Renewal of the Fixed Railway Track in Zurich Airport Station by means of UHPFRC

Antonina Hochuli (corresponding author), Doctoral student, Laboratory for Maintenance and Safety of Structures, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland,
Email: antonina.hochuli@epfl.ch

Eugen Brühwiler, Full Professor, Laboratory for Maintenance and Safety of Structures, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland,
Email: eugen.bruehwiler@epfl.ch

Jean-Georges Trouillet, Senior Railway Engineer, Head of the Railway Engineering Department, Engineering office A. Aegerter and Dr. O. Bosshardt AG, Basel, Switzerland
Email: j.trouillet@aebo.ch

Abstract

This contribution presents a probably worldwide first application of UHPFRC for the renewal of an existing fixed railway track in a heavily trafficked underground railway station. The existing fixed railway track of the Zurich Airport train station was constructed in 1980. It consists of four 640 m (700 yards) long tracks constructed as slabs in concrete. According to the state-of-technology at that time, the fixed railway track was built as a reinforced concrete slab and prefabricated monoblocs of the LVT L77-B type (Low Vibration Track), which were fixed by unreinforced concrete casted on top of the reinforced concrete slab. Already after a few years of operation, first cracks were detected in the monoblocs, and after 30 years of operation, significant damage in terms of cracking and fracture of monoblocs was detected, making the replacement of the blocks necessary.

The use of UHPFRC allowed to reduce significantly the monobloc size and to accommodate for new requirements regarding the height of the platform, avoiding costly construction interventions, thus leading to a reduction of overall construction cost by 30% compared to traditional renewal methods using concrete. The use of UHPFRC and novel technologies allowed to improve the existing fixed railway track in terms of fatigue resistance and to increase the service duration to a very long service duration. The paper presents the design of the UHPFRC pedestals, and the execution of works including quality control.

Keywords: fatigue, railway application, fixed railway track, rail fasteners.

1. Introduction

The underground railway station Zurich Airport was built just over 40 years ago. The tracks were put into operation in 1980. It consists of four 640 m (700 yards) long fixed railway tracks made of traditional concrete. According to the state of the technology at that time, the fixed railway track was built as a lightly reinforced concrete slab and prefabricated monoblocs of the LVT L77-B type, which were fixed by unreinforced concrete casted on top of the reinforced concrete slab (Figure 1).

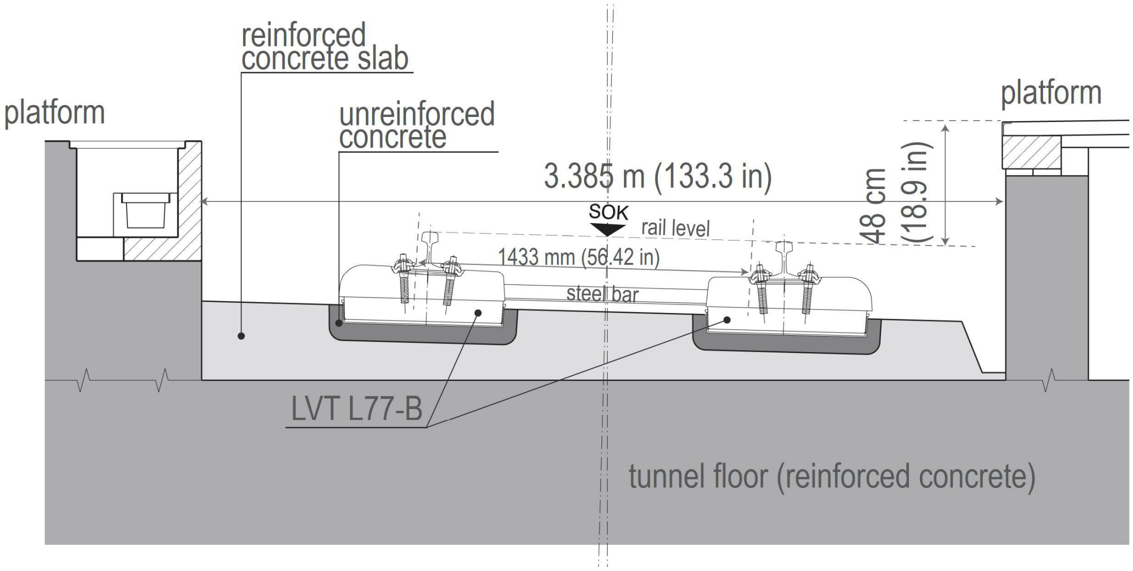

Figure 1 Fixed railway track at Zurich Airport station built in 1980

Ten years ago, the existing monoblocs showed significant damage due to concrete cracking near the steel bars linking the two blocs. Therefore, these steel bars were removed from the monoblocs as an immediate measure. After removing these bars, existing cracks in the monoblocs propagated further.

At the time the decision was taken to renew the fixed railway track, it was noted that platforms, which had been put into operation in 1980, did not meet the requirements of the Disability Equality Act, which is in force since 2004. Therefore, the measurement for adjusting platform heights should be planned as part of the project. Since Zurich Airport railway station is heavily trafficked, the Swiss Federal Railways (SBB AG) ordered the following general conditions for the construction work:

1. During works, only one track (out of four) can be taken out of operation at the same time. Trains run on the three remaining tracks.
2. The platforms remain in operation with few exceptions.
3. No noise and dust emissions in the area of the railway station under operation.
4. Taking out of the operation of one track for the engineering works may not last longer than four weeks.

2. Project development

2.1 Evaluation of possible renewal measures

As part of the study of variants, two traditional variants were developed first, in which the existing platforms should be rebuilt fully, and the existing fixed railway track should be partwise rebuilt. Since these traditional variants proved to be cost-intensive, an alternative variant was developed, in which just the rail position was lowered while the existing platforms and the reinforced concrete slab of the fixed railway track remained unchanged.

Table 1 summarizes the estimated construction costs, excluding planning, safety measures and railway equipment, and provides the expected CO_2 emissions due to concrete, respectively UHPFRC production for each variant.

Table 1 overview of cost estimation and environmental impact

Variant 1	Variant 2	Variant 3
Integral replacement of the monoblocs and rebuilding of the platforms	Partwise rebuilding of the existing fixed railway track underneath monoblocs	Direct fastening of rails on UHPFRC pedestals of reduced dimensions
7.4 Mio. CHF	5.6 Mio. CHF	3.6 Mio. CHF
1’400’000 $kgCO_2$-eq	850’000 $kgCO_2$-eq	190’000 $kgCO_2$-eq

The low costs of variant 3 could be achieved due to desisting of platforms and reinforced slab track reconstruction using UHPFRC. In addition, variant 3 offered the lowest construction site emissions and the shortest duration of works.

Moreover, variant 3 is more environmentally friendly as only $50m^3$ (65.4 yd^3) of UHPFRC and $529m^3$ (692 yd^3) of concrete should be used; the estimated environmental impact is 190’000 $kgCO_2$-eq. For the complete rebuilding of the platforms and the tracks in variant 1 would be needed ~$4600m^3$ (6017 yd^3) of concrete; the expected CO_2 emissions due to concrete production is about 1’400’000 $kgCO_2$-eq. The complete rebuilding of the platforms and the partwise rebuilding of the tracks in variant 2 would require ~$2300m^3$ (3008 yd^3) of concrete; the expected CO_2 emissions due to concrete production is about 850’000 $kgCO_2$-eq. Moreover, the monoblocs of concrete in variants 1 and 2, which are considered to be the wearing components, should be replaced every 30-40 years on average, corresponding to 345 m^3 (451.2 yd^3) concrete and 176’000 $kgCO_2$-eq.

2.2 Development of the concept and use of UHPFRC

The concept of variant 3 was to adapt the height of new, casted on-site pedestals to the target track geometry. It was planned to cast new pedestals in the recesses of the existing fixed railway track, which remain after the removal of the damaged concrete monoblocs. This concept presupposes that the size of these recesses provides enough space to adjust rail position in the vertical and horizontal directions, respectively, to fix the rails asymmetrically on the pedestals to meet the target track geometry. Moreover, the previous rail profile 54E2 (161 mm (6.33 in) high) should be replaced by 60E2 (172 mm (6.77 in) high). Thus, it resulted from a maximum track lowering of 68 mm (2.68 in) and a maximum side shift of the track of 54 mm (2.13 in).

It soon became apparent that the required adjustments led to such thin pedestals that they could not be produced in reinforced concrete for geometrical and technical reasons. Since, the minimum thickness of reinforced concrete elements is determined by reinforcement layout (minimum bending radii of rebars, overlapping length, and space for pouring fresh concrete).

In addition, the traffic loadings (including dynamic effects due to passing trains, traction, and braking forces) should be resisted by the pedestals of reduced heights.

Using UHPFRC, the pedestals of height 11.9 cm (4.7 in) could be designed with a much smaller reinforcement content and a simple reinforcement cage.

Thus, the reinforced concrete slab as a part of the existing fixed railway track and the platforms could remain unchanged. Note that by applying the proposed approach, the structural definition for new elements was changed; the new UHPFRC pedestals became part of the bearing structure with a longer service duration instead of being a wearing elements like rails and rail fasteners with relatively short service duration.

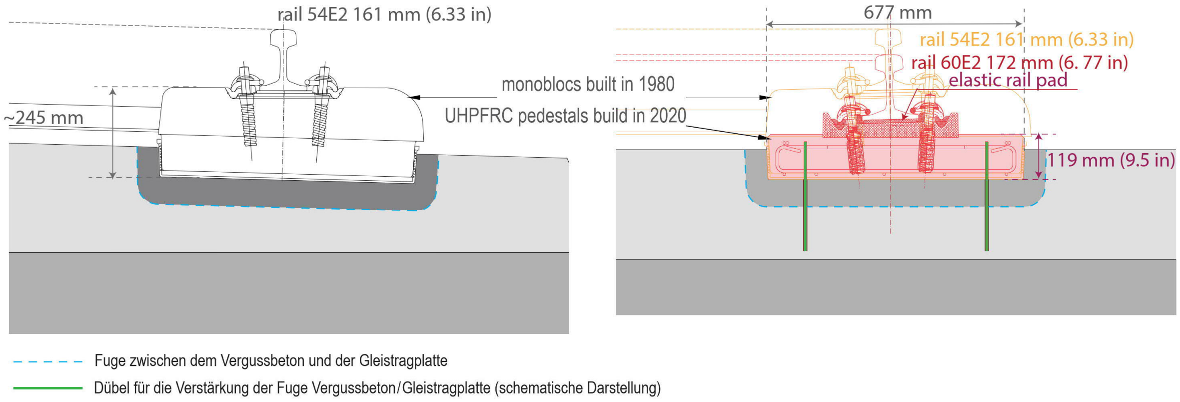

Figure 2 Fixed railway track at Zurich Airport Station. Variant 3

2.3 Dimensioning of UHPFRC pedestals

2.3.1 Modelling

Since an existing system was planned to be rebuilt, hazard scenarios had to be investigated. This was done by finite element analysis, using the results for the dimensioning of the new UHPFRC pedestals.

New UHPFRC pedestals were designed to be compact components with a base surface of 247 mm by 677 mm (9.72x26.65 in) and variable height, which depends on the track geometry. Elements with the smallest and largest height and the maximum side shift of the rail fastening were modelled using the nonlinear finite element program ATENA with 3-dimensional macro elements to which the compressive and tensile properties of UHPFRC UB according to the Swiss standards 2052 were assigned. The reinforcement bars were modelled as 1-dimensional elements with properties of B500B (SIA262). Non-linear elastic surface springs, which transmit only compressive forces, were assigned to the edges of the macro-element.

In the numerical analysis, the spring displacement of the lateral supports was varied to consider possible micro crack formation due to of UHPFRC shrinkage, at the interface with the existing concrete. For the simulation of surface variation under the pedestals, the stiffness of the vertical elastic supports was varied.

The vertical and horizontal forces acting on the pedestal were modelled as distributed loadings on the contact surface between the rail pad and the UHPFRC macro element.

2.3.2 Rail track loading

According to the Swiss standards SIA 261, new load-bearing structural components of railway infrastructure should be designed for a characteristic axle load of 250 kN (56.202 kip). For a static check of the existing load-bearing structure, updated load models according to the Swiss standards SIA 269 are considered. Thus, the dimensioning of the new UHPFRC pedestals was performed according to SIA 261, and the static check of the existing reinforced concrete slab was conducted according to SIA 269.

Two decisive cases were analysed (Figure 3):

1. Due to the distribution of the wheel loading along the continuous rail fixed on the pedestals, the maximum vertical loading of one pedestal is about 40% of the total wheel load. ($Q_{\text{axle load}}$ = 250 kN (56.202 kip), $Q_{\text{wheel}} \approx 0.5 Q_{\text{axle load}}$ for straight track)
2. The tensile force acting on the rail fixation and pedestal due to the uplifting of the rail in front of the running wheel is: $Q_{\text{rail\_uplift}}$ = 2 kN (0.45 kip) as obtained from structural analysis according to Figure 3.

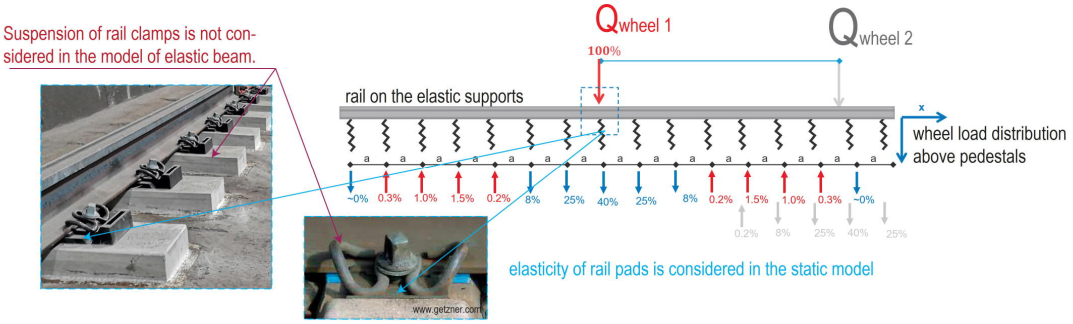

Figure 3 static system of elastically supported rail

2.3.3 Results

The rail supporting system was modified from elastically supported concrete monoblocs to rigid UHPFRC pedestals on which the rail is fixed via an elastic pad placed directly under the rail. This significantly reduced (and even eliminated in the extreme case) tensile stresses in the bottom part of UHPFRC pedestals. Tensile stresses in the top part of UHPFRC pedestals are resisted by the UHPFRC. At ultimate limit state of type 2 (ultimate resistance), the calculated tensile stress was 1.9 MPa (275.6 psi) and at ultimate limit state of type 4 (fatigue resistance), the maximum tensile stress was only 0.9 MPa (130.5 psi).

The steel reinforcement bars in the pedestals (Figure 2) serve to position the rail anchors, as prescribed by regulations, and to increase the bond between the newly casted UHPFRC pedestals and the existing reinforced concrete slab. From a static viewpoint, rebars would not have been required for absorption of tensile stress in the UHPFRC as these stresses remain in the low range of the elastic domain at ultimate limit state.

For the fatigue safety check, the fatigue strength was determined according to the provisions of the Swiss standard SIA 2052 with the fatigue endurance limit: $\sigma_{U,D}=0.3\cdot(f_{Ute}+f_{Utu})\approx 6.6$ MPa (957.3 psi), where f_{Ute} of 10 MPa (1.45 ksi) is the elastic limit stress and f_{Utu} of 12 MPa (1.74 ksi) is the tensile strength.

3. Execution of works

During the works, the above-mentioned operational constraints had to be respected. Work stages of 4-weeks were defined for each track.

In addition to noise and dust emissions, the ambient temperature at the construction site also had to be permanently controlled. Just before the entrance to the station, there is a pressure release shaft with a large opening in the tunnel ceiling, through which cold air from outside flies into the railway station from October to March. Therefore, measures had to be taken to keep the ambient temperature higher than 5°C (41°F). For curing, the freshly casted pedestals were covered.

The casting of UHPFRC pedestals required strict logistical procedures. Only a small area on the neighbouring platform could be used as an installation area. The remaining platform area was reserved for passenger traffic and the reconstruction of the platform lighting. Therefore, it was decided to use a specially developed small hopper car on rails to transport the fresh UHPFRC batch from the mixer to the casting location. The maximum weight of the loaded hopper car was about 2 tonnes, and the maximum 0.5 m^3 () of fresh UHPFRC-mixture could be transported in one go.

In addition, material tests showed that the casted UHPFRC pedestals had reached a compressive strength of more than 12 MPa (1,74 ksi) after only 16 hours at an ambient temperature of 5 °C (41°F) and thus could be driven over by the light construction site vehicles.

Moreover, an additional work shift per track was planned in order to finish the UHPFRC casting seven days before putting the respective track into operation.

The most important construction process stages are briefly described:

1. Removing the existing rails and original LVT monoblocs (Figure 4 (a))
   The existing rails were cut into 6 m (236.22 in) long track panels and removed from the construction site by a rail crane. Small parts of the rubber shoes and plastic that adhered to the concrete surface of the existing concrete slab in the recesses caused extra work due to additional cleaning.
2. Surface cleaning (Figure 4 (b))
   The remains of rubber shoes and plastic were removed using electric jackhammers and pneumatic needle hammers. The resulting rough surface was advantageous for the bond between UHPFRC pedestal and the existing concrete. Just before casting, the surfaces were cleaned with a high-pressure water jet and moistened.
3. Reinforcement (Figure 4 (c))
   Since UHPFRC has relatively high tensile strength, simple rebar cages with low steel reinforcement content were installed, thereby, a tolerance of ± 5 mm (0.20 in) was met.
   Moreover, additional steel anchors between the new pedestals and the existing concrete slabs were installed to ensure this bond (Figure 2).

4. Assembly and fixing of rails, fasteners and formwork for UHPFRC pedestals (Figure 4 (c))
   First, rails including rail fasteners were fixed on a lift and position system. Afterwards, the exact rail position was precisely aligned, and the rails were fixed on the target position. For casting the pedestals, wooden formwork with adjustable height and resisting to hydrostatic pressure was used.
5. Casting (Figure 4 (d), Figure 5)
   The fresh UHPFRC was transported by the hopper car on rails in quantities of 0.5 m^3 directly to each UHPFRC casting place, where it was casted manually.
   Afterwards, the target track geometry was checked by the track alignment system. The tolerance of Swiss Railways according to regulation I-22070 was met with +3/-1mm (±0.12/0.039 in) for the track gauge and ±0.5 ‰ for rail twist. After finishing the track construction works, the track lubrication system was installed, and the overhead line was regulated before the track was put into operation.

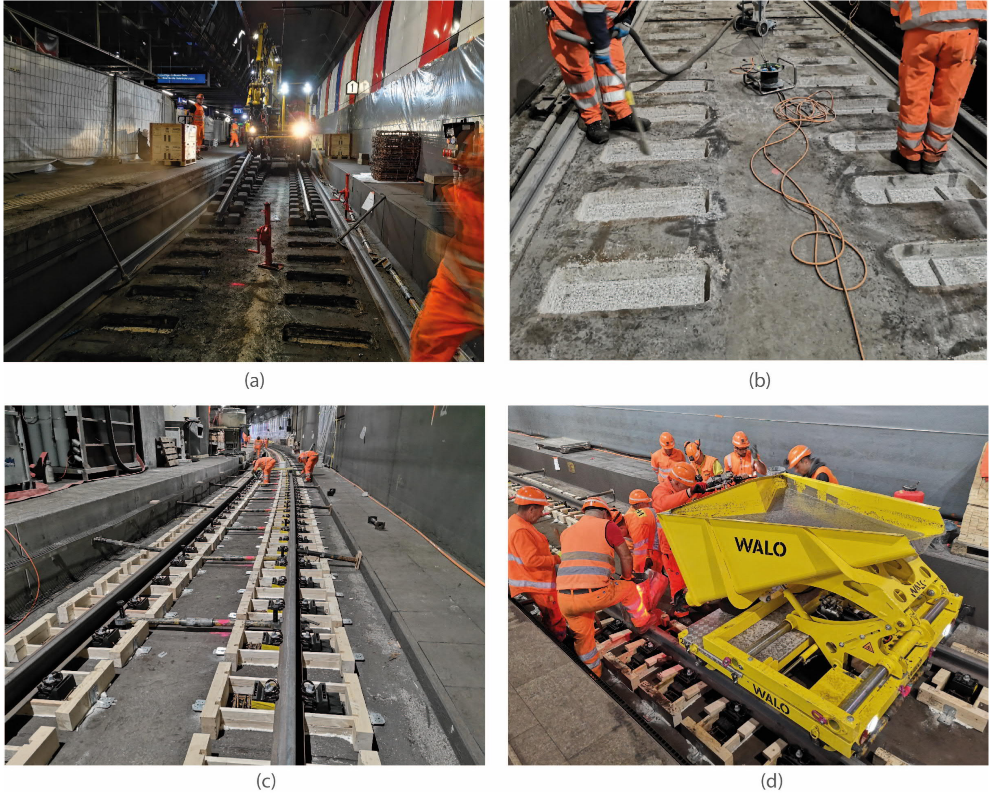
(a) (b)
(c) (d)

Figure 4 stages of the construction process stages

4. Conclusion

The use of the UHPFRC for the renewal of fixed railway track systems according to the concept of direct rail fastening on thin UHPFRC pedestals enabled a technically high-quality and economical solution by:

1. reduction of the pedestal height from 24 cm to 11.9 cm (9.5 to 4.7 in), thus avoiding costly rebuilding of the platforms

2. reduction of the reinforcement content, simplification and acceleration of the construction process
3. increase the service duration and reduction of maintenance

For future applications of UHPFRC, the experience gained from this project can be used and the design of heavily trafficked fixed railway tracks can be further optimized.

5. Acknowledgements

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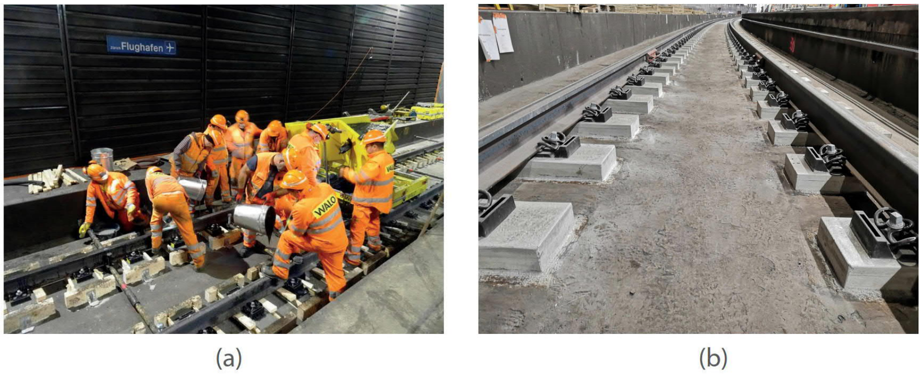

(a) (b)

Figure 5 (a) casting UHPFRC, (b) Renewed track ready for putting into operation

6. Literature

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