New Railway Routes, Cross Section and Water Evacuation System Problems at Tunnels in Romania

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Abstract. Adoption of the maximum circulation speed of passenger trains of 160 km/h and 120 km/h for freight trains conducted to rectification of 300 Railway Magistral. In the railway rehabilitation project between Brasov and Simeria, component part of IVth Pan European Railway Corridor along Romania were provided a series of art works like tunnels and bridges. The paper presents the new constructive routes adopted in the railway rehabilitation project for three zones, corresponding to the new three tunnels: Sighisoara, Danes and Turdas and the new rail curves adopted in order to ensure the designed speed. In the second part of the paper it is made a research regarding the technical solution of tunnels cross section and the implication of the works connected. A brief comparison between the Sighisoara, Danes and Turdas tunnels cross section and the problems encountered during construction is made. In the third part of the paper are presented the deficiencies of the water evacuation canal, central canal, drainage pipes and deficiencies in conception of water drainage system of tunnels.

1. Introduction
The Pan European Road and Rail Corridors in Romania are crossing the country and finish in Constanta Port, are presented in figure 1.

The IVth Pan European Railway Corridor is crossing Romania on the axis Frontiera - Curtici – Arad – Simeria – Sighisoara – Brasov – Bucuresti – Constanta, being part of Railway Magistral 300. Until now is rehabilitated the sections between Constanta – Bucuresti – Predeal and are in progress of finishing the rehabilitation between Brasov and Simeria.

In order to obtain the design speed for passenger trains of 160km/h were adopted higher radius for curves conducting to new routes and a series of art works. The entire railway between Brasov and Simeria was divided in:[1]

- Brasov – Sighisoara section, with 112.63 km length, divided in other three parts, Brasov – Apata, Cata – Apata and Cata – Sighisoara that in this time are almost contracted (2 from 3 parts);
- Sighisoara – Coslariu section, with 99.04 km length, the rehabilitation is finished and the principal art works, beside the rail rehabilitation that are along this section, are:
  - Steel arch bridge over Tarnava Mare river – at km 299+740, with 134.60 m length;
  - Danes tunnel;
  - Sighisoara tunnel;
Figure 1. Pan European Roads and Railways Corridors in Romania [2]

- Coslariu – Simeria section, with 74.43 km length that was divide in two parts:
  - Plot 1: Vintu de Jos – Simeria, with 41.41 km length that contains rehabilitated railway line on existing route of 29.137km and new railway line on new route of 12.273km and one new double track railway tunnel;
  - Plot 2: Coslariu – Vintu de Jos, with 33.02 km length that contains rehabilitated railway line on existing route of 27.533km and new railway line on new route of 5.487km;

In this paper are presented tunnel art works along the two sections between Sighisoara and Simeria, where we can find the new three tunnels Sighisoara, Danes, Turdas and on the abandoned route the Hetur tunnel.

Were designed three new double track railway tunnels on the new route, first Sighisoara, with 401 m length, between km 299+910 and km 300+311, the second is Danes, with 969 m length, between km 301+543 and km 302+512 and the third is Turdas, with 780 m length, between km 465+296 and km 457+075.

The old routes and the new routes adopted in the rehabilitation project are presented below in figure 2 and figure 5.

Figure 2. Comparative presentation of old route – new route around Danes and Sighisoara area
Sighisoara and Danes tunnels are executed with both methods in underground and from surface – shallow execution with the Cut and Cover method at the ends. Turdas tunnel is entirely executed from surface with Cut and Cover method.

The old route is longer and we can find the double track Hetur tunnel, between km 301+173 and km 301+319 - 146m length, in plan has a curve with radius - R=355m, in longitudinal profile the declivity is ≈5‰.

The new designed route has five curves with radius between 355m and 15000m and declivities between 4‰ and 5.9‰. [3]

The construction technology of Sighisoara tunnel, located between the railway stations Sighisoara and Danes, has three distinct parts, because of the natural ground configuration:
- Shallow tunnel – 20 m, between km 299+910 and km 299+930;
- Underground tunnel – 325 m, between km 299+930 – 300+255;
- Shallow tunnel – 56 m, between km 300+255 and km 300+311;

In plan the tunnel has a curve with a radius of 404m for 81m length, a connection progressive curve for 60m and alignment for 260m length, in longitudinal profile the declivity is 4‰ and underpasses the National Road 13 – DN13 (figure 3).

The construction technology of Danes tunnel, located also between the railway stations Sighisoara and Danes, has three distinct parts, because of the natural ground configuration:
- Shallow tunnel – 20 m, between km 301+543 and km 301+563;
- Underground tunnel – 862 m, between km 301+563 – 302+425;
- Shallow tunnel – 87 m, between km 302+425 and km 302+512;

In plan the tunnel is entirely in alignment, in longitudinal profile the declivity is 4.5‰ and is the longest railway tunnel in Romania, built after 1990 (figure 4).
Around Turdas tunnel, the old route contained three curves and the new route contains only one curve. Turdas tunnel has the length of 780 m, in plan has a curve with radius of $R=3000\text{m}$ for 605 m length, a connection progressive curve for 80 m length and alignment of 95m length, in longitudinal profile the declivity is $5\%$.

![Figure 5. New and old route around Turdas tunnel area [4](image)](image)

2. Cross sections
The first steps in conception of a railway tunnel is determination of inner rolling gauge and the interior free cross section and takes into account the following:

- Characteristics of line in plane (curves radius) and in longitudinal profile (declivity);
- Characteristics of line in transversal profile – distance between lines, elevation;
- Gauge for rolling material, pantograph, catenary;
- Gauge for installations, equipments;
- Gauge for maintenance staff;
- Execution tolerance.

In order to establish the optimal cross section of a railway tunnel is necessary a detailed study regarding cross section correlated with the regulations of UIC - International Union of Railways such as:

- construction rolling gauge of rolling stock based of UIC norms 501-1, 505-4, 505-5 and 506;
- pantograph isolation rolling gauge based on UIC norms 505-1, 505-4, 606-1 and 608;
- catenary isolation rolling gauge (fixed rolling gauge) based on UIC norm 606-1;

A study made by Systra and MVA Consultancy [5] about the free cross sections stated that the free cross section calculated based on aerodynamic effects for trains travelling at 250 km/h, is larger than the cross section that would be required for trains travelling at 230 km/h.

Also, for lower speeds than 250km/h it is not demonstrated that aerodynamic criteria are the most suitable for cross section area design and attention should be paid to other criteria, such as train gauge, space for walkways, clearance for any fixed equipment in the tunnel.
Table 1. Ratio between excavated section and free cross section in constructed HSL [5]

| High speed rail line – tunnel name          | Excavation method                          | Length (m) | Free section (m²) | Excavated section (m²) | Speed design (km/h) | Ratio excavated/free |
|---------------------------------------------|--------------------------------------------|------------|-------------------|------------------------|---------------------|----------------------|
| Atlantique - Vouvray                        | Traditional method                         | 1496       | 71                | 100                    | 270                 | 1.41                 |
| Paris / Marseille – Pennes - Mirabeau        | Traditional method, full section excavation| 1530       | 63                | 90                     | 230                 | 1.43                 |
| Taiwan HSR                                  | Traditional method                         | 2000       | 90                | 130                    | 350                 | 1.44                 |
| Paris / Marseille - Tartaignelle             | Traditional method, full section excavation| 2430       | 100               | 150                    | 320                 | 1.50                 |
| Paris / Marseille – La Galaure              | Traditional method with pre-cut            | 2759       | 100               | 150                    | 320                 | 1.50                 |
| Cologne / Rhine/Main - Schulwald           | Constructed in mining technique, headed with excavators and drill&blast | 4460 | 92 | 140 | 300 | 1.52 |
| Paris / Marseille - Marseille               | Traditional method, full section excavation| 5414       | 63                | 90                     | 230                 | 1.43                 |
| Paris/Amsterdam - Groene Hart               | Driven with a slurry shield TBM            | 8636       | 109               | 174                    | 300                 | 1.60                 |
| Tohoku Shinkansen (Japan) – Iwate - Ichinohoe | Drill&blast or mechanical excavation and full face or bench cut methods | 25810      | 61.9              | 70 to 85               | 250                 | 1.13-1.37            |
| Brussels/German Border - Soumagne           | First mechanical excavation, then drill&blast. | 6405      | 69                | 110                    | 200                 | 1.59                 |

Cross section of Turdas tunnel
The initial cross section of Turdas tunnel and the entire project was revised, because in the initial project, apparently assumed the inner section was design for a speed between 250km/h – 300km/h, based on the statistic dates of SYSTRA and MVA Consultancy study, speed that will be obtained in the future, however were not made any specific analyses for the future routes. [6]

The initial cross section includes surface execution, at the ends, for a cumulated total length of 270m and underground execution in the middle of 510m (figure 6).

Figure 6. Longitudinal view of initial Turdas tunnel [6]

Also the initial cross section had a series of problems and deficiencies such as: [6]
- sidewalks of approximate 1.10m, though the minim is 75cm according to TSI 2008/163;
- the distance between the railway axis and the sidewalk was 2.02m, but for the mechanized refaction, for railway on ballast bed, is necessary at least 2.20 m, according to Richtlinie 853 Eisenbahntunnel planen, bauen und instand halten, from 2002;
- the drainage pipes are discharging the water in the broken stone prism and then in the longitudinal central canal that can conduct to easy clogging – the 314 Romanian Instruction recommends lateral longitudinal collector canal instead of central longitudinal canal.
- The thickness of columns and straight legs;
- Adopting a bigger section conducted to bigger free section and bigger excavated section (figure 7).

![Figure 7](image)

Figure 7. Comparative cross section – present(left)/initial (right) of the tunnel and areas of free and excavated sections

The revised cross section adopted for the entire tunnel includes only surface execution and with this, were reduced the work quantities and resolved all other issues that were not correlated with the maxim designed speed regulations, water evacuation system in tunnel and sectional efforts.

The rolling gauge of the new section is adopted for the maxim speed of passenger trains of 160 km/h and is based on the application of the following regulations, used for the revised project:
- construction rolling gauge of rolling stock based of UIC norms 501-1, 505-4, 505-5 and 506;
- pantograph isolation rolling gauge based on UIC norms 505-1, 505-4, 606-1 and 608;
- catenary isolation rolling gauge (fixed rolling gauge) based on UIC norm 606-1;
- Rolling gauge – STAS 4392-84;
- Safety in railway tunnels – TSI 2008/163.

The revised cross section conducted to major savings from the reduction of the free section (figure 7) from $S_{\text{free}}=84 \text{m}^2$ to $S_{\text{free}}=80 \text{m}^2$ and from the excavated section $S_{\text{exc}}=234 \text{m}^2$ to $S_{\text{exc}}=176 \text{m}^2$ (figure 7).

Another conception problem that was revised for the Turdas tunnel is the position of the longitudinal water evacuation canal that in the first was located in the axis of the tunnel and after, was moved in the lateral ways, resulting two longitudinal lateral canals, one on left and other, on the right side.
The disadvantages of using a longitudinal central evacuation canal are in exploitation, when is needed the maintenance process – the circulation of trains must be stopped; the length of the transversal drainage pipes that is very big and a small declivity in the canal can conduce to easy clogging.

The new designed water evacuation system has the advantages of easy and better access even under trains circulation, also the declivity of transversal drainage pipes and lateral longitudinal canal prevents clogging.

The new cross section (figure 8) has the following characteristics that were improved with the new structural solution of surface execution for the entire length of the tunnel:
- Diaphragm walls, C25/30, 80 cm thickness – reduced from 1.20m pilles;
- Reinforced concrete lining, C30/37, 60 cm thickness – reduced from 1.00m;
- Reinforced concrete invert, C30/37, 1.00 cm thickness;
- Straight legs of 1.38m – reduced from 2.75m;
- Distance between diaphragm walls of 14.40m – reduced from 17.00m.

![Figure 8. Cross section Turdas tunnel [4]](image)

3. **Water evacuation canal, central canal and deficiencies in conception of tunnels**

In general, the water evacuation system of tunnels is composed from:

- transversal canals – transversal drainage pipes (barbacans) which conducts water from the collecting disposal to the evacuation canal – longitudinal canal; Transversal canals are often found made from tubes of different materials and diameters mounted in function of level and debit of infiltrations, but generally between the niches.

- longitudinal canals which evacuates the water to the exterior of the tunnel; Longitudinal canals are often found in shape of rectangular canals with covers, mounted in the invert, often on lateral parts and rarely in axis for double railway tunnels. The location, on lateral side
of tunnel, beside the bench presents the advantages of easier intervention, without visiting chambers and also, permits the mechanized refaction.

- visiting and interventions chamber which permits the supervision and cleaning of transversal drainage pipes and longitudinal canals.

The visiting chambers can have rectangular or circular shapes and can be placed at 25m distance for easy cleaning.

In Romania, for tunnels or maintenance of the tunnels, we have less regulations or preventions of the elements of the water evacuation system.

However, in Romanian Instruction 314/1989 – ”Norms and tolerances for construction and maintenance of railway” at the 34 article we can find: “In inverts will be drains for water evacuation from the tunnel. Typically these drains will be located on sideways in order to clean them without disturbing of the way” and also, the NE 031/2004 – ”Normative for the tunnel waterproofing for communications paths with PVC foils” contains some provision in:

- Chapter 5.9. - System for collecting and evacuating of infiltrations water in tunnel: water collecting it is realized, in generally, at the arch birth level and from here it will be guided to the bench level with the help of barbacans, executed from 25 to 25 m, one side and another of the tunnel
- Chapter 8 – Rules in service and maintenance – 8.1. The maintenance activity is a beneficiary duty. During the warranty period, the contractor will remedy the deficiencies found due to the quality of the execution or the materials” and 8.2. The beneficiary will check, with the maintenance personnel, the status of the waterproofing works periodical, every six months (in spring and autumn) and occasional when deficiencies appear.

In other countries, more known and accessible recommendations are:

- The French tunnelling and underground space association – Maintenance and repairing of underground constructions, in chapter 10.6. Aqueducts and drainage works contain provisions on longitudinal drainage and visiting chambers:
  - For longitudinal drainage minimum declivity of 0.2 – 0.3%;
  - Replacing of central visiting chamber with lateral ones;
  - Distance ≤ 25m between visiting chambers;

- International union of railways report – Tunnels subcommittee – Water evacuation devices in tunnels - 1975, based on a questionnaire answered by nine member countries, contains the most comprehensive data on this topic, cumulated in representative chapters.

- Factors considered in choosing and conception of water evacuation devices:
  - Water debit;
  - Suspended elements in water;
  - The route, the profile and the declivity of the work (minimum accepted declivity is 2% for transversal canal and 0.2% for longitudinal canal);
  - Climate and other factors.
- Study of different elements of water evacuation system (transversal and longitudinal sewer, visiting chambers).
- Choosing of manufacturing materials of transversal sewers is influenced by the nature of the water transported and by the suspended elements.

The transversal sewers are generally adopted on the sideways in simple way tunnels. For tunnels with double track railway is also preferred the sideline position of the transversal sewer because of the ease of maintenance and cleaning process and for a mechanized maintenance.
The visiting chambers can have different shapes and dimensions and are placed near the entrance of the transversal drains in longitudinal canal, at distances between 25-30m.

Danes and Sighisoara tunnels case
In the initial project of Danes tunnel the water evacuation system was composed from a longitudinal central canal located in the tunnel axis that collects the water from the broken stone prism, where the transversal drainage pipes were discharging (figure 9). The declivity of longitudinal central canal was 4.5‰ and for the transversal drainage pipes was 3‰. The same system was provided for Sighisoara tunnel. [3]

The conception of the cross section and water evacuation system weren’t enough studied and during construction some problems appeared. The cross section could not be modified, but the water evacuation system could, so the project was revised and the solution was updated. The adopted solution (figure 10) was composed from:

- Extended transversal drainage pipes through the filling concrete until the longitudinal central canal;
- Realising of visiting chambers between the two tracks on the longitudinal central canal;
- Adopting the distance between rail axis and sidewalk of 2.20m in order to ensure the mechanised refaction on maintenance process.

In the initial project one of the principal disadvantages of using longitudinal central canal is that it can clog, because of the very small declivity and the access to this wasn’t provided, also the discharging of the transversal drainage pipes in the broken prism can clog the broken stone prism and in both cases is needed to stop the trains circulation in order to make the maintenance.

The solution adopted of extending the transversal drainage pipes into the filling concrete until the longitudinal central canal has the advantage of the direct discharging, but has an important disadvantage that is the significant length of the transversal pipes and the small declivity that can easily conduce to clogging and the unclogging process is very difficult and hard.

To combat the lack of access to the central canal were provided visiting chambers that permits the maintenance during the trains circulation and quick access.

Figure 9. Initial water evacuation system of Danes tunnel [3]  
Figure 10. Revised water evacuation system of Danes tunnel [3]
4. Conclusions
Adopting of a higher speed for passengers and freight trains conducted to new routes for the 300 Railway Magistral and IVth Pan European Railway Corridor in Romania that put a challenge on Romanian authorities and engineers in order to assure an optimal solution, technical and economical, along the corridors.

Increasing the speed along the present rehabilitated route in Romania means passing to HSL and this can come only with improving the present route in order to obtain the designed speed, conducting to new art works and challenges for the Romanian engineers.

Finding and conception of a new cross section for a tunnel impose the study of the local and European norms that will conduct to the best solution. An optimal cross section obtained after research and study of the options and correlated with the design speed will reduce the costs of the entire project, which is the main problem in construction and realising of new railways or roads routes with tunnels and bridges. In this process, the experience of the engineers involved is one of the most important criteria for the review of a project and improving it.

The lifetime of a tunnel depends on the conception and the execution quality. For a tunnel the lifetime can be affected by infiltrations, therefore is extremely important to study and adopt a water collection and evacuation system that can satisfy the needs for the designed tunnel that can assure easy access and maintenance, with low costs and without interruption of circulation.

Not the least, the execution technology must be correlated with the real time situation encountered on the ground in the construction process and improved or modified as many times as necessary for safety during construction and in exploitation.

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