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Identifying the Challenges of Large-Scale Adapting of UHPFRC to Use in Bridge Repair in Norway



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ABSTRACT

Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC) offers significant potential for rehabilitating aging infrastructure, especially in cold regions like Norway where freeze–thaw cycles accelerate deterioration. With compressive strengths above 120 MPa, high fibre content, and exceptional durability, UHPFRC enables structural upgrading without imposing substantial additional deadload. This article proposes six key steps that have facilitated successful international implementation of UHPFRC ranging from laboratory mix development to the establishment of national standards. The purpose is to evaluate why Norway has yet to adopt the

material at industrial scale. While countries such as Switzerland, France, and the United States have followed a clear implementation pathway, Norway remains behind despite strong academic results, including locally developed mixes reaching 171 MPa. Remaining problems related to material logistics, risk allocation, and the absence of national guidelines continue to hinder broader deployment.

Key words: UHPFRC, Norway, Bridge Rehabilitation, Large Scale, UHPC

1. INTRODUCTION

The Norway's concrete infrastructure is aging and in need of rehabilitation [1], further challenged by harsh climatic conditions. Norwegian infrastructure is exposed to frequent freeze-thaw cycles, de-icing salts, and surface wear from studded tires, accelerating surface degradation and reinforcement corrosion. Many bridges now suffer from insufficient load-bearing capacity, and traditional concrete may be unsuitable, as its self-weight can exceed the remaining capacity of weakened structures [2]. These problems highlight the need for innovative and efficient materials.

One promising alternative is Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC), which combines high strength and durability with low weight and excellent bonding. The definition of UHPFRC differs across borders, and this paper will be based on the one used in Switzerland. According to the Swiss UHPFRC Model Standard [3] UHPFRC is a product of cement, fine aggregates and particles, additives, water, admixture and a high content of steel fibres. The lower limit for cube compressive strength after 28 days is 120 MPa, while the material reaches a tensile strength above 7.7 MPa and a strain-hardening behaviour. It enables structural upgrades without overloading the old structure [4] and is well-suited for Nordic infrastructure exposed to increasing climate stress. Since 2004, over 400 structures in Switzerland have been rehabilitated with UHPFRC [5]. It was introduced to extend the service life of aging bridges affected by chloride ingress, cracking, and growing traffic demands [2], offering a fast, durable, and low-maintenance solution with minimal traffic disruption.

In 2020, a review of five different countries' approaches to using UHPFRC in bridge construction was conducted to gain an international perspective on the technology [6]. Switzerland, South Korea, France, Malaysia, and the United States were studied, focusing on UHPFRC applications, benefits, and problems when used in bridge design. It examines various case studies and projects from different countries to highlight the diverse approaches and outcomes associated with UHPFRC in bridge construction and rehabilitation. According to the review [6], France, Switzerland, and the United States started with lab scale testing, focusing on designing and verifying UHPFRC mixes suited to local conditions. Once the properties were confirmed, the material's thixotropy needed to support effective casting. South Korea and Malaysia demonstrated constructability through full scale casting, using large girders and precast segments to showcase UHPFRC in practice. Switzerland also applied UHPFRC in full scale casting, specifically for the rehabilitation of existing bridge decks, using thin, durable overlays to extend service life without compromising structural capacity. France and the United States engaged industry partners early, involving manufacturers, contractors, and suppliers to standardize mixes and develop mobile mixing solutions. These efforts supported on site application, with the U.S. introducing mobile mixers and Switzerland developing transportable UHPFRC mixes for both urban and remote bridge repairs. As confidence in the material grew, Switzerland, France, USA, and South Korea launched pilot bridge projects to demonstrate UHPFRC's structural and aesthetic value. To support broader adoption, Switzerland, France, and the United States also played key roles in

developing national standards and guidelines, ensuring consistent and reliable implementation across infrastructure projects.

The implementation of UHPFRC compared to conventional concrete has resulted in more durable construction, less time-consuming construction process, reduced cost, maintenance cost and material use [5]. The original design concept using UHPFRC to bridge rehabilitation, involves creating a composite material consisting of the existing normal reinforced concrete (RC) and a supplementary UHPFRC layer (UHPFRC-RC). Despite international experience and promising laboratory results, UHPFRC has yet to be applied on an industrial scale in Norway. To the authors' knowledge, there is no standardised process for implementing UHPFRC in a country. Over the past two decades, several countries have established standards for UHPFRC through various parallel processes, with applications ranging from prefabricated elements and new structures to architectural features and rehabilitation projects. Nevertheless, despite Norway's considerable need for more efficient bridge rehabilitation methods, it remains one of the countries that has not adopted UHPFRC on a large scale.

2. OBJECTIVES AND SCOPE

The paper will focus on how UHPFRC has been successfully implemented internationally, and what steps were taken in the process. It will then evaluate Norway's status in relation to these practices and identify the key barriers preventing the widespread adoption of UHPFRC to rehabilitate concrete bridge deck. The aim is to uncover the specific problems and constraints that hinder the large-scale implementation of UHPFRC in Norwegian bridge repair projects.

This report seeks to answer the following research question:

What steps have enabled successful UHPFRC use for bridge deck repair internationally, and how does Norway compare?

3. METHODS

This study is based on a combination of a literature review and qualitative consultations with key stakeholders in the Norwegian construction industry. International experience was evaluated through a review of relevant international literature, including scientific journal articles, reports, and industry publications. The aim of the literature review was to identify established practices, documented performance, and reported experiences from international projects.

The available literature describing Norwegian experience and current status is limited. To complement the scarce national literature, Norwegian experience was assessed through an examination of selected Norwegian research projects, with particular emphasis on project objectives, methodologies, and reported outcomes. In addition, the data material was supplemented by qualitative consultations with leading experts in the Norwegian concrete industry. These consultations were informal; no formal or structured interviews were conducted. Further insight was obtained through participation in a newly established working group within the Norwegian Concrete Association, which works towards developing a national recommendation for the use of UHPFRC. Close dialogue during ongoing UHPFRC-related projects and meetings within the working group were used to provide additional inputs to the paper. The contributors to this paper represented contractors, research institutions, and concrete producers, thereby

providing perspectives from across the value chain. These consultations were conducted to obtain practice-based insights into current implementation, technical problems, and the level of maturity in Norway. The information obtained was used to support a comprehensive assessment of the Norwegian status and to contextualize the findings from the literature review and project analysis.

4. RESULTS AND DISCUSSION

4.1 Approach to Implement UHPFRC

Switzerland is the country with the highest use of UHPFRC technology in the world relative to its size [5]. Swiss Federal Institute of Technology Lausanne (EPFL) has played a pivotal role in the implementation of UHPFRC to the Swiss industry. Since the early 2000s, the UHPFRC technology has evolved from lab-scale innovation to widespread use in bridge rehabilitation and constructions. In 2021 a review of the application of UHPFRC in Switzerland were conducted by Bertola et al [4]. Switzerland's journey began with academic-led research, focusing on durability, mechanical behaviour, and composite action with reinforced concrete (RC) structures. Over time, it integrated industry collaboration, leading to premixed UHPFRC availability, pilot projects and most recently policy and guideline development, culminating in SIA 2052 [3].

Recent studies evaluated from Switzerland [4, 6] have identified several key enablers that contributed to the country's leadership in adopting UHPFRC for bridge construction. These includes (1) a robust system of engineering and vocational training that equips professionals with the expertise and confidence to work with emerging technologies, (2) the establishment of the national design standard SIA 2052 [3], which offers a clear yet flexible regulatory basis for UHPFRC applications, and (3) motivating professional and financial incentives that make the use of UHPFRC both technically satisfying and economically viable. While these elements are specific to the Swiss context, they align closely with some broad patterns and similarities identified in the review of the five countries [6] introduced in Section 1.

Based on a comparative synthesis of the international literature, the present study identifies a set of common implementation steps that recur across national contexts. Although no fully systematic or standardized framework for UHPFRC implementation has been universally defined, Switzerland, South Korea, France, Malaysia, and the United States exhibit similar progression pathways in their adoption processes. From the reviewed studies, these steps can be defined as follows: (i) lab-scale testing, (ii) concepts and casting, (iii) industrial collaboration, (iv) ready-mix UHPFRC, (v) pilot projects, and (vi) the development of standards and guidelines. Figure 1 illustrates the suggested pathway based on the five countries consisting of the six sequential steps.

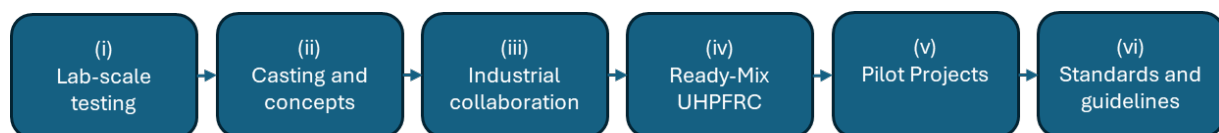


Figure 1 – The approach to implement large-scale UHPFRC to the industry.

In Switzerland's case [4], the strong educational foundation supports early-stage innovation and testing (i, ii), while the motivation and capacity of local professionals contribute to successful industry collaboration and pilot implementations (iii, v). The availability of a commercial premix since 2013 and the clarity offered by SIA 2052 [3] directly support steps (iv) and (vi), enabling widespread application. The following sections will use the suggested six-step framework to

examine the international approach and evaluate how it may contribute to uncover the key problems preventing large-scale adoption of UHPFRC in bridge repair projects across Norway.

4.2 Lab-Scale Testing

This subsection describes the first step of the proposed approach, focusing on the lab scale testing of UHPFRC. Considering the academic-led research focusing on lab scale, the material properties have been closely evaluated. To obtain a workable mix design with sufficient strain-hardening, EPFL specifies a fibre content of at least 3 vol.-% [4]. For the mix to be workable, the mix must be self-compacting ensuring uniform fibre distribution and performance in tight spaces. Thixotropic behaviour is crucial when casting, to avoid issues like fibre misalignment or segregation. The recommended maximum aggregate size is 1 mm, according to the Swiss UHPFRC Model Standard [3].

According to SIA 2052 [3], several tests are required to ensure that UHPFRC meets essential performance standards. Compressive strength is assessed using EN 12390-3 for conventional concrete [7] to evaluate the material's primary load-bearing capacity at 28 days (Appendix C.1 [3]). In Switzerland, the compressive strength typically ranges between 150 and 200 MPa [8], with a minimum requirement of 120 MPa [3]. According to Azanaw [9], UHPFRC may exhibit compressive strengths of up to 250 MPa. Similarly, the French standard NF P18-710 [10] defines compressive strength within a range of 130 MPa to 250 MPa, while allowing for lower values provided that durability performance is not compromised.

Modulus of elasticity is measured per EN 12390-13 [11] to determine stiffness, using 6 specimens for initial tests or 3 for quality checks (Appendix C.1 [3]). UHPFRC usually obtains a modulus of elasticity between 40 and 55 GPa [8, 9]. Flexural bending strengths are tested at 28 days as described in [3] Appendices D and E and used to categorize ductility. Impermeability is verified using the capillary absorption method (EN 13057 [12] to confirm low water ingress, ensuring durability. The minimum tensile strength of UHPFRC is 7.7 MPa, according to the SIA 2052 [3]. It exhibits very high resistance to chemical degradation, freeze-thaw cycles, and water penetration due to its strain-hardening behaviour when the fibre content exceeds 3 vol.-% [8]. In such cases, the tensile strength after strain hardening typically ranges between 8 and 14 MPa. Anzanaw [9] noted that tensile strength varies with fibre content. UHPFRC containing 0-2 vol.-% achieves a tensile strength between 8 and 12 MPa, while a mixture with 2-4 vol.-% reaches 10-15 MPa.

Crack resistance differs correspondingly and is usually higher for UHPFRC containing more than 2 vol.-%. In Czech Republic [13], composite beam elements, consisting of a 120 mm reinforced concrete (RC) layer topped with either a 30 mm or 50 mm UHPFRC layer, were tested under four-point bending with the UHPFRC layer placed in both tensile and compression zones. The addition of the UHPFRC layer enhanced the load-bearing capacity in both configurations. However, the 30 mm UHPFRC layer with 2 vol.-% fibres and no additional reinforcement did not provide sufficient ductility, leading to an early failure shortly after crack initiation. The UHPFRC mix was thus altered with a fibre content of 3 vol.-% to achieve a water tightening effect and supports Brühwiler's [8] recommendation of a fibre content of minimum 3 vol.-%. The French standard NF P18-710 [14] does not specify a required fibre content for UHPFRC. However, in practice, the French industry commonly uses a simplified table based on NF P18-710 [10] and NF P18-470 [14] for the preliminary design of UHPFRC structures. This table relates fibre volume content to corresponding mechanical performance parameters. It is clearly noted that when using less than 2

vol-% of fibres, the material does not exhibit the same level of durability, particularly with respect to water ingress resistance and tensile strength.

Fresh mix properties, slump, density, and air content, are measured to ensure proper workability, using EN 12350 series standards (Appendix C.4 [3]). Slope suitability is tested by casting UHPFRC on an inclined slab and visually inspecting deformation post-hardening, see Figure 2 (Appendix C.5 [3]). For the repair of bridge decks, the ability to cast on a slope is particularly important. A patented composition developed by TBG Metrostav is one of the products that enables slope casting [13]. This material was used in a pilot project on the Barrandov Bridge in the Czech Republic, where casting was successfully carried out on a slope of up to 8%. The mix used a $D_{\max}$ of 4 mm and contained 3 vol.-% of fibres. LaFarge Holcim's Ductal may be cast in a slope of 0-15 % with a high content of fibres and $D_{\max}$ 0.6 mm.



Figure 2 – Suitability test for inclined slab.

In Norway, the focus has been on developing UHPFRC materials with local constituents. Some of the research work on locally produced UHPFRC started over ten years ago, initiated by Elkem [15]. Fidjestol et al. [15] investigated the possibility of developing UHPFRC with local materials. Compressive strength above 140 MPa was achieved for some of the mixes. Following this, research at the University of Agder investigated the possibility of using only crushed aggregates [16]. The crushed aggregates were filtering harvested granite dust gathered in the cleaning system from the production of gravel. $D_{\max}$ was 0.3 mm. An average compressive strength above 170 MPa was achieved using the standard for strength properties of cement mortar (40 mm). The binder content was in the next step reduced [17], as well as applying normal crushed aggregates with $D_{\max}$ 6 mm [18]. The compressive strength achieved was 155.4 MPa for heat cured 50 mm cubes at 90 °C for 48 hours and 150 MPa for 100 mm cubes [17]. Following this, a research project in cooperation with the industry has been conducted, including laboratory mixing of UHPC [19]. The recipes were based on locally available materials on silo in Norway at Ready Mixed Concrete (RMC) plants with normal natural sand with $D_{\max}$ 8 mm. The compressive strength achieved during laboratory production was from 136 MPa [19] up to 170 MPa [20]. An overview of some of the laboratory programs in Norway is shown in Table 1.

Table 1: Overview over laboratory tests in Norway

Laboratory program	Year	Sand type	$D_{\max}$ [mm]	Binder content [kg/m ³]	Max. av. compressive strength [MPa]	Test specimen size [mm]	Reference
Elkem and UiA	2010	Sieved natural sand	1	1168	154 ¹	50 cubes	[15]
Elkem and UiA	2010	Sieved natural sand	0.5	1303	147 ¹	50 cubes	[15]
UiA 1	2015	Crushed granite dust	0.3	1153	170 ²	40 prisms ³	[16]
UiA 3	2017-2018	Crushed granite dust	0.6	891	130 ¹ , 152 ²	100 cubes	[17]
UiA 2	2018	Crushed aggregate	6	958	155 ²	50 cubes	[18]
UiA 4	2018-2019	Crushed granite dust	6	945	150 ²	100 cubes	[17]
National R&D project	2020	Natural sand	8	913	136 ¹	100 cubes	[19]
R&D project	2024-2026	Natural sand	8	916	171 ¹	100 cubes	[20]

¹ 28 days strength cured at 20 °C, ² Cured at 90 °C for 48-72 hours, ³ Tested halves of 40 × 40 × 160 mm prisms

4.3 Casting and Concepts

After the mechanical properties of the UHPFRC have been evaluated, the next phase is regard the casting and concepts. This subsection describes some conceptual designs from Europe both with regards to casting and how to use it.

The fresh-state properties must align with the functional requirements of the UHPFRC. In applications involving exclusively horizontal casting surfaces, a self-compacting UHPFRC may be employed [13]. However, for bridge decks intended to serve as the final wearing surface without additional overlays, the material must possess sufficient workability to be cast on sloped surfaces. This necessitates a thixotropic formulation, as outlined in the laboratory testing procedures described in the preceding subsection.

During the last 25 years [2, 4, 5], three distinct cross-sections are designed and tailored to specific structural needs. Figure 3 (a) illustrates how a layer of UHPFRC (minimum 25 mm in tensile

zones) may be used to protect existing concrete as well as act as a waterproofing layer to increase the durability of the structure. Figure 3 (b) and (c) show two different versions of adding a layer of reinforced UHPFRC (R-UHPFRC) to existing reinforced concrete. In both cases the minimum thickness of the R-UHPFRC layer is 40 mm and the purpose is to increase the load bearing capacity, durability and protect the structure. In cases where the rebar in the existing concrete is compromised, damaged concrete needs to be removed and replaced with R-UHPFRC to restore durability and the structural integrity, Figure 3 (c).

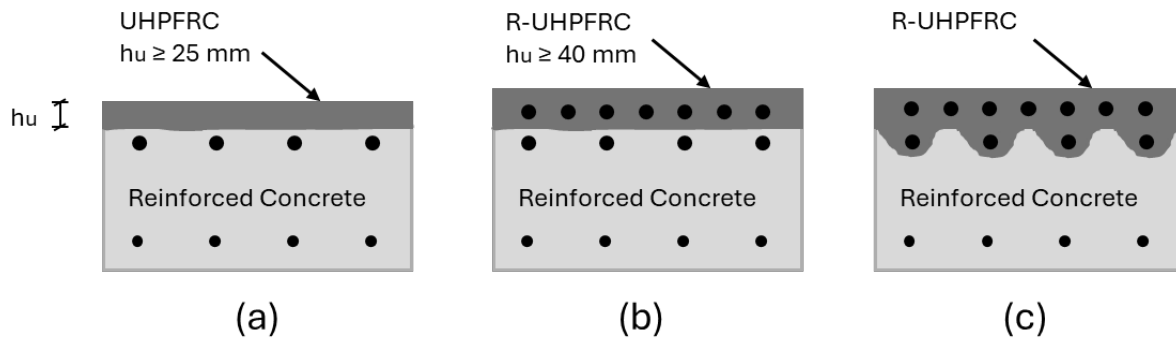


Figure 3 – Design concepts of UHPFRC-concrete composite construction: a) Unreinforced UHPFRC layer to protect the existing structure, b) Reinforced UHPFRC layer to protect and strengthen the existing concrete, c) Reinforced UHPFRC layer to protect, strengthen and restore capacity of the existing concrete. Adapted from [5].

The design concepts developed by Brühwiler et al. [4] are commonly used throughout the UHPFRC community. In Switzerland, the use of an asphalt overlay has become a standard practice, offering increased flexibility during installation [21]. However, it may result in a higher dead load, and increased material consumptions. In Austria a construction sequence on how to use UHPFRC in retrofitting of bridge deck without asphalt overlay was developed [22]. The possible construction sequence consists of removal of existing material, roughening the surface and apply the UHPFRC overlay in two stages. In [22] [23], water jetting is often used to remove the existing material, as well as providing a roughened surface to ensure sufficient bonding. After finishing the first section, it is important to achieve a sufficient bond in the construction joints by roughening the UHPFRC joints using water jetting. When water jetting the existing RC surface, prior to casting UHPFRC, an increased shear capacity is achieved according to research conducted in Germany [23]. The suggested surface design varies from road bridges to pedestrian bridges [22]. For road bridges, a "grinding method" creates surface roughness, with protruding steel fibres breaking off after freeze-thaw cycles. For pedestrian bridges, quartz sand may be used, and no steel fibres should protrude to prevent injury.

4.4 Industrial Collaboration

Industrial collaboration between academia and industry is a key enabler for the testing and development of UHPFRC. This subsection examines this topic in more depth, focusing on how collaborative frameworks contribute to material validation and industrial implementation. France began its UHPFRC journey in the 1996-1998 timeframe [6], with strong support from the industry [24]. The concrete producer Lafarge-Holcim quickly emerged as one of the leading players in UHPFRC production, notably with its Ductal product line. Due to the high cost of UHPFRC, producers, contractors, and academia collaborated to establish guidelines for when its use is

economically viable. For example, a UHPFRC structure should ideally use only 30-50% of the material used of conventional concrete structure. When it comes to durability, the economic benefit is not realized by the contractor, but rather by the project owner, who is responsible for maintaining and using the structure throughout its service life. If only the initial construction cost is considered, UHPFRC may not offer a clear advantage over conventional concrete. However, when producers, contractors, and owners collaborate and take the entire life cycle of UHPFRC into account, significant long-term benefits can be achieved. To successfully implement UHPFRC solutions, it is essential to engage the entire industry, including producers, contractors, and owners, and to consider the bigger picture.

Since the early 2000s, EPFL's Laboratory of Maintenance and Safety of Structures has been actively involved in projects where UHPFRC could potentially be applied in Switzerland [4]. This close collaboration between researchers and the construction industry significantly accelerated the adoption of UHPFRC by rapidly transferring cutting-edge research into practical applications. Contractors were also able to provide direct feedback, contributing to the further development of the material, particularly in making it more user-friendly and easier to handle during casting. In Germany, during a rehabilitation of Karl Hene Canal bridge in Leipzig, the construction contract Strabag AG, first tried to find a dry-mix concrete appropriate for this case [25]. However, there was no such product available on the German market. In collaboration with the cement producer Dyckerhoff GmbH from Wiesbaden, the company decided to develop its own formulation. 4 weeks after the initial contact between the two partners, the casting work could be carried out on the construction site.

Norwegian experience with UHPFRC shows that collaboration between industry and academia works very well. Contractors working with the material today particularly highlight close and positive cooperation with several universities. Already in 1999, a report on ultra-high-strength concrete for defence applications was published [26]. As part of a Nordic development project between the Norwegian, Swedish, and Danish armed forces, full-scale test elements were produced and tested against penetrating weapons. The Norwegian material achieved performance comparable to the Danish solution developed by Densit, while the Swedish version performed less well. Although none of the concepts progressed to production, the project provided valuable expertise to Norwegian technical communities. Since then, collaboration between industry, universities, and research institutions such as SINTEF has been central to further development, scaling, and practical application of high-performance concrete in Norway. One large initiative was the project New applications of UHPC carried out in Norway, 2017-2020 [27]. The project was a cooperation between industry partners and academic institutions. One of the central goals was to develop a UHPC mix using constituents on silo at conventional concrete plants.

More recently, several clients have approached academic institutions to test UHPFRC in practice, focusing on rehabilitation of old concrete structures with UHPFRC. This may potentially lead to pilot projects and move the implementation of UHPFRC one step further in Norway.

4.5 Ready-Mix UHPFRC

The use of ready-mix UHPFRC represents an important step toward industrial implementation. This subsection considers the commonly used ready-mix, and other possible supply concepts. The majority of countries that have conducted pilot UHPFRC projects have developed ready-mix formulations in collaboration with industry partners. Notable examples include TBG Metrostav in the Czech Republic [13, 28], Ductal, BSI and SmartUp in France, CRC in Denmark [29] and

several formulas developed by EPFL in Switzerland. Depending on the volume required and the transportation distance from the concrete plant to the construction site, UHPFRC is either mixed at the plant or delivered in pre-mixed big bags containing all dry components (e.g., sand, cement, silica fume), and bags of steel fibres. On-site production is then facilitated by a local mixer, allowing for UHPFRC to be prepared directly at the construction site.

An alternative approach involves pre-bagging dry materials using locally sourced constituents. In 2020, a concrete bridge deck in Socorro, New Mexico, was repaired using a non-proprietary UHPFRC overlay [30]. A key feature of this project was the use of local materials, which significantly reduced costs while maintaining the high performance of the UHPFRC. By using local aggregates and other materials, the rehabilitation was both economically viable and sustainable, especially in areas where high-quality, imported materials are limited. The UHPFRC mix used in the Socorro project did not achieve the typical 120 MPa compressive strength associated with commercial products. Instead, the average compressive strength was approximately 96 MPa. However, the mix was still highly effective for rehabilitation, as the primary advantages of UHPFRC lie in its exceptional durability, crack resistance, and bond strength, rather than compressive strength alone. The lower strength did not hinder its resistance to environmental degradation or its ability to extend the structure's service life. This performance is supported by standard NF P18-710, which permits lower compressive strength without compromising durability [10]. To optimize the batching process, a pre-filled dry mix approach was tested. In this method, bags were pre-loaded with sand, cement, and fly ash, while the remaining components were added on-site [30]. This technique simplifies application, reduces on-site labour, enhances mixing consistency, and improves logistics such as storage and transportation. It is particularly suitable for regions with limited access to skilled labour or specialized materials, helping to facilitate UHPFRC use in small-scale or localized projects. Nonetheless, this method presents certain problems. Proper storage is essential to prevent moisture ingress, which could compromise material quality. Additionally, the moisture content in aggregates must be carefully controlled, as it can prematurely trigger hydration of the cementitious components.

A similar mix was developed by Strabag AG and Dyckerhoff GmbH [25] using CE-made standard materials. The dry mix included separately bagged cement and dried sand and was found to be more cost-effective than commercial premixes, requiring only slightly more on-site handling. The mix met the performance criteria of SIA 2052[3], and a full-scale site trial was successfully conducted on a test platform with a 5.5% slope to simulate bridge deck conditions.

A notable challenge when using pre-bagged local materials, as opposed to ready-mixed UHPFRC, relates to quality control and documentation [24]. A ready-mix UHPFRC is not certified as a UHPFRC unless the dosing facilities and manufacturing procedure meet strict tolerances, specifically -2% to $+4\%$ for fibres and $\pm 2\%$ for all other weighed constituents [14]. In key countries such as France and Switzerland, national standards are based on ready-mixed products prepared by authorized personnel. This approach ensures accurate w/b ratios, consistent fibre content, and overall compliance with performance requirements, guaranteeing that the material is suitable for its intended use. It minimizes the risk of errors by untrained persons who are typically accustomed to handling conventional concrete.

In Norway, the situation is different. Even though most research and international experience is based on commercial mix designs or pre-bagged UHPFRC, Norwegian concrete plants prefer to use the materials already available in their silos. The current aggregate fraction is 0/8 mm, which exceeds the recommended maximum aggregate size of 2 mm for UHPFRC. Large-scale

production of UHPFRC at conventional concrete plants has been conducted at several locations in Norway using 0/8 mm aggregates [27]. It has been found possible to produce and transport the UHPFRC using conventional equipment [19, 20]. The mixing time was significantly longer, 7-8 times longer than for traditional ready-mixed concrete. The UHPFRC mixes obtained sufficient compressive strength, often above 160 MPa at 28 days [19, 20]. Figure 4 shows pictures from a full-scale production at an RMC plant. Challenges remain regarding efficient addition of steel fibres efficiently during production, as well as the incorporation of high contents of steel fibres (> 3 vol.%) in UHPFRC mixes with normal sand (0/8 mm).



Figure 4 – Production of UHPFRC at Norwegian RMC plant.

Research from Norway shows that local materials can be used; however, the question is who should take the risk. The knowledge regarding large-scale production of UHPFRC with larger aggregate sizes is still insufficient. From the concrete plant's perspective, it is too expensive to have a separate silo for sand used only for UHPFRC, since the quantities needed are too small. In addition, it may be too resource-demanding to pre-bag UHPFRC, and the material may harden before use if it is not stored properly. The product is also not yet in high demand. Another problem with silo-based UHPFRC is that the material already has a low w/b ratio, which may be compromised if the sand contains too much moisture. It is difficult to account for this variation, and more research is needed on how UHPFRC reacts when the sand properties differ, if we are to use the material available in the silos. In contrast to the concrete plants, contractors in Norway state that they would prefer to use a patented UHPFRC. This is because they do not want to take on the risk themselves. Contractors expect the material to achieve the required strength, and they would rather pay a higher price if it results in a faster execution process and lower risk. From an environmental perspective, contractors would benefit from using local materials, but to make this feasible, a certification system for UHPFRC is needed to ensure proper quality control.

4.6 Pilot Projects

Pilot projects are essential for translating UHPFRC from controlled development stages to real-world application. This subsection examines how pilot projects can be used to evaluate practical feasibility, reveal necessary improvements, and initiate iterative processes that feed back to earlier development steps to support continuous improvement. In France, several new buildings and bridges have been constructed using UHPFRC. These include the aqueduct over the Ourcq Canal, the widening of the Pinel Bridge in Rouen, the new road bridges at Philibois and Orne, the Toulouse-Lautrec Museum in Albi, the swimming pool in Saint-Nazaire, and the Saint-Jean

station in Bordeaux. These structures were primarily made with precast elements, resulting in both cost and environmental savings. Like Switzerland, UHPFRC has also been used in France for the rehabilitation of bridge decks. However, only six bridges have been rehabilitated using UHPFRC by June 2025 [31]. The main challenges include the need for casting on sloped surfaces and the dependence on skilled workers who know how to cast UHPFRC.

The Danish product, CRC by Hi-Con, has been used to construct Catharinabridge in Leiden already in 2016, using precast elements [29]. The bridge was slender and was designed to reach a compressive strength of 120 MPa, using a $D_{\max}$ of 8 mm. CRC has also been used to produce balcony's in Sweden and façade elements in Denmark. In the Nordic countries today, the majority of the use of UHPFR are precast elements, or for non-structural purpose. However, the possibility of using it to rehabilitate bridge decks is growing. In Leipzig, Germany, a footpath bridge were repaired in 2022 using UHPFRC with PVA fibres [25]. The project followed the Swiss code and was completed in a single operation (10 hours). Despite the challenge of a 5.5% slope, the 30 mm thin UHPFRC overlay effectively provided both structural reinforcement and waterproofing in one step. The use of plastic fibres successfully generated multiple controlled cracks, validating their effectiveness. This pilot demonstrated that UHPFRC enables durable and efficient repairs, providing a service life of over 100 years with minimal maintenance requirements. The successful outcome reinforces UHPFRC's potential for broader use in the repair and strengthening of aging infrastructure.

The Riddes Viaduct in Switzerland was built in 1970s and suffers from severe damage due to Alkali-Aggregate Reaction (AAR), spalling and corroded prestressing steel [32]. To limit the development of de degradation, a waterproofing and a structural layer was needed. UHPFRC was cast on the bridge deck with additional rebars which resulted in increased stiffness, higher durability and increased load bearing capacity.

A field evaluation of UHPFRC overlay on the Socorro bridge deck, New Mexico, highlighted key best practices using verified local materials and proper surface preparation by light sandblasting [30]. The surface was maintained in a saturated surface-dry condition for 24 hours and protected from traffic. Contractors had a thorough understanding of UHPFRC handling, and batch placements were kept within 15 minutes to avoid cold joints. Aggregates were pre-weighed with moisture control, and mixers were tested to confirm actual UHPC capacity. Excess surface moisture was removed before placement, curing compound was applied after finishing, followed immediately by plastic sheeting, and construction activities were delayed for at least seven days for strength development.

In Norway, several state and regional actors have shown increasing interest in the use of UHPFRC, and a plan is now being developed to carry out pilot projects for bridge rehabilitation. So far, only a few projects have been completed. At the newly built Bukkestein Bridge on the E39 highway, UHPFRC was applied to repair casting defects ensuring durable bonding and surface integrity, see Figure 5. The material was mixed on-site using a transportable mixer and pumped directly, which gave good results. Another early application took place at a fish farming facility, where a laminated solution combining UHPFRC with C40/50 concrete was in service for over six months. The system was fully accepted after extensive testing, including bending and adhesion trials. Experiences with casting have highlighted problems such as elephant skin. A spray-applied membrane designed to mitigate this problem proved only partially effective, but good results were achieved when plastic sheeting was placed immediately after casting, or when automated plastic rollers were used on bridge sites. Both pumping and bucket placement methods have been tested, with pumping from the bottom upwards found to eliminate elephant skin, while bucket placement

provided good fibre orientation when UHPFRC was allowed to flow ahead of the mix front. Proper surface preparation has been essential, involving water-jetting, sandblasting, and thorough pre-wetting. Most projects so far have relied on Ductal formulations, though attempts to develop local mixes continue to face challenges related to viscosity, fibre settlement, and admixture effects. Fibre distribution has been most successful when added at the end of mixing, and results indicate that water hardness and lime content also play a role in fresh concrete behaviour.



Figure 5 – Beam on Bukkestein Bridge before (left) and after (right) repair with UHPFRC.

4.7 Standards and Guidelines

The final step that would facilitate the implementation of UHPFRC in Norway, is the development of national standards and guidelines. This subsection will describe the development of guidelines for different countries, to highlight the importance of this step. In 2002, the first recommendations for UHPFRC were published in France, and later revised in 2013 [24]. These recommendations consisted of four parts, covering material behaviour and mechanical characterization, structural design methods consistent with Eurocode 2, durability, and sustainable development. Between 2016 and 2018, the French standards were formally published, serving as a national appendix aligned with the content and principles of Eurocode 2. The same year two different standards considering UHPFRC were published in France and provides comprehensive guidelines for UHPFRC. NF P 18-710 [10] and NF P 18-470 [14] are focusing on structural design rules and principles, and material specifications and performance criteria, including UHPFRC for structures and non-structural elements, respectively. In 2016, the first official standard on UHPFRC was developed and published in Switzerland, Swiss Standard SIA 2052 [3]. The document contains material classifications, design and execution guidelines, and testing procedures. SIA 2052[3] was developed by a working group consisting of both academic partners (EPFL), research institution (EMPA) and industrial partner (ASTRA). The national standards are closely developed by industrial partners and academia. In 2017, ASTM International approved the ASTM C1856/C1856M [33] in USA. This standard provides guidelines on standard practice for fabricating and testing specimens of UHPFRC. In addition to ASTM C1856/C1856M, FHWA has published several reports that are widely used as references and in bridge and infrastructure applications, even though they are not legally binding.

Several countries are under developing or have developed standards based on the once mentioned above. In the Czech Republic, two companies began developing UHPFRC mixes using local constituents in 2010. However, they faced problems convincing clients to permit their application in structures due to a lack of experience and the absence of standards and guidelines [13]. To take further steps toward implementation in the country, a guideline was initiated, building on the experiences of the university and the two companies. The document was based on national experiences and supplemented with data from standards in France and Switzerland. In 2024, the guidelines were approved by the Ministry of Transport and published as Technical Conditions for the Application of UHPC No. 267[34]. A key factor in developing these guidelines was the already completed pilot projects. Experience from these was used to gain local insights before referring to other standards.

In Norway, the Norwegian Concrete Association has developed and published national recommendations for the use of fibre-reinforced concrete (FRC) [35]. A similar standard for UHPFRC is currently under development and is scheduled for publication in 2028. In preparation for this publication, ongoing research will evaluate test methods that may be used for quality control of the material, supporting large-scale implementation using locally produced UHPFRC in Norway. Both the three-point bending test, commonly used for characterizing fibre-reinforced concrete, and the four-point bending test, described in SIA 2052 [3], will be assessed as part of the next research phase.

5 CONCLUDING REMARKS

Based on experiences from pivotal countries such as Switzerland, the USA, and France, a six-step pathway for successful UHPFRC use has been identified:

1. Lab-Scale Testing: Designing mixes to ensure sufficient strain-hardening (typically requiring ≥ 3 vol.% fibres) and self-compacting behaviour.
2. Concepts and Casting: Developing design concepts, often involving composite construction with existing reinforced concrete structures.
3. Industrial Collaboration: Engaging producers, contractors, and owners to make the material user-friendly and economically viable across the entire lifecycle.
4. Ready-Mix UHPFRC: Developing commercial or pre-bagged mixes to ensure consistent quality and performance.
5. Pilot Projects: Demonstrating the structural, aesthetic, and practical benefits of UHPFRC on real bridge sites.
6. Standards and Guidelines: Establishing national standards (e.g., SIA 2052 [3] in Switzerland, NF P 18-710/470 [10, 14] in France) to regulate material specifications, testing, and structural design.

Although Norway has a growing need for efficient bridge rehabilitation, its current position is behind the international leaders in adopting UHPFRC at an industrial scale. Table 2 summaries Norway's status in each step.

Table 2 – Summary of the six steps and Norway's status.

Step	International Practice	Norway's Status	Comments
1. Lab-scale Testing	Development and verification of UHPFRC mixes	Completed	Successful with local mixes, strengths up to 171 MPa
2. Casting and Concepts	Testing of casting and construction methods	Partially completed	Concepts developed, but few practical trials
3. Industrial collaboration	Early involvement of manufacturers and contractors	Completed	
4. Ready-Mix UHPFRC	Production in concrete plants using local materials, standardization of mixes	Partially Completed	Local production possible, but plants lack certifications. Patented mixes are currently used
5. Pilot Projects	Demonstration on bridges, knowledge transfer	Missing	Only a few projects, often using foreign mixes. Plan for several projects are under production
6. Standard and Guidelines	National standards and recommendations for implementation	Missing	No national standard yet. Currently developing, planned in 2028, recommendations from the Norwegian Concrete Association.

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