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INNOVATIVE REHABILITATION TECHNOLOGY FOR CORRUGATED METAL PIPE CULVERTS USING WET-MIX SPRAYED UHPFRC

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Abstract

The rehabilitation of corrugated metal pipe culverts under roads and highways using an inner ultra-thin concrete shell made of sprayed UHPFRC provides road owners with a strengthening solution that is about the same price but more robust than traditional solutions, allowing them to select the best technical and financial solutions for their projects, while ensuring the safety of the users and the durability of the structures. Developing sprayed UHPFRC for structural repair and strengthening marks a technological leap, in particular the development of integrated equipment for on-site fabrication, pumping and spraying. It was a major challenge that Freyssinet wanted to take up before deploying the technology for a broad spectrum of applications. This equipment was designed and successfully tested under site conditions in the year 2017 by Freyssinet in preparation of the execution of an experimental construction project for retrofitting a corrugated steel pipe culvert by sprayed Ductal®; the project is being carried out under the aegis of CETU and CEREMA as part of the innovation award "Routes et Rues 2016" granted to Freyssinet and LafargeHolcim.

Résumé

La régénération des buses métalliques sous routes et autoroutes par une coque ultra-mince intérieure en BFUP projeté a pour objectif d'offrir à la maitrise d'ouvrage routière un procédé de renforcement économiquement compétitif et plus performant que les solutions traditionnelles, et de lui permettre de rendre les meilleurs arbitrages techniques et financiers tout en assurant la sécurité des usagers et la pérennité des ouvrages. La projection du BFUP appliquée au domaine de la réparation et du renforcement structurel des ouvrages marque un saut technologique ; en particulier le développement d'une chaîne intégrée de production et de projection sur chantier, robuste et fiable, était un défi de taille qu'a relevé Freyssinet avant d'envisager de déployer la technologie à un large spectre d'applications. Cet équipement a été mis au point et testé avec succès par Freyssinet en conditions de chantier au cours de l'année 2017 lors de préparation d'un projet expérimental de régénération d'une buse métallique par coque en Ductal® projeté ; le projet est mené sous l'égide du CETU et du CEREMA dans le cadre de l'Appel à Projet d'innovation « Routes et Rues » pour l'année 2016 pour lequel Freyssinet et LafargeHolcim ont été lauréats.

1. CONTEXT

Sprayed UHPFRC applied to the structural strengthening of metal culverts under roads and highways will mark a technological leap which will provide gains in terms of technical performance, production and maintenance costs, material consumption and speed of construction. This strengthening solution is based on LafargeHolcim scientific and technical expertise in the field of UHPFRC and on Freyssinet's know-how and experience in structural strengthening works involving wet and dry-sprayed concrete.

Although applicable to the strengthening of many types of structures, in the first instance Freyssinet and LafargeHolcim are considering the emergence of this innovative technology with the rehabilitation of buried structures under roads and highways, in particular those subjected to clearance constraints and to water ingress in the ground, such as tunnels, vaults, metallic culverts and galleries. It is a matter of producing on the intrados of the structure an ultra-thin UHPFRC shell placed by wet- spraying.

This innovative technical solution applies very well to corroded (but not excessively deformed) metal pipe culverts, which are quite numerous in France. This method allows the road authorities to now use a new "semi-rigid" strengthening technique that is more efficient and creates much less impact than the conventional approach based on a rigid and thick reinforcement that radically modifies the structures function (reinforced polymer prefabricated segmental lining threaded in the culvert and subsequently injected with cement grout; or thick and rigid confinement in dry-mix sprayed concrete using reinforcing meshes).

2. TECHNICAL SPECIFICATIONS

The reinforcing UHPFRC shell, the thickness of which usually ranges from 3 to 6 cm, has to comply with the following requirements:

- It respects the mechanical function of the semi-rigid structure
- Strengthens the structure in a sustainable way
- Participates in the waterproofing against water ingresses from the ground
- Provides good hydraulic capacity
- Provides good abrasion resistance
- Has a low impact on the hydraulic capacity

More generally, this new solution makes it possible to:

- Limit construction and maintenance costs
- Limit time periods of intervention by avoiding the installation of reinforcement bars
- Reduce environmental impacts by reducing the quantities of materials to be transported

3. TECHNOLOGY

The UHPFRC wet-mix sprayed concrete features specific properties compared to a cast-in-place UHPFRC which makes it an attractive solution to produce reinforcing shells. Under the impact on the surface, on the one hand, the metal fibers orient themselves in an isotropic manner in the plane of the facing and, as a consequence of the process, most of the air is expelled from the concrete mixture. This results in both an optimal orientation of the fibers in the same plane

than the tensile stresses which develop in the shell and in an increase of the compressive strength of the material.

The scientific and technical requirements of this technology are as follows:

- In terms of material: the UHPFRC sprayed by wet-mix method must be designed with special rheological properties. In its fresh state, it must have rheological properties adapted to each of the processes constituting the production line: good fluidity to facilitate pumping over large lengths, good cohesion to be pumped and sprayed with compressed air without segregation, high yield strength to stick on a vertical or ceiling walls without flowing under its own weight and at last a low viscosity allowing fibers to be oriented parallel to the wall both in the pipe and at the moment of impact. A key of success was the simultaneous development of the production equipment and the final design of the UHPFRC material.
- In terms of equipment: the equipment developed by Freyssinet is specially designed to avoid robotic spraying in order to enable a wider scope of applications but which generates specific and challenging constraints: pumping the UHPFRC in flexible pipes with a maximum diameter of 50 mm over a length of at least 60 m, i.e. a half-length of the longest culverts, without formation of flow restrictors or plugs despite the high steel fibers content in excess of 2% in volume and with a capacity of 20 to 30 T/day depending of the conditions of application.
- With regards to sprayed concrete quality: the technology must also allow the build-up of the shell in several successive passes in a prescribed manner that respects curing times. The metallic fibers protruding at the extreme surface facilitate the attachment of the new pass on to the previous one. After spraying, the product can either be let rough or be smoothened to obtain a surface that have limited protruding metal fibers and which is favorable to laminar hydraulic flows.

The challenge is to maintain the production process stability throughout the working day, without major modifications to production parameters, without machine shutdown and cleaning of the hoses and equipment. This results from the conjunction of a material with reproducible rheological properties from one batch to another, thus a specific and robust concrete mix design, and the setting up of a specialized team implementing a strict quality control scheme is essential.

4. VALIDATION PROTOCOL

The protocol for validating the wet-mix UHPFRC sprayed concrete technology before its deployment on an experimental structure includes three prerequisite phases: first study tests, second a suitability test and thirdly a load test, all of them carried out with the site equipment.

- The aim of the preliminary study tests is to successively validate each production station: mixing, pumping and spraying by checking the quality consistency of the UHPFRC material.
- The suitability test is intended to validate the production chain as a whole by strengthening a full scale 3 m-long witness element and to fabricate test specimens under conditions similar to those being encountered on site.
- The purpose of the loading test is to check the mechanical behavior of a metallic culvert pipe section, previously UHPFRC-reinforced and loaded until failure.

To carry out these tests, various test set-ups have been installed on a dedicated test area at the Freyssinet agency in the Auvergne-Rhône-Alpes region (Fig. 1):

- A first test structure was specifically designed and installed to evaluate the quality of the UHPFRC spraying on a concrete substrate. It consists of a metal framework supporting three concrete panels of 2 x 3 m positioned vertically, inclined at 45 ° and at the ceiling. The panels were prepared by abrasive blasting.
- To check the feasibility and quality of the spraying inside a corrugated metal pipe, an element of 2.5 m in diameter and a length of 3 m plus was installed in the test area. For practical reasons the pipe was new, not corroded and abrasive blasted.

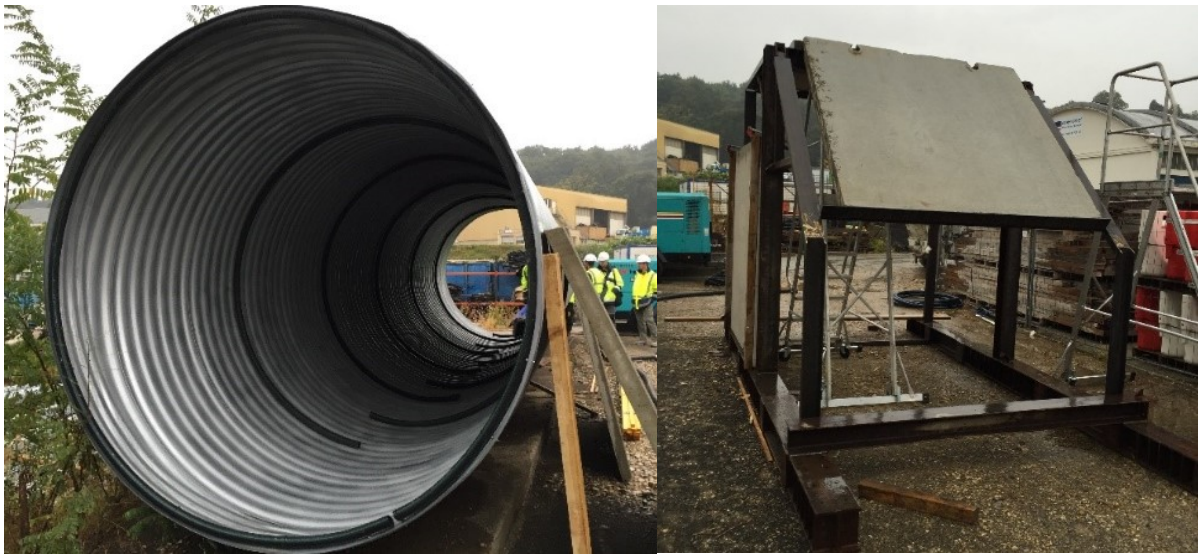

Figure 1: Suitability test lay out

Figure 2: Internal control during fabrication

During the execution of the study and suitability tests, Freyssinet implemented a rigorous quality control scheme (Fig. 2) covering, in particular, the measures of the constituents' weight, the temperature conditions, the mixer power follow-up, the rheology of the mix before and after incorporation of the fibers, and lastly the measurement of the fiber content.

Due to the lack of regulations related to UHPFRC sprayed by wet-mix method (Fig. 3 – 4), Freyssinet has defined a test protocol on hardened concrete based on an adaptation of existing standards for fiber reinforced sprayed concrete (NF EN 14 488 part 1 [1] and 2 [2]) and molded UHPFRC (NF P18-470 [3]). The objective is to test specimens that are representative of the in-situ manufactured reinforcement shell. For this purpose the test specimens are sprayed into panels.

The evaluated properties are the following:

- The compressive strength of the UHPFRC incorporated in the structure is evaluated from cores taken from test panels filled by sprayed concrete and made in accordance with the NF EN 14 488 standard. The compressive tests on the cores are carried out according to the standard NF EN 12 390 -3 [4].
- The flexural strength is evaluated by three-point and four-point bending tests carried out on thick and thin plates in two orthogonal directions according to NF P 18-470 standard. This made it possible to verify the elastic limit and the post-cracking characteristics of the material according to two orthogonal directions.
- Finally, in order to demonstrate the monolithic character of the repaired structure, in case of a reinforcement intended to be bonded to an existing concrete support, the adhesion of the hardened UHPFRC sprayed onto previously prepared concrete panels was checked by direct tensile tests on cores according to the standard NF EN 14 488-4 + A1 [5].

At 28 days and after determination of the concrete strength and stiffness on cores, a loading test is scheduled to check the behavior of the reinforced corrugated steel sheet pipe element.

- FREYSSINET used the ASQUAPRO (ASsociation for QUAlity of the PROjection of concretes) rules based on the model code 2010 for fiber reinforced concrete to calculate the reinforcement shell.
- The instrumentation of the test element allows to measure its deformations and strains under determined loads.
- The comparison between the results of the calculations and the monitoring measurements allowed fine tuning of the calculation rules.

Only after successful completion of these tests, Freyssinet will deployed the technology on a first experimental site.

5. AVERAGE CHARACTERISTICS (2% FIBER VOLUME CONTENT)

The mechanical properties obtained on the wet-mix sprayed UHPFRC were as follows:
- Characteristic value of the compressive strength at 28 days: f_{ck} = 152 MPa
- Characteristic value of the tensile elastic strength: $f_{ctk,el}$ = 6,3 MPa
- Characteristic value of the tensile post-cracking strength: f_{ctfk} = 5,5 MPa
- Resistance to hydraulic abrasion: CNR index between 0.7 and 1

These results allowed to validate the UHPFRC mix design, the chosen equipment for mixing, pumping and spraying, as well as the fabrication procedure.

Figure 3: Suitability tests: during spraying

Figure 4: Suitability tests: after spraying

6. CONCLUSION

The rehabilitation technique of corrugated steel sheet metallic pipe culverts accessible for man-inspection using wet-mix sprayed UHPFRC open a new way to repair corroded structures with or without loss of bearing capacity (but without excessive deformation), in a robust and durable way, without radically modifying their mechanical behavior or excessively reducing the diameter.

The technology provides road owners with the following advantages:

- The execution of the UHPFRC liner works does not require interruptions of road traffic and provides little harm to neighbors.
- As the spraying station is compact, the site set up requirements are minimal
- The duration of the works is reduced due to the low quantities required and the use of one single technology. The management of the watercourse by diversion or pipeline will therefore be less sensitive to the risks of accidental floods.
- The carbon footprint of this innovative solution falls within the objectives of Freyssinet and LafargeHolcim which, through the use of products and materials designed in the territory, adhere to the commitments made at COP 21.

Based on the positive results of the above qualification process for both the material, the equipment and the methods, the Foreva® Sprayed Ductal® solution is now proposed by Freyssinet to a wide range of applications to repair, strengthen and extend life of structures of any kind.

REFERENCES

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