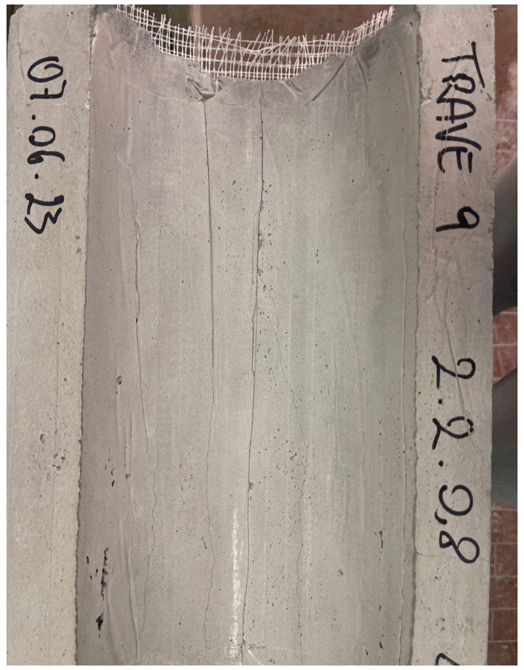
The lateral sides as we'll see are expected to more very stressed when loaded, then for this reason this specimen has not a double but a triple layer fiberglass net reinforcement.

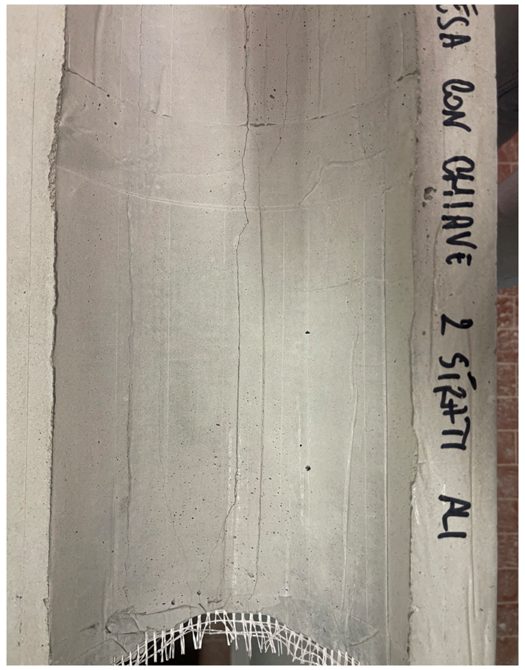
It's important to say that this last layer of reinforcement is not prestressed but is simply slow. It is interesting for this work's thesis testing to reach the best possible solution.

Reinforcing the lateral basis should guarantee a stronger resistance to stresses at a point in which stresses are extremely concentrated. Another specific area that is extremely stressed when loaded, is the top point of the arch, but for this specific specimen, they are no added layers on this area.

The previous procedure of having the stratigraphy composed of a layer of mortar, a double layer of fiberglass mesh, and another layer of mortar on top, has remained the same.

Tests | 9 04.6





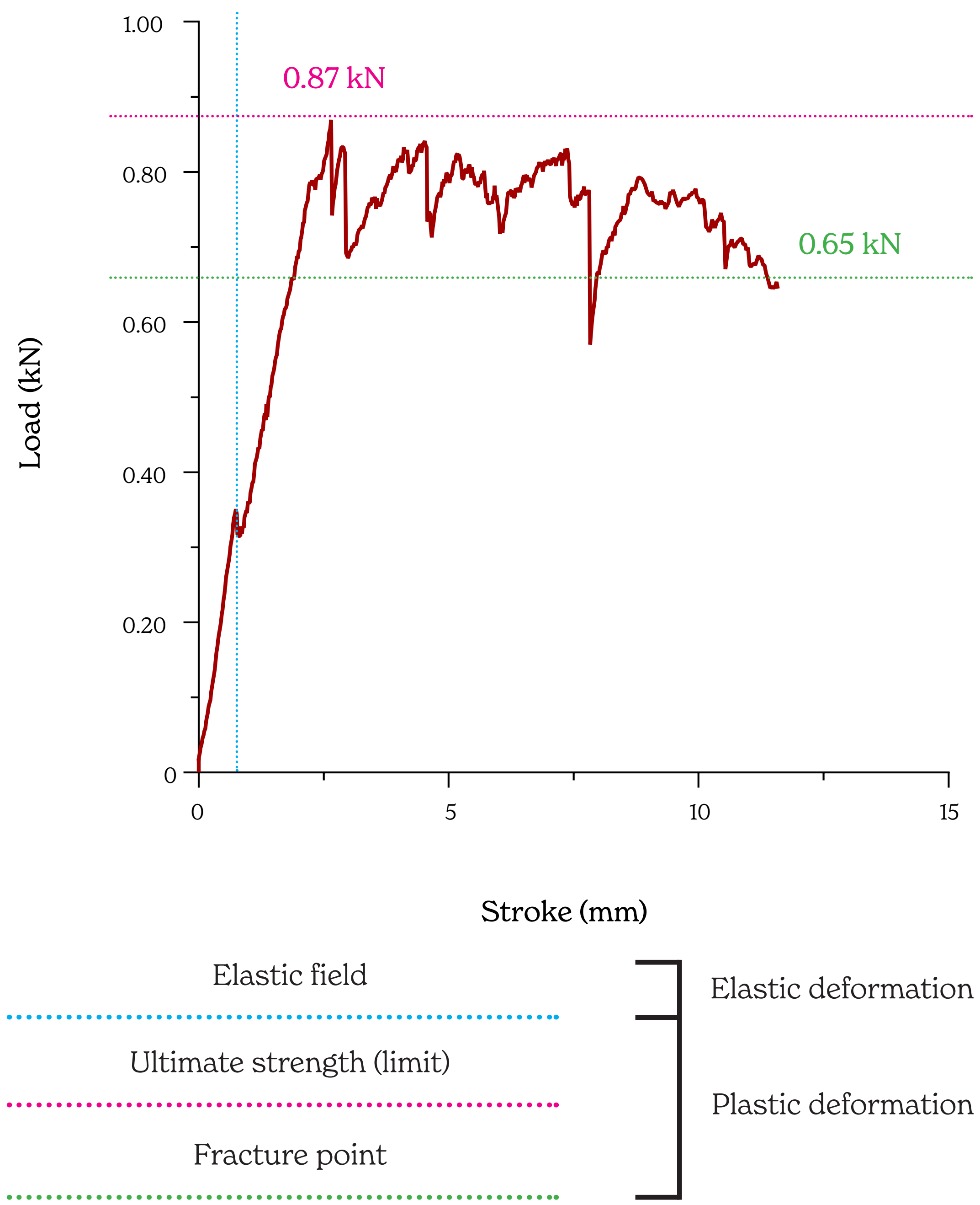
Specimen 9 | Test Results

Now, let's delve into the analysis of another specimen with a maximum strength of 0.87 kN. Upon examination, it became apparent that this specimen was restrained at its four side points, leading to the collapse of the concrete layer under compression.

The accompanying pictures clearly demonstrate the presence of cracks running along the longitudinal direction within the internal part of the specimen. Surprisingly, the reinforcement on the wings did not provide the anticipated benefits. Instead, the fracture occurred at the top part of the specimen, indicating that the load was concentrated on the curved section where the thickness was lower. Within the plastic field, the specimen gradually experienced a decrease in strength, thereby avoiding an immediate collapse.

Despite the unsatisfactory numerical outcome, this section is still of interest, as it highlights the importance of a well-balanced reinforcement on the wings when considering the thickness of the entire section. Additionally, it can be compared to the previous specimen (number 8) due to the striking similarity in maximum strength values, albeit with a notable distinction in the behavior during the collapse.

In this case, the collapse occurred at a slower rate, demonstrating a more favorable response in this phase.



Specimen 10 | Description

This particular specimen stands out due to its distinct mixture ratio compared to the others. In actuality, the composition of this specimen comprises 2 kilograms of cement, 2 kilograms of sand, and 1 kilogram of water. It should be noted that there was an error in the quantities used for this specimen.

However, despite the discrepancy, it was decided to include this specimen in the testing phase after the setting phase had already commenced. The purpose behind including this specimen was to investigate the variations that arise from altering the water content, thereby affecting the water-to-cement (w/c) ratio.

Remarkably, the weight of this specimen consistently remains at 3.9 kilograms, similar to the preceding specimens. As for its stratigraphy, it adheres to the conventional pattern, featuring a double layer of pre-stressed fiberglass net sandwiched between two external layers of concrete

Specimen 10 | Tests Results

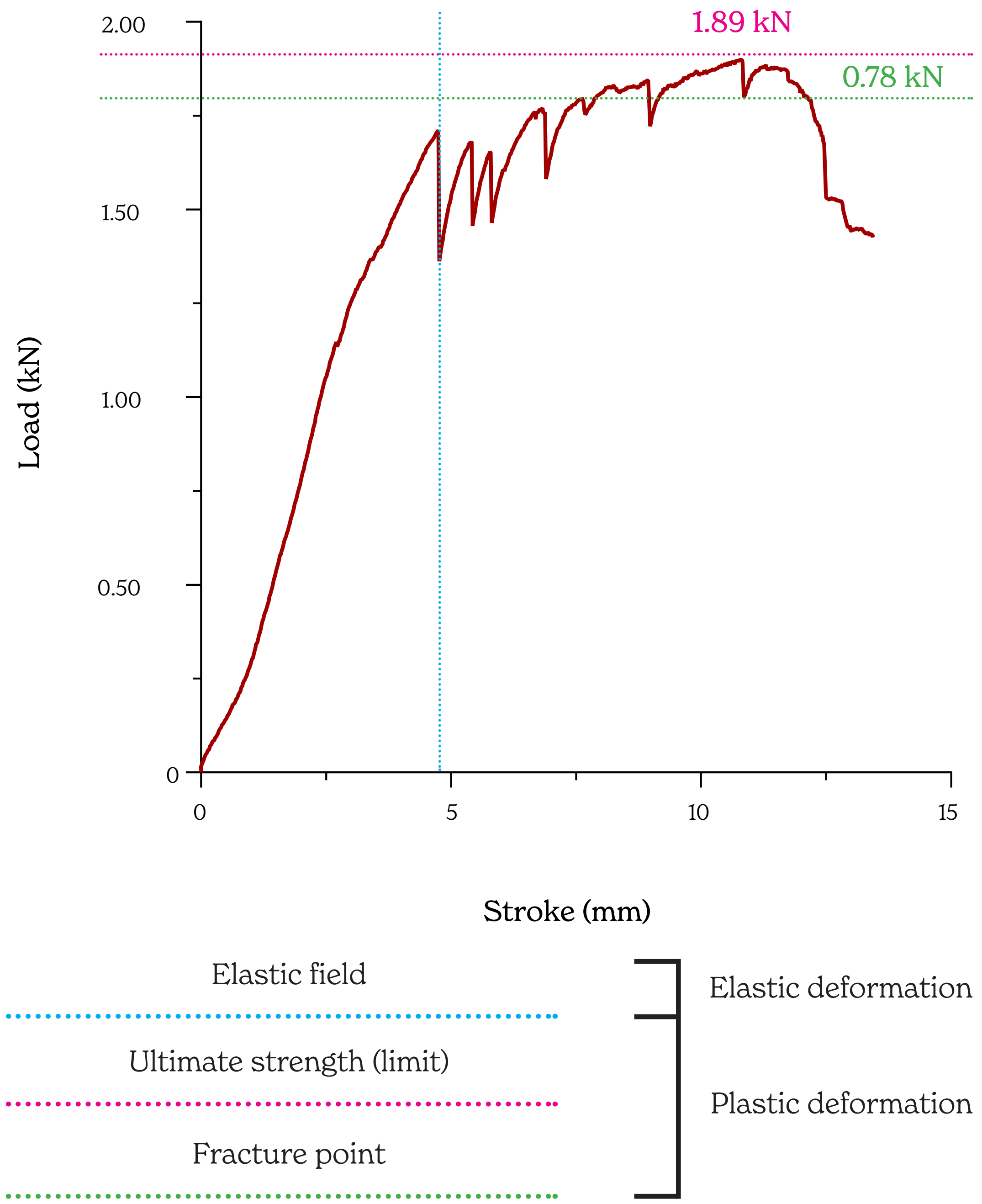
This particular specimen demonstrated a maximum strength of 1.89 kilonewtons (kN).

During the plastic phase, multiple flexural cracks emerged on the two wings, gradually propagating until reaching the breaking point.

Notably, a localized failure of the concrete occurred at the loading point, leading to the collapse of the section.

However, what truly set it apart was the exceptional ductility it showcased even after surpassing the breaking point. This remarkable ability to deform plastically while retaining structural integrity was truly noteworthy. Within the realm of plastic deformation, the specimen exhibited a consistent and gradual decline in its strength.

This behavior, observable throughout the examination, further highlighted its impressive ability to withstand considerable deformation without catastrophic failure.



Specimen 11 | Description

The specimen in question possesses a weight of 4.2 kilograms. Its composition comprises a mixture consisting of 2 kilograms of cement, 2 kilograms of sand, and 1 kilogram of water.

The primary purpose of creating this specimen was to generate another specimen with a conventional stratigraphy, resulting in an overall thickness of 1 centimeter.

In essence, this specimen contains only two layers of pre-stressed fiberglass net sandwiched between two layers of concrete.

The decision to create another specimen with a simpler stratigraphy stemmed from the fact that over time, the execution technique had been enhanced.

It was deemed intriguing to examine the response of a specimen with the same stratigraphy but executed with improved precision, in order to ascertain whether any substantial differences would emerge during the conducted tests.

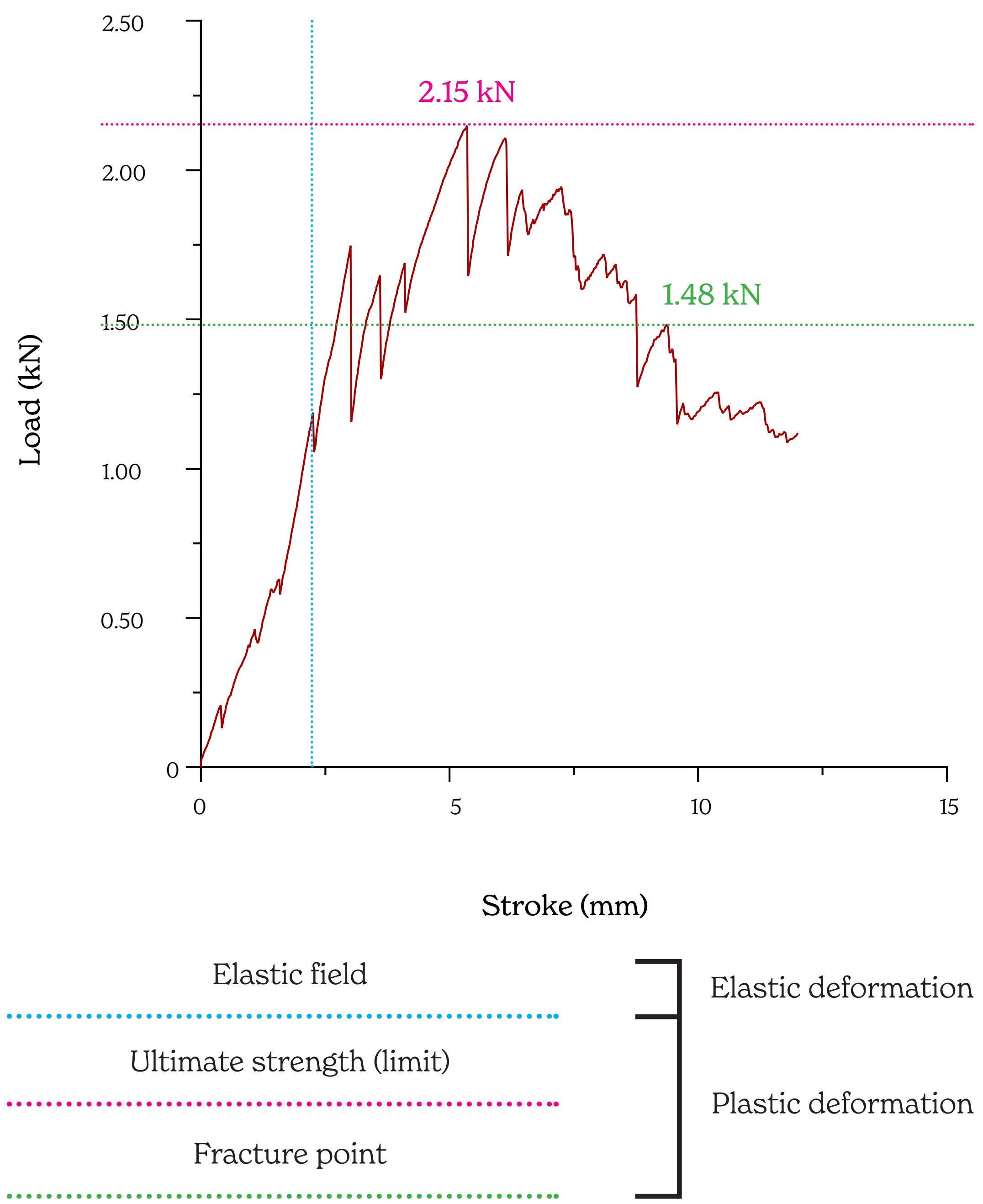
Specimen 11 | Tests Results

Let's now focus on the analysis of the specimen with a maximum strength of 2.15 kN.

During the testing phase, observations were made regarding the behavior of the specimen. Initially, within the plastic range, the specimen displayed the development of multiple flexural cracks along its wings. These cracks, indicative of the specimen's response to applied forces, served as a prominent sign of structural deformation.

However, as the investigation progressed and in accordance with the figures provided for reference, a significantly larger flexural crack emerged. This crack, surpassing the size and magnitude of the previous ones, played a crucial role in the subsequent events. Ultimately, this expansive flexural crack led the section to reach its ultimate breaking point.

The failure mode experienced by the concrete material in this scenario was primarily characterized by flexural failure. The inability of the material to sustain the applied loads resulted in the complete collapse of the section under examination. This catastrophic outcome can be attributed to the excessive strain imposed on the specimen, ultimately surpassing its capacity to bear such forces.



Specimen 12 | Description

This is another specimen built to try a different configuration.

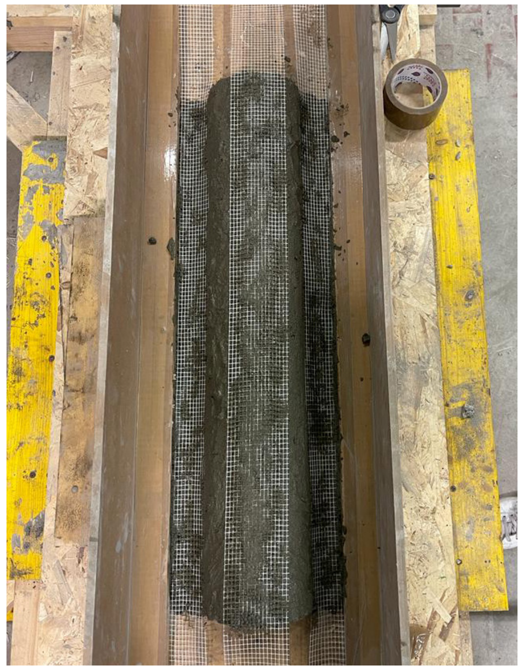
This trial is focused on the lateral supports and on the top part of the arch, as it is considered one of the crucial points to pay attention to. Here, the idea is to put more layers of fiberglass on the upper part and on the wings of the specimen in order to increase the flexural resistance to stresses on this area.

Then, after putting the first layer, always made of 2 kg of cement, 2 kg of sand, and 0,8 kg of water, the first two layers are pre-stressed as in the previous specimens, and in the same way, the other two layers are pre-stressed over them.

So this specimen focus is on having a stronger resistance, and it could be very useful to understand if is worth double the number of layers of fiberglass net reinforcement would lead to a more convincing result than the specimens with only two layers of reinforcement.

As always, after the four pre-stressed layers, another layer of mortar is spread on the body, maintaining the same specimen's stratigraphy.

The registered weight for this specimen is 4,1 kg and the achieved thickness is 1.5 cm.



Specimen 12 | Tests Results

Turning our attention to another specimen, which achieved a maximum strength of 2.64 kN, it experienced several flexural cracks along both wings as it entered the plastic phase.

These cracks eventually led the section to the breaking point, accompanied by a localized breakthrough at the loading point.

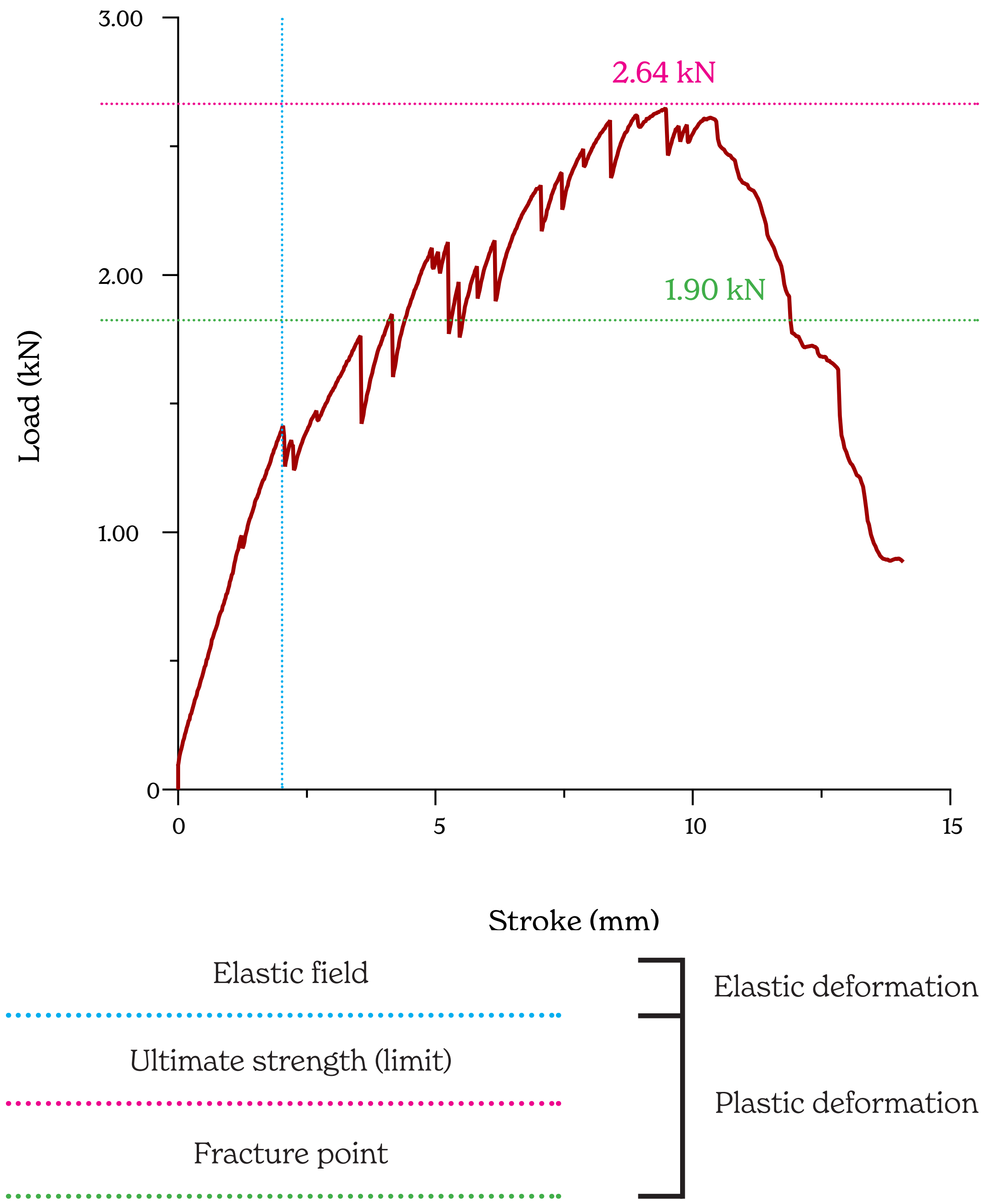
The figures clearly illustrate this specific area, with a significant central crack extending from the external part to the internal part of the specimen. Remarkably, the reinforcement mesh remained undamaged.

In contrast to section number 13, which will be discussed later, the post-peak behavior of this specimen revealed interesting results.

The inclusion of fiberglass fiber reinforcement in this section proved to be highly beneficial, as it prevented sudden and vertical collapse.

The graph indicates that the strength of the section contributed to a more controlled collapse compared to the other analyzed sections.

This finding suggests that reinforcing the most stressed areas of the section with multiple layers can help prevent instantaneous collapse.



Specimen 13 | Description

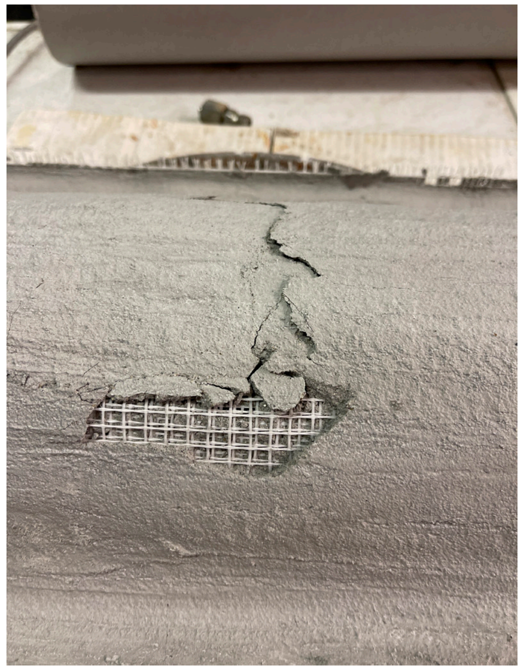
This is another specimen that has been constructed with the aim of gradually obtaining stronger specimens, particularly in terms of their predictive capabilities. Unlike the previous trial, which focused on a selected area, this trial encompasses all the specimens. The main idea here is to enhance the strength of the specimens by doubling the number of layers of fiberglass net across their entire length and width.

This modification creates a distinct cross-section that is likely to offer improved resistance. The thickness of this newly reinforced section remains consistent with the previous trial at 1.5 cm.

The construction process involves the initial application of a layer consisting of 2 kg of cement, 2 kg of sand, and 0.8 kg of water. Subsequently, the first two layers are prestressed using the same method as in the previous specimens. Two additional layers are then prestressed on top of the initial ones.

The primary objective of this particular specimen is to achieve enhanced resistance throughout its entirety. The findings from this specimen could prove invaluable in determining whether doubling the number of layers of fiberglass net reinforcement is a worthwhile approach. Naturally, this alteration in the construction process leads to a twofold increase in the consumption of fiberglass. Considering the emphasis placed on material conservation during this research, this increased consumption should be taken into account.

Tests | 13 04.6



Specimen 13 | Tests Results

Finally, let's examine the specimen that exhibited the best result during the testing phase, achieving a maximum strength of 4.3 kN.

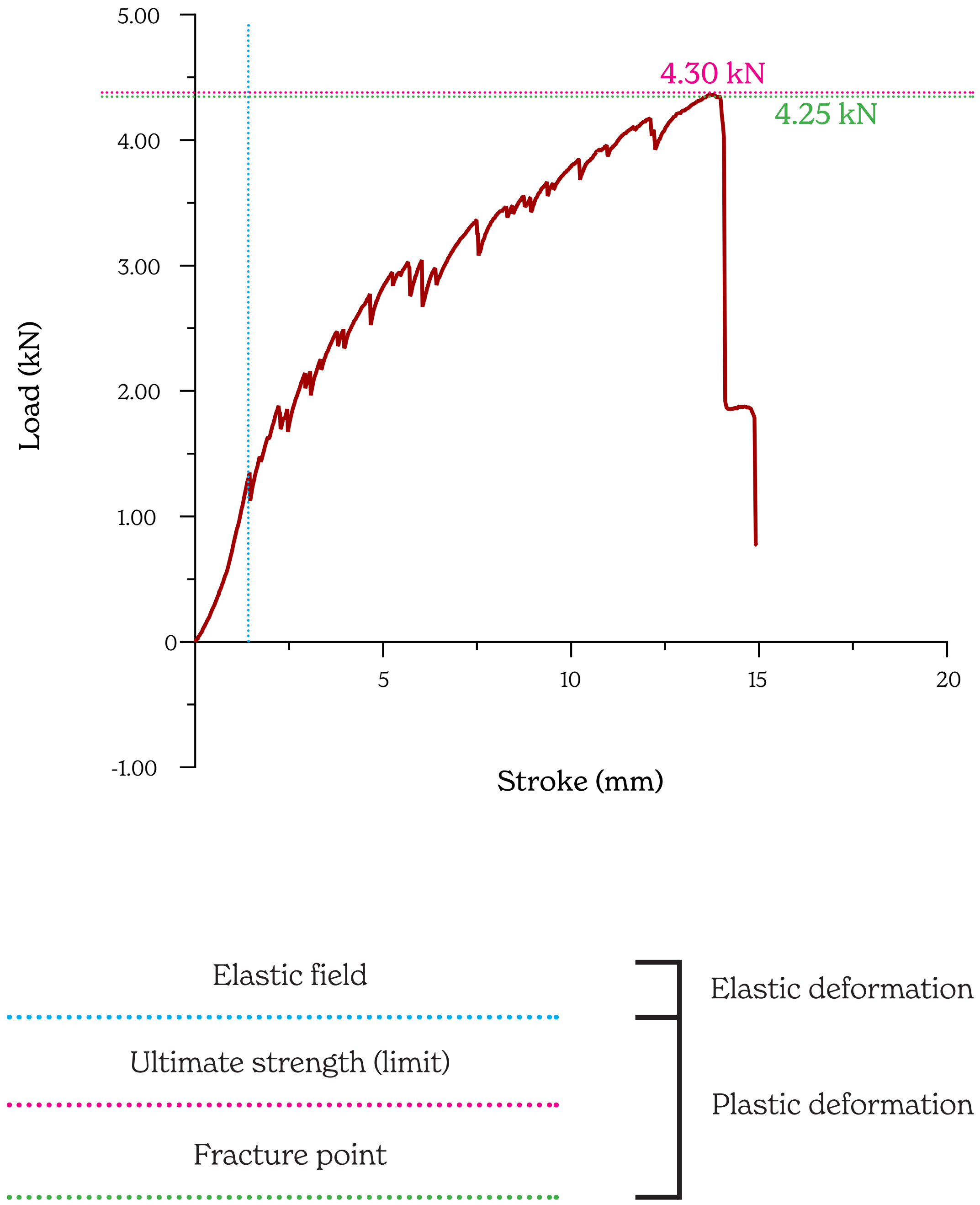
It demonstrated an astonishing resistance to external loads.

As the specimen entered the plastic field, multiple flexural cracks developed on the wings, a typical phenomenon observed in these types of specimens. As the loading on the specimen persisted, a significant localized fracture occurred at the loading point, ultimately leading to the complete collapse of the section.

The collapse happened suddenly, with the strength rapidly decreasing from 4 kN (pre-collapse settlement) to 1.9 kN, resulting in the collapse of the section.

The numerical disparity observed in comparison to all the previous specimens has prompted distinct considerations, which will be addressed in the subsequent section.

However, similar to section number 12, the collapse of this section occurred more abruptly.



Specimen SR | Description

This test sample was created with the purpose of providing a direct comparison between a metal mesh reinforcement and the fiberglass mesh used for the other samples.

A single layer of metal mesh, slightly tensioned by hand, was placed, upon which the concrete layer was applied using the same proportions as the other samples: 2 kg of sand, 2 kg of cement, and 0.8 kg of water.

As can be seen from the photos on the following page, the mesh size of the metal reinforcement is considerably larger than that of the fiberglass mesh. For this reason, the mortar did not adhere perfectly in all points of the sample, and its thickness is not uniform.

Specimen SR | Tests Results

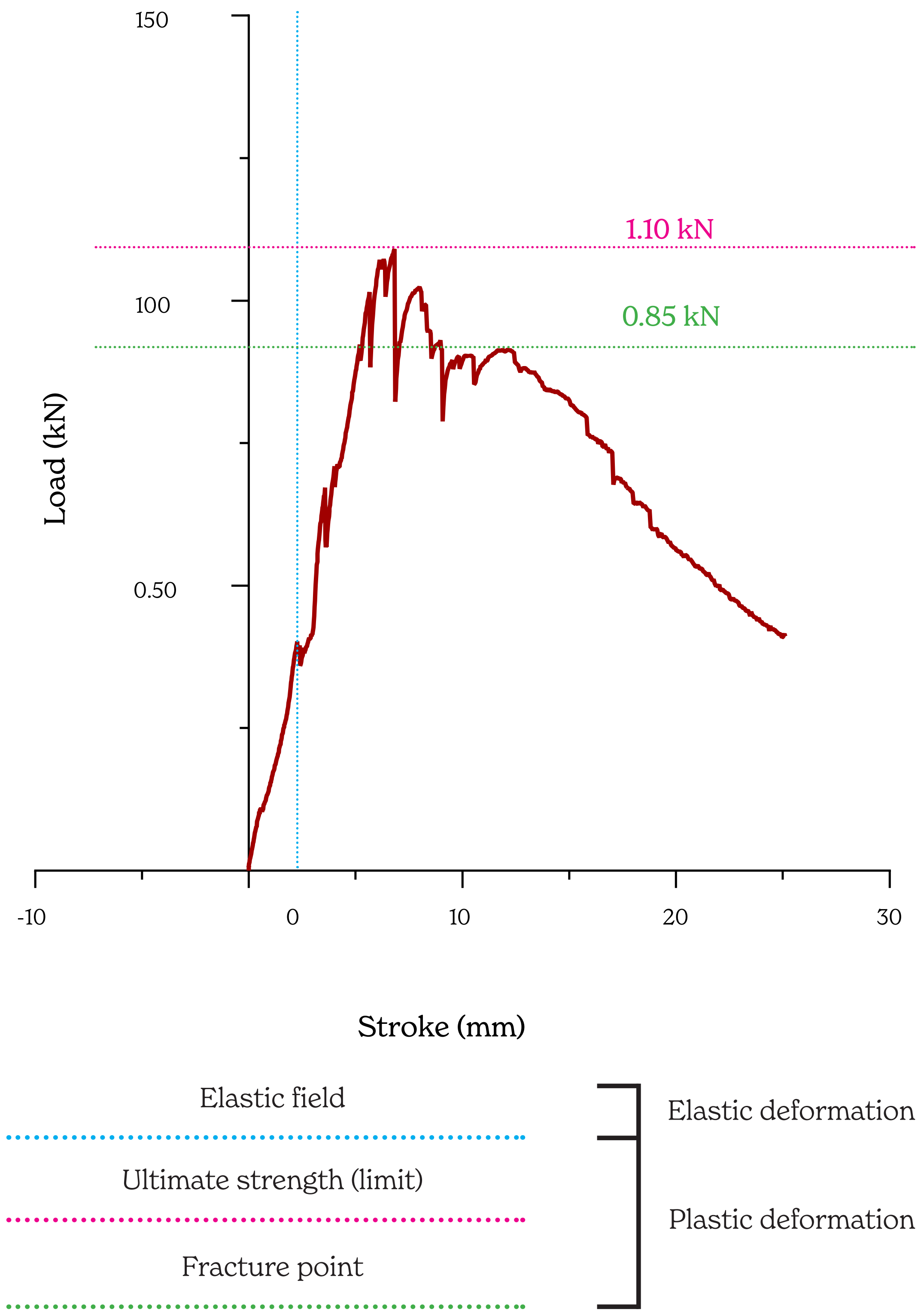
This specimen was produced and tested to provide a direct comparison of the performance between fiberglass mesh and steel mesh used in this specimen.

In the initial phase of the plastic region, the section exhibited several flexural cracks, and it is also evident from the graph that the steel reinforcement imparts ductility to the section.

Considering that the thickness of the steel mesh is significantly greater than that of the fiberglass mesh, this resulted in the incomplete embedding of the mesh within the concrete thickness. As a result, the obtained load performance may not be entirely exhaustive.

As can be observed from the graph, it reaches maximum stress at 1.10 kN and breaks at 0.85 kN.

However, further research can be conducted on this type of specimen to achieve a better comparison between the two types.



04.6.1 Comparison specimens

In this part, two comparison specimens are described. It was interesting to better understand the potentiality of this research, having a comparison with other two different options.

Then, a first specimen was tried with just mortar, without any reinforcement material. The mixing is always composed of 2 kg of cement, 2 kg of sand, and 0,8 kg of water, and a thin concrete omega profile was obtained.

This experiment was done to demonstrate the efficiency of the fiberglass net reinforcement. In fact, without reinforcement, the expectation was one of having a less resistant specimen. This prediction turned out to be true, and the specimen cracked just after the remotion phase from the body. It wasn't expected to be so fragile, but this surprising event has been very useful to understand how much the difference between a specimen with a fiberglass net reinforcement and a specimen without any reinforcement. Also, it is very interesting to analyze where the first crack occurred we are talking about an area already mentioned before, which is the part that connects the arch to the two wings. This area was the first one to crack just after the remotion of the specimen from the body.

So, to recap, the importance of reinforcement and in particular the difference that the fiberglass net has done in resistance is vital

to understand what is possible to do with this new material as reinforcement, also because without it, this mixing of concrete turned out to be very fragile.

The second comparison specimen is different for the type of reinforcement that has been decided to use. The selected reinforcement is always a net, but it is composed of steel and it has a larger mesh respect to the fiberglass net used for all the specimens of this research. This choice has been made to have a complete view of the potentiality of fiberglass and how much can resist to stresses in comparison with a steel net. The latter, is made of larger meshes respect to the used fiberglass and the other big difference is that the mesh of the yarn is not welded but woven, and this feature definitely creates more distortion of the meshes when this is pulled. for this reason, pretension on this type of mesh was minimal and done by hand, to safeguard the integrity of the textile structure as much as possible.

There is to be said in favor of this type of mesh, that having less elasticity, this adheres better to the body of the formwork, ensuring precise adhesion without where to resort to special techniques. it is certain, however, that the weight of this specimen is definitely higher than a specimen with fiberglass reinforcement, consequently the concept of wanting to keep the weight of the beam as low as possible so as to obtain the various advantages already mentioned before.

Project

05

This chapter focuses on the analysis of three distinct projects that, despite having different characteristics in terms of usage, technological solutions, and spatial aspects, share a common element: reinforced concrete beams with fiberglass mesh. The primary objective of these projects is to ensure the development of a product that is economically viable, lightweight, and environmentally friendly. Additionally, attention is given to the ease of transportation and assembly through simple yet functional procedures.

These projects are positioned within contexts characterized by emergencies, necessity, and temporariness. However, it is important to highlight that this does not exclude the possibility of these solutions evolving over time to become something more stable and long-lasting.

The choice to use reinforced concrete beams with fiberglass mesh in emergency contexts responds to the need to provide reliable and easily implementable structural solutions promptly. The lightweight nature of these beams makes them ideal for transportation and easy assembly, enabling a swift response to crisis situations. Alternatively, as demonstrated through laboratory experimentation, there is a concrete possibility of self-building the beams on-site without requiring large spaces or machinery. Furthermore, the low cost involved in constructing these beams makes them accessible even in situations with limited financial resources.

Despite their initial scope of application being emergencies, these projects can offer long-term perspectives. The evolution of such temporary solutions can occur through the introduction of additional elements or modifications that transform temporary structures into buildings with a forward-looking approach. This flexibility and adaptability of the projects represent a significant advantage as they address initial needs while ensuring the possibility of future development.

The first project involves a module for a residential unit with masonry partitions. In this case, reinforced concrete beams with fiberglass mesh are used to cover a warm environment. Optimal comfort performance needs to be guaranteed, and thus, a structured floor package providing effective thermal insulation is adopted.

The second project consists of a steel-structured shed where reinforced concrete beams with fiberglass mesh are employed to cover a cold environment. In this case, the roofing package does not require the same structuring as the first project but must be waterproof to ensure protection against weather elements.

Lastly, the third project concerns a temporary pavilion, where reinforced concrete beams with fiberglass mesh are used as both beams and columns. The pavilion is a closed yet cold environment and does not require heating systems as it is temporary in nature.

In conclusion, the analysis of these three projects emphasizes the importance of considering not only structural efficiency but also economic and environmental aspects in the design of reinforced concrete beams with fiberglass mesh. Although initially conceived to meet emergency and temporary needs, these projects have the potential to transform into more stable and durable solutions. Their

flexibility, lightweight nature, and ease of assembly offer advantages in terms of rapid implementation and future adaptability, paving the way for sustainable and cost-effective construction practices.

Module – Close Cover

05.1

The beam that has been analyzed so far has found its first practical application in the design of a housing module. This module serves as a base unit and allows for the creation of a complete dwelling by combining multiple modules.

It is important to emphasize that initially the module will be used in emergency situations where a quick response is crucial. However, it is important to highlight that the ultimate goal of the module is not limited to this emergency condition. On the contrary, its main purpose is to serve as a foundational module that will develop over time and become a durable and stable housing solution over the years.

Based on the dimensions obtained in the laboratory, a prototype of the housing module has been created, which measures 2.85 meters per side. The supporting structure of the module has been designed with a very simple model, using standard ISO bricks with a three-headed configuration to ensure better adherence to the roof beams. The beams are connected to the underlying walls by applying a layer of mortar to ensure a solid connection between the two elements. The beams are arranged side by side to balance the mutual horizontal forces.

As shown in the detailed drawings below, there is a layer of cement between each beam to make the contact point stronger and sealed. On top of the beams, a concrete slab- tickness 4.5 cm - is placed, reinforced with a fiberglass mesh and potentially self-made on-site, serving as a support base for the upper layers.

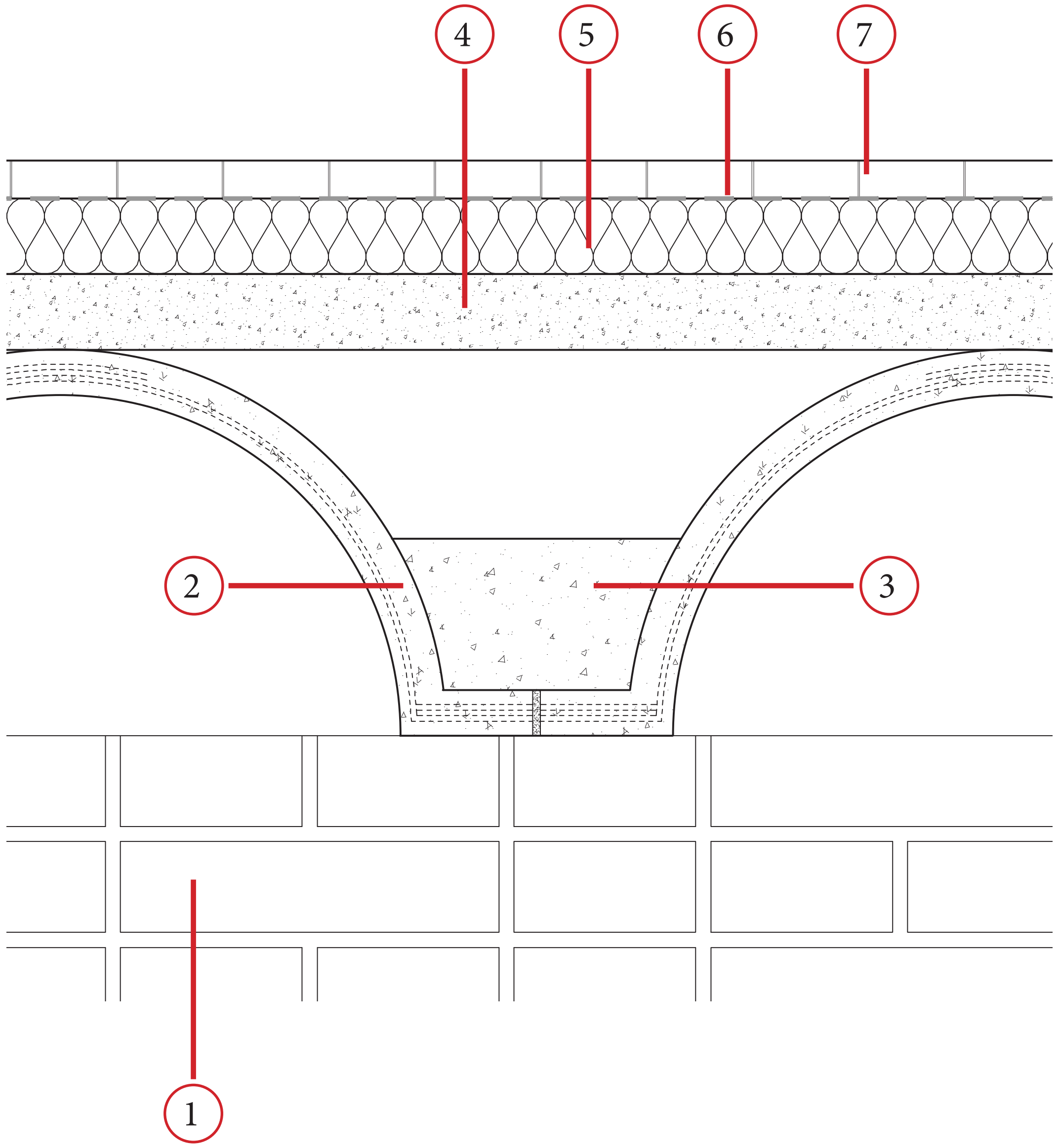
On top of the concrete slab, a layer of insulation with a thickness of 5.0 cm has been placed. The thermal insulation used is called ‘SINTHERM FR,’ manufactured by Maiano manifattura. It is a 100% polystyrene fiber insulation, of which at least 75% is made from recycled plastic bottles (PET). It is fully recyclable and/or reusable, and no chemical additives are present. Subsequently, a waterproofing membrane is installed, sealing the entire roof and protecting the underlying layers from weather elements.

Finally, there is a finishing layer of cement wood, with a thickness of 3.0 cm.

The roof is sealed along the perimeter using a row of individual bricks on which the coping is placed. This project demonstrates the efficiency of the beams in finding practical solutions.

Stratigraphy

05.1.1



[1] - Load-bearing wall made of standard ISO bricks - 5.5 cm, 12 cm, 25 cm - constructed using a three-course block bond

[2] - Reinforced concrete beams with fiberglass mesh -Omega section- dimensions 63 cm, 25 cm, 240 cm.

[3] - Valley concrete 10 cm

[4] - Fiberglass reinforced concrete slab - thickness 4.5 cm

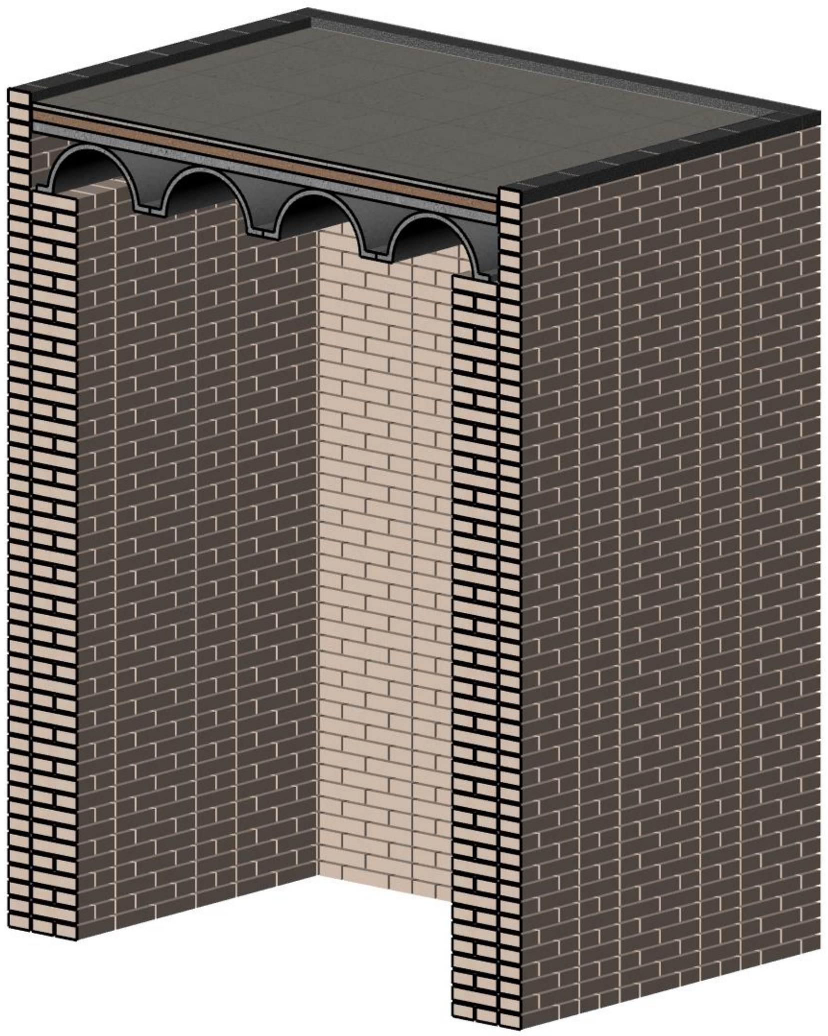
[5] - Thermal insulation panel - SINTHERM FR - thickness 5.0 cm

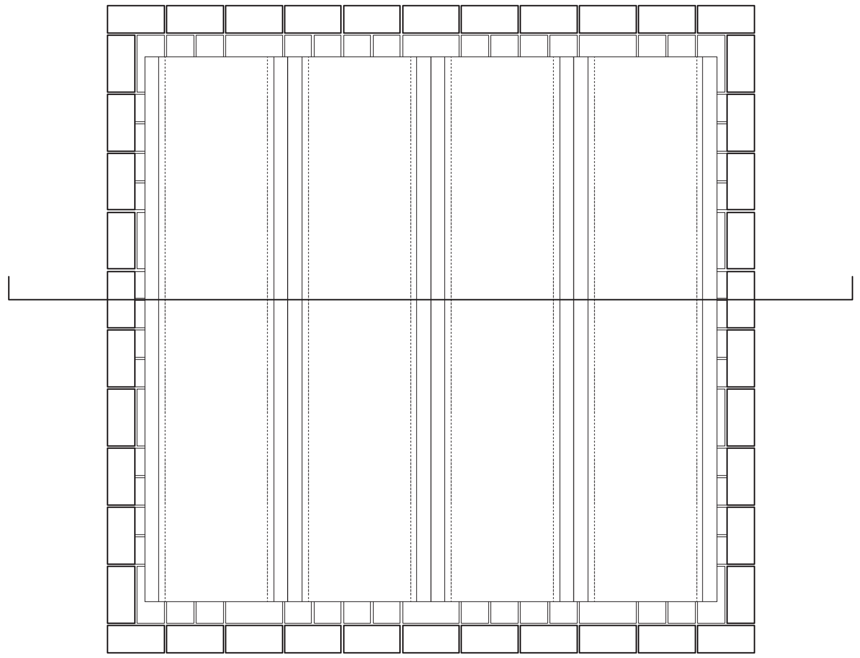
[6] - Water-proofing layer

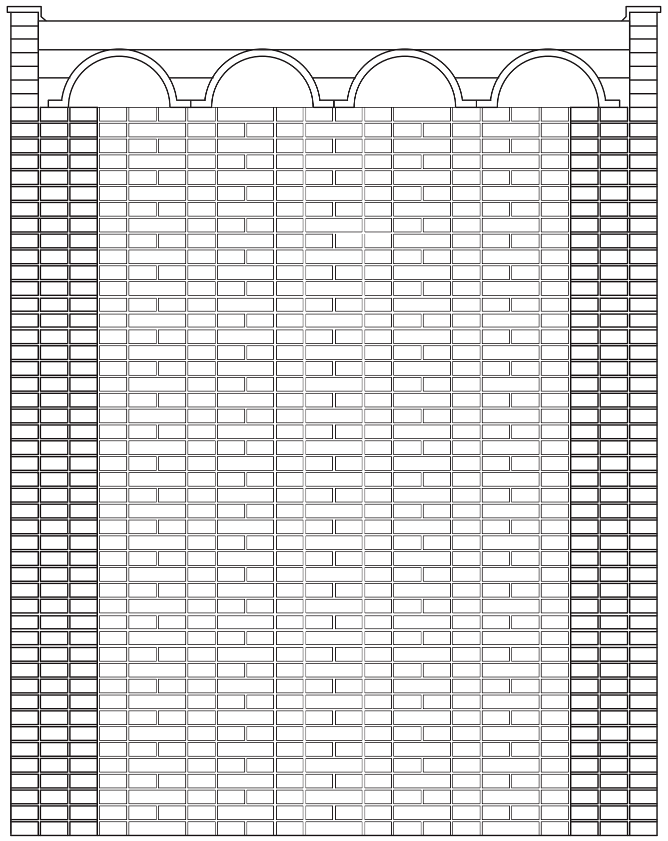
[7] - Finishing layer - Cement wood - thickness 3.0 cm

Drawings

05.1.2







Pavillion

05.2

The second application project proposed is an exhibition pavilion with the goal of trying to introduce an innovative construction approach.

For this project the fiberglass net reinforced concrete elements not only serve as load-bearing elements but also function as pillars, creating a beam-to-column connection. Its design, given the temporary nature of the pavilion, takes into account the need to create a cool and semi-open environment for visitors. As such, the decision was made to leave the roof beams exposed, devoid of any conventional coverings or roofing materials.

The choice to expose the beams provides an aesthetic appeal that harmonizes with the overall design concept, while also allowing for efficient air circulation and a sense of openness within the pavilion. Also, to ensure a visually pleasing and uniform surface finish, a thin layer of finishing plaster has been carefully applied, resulting in an aesthetically captivating and harmonious visual experience.

When it comes to the critical connection points between the beams and pillars, a meticulous and well-thought-out approach has been employed. The chosen method involves utilizing L-shaped wooden joints, which are meticulously fitted and securely fastened using bolts. This dry joining technique ensures precise alignment and a strong connection between the beams and pillars, promoting stability and structural integrity.

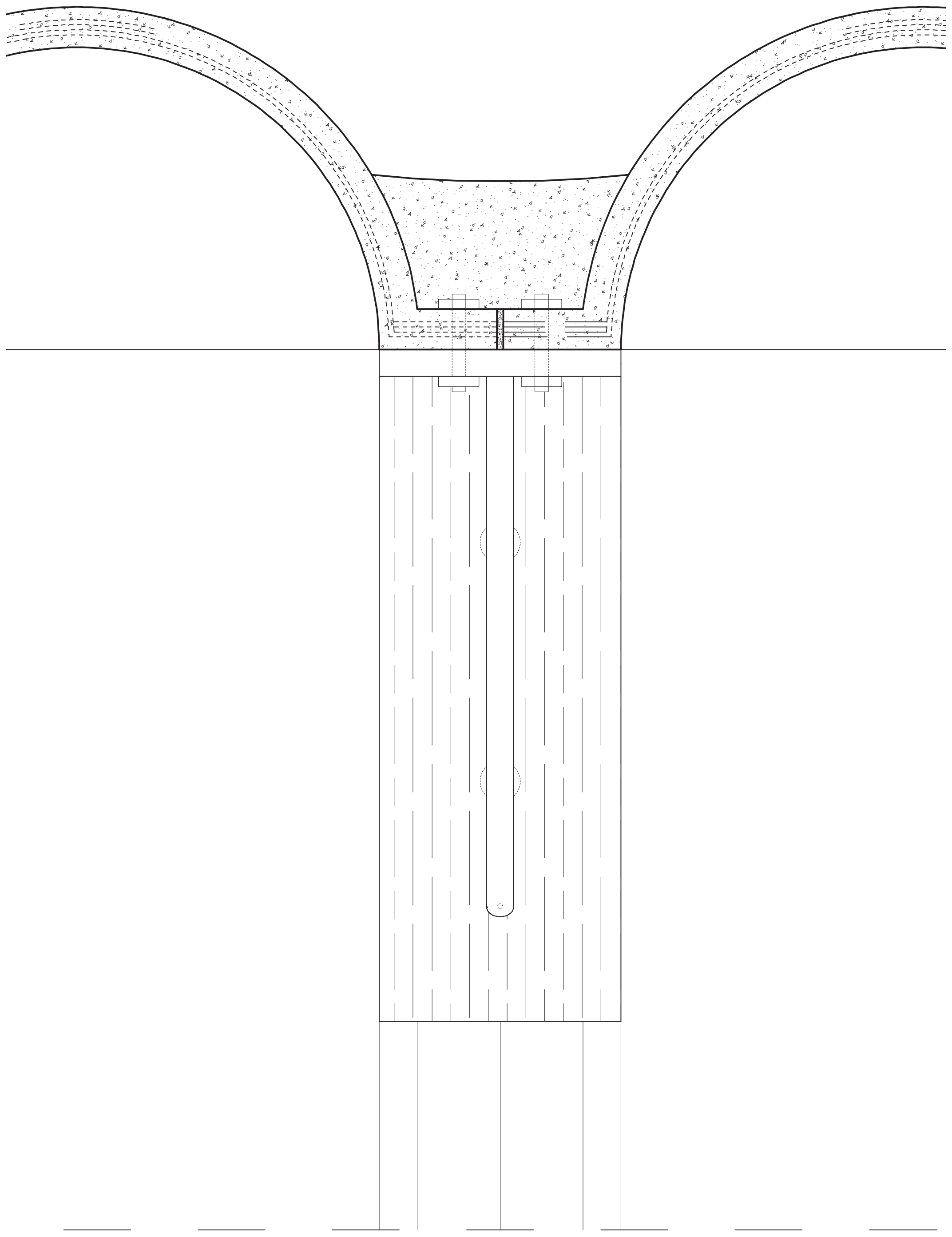
To further enhance the bond and cohesion between the different elements, a thin layer of mortar has been strategically applied, optimizing the adhesion and creating a seamless integration between the pillars and beams.

The emphasis on a lightweight and transportable design ensures that the pavilion can be relocated to different locations, facilitating its accessibility to a wider audience. This mobility factor contributes to the pavilion's sustainability credentials, as it eliminates the need for constructing new exhibition spaces at each venue and reduces the overall material consumption.

From the architectonical point of view this construction technique results to be an optimum solution for temporary exhibition spaces that require flexibility and adaptability.

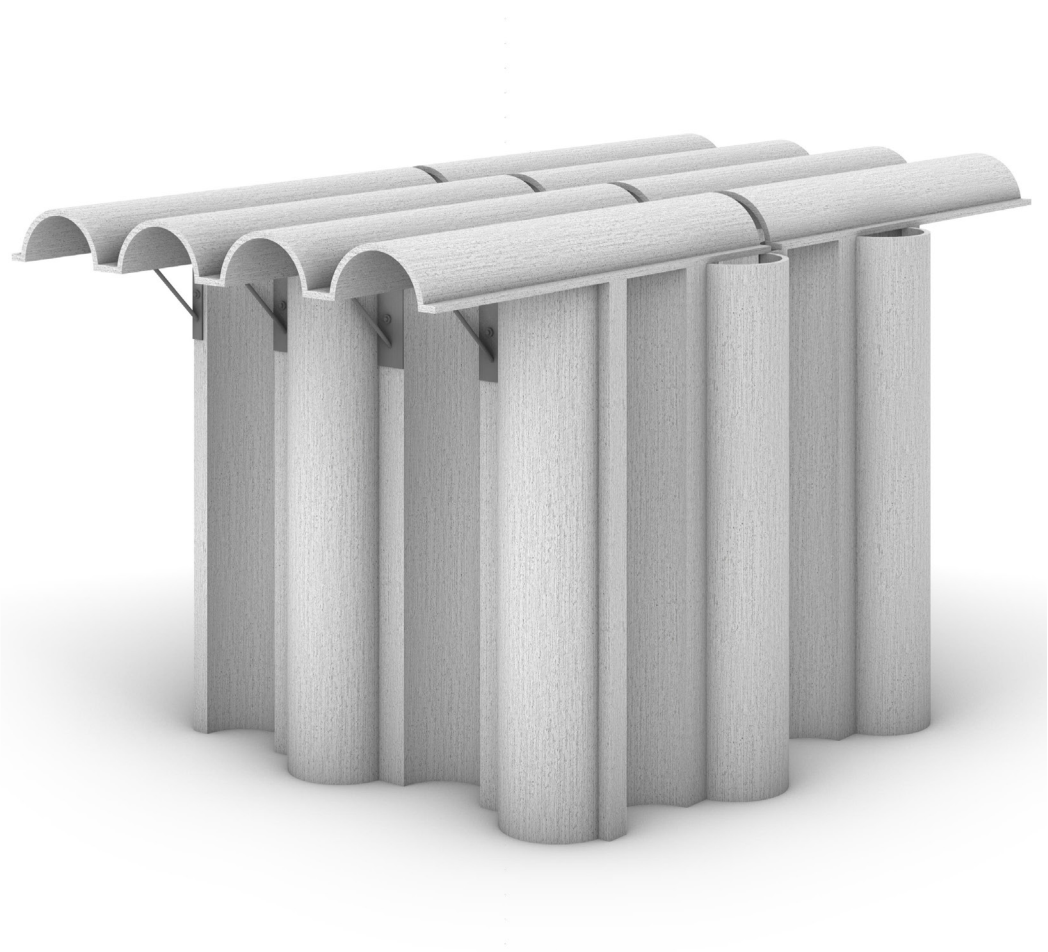
Also, some design choices such as leaving the roof beams exposed and employing a meticulous connection methodology, further contribute to the pavilion's uniqueness, making it a building with sinuous and impactful shapes, thus attracting the attention of possible visitors who are thus enticed to enter.

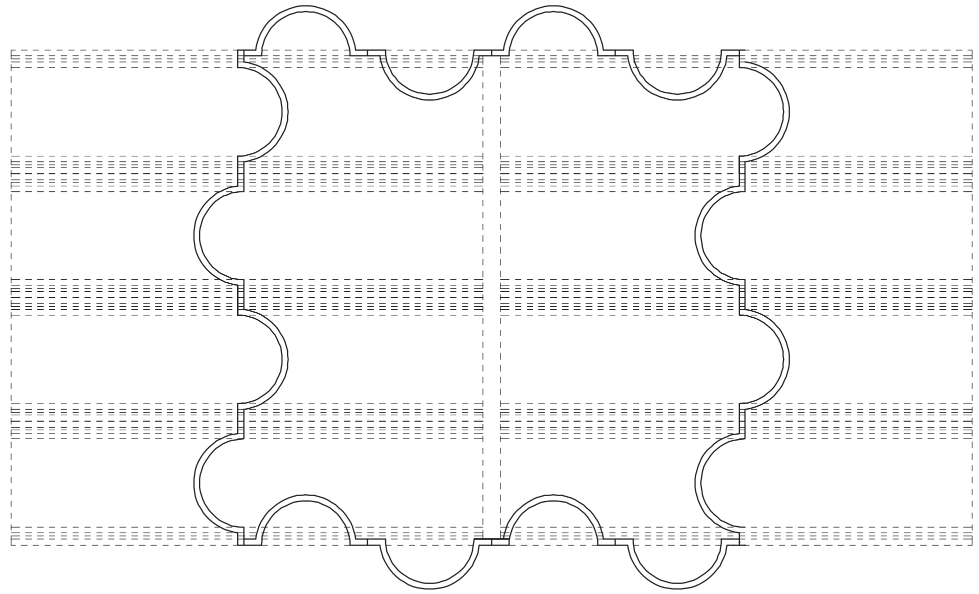
Stratigraphy 05.2.1

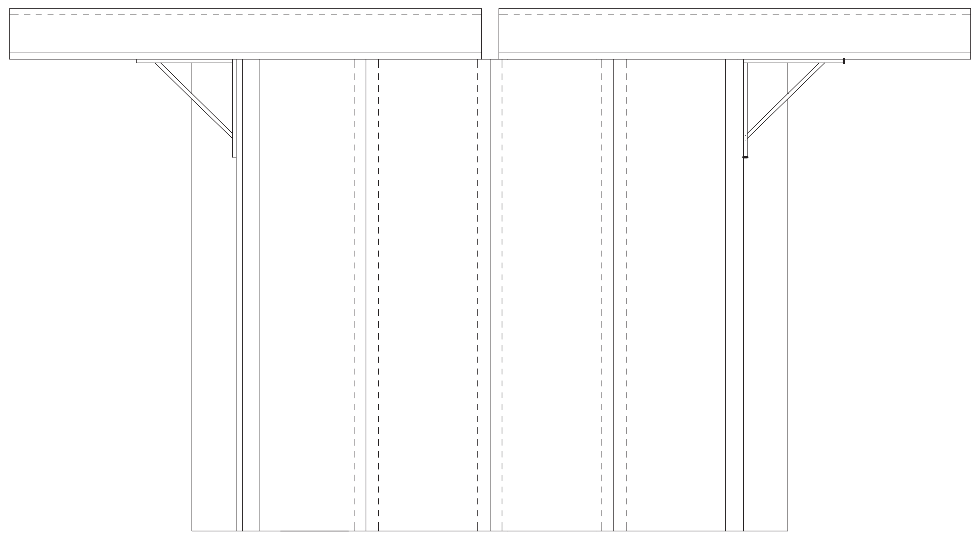


Drawings

05.2.2







Conclusion 06

Upon analyzing the various observations and data, several key findings can be derived. The specimens exhibited flexural failure upon reaching their maximum strengths, which varied between specimens.

The maximum strength values ranged from 0.87 kN (specimen 9) to 4.3 kN (specimen 13), indicating different levels of strength and ductility among the tested specimens. Additionally, the corresponding beam deflections at the breaking points varied from 2.3 mm (specimen 5) to 13.8 mm (specimen 13), further highlighting the variations in behavior.

Crack patterns were a notable feature observed in the specimens. Multiple flexural cracks developed on the wings, gradually propagating until reaching the breaking point. These consistent crack patterns across the specimens suggest characteristic behavior under flexural loading.

Localized fractures were also observed at specific points, such as the top of the curvature, indicating potential stress concentration areas.

The role of reinforcement, particularly fiberglass fibers, on the wing sections of the specimens proved to be crucial. Specimen 12, featuring fiberglass fiber reinforcement in more stressed areas, exhibited a more controlled collapse compared to the other specimens.

Conversely, specimen 13, with fiberglass reinforcement throughout the entire section, demonstrated the highest resistance but experienced a sudden collapse. These findings emphasize the importance of considering the distribution and quantity of reinforcement when designing reinforced concrete sections for optimal performance.

Furthermore, the thickness of the section emerged as a significant factor influencing specimen behavior. Thicker sections with reinforcement in critical areas provided increased resistance and controlled collapse. Thus, selecting an appropriate section design should consider a balance between strength and ductility.

Future research could explore alternative reinforcement materials, optimize reinforcement distribution, and investigate the effects of varying section thicknesses to achieve an optimal balance.

In conclusion, the test results underscore the significance of section thickness and reinforcement distribution in determining the flexural behavior of these types of reinforced concrete specimens. The use of fiberglass fiber reinforcement shows promise in enhancing resistance while controlling the collapse phase. Further research and development in this field will contribute to advancing the understanding and application of reinforced concrete sections in the construction industry.

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