REHABILITATION AND STRENGTHENING OF EXISTING RC STRUCTURES WITH UHPFRC: VARIOUS APPLICATIONS

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Abstract

Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) exhibiting high tensile strength and ductility and low permeability is adapted to protect and strengthened existing reinforced concrete structures.

The contribution of UHPFRC is not limited to a waterproof layer but it is extended to mechanical reinforcement. Furthermore, UHPFRC layer combined with passive reinforcement can increase the flexural and shear strength of a structure. In this paper, rehabilitation and strengthening of various reinforced concrete structures (building and bridges) with UHPFRC layer are presented and discussed.

The rehabilitation and strengthening of existing reinforced concrete structures with UHPFRC layer is effective as it allows extending the lifecycle of a structure with limited cost.

Résumé

Les bétons fibrés ultra-performant (BFUP) qui sont caractérisés par une résistance et une ductilité élevée en traction ainsi qu’une faible perméabilité sont adaptés pour protéger et renforcer des structures existantes en béton armé.

La contribution du BFUP n’est pas seulement limitée à la couche d’étanchéité mais elle peut être étendue au renforcement mécanique. De plus, en combinaison avec de l’armature passive, la couche de BFUP peut augmenter la résistance à la flexion et au cisaillement. Dans cet article, la réhabilitation et le renforcement de différentes structures en béton (bâtiments et ponts) avec une couche de BFUP sont présentées et discutées.

La réhabilitation et le renforcement de structures existantes en béton armé avec une couche de BFUP est méthode efficiente car elle permet d’augmenter la durée de vie d’une structure à moindre coût.

1. INTRODUCTION

Rehabilitation and strengthening of reinforced concrete (RC) structures is a consequence of severe environmental influences, increasing load, inappropriate details, extending lifecycle, modification of load and change of function. It is a challenge for structural engineers and requires innovative methods.

Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) exhibiting high tensile strength and ductility and low permeability is adapted to protect and strengthened existing RC structures. Since 2004, thin UHPFRC layer had been applied successfully on existing bridge deck in order to replace traditional waterproofing membrane.

The contribution of UHPFRC is not limited to a waterproof layer but it is extended to mechanical reinforcement. Furthermore, UHPFRC layer combined with passive reinforcement can increase the flexural and shear strength of a structure. In this paper, rehabilitation and strengthening of various RC structures (building and bridges) with UHPFRC layer are presented and discussed.

2. BRIDGE STRENGTHENING IN VUARRENS

A large number of existing reinforced concrete road bridges are deteriorated due to severe environmental influences, high traffic loading and inappropriate details. The corrosion of steel reinforcement of the deck slab is often due to defect of the waterproofing membranes causing exposure of reinforced concrete to chloride ions. Thanks to his low permeability and high durability, UHPFRC can replace traditional waterproofing membrane and protect RC deck slabs. In comparison with conventional waterproofing technique, UHPFRC layer shows higher durability and lower intervention time.

The reinforced concrete road bridge in Vuarrens built in 1964 is illustrated in Figure 1. The bridge length is 24.60 m. The deck is composed of a flat slab 40 cm thick and 10.70 m wide. The deck slab is rigidly connected to both piles and supported on elastomeric bearings at the abutments. The central span has a length of 10.00 m and the side spans have 7.30 m length. The principal damages observed are the degradation of the parapets and the abutments, corroded rebars and defects of the waterproofing membrane.

The project consists of transforming the existing static system by taking away the supports at both abutments. An integral bridge is created which allow extending the lifecycle.

The waterproofing membrane is replaced with a thin UHPFRC layer of 30 mm thick applied on the deck slab as illustrated in Figure 1. The roughness of the existing concrete surface is obtained by hydrodemolition of the concrete deck on a depth of 10 mm.

Figure 1: Views of the existing bridge in Vuarrens

The UHPFRC layer is built in two stages, one half of the bridge after the other. The traffic is limited to half of the bridge and the rehabilitation is done on the other half. The construction in two stages allows reducing the impact on traffic. It requires a longitudinal joint between the two stages. This joint has a width of 50 mm and the connection is insured with rebars.

The UHPFRC is produced directly on site which represents a total volume of about 8 m^3.

Both parapets are casted in place and linked with the reinforcement of the existing bridge. The UHPFRC layer penetrates into the parapets thanks to a little slot in order to insure the continuity of waterproofing as illustrated in Figure 2.

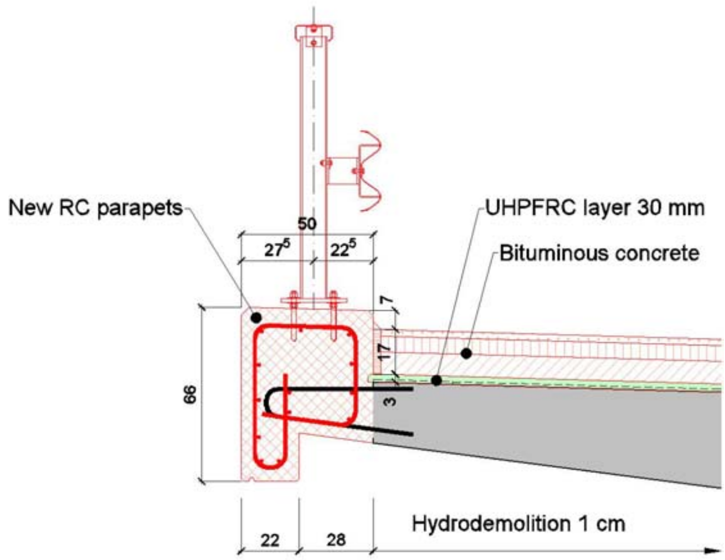

Figure 2: Detail of the new parapets and the UHPFRC layer over the concrete deck

3. SLAB STRENGTHNING OF A BUILDING IN GENEVA

The refurbishment of a building, built in 1920, which includes 6 floors and one basement in the centre of Geneva is presented in this section. The existing floors are made of thin reinforced concrete ribbed slabs and supported by masonry walls as illustrated in Figure 3. The existing slabs do not cope with the actual requirements and is not be able to support the new load as the flexure-shear resistance is not sufficient. The area of the floor to be strengthened is important as it reaches 3’000 m^2.

Figure 3: Ribbed slab to be strengthened in Geneva

The strengthening method proposed is to add a thin reinforced UHPFRC layer, 30 mm thick on the existing slabs as shown in Figure 4. The reinforcement consists of a mesh ϕ 6 #100 mm. The connexion between the slab and the UHPFRC is ensured by the roughness of the support which is prepared by gritbalsting as illustrated in Figure 5. The UHPFRC layer is connected into the walls and columns with anchored rebars. In comparison with other strengthening techniques, the UHPFRC allows the limitation of the dead load which on one hand, avoids foundations strengthening and on another hand, limits the construction time.

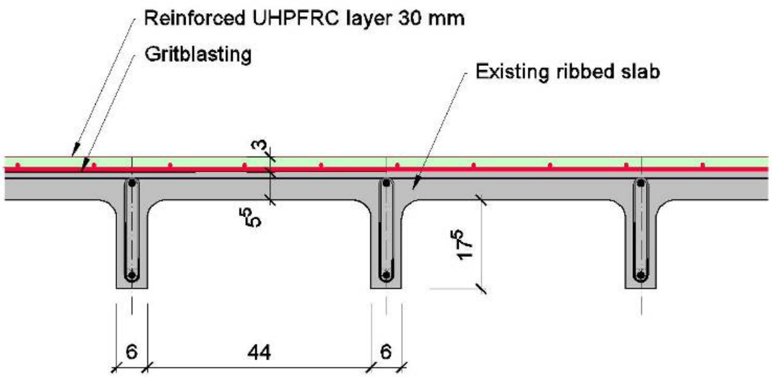

Figure 4: Cross section of the strengthening of the ribbed slab with UHPFRC

Figure 5: surface of the slab after gritblasting of the building slab in Geneva

Several new developments highlighted the beneficial contribution of combining rebars and UHPFRC layer. Oesterlee [2] shows the contribution on the flexural resistance of composite structures and Noshiravani [3] shows the contribution on combined flexure and shear stresses. Some experimental tests highlighted that strengthened members present a significantly higher stiffness and ultimate resistance in comparison with reference members without strengthening. Strengthening with rebars and UHPFRC layer limits the flexural crack opening and changes the diagonal stress fields in the members. The rebars ensure a high strain capacity of the UHPFRC layer and delay the formation of macro-cracks. Moreover the rebars diminish the sensitivity of the fiber orientation.

The UHPFRC is applied on each floor within a single stage; a volume of about 15 m^3 is poured at a time for each floor. The UHPFRC is produced directly on site with a movable concrete mixer of 500 litres installed in the floors. The general contractor performed some preliminary tests as illustrated in Figure 6 in order to finalize the design process, the casting method and choose the optimal UHPFRC.

Figure 6: Building in Geneva; preliminary tests of UHPFRC layer

4. STRENGTHENING OF BRIDGES OVER MONTREUX

The projects presented in this section include partial reconstruction and strengthening of four bridges and sidewalk slabs over Montreux; two of them are illustrated in Figure 7. The existing bridges show degradations and are not adapted to additional traffic loads.

The project proposes to demolish partially three structures and strengthened the maintained parts. One bridge is rebuilt and two structures are transformed into restraint walls.

The road shows a significant slope of about 9 to 12% what not particular to Switzerland! Therefore, a special UHPFRC is necessary and the mix developed at EPFL [4] is used with a thixotropic behaviour at fresh state.

Figure 7: Views of the different RC structures

One of the bridge requires a new sidewalk which is supported on the restraint walls as illustrated in Figure 8. On the new sidewalk, a new layer of UHPFRC which is 30 mm thick is placed for waterproofing protection. The new concrete surfaces are washed out before the concrete hardening in order to obtain a sufficient roughness for the UHPFRC layer. In this application, the UHPFRC layer is placed over a new RC-sidewalk as a protection layer.

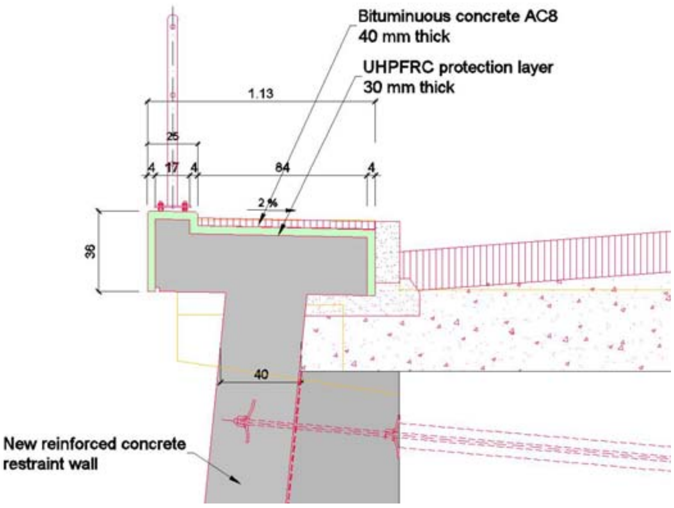

Figure 8: Cross-section of new sidewalk slab protected with a UHPFRC layer

Another application deals with an existing bridge which is replaced by a new RC slab, 35 cm thick as illustrated in Figure 9. The new RC structure is protected with a UHPFRC layer of 30 mm as waterproofing. The new concrete surfaces are washed out before concrete hardening in order to obtain a sufficient roughness. The UHPFRC layer is extended over the existing bridge in order to insure the protection of the whole deck.

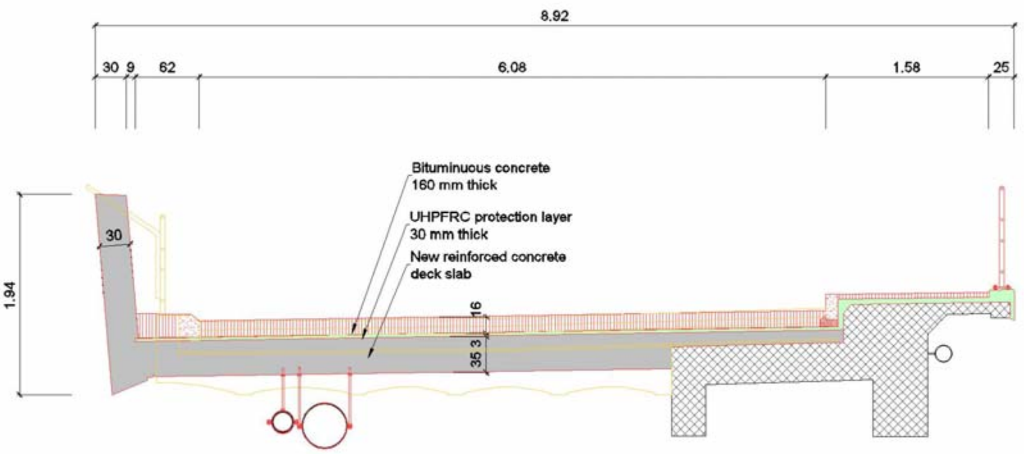

Figure 9: Cross-section of maintained sidewalk slab with the reinforced-UHPFRC layer

Two sidewalks of two different bridges are strengthened with combined rebars and UHPFRC layer 50 mm thick as illustrated in Figure 9. The parapets are also protected with a UHPFRC layer. The concrete surface is treated by hydrodemolition in order to obtain a sufficient roughness.

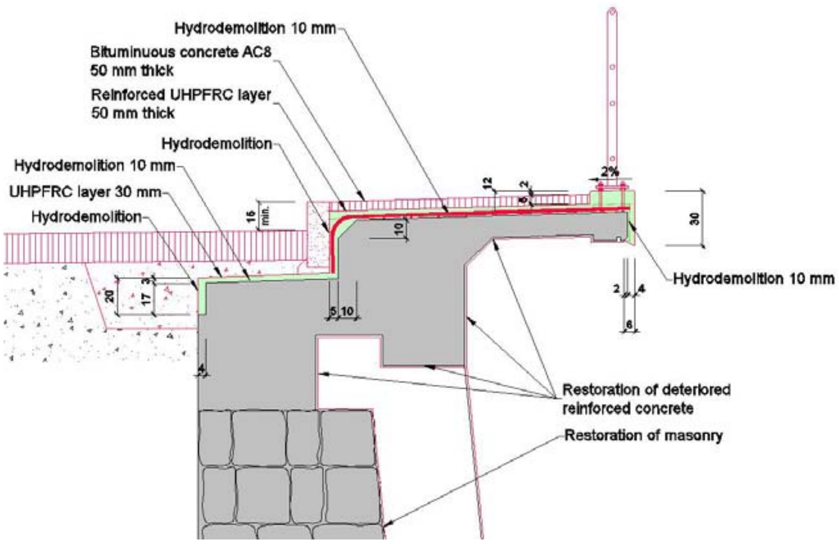

Figure 10: Cross-section of maintained sidewalk slab with the reinforced-UHPFRC layer

5. STRENGTHNING THE CHANDELARD BRIDGE

The bridge over the Chandelard River between Pully and Belmont-sur-Lausanne is a prestressed concrete bridge built in 1967. It has a length of 81.00 m and a width of 11.50 m; it is illustrated in Figure 11.

Figure 11: View of the bridge over the Chandelard River

The deck is composed of a hollowed slab, 1.06 m thick and two sidewalks as illustrated in Figure 12. The deck slab is rigidly connected on two thin reinforced concrete piles and supported on fixed bearings on the abutment in Belmont and on mobile bearings on the abutment in Pully. The principal degradations of the reinforced concrete deck are localized at the parapets and on the sidewalks. Furthermore, it can be mentioned that the two sidewalks have been built without any waterproofing membranes.

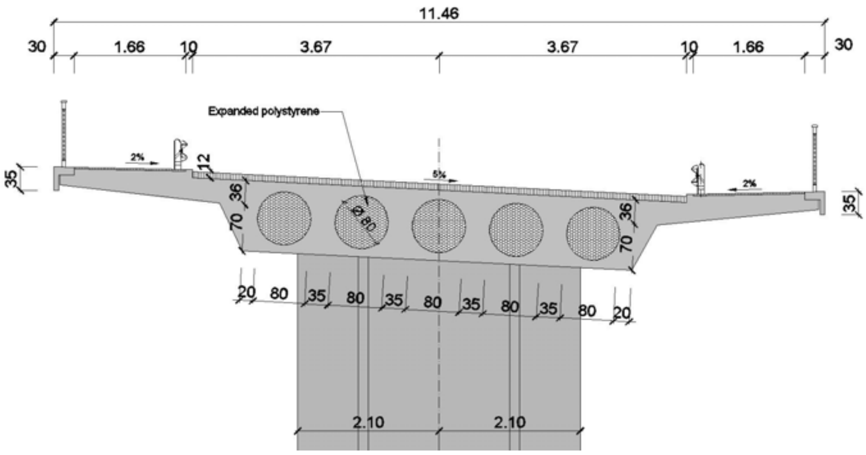

Figure 12: Geometry and cross-section of the existing Chandelard's bridge

The control of the carrying capacity has highlighted a shear deficiency of the deck near the piles. The proposed shear strengthening consists of replacing the expanded polystyrene holes near the piles by a High Performance Fiber Reinforced Concrete (HPFRC) as illustrated in

Figure 12. HPFRC was preferred over UHPFRC due to the important volume to be filled with and also due to the shrinkage requirement.

The HPFRC is characterized by a compressive strength between 70 to 120 MPa, a matrix composed of coarse aggregates and a limited fibres dosage of about 80 kg/m^3. It mechanical properties, particularly the post-cracking response, are sufficient for structural applications particularly for carrying the shear force as demonstrated in [5]. Inclined prestressed tie bars are also added as shown in Figure 12.

This shear strengthening with HPFRC allows bridge strengthening without visible tie bars, so that the image of the bridge is not modified.

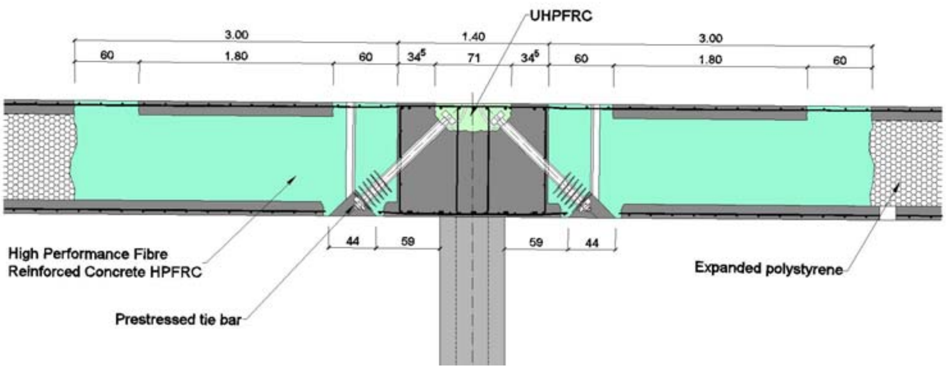

Figure 13: Detail of the shear strengthening near a pile

A thin UHPFRC layer, 30 mm thick, is built over the sidewalks and the parapets after the hydrodemolition of the surface. On the sidewalk, no bituminous concrete is applied as the UHPFRC acts as the pavement layer. In order to obtain a sufficient roughness pavement, hard aggregates 4-6 mm are spread on the UHPFRC layer before concrete hardening as illustrated in Figure 13.

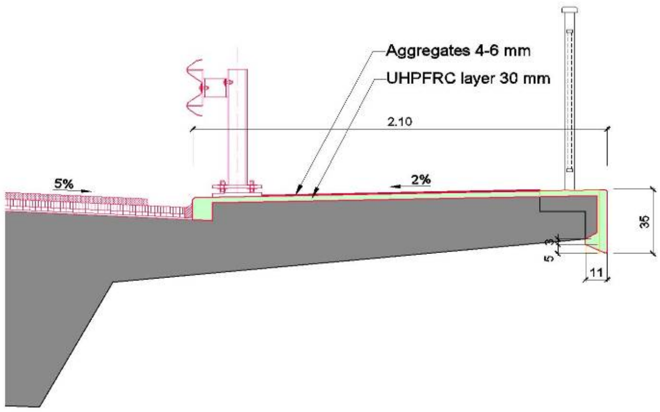

Figure 14: Detail of the sidewalk slab with the UHPFRC layer

6. CONCLUSIONS

Rehabilitation and strengthening of reinforced concrete (RC) structures is a consequence of severe environmental influences, increasing load, inappropriate detail, extending lifecycle, modification of load and change of function. It is a challenge for structural engineers and requires innovative methods.

UHPFRC exhibiting high tensile strength and ductility and low permeability is adapted to protect and strengthened existing RC structures. Since 2004, thin UHPFRC layer had been applied successfully on existing bridge deck in order to replace traditional waterproofing membrane.

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Various applications have been described showing the multifaceted of rehabilitation and strengthening with UHPFRC. It also illustrated that it should be applied with care as special considerations like the link between the existing and new structure, the influence of the slope, the contribution of the passive reinforcement are always necessary.

The rehabilitation and strengthening of existing reinforced concrete structures with UHPFRC layer is effective as it allows extending the lifecycle of a structure with limited cost.

Finally, researches on the contribution of UHPFRC layer should be encouraged in order to give design tool for flexural and shear contribution.

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