1. ABSTRACT

This paper presents the results of polyurethane resins testing for sealing and consolidation of the railway tunnel lining affected by infiltration. In order to know the technical state of lining at intrados, within its mass and at extrados, both before and also after the injections with PUR, a program with non-destructive and destructive investigation was performed, consisting of: - detection of viewable infiltration and damages at intrados of lining; - taking out samples cores from the lining body and their testing before and after injection; - investigation by Geo-radar method in three sections before and after injection. The success of experiment was confirmed by the following arguments: - the actual state of intrados of lining from which the infiltrations disappeared; - the results of GEORADAR investigations, which evidence the removal of water from lining and even its removal from extrados; - the very precious information obtained, regarding the technical state of existing lining (thickness, damages, caverns) and also the behavior of lining at the pressure given by injections; - the results of testing the samples cores, which reveal the important increase of compressive strength and decrease of permeability.

2. TESTING OF POLYURETHANE RESINS IN PREDEAL TUNNEL

2.1. Generalities

With a view to introduce the new technology with PUR at tunnels a demonstrative testing was performed at one railway tunnel affected by infiltrations. The tunnel Predeal was selected for testing with agreement of national railway company CNCF – CFR SA. This tunnel realized between May 1939 and August 1940, is placed on the 4<sup>th</sup> pan-European corridor between Predeal and Brasov stations and has the following characteristics: - 952m length; - 2.3% declivity; - 281m minimum radius; - horse-shoe shape; - cast in place concrete structure with stone masonry at intrados of vault as fume protection. The massive under
passed is composed of gray, sandstone, clay and lime conglomerate, strongly corrugated and fissured. The ring 12 selected for testing present strongest infiltrations on vault, appearing as moisture and leakages in summer and icicles and ice blocks in winter. These infiltrations have a negative action on the tunnel lining damaging concrete especially.

2.2. Description of PUR injection works.

The test was made by common effort of following companies: MINOVA CarboTech Germany (supplier of materials), MINOVA Bohemia (supplier of equipments and skilled personnel), AAA Izoconstruct Bucharest (sponsor of works), UTCB (maker of investigations and expertise report) and CNCF-CFR SA which has ensured the railway enclosures for execution, rail wagon with working platform, locomotive with skilled personnel, electricity and compressed air.

The following works have been made:

1. Drilling of grouting holes (D = 29mm) through the structure of existing vault, composed from layers, an inner stone masonry of 30cm thickness and an unreinforced concrete layer with thickness varying between 50cm and 100cm.

2. Injection via holes of two component polyurethane resins, CarboPur WFA type, into the wet masonry and country rock at extrados of lining, for void filling and sealing.

3. Injection via holes of two component polyurethane resins, CarboPur WFA type, into the wet masonry and country rock at extrados of lining, for void filling and sealing.

4. Injection via holes of two component polyurethane resins, CarboPur WFA type, into the wet masonry and country rock at extrados of lining, for void filling and sealing.

5. Injection via holes of two component polyurethane resins, CarboPur WFA type, into the wet masonry and country rock at extrados of lining, for void filling and sealing.

6. Injection at high pressure of two components PUR into the mass of lining, near the joint between ring 12 and 13 (row 1 and 2) for consolidation of damaged concrete and sealing of joint.

7. Filling of joint between ring 12 and 13 with an elastic PUR for maintaining the sealing even in conditions of joint opening.

In the moment of holes drilling preciousness information had been obtained regarding of:

- the real thickness of lining;
- the damaging state of concrete;
- the existence of some cavities and of water inside the concrete mass or at the extrados of lining.
117 holes with an average length of 1.2m have been drilled and 101 holes have been injected, 16 holes being filled by communication. The total consumption of material has been of 3432 liters, meaning an average per hole of 34 liters, and reported to the whole sealed surface of 49m² it results a consumption of 69 l/m². The works has been realized in 9 days (1m/day) working almost 6 hours/day in the traffic window.

3. CONCLUSIONS
The success of experiment is confirmed by the following arguments:

- the actual state of inner-shell of dome from which the infiltration's disappeared;
- the results of Georadar investigations which evidence the removal of water from lining and even its removal from extrados;
- the very precious information obtained, regarding the technical state of existing lining (thickness, damages, caverns) and also the way of behavior at the pressure given by injections;
- the results of core samples testing which reveal the important increase of compressive strength and decrease of permeability by realization of consolidation injection.

The success of this experiment is an argument supporting the introduction of the new technology at rehabilitation (sealing and/or consolidation) of some tunnels existing upon railway network.

The implementation of the new technology must be done, anyhow, with much attention and respecting the following principles:

- certificates of materials and technology;
- offering the execution to an experienced specialized company;
sustaining the choice with non-destructive investigations as much as possible consistent;
creating a system of monitoring up execution and of checking the results.

II. REABILITATION OF FABIAN III TUNNEL

Fabian III Tunnel is located on Craiova Railways Branch, Filiași – Livezeni section, between Pietrele Albe train station and Strâmboța flag station, between km 112+145 and km 112+545, on the right bank of Jiu river. The tunnel was built in rock using the so-called “Belgian Method” and opened in 1948. It is 400 m long and an average in-tunnel gradient of 11.6% (slant towards Livezeni station) and has the following layout: at the entrance, the route makes a right turn with a 300.85 radius to km 112+263.04, then a left turn with a radius of 2,000.03 m to km 112+428.54, then straightway to the exit. During operation, major water infiltrations occurred in the upright walls area under the longitudinal drainage ditches located on both sides at 4.00 m above the tunnel highest point and on the arch (mostly at the tunnel end sections and some in the middle section). As time went by, this process became critical and – as the infiltration water is a degrading factor for concrete – the concrete in the upright walls eroded and some segments of the lining came off while in some areas voids occurred. Linings no. 36-40 have side elements made of segregated, degraded, highly-porous concrete. In its position of designer, Railway Studies and Planning Institute has implemented an innovative method in the railway field a based on waterproofing, water tightening and consolidation of the tunnel and the ancillary area using bi-component polyurethane resins. The contractor of work, AAA IZOCONSTRUCT Bucharest, has completed about 95% of the works in 75 working days. The results are beyond any expectation, the damp areas and high-infiltration areas (with leakage and springs) have receded and areas featuring degraded concrete (linings no. 36-40) have been consolidated performing grouting in the concrete body using bi-component resins featuring a high mechanical strength. These resins ensure a 35-40% rise in the compression strength. Also, the soil behind the tunnel lining in the above areas has been stabilized using IBO R 25 anchors injected with resins.

The undisputed advantages of the above method compared to classical methods are the following: - better building records (1m/day outside operating hours) with shorter construction time, reduced manpower, information on the lining condition during construction works and opportunity to adapt technology depending on the above information.
III. THE INTERVENTION TO THE COMMERCIAL CENTER MILLENNIUM.

A. Construction Characteristics of the Structure

Deep excavation hole: 16 m (with about 11 m under the underground water level)

To provide the stability of the digging hole and sealing against infiltration coming from the underground water, it was projected a room of moorage walls in terrain, without to connect of the moorage walls by a perimeter steel bars.

B. Problems

After the technical expertise of the protection moorage walls room, it was resultant that for the motive of some technical errors during the executions were resulted some damages to the neighbors constructions: local collapses of the ground, fracture of the terrain, infiltrations, etc.

In 4 zone of the digging foundation hole, at – 16 meters, it was appear a large water infiltrations together with large quantities of sand (approximately hundreds of square meters of sand).

C. Measurement of intervention in emergency regime
- execution of the concrete readier with reducing to the minimum of the infiltration with solid debit in the inside area.
- montage of a row of retaining inside elements from steel profiles, at the cote between first and second line of anchors.
- execution of a collect system and evacuation for infiltration water.
- water proofing of the inside zone by injecting in the joints, and the bottom of the excavation.
- increasing of the work speed for finalizing more faster the infrastructure.
- improvement of the foundation terrain under the nearby constructions buildings.

IV. ANCHORING AND STABILIZATION OF THE NATIONAL ROAD NR. 73, KM. 66 + 273 RIGHT

A. Initial situation: right way track had problems of stability, specially the border side of the road where is situated the protection steel bar, with slide slope of the terrain.

B. Location: National Road which make the connection between Pitesti City and Brasov City, in Carpathian Mountains, in Dragoslavele village.

C. Solving the problem: it was try to stabilize the slope by traditional technology with micro piles with pre drilling and casing technology, provided by Zublin Company. Because the rhythm of the execution it was not pleased for the beneficiary, the client (general contractor Romstrade) was decided to change the technology. So, it was adopted the self-drilling technology and grouting system.

D. The projecting solution: to install 2 rows of micro piles along the right side of the road under the projecting concrete slab which sustain the protection heavy steel bar. One of the row, the exterior one, it was install with 20° declination from vertical line, in number of 36 anchors in length of 14 meters from the existing asphalt level. The second row, toward the road ax, it was install in the vertical position in the same number of anchors (36 pieces) and in the same length of 14 meters.

E. Distance between anchors: 1,50 meters between the anchors from the same row. Install in chess position.


G. Equipment: drill machine MORATH, bagger of 6 tones, electric cement pump IBOREP, oil-hydropower generator MORATH.
H. Problems during execution: at level – 8,90 had appear a crystalline shiest in width of 2,5 meters which create big problems for what regard toward of the drill bit.

I. The grouting was done with cement suspension in consistence of 1400 kg / m$^3$. During the injection, the geological profile, specially the gravel with divers granulometry, made for some anchors very difficult the procedure to fill it up the drilling hole for the motive of big caves under the ruttier system, which create in the end a big consumptions of the cement suspension.

V. TALASMANI RAILWAY TUNNEL

A. Problems to solve: important water infiltrations inside of the air-changer of the tunnel which were penetrate the concrete walls.

B. solution adopted: sealing by injection of the air-changer system from the tunnel, by drilling holes into concrete walls and inject polyurethane resins.

Before the works was made a test by common effort of following companies: AAA Izoconstruct Bucharest (sponsor of works), UTCB (maker of investigations and expertise report) and CNCF-CFR SA.

The following works have been made:

1. Drilling of grouting holes (D = 14 mm) through the structure of existing concrete wall.
2. Injection via holes and packers of two component polyurethane resins, CarboPur WFA type for void filling and sealing.
3. Injection at high pressure of two components PUR into the mass of lining for consolidation of damaged concrete and sealing of joint.

In the moment of holes drilling preciousness information had been obtained regarding of:
- the real thickness of lining ( existing concrete wall, which was presented some zones which were not capable to sealing properly the structure against water underground infiltration;
- the damaging state of concrete;
- the existence of some cavities and of water inside the concrete mass or at the extrados of lining.

95 holes with an average length of 0,30 m have been drilled and 76 holes have been injected, 19 holes being filled by communication. The total consumption of material has been of 2430 liters, meaning an average per hole of 25 liters. The works has been realized in 4 days.
VI. BRAZI RAILWAY STATION UNDERCROSSING-PASSAGE.

A. Initial situation: large zone with big water infiltration which create deeply damages in the concrete structure, like it shows in photo. One from the motive of present situation it was the fact that in the area of railway station is one of the most important railway traffic with chemical and petroleum substances, like oil, petrol, benzene, gas, and so on, which in time was affected the concrete structure under. The result it was that the concrete structure became fragile and easy damaged for actions like carbonation of concrete.

B. Solution adopted: Sealing by injection with two component polyurethane resins, CarboPur WFA

The following works have been made:
- Drilling of grouting holes (D = 14 mm) through the structure of existing concrete wall.
- Injection via holes and packers of two component polyurethane resins, CarboPur WFA type for void filling and sealing.
- Injection at high pressure of two components PUR into the mass of lining for consolidation of damaged concrete and sealing of joint.
- Also, were treated the rectangular joints between the walls, roof and layer.
- The was executed also in the concrete structure but even behind the concrete lining.

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