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RESEARCH REPORT

„Study of the tunnels executed from the surface”

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1. Execution technology

Execution technology for underground works can be divided in two big categories^[1]:

- Execution technology in open ground – open dig executed from the surface of the ground with one of the methods „**cut and cover**” – **tunnel in fully open trenches or „cover and cut” – tunnel in partially open trenches.**
- Execution technology in closed ground – closed dig, using specific methods for tunnels realized in rocks with TBM, NATM.

Choosing of the execution technology in underground or in open ground is made based on a multi criteria analysis where are taken into account the following factors:

- ❖ Ground nature and coverage;
- ❖ Tunnel location, in urban area or non urban area;
- ❖ Proclaim regarding environment by protecting areas with vegetation or animals;
- ❖ The legal situation (expropriation) of land.

A special importance is establishing the method of execution, because because designing will be done depending on the chosen execution method. Being a complex

As a complex work, it isn't possible to establish general rules that could be followed, but it is necessary to take into account several factors imposed by the site of the work and the geological conditions.^[2]

- a. If the site is in an urban area should be taken into account:
 - The city structure;
 - The type of used transport;
 - Future development of the city;
 - Urban networks in the area;
 - costs;
 - the geologic structure of the soil;
 - time of execution and design.
- b. If the site isn't in an urban area should be taken into account:
 - the geologic structure of the soil;
 - the necessities imposed by rolling speed in case of motorways or railways;
 - the expropriation limit – in case of open trenches;
 - costs;

- time of execution;

Tunnels realized by surfaces methods can be cover and cut tunnels or cut and cover tunnel which are compared with the solution of realizing the communication path in open trenches. A comparative analysis of the three solutions with specific features is presented below:

a. Tunnel in open trench – realizing an open digging, with natural slope or which requires support for both or only one of the walls of the trench.

The realization of a tunnel in open trench presents the following specific characteristics:

- Bigger footprint – because of natural slope;
- environment – is permanently disturbed;
- high costs for excavation, transportation and storage of a significant amount of soil;
- maintenance and safety issues during service (landslides, snowing).

b. Tunnel in a completely open trench (cut and cover) – realizing of the trench excavation until the quota of the support system, realizing of a support system capable of taking the loads from the ground, then excavates inside the trench until the foundation quota and the tunnel is being built, from interior, bottom – up, after the completion of the tunnel the surface ground will be restored to the original condition.

The realization of a tunnel in a completely open trench (cut and cover) presents the following specific characteristics:

- Reduced footprint and provisional opening than when using the open trench;
- The environment is temporarily disturbed, being restored to its original state at the completion of the works;
- High cost resulting from the provision of the system of temporary or definitive support, but reducing the disturbed area from surface;
- Provides safety during execution – there is no possibility of landslide and as well as in service because it doesn't require maintenance during winter;

c. Tunnel in a partially open trench („cover and cut") – realizing of excavating until the quota of the execution of the support system, realizing of the definitive support system, which is composed from vertical walls for support and a superior protection, which can be arch or floor, then under the protection of the support system, the soil is excavated until the foundation quota in underground.

Realizing a tunnel in partially open trench presents similar characteristics with the tunnel realized in completely open trench with the following differences:

- Quicker land restoration at surface;
- Reducing costs by quicker land restoration at surface.

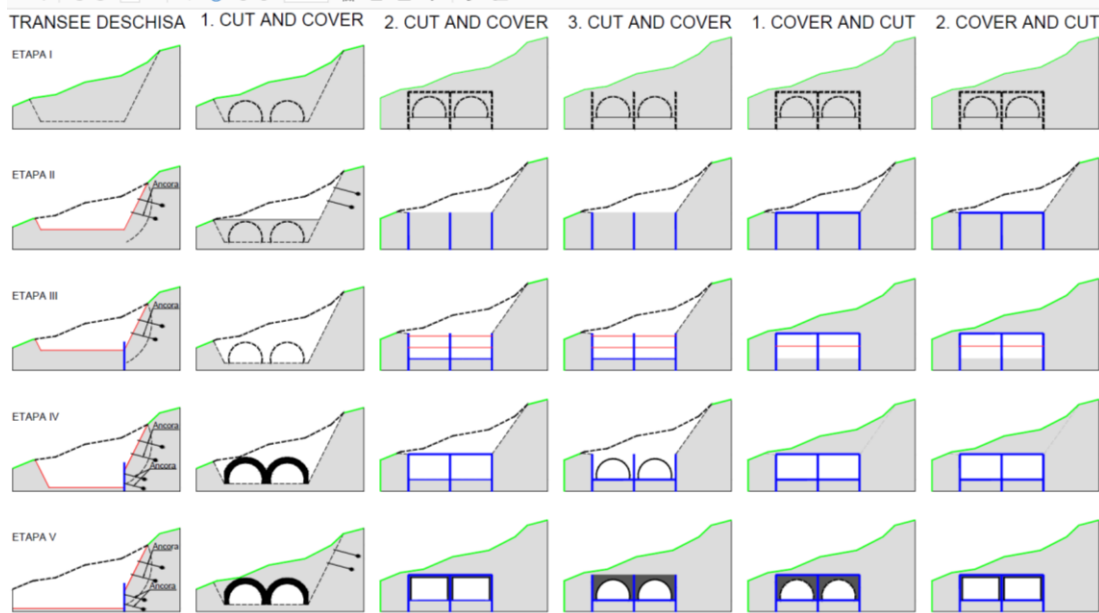


Fig. 1. Surface execution technology

1.1. Tunnel executed from surface using Cut and Cover method – tunnels executed in completely open trench

Cut and Cover execution method, was used for the first time for the construction of London's subway system, in the middle of XIX's century. At the beginning of XX's the century, the method was developed and applied in Berlin, Germany and then spread all over the world. [3]

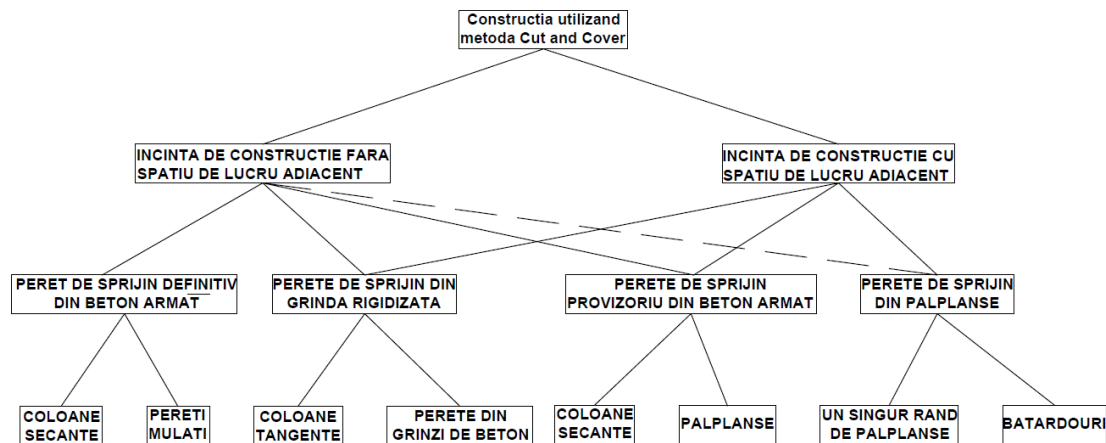


Fig. 2. Cut and Cover method according to available adjacent space [3]

Cut and Cover method can be divided in two submethods, first one when the supporting walls are an integral part of the supporting system – definitive walls and the second method when the supporting walls – provisional walls are used only during execution, the tunnel being built in the interior of the trench.

This method of tunnel execution can be made in the trench with provisional support or with final support, which can be:

- In slope trench – without support [2]

Execution method in slope trench is one of the simplest, because excavation can be automatize, taking advantage of the shore sloping.

The use of this solution requires some conditions:

- available emplacement, space is necessary to ensure slope and field surfaces stability for the excavation technology;
- lowering the level of groundwater in order to remove the need of dewatering during execution;
- field stratification from the area to be advantageous from the point of view of tightness and slope stability (cohesive layers);

- Small coverage.



Fig. 3. Tunnel in sloped trench ^[2]

In order to apply this method it can be used „ABM” supporting system proposed by the company with the same name:



Fig. 4. Tunnel type „ABM” ^[4]

- In trench with provisional support from:
 - sheet piles ^[2]

Pereții de incintă din palplanșe metalice se realizează prin batere sau baterea combinată cu vibrarea a palplanșelor în teren, pas cu pas, până la închiderea completă a incintei. Pe parcurs se urmărește realizarea corespunzătoare a păsurii și a îmbinării între palplanșele succesive. Pereții din palplanșe se sprijină prin intermediul filatelor, așezate longitudinal și a șpraițurilor dispuse transversal.

The walls of the trench from the sheet piles, are made by beating or beating combined with vibration of the sheet piles in ground, step by step, until complete closure of the trench. When are realized is being watched to execute the correct distance and jointing between consecutive sheet piles. Walls of sheet piles are lying longitudinal on tie backs and then transversal on struts.

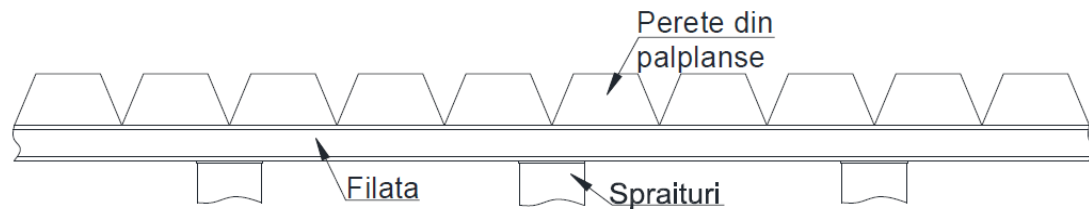


Fig. 5. Sheet piles supporting system^[2]

This method of support is recommended to be used in urban areas where spaces are very small, the adjacent field being already occupied with different types of constructions or in case of presence of the urban network.^[2]

One of the advantages of using this method of support with steel sheets is keeping the field in very good conditions outside the future excavation, this one being a very important advantage for the constructions executed near other constructions already existing or for a limited emplacement.^[2]

The disadvantages are mainly in the high cost of steel sheets and for the execution method because it is used vibration, which can affect the surrounding constructions.^[2]

The sheet piles can have different shapes and combined so:

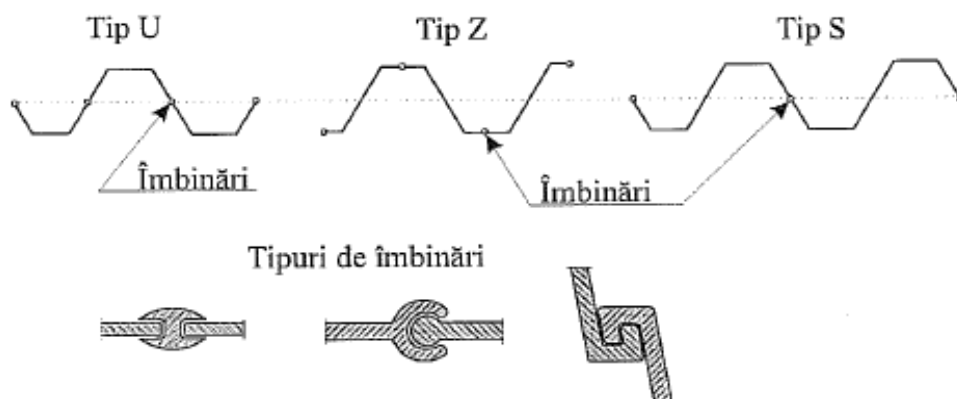


Fig. 6. Types of sheet piles and joints^[5]

- Berlinez type walls

The berlinez method of execution was used for the first time in Berlin, Germany, being specific for the geological layers in that area, which were mainly sand and clay.

The method consist of beating I profiles at distances of 1.50 – 2.50 m, with depth flush of 2.00 – 3.00 m, followed by placing some wooden cases of 5 – 10 cm

thickness during the progress of the excavation. The tunnel is built tangent of this walls, therefore is a direct contact between waterproofing and berlinez wall. Once the tunnel has been made inside the support system it is proceeded to extractions of metallic profiles I and wooden cases, when is possible to affect the waterproofing.

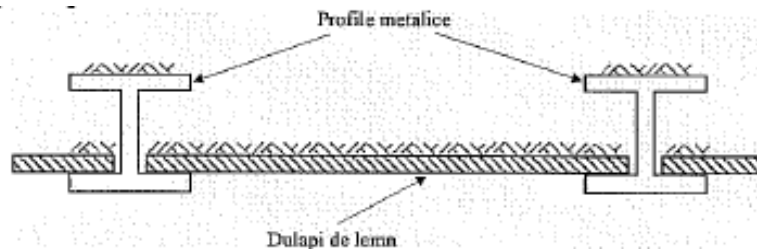


Fig. 7. Berlinez type support^[5]

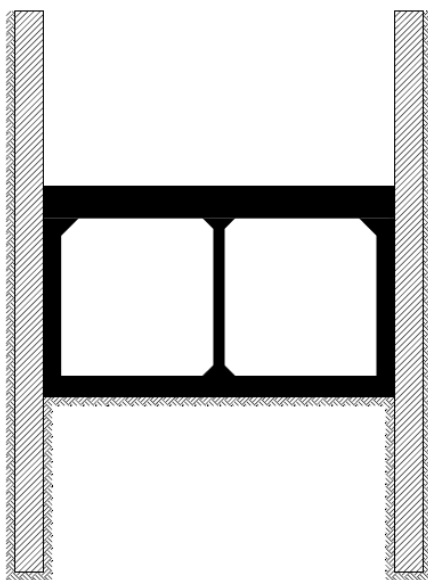


Fig. 8. "Berlinez" method of execution - "berlinez" support

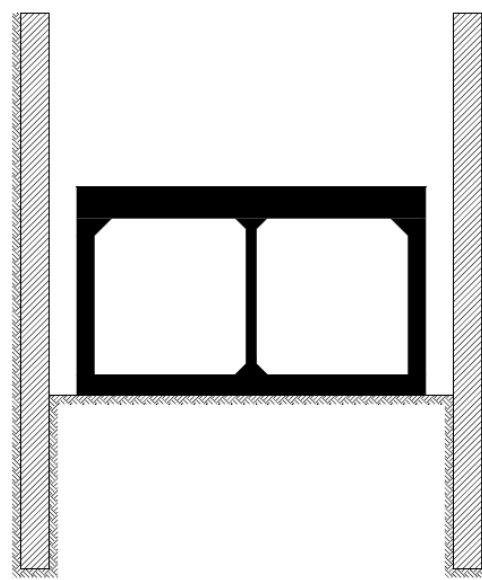


Fig. 9. "Hamburghez" method of execution - "Hamburghez" support

- Hamburghez type-walls

After the use of the berlinez method of execution on the subway construction from Hamburg, Germany was attempted an improvement and due to the specific geological conditions of the town, it appeared a new type of support – hamburghez type wall.

Diferences towards berlinez method are the use of type U metallic profiles and for a better execution of the future tunnel it was decided to add at the lateral parts of the tunnel a 80 cm distance. Thereby it was avoided the waterproofing distruction during recovery metallic profiles and the possibility of sand filling in the available space.

- Walls of drilled columns with interspaces, tangent or secant

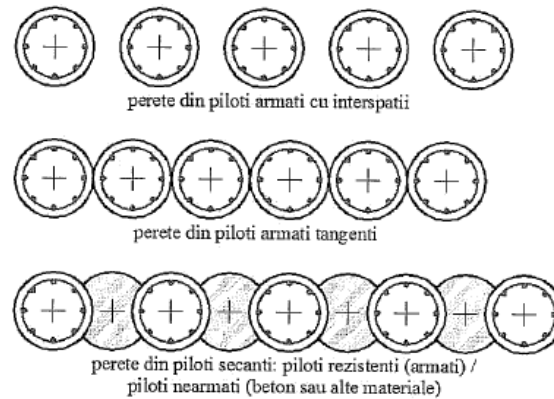


Fig. 10. Walls from drilled pilots ^[5]

- Monolith molded walls or prefabricated

When the Cut and Cover execution method is being used, the support of the molded walls is made with struts, arranged on one, two or even three rows, depending of the pushing that is applied and the height of molded walls. ^[2]

For the execution of the walls it will be used guiding beams which once are cast, it can pass to ground excavation for the execution of the molded wall. The support will be made with the help of bentonitic mud, which sustain the vertical soil walls until is inserted the reinforcement and is concreting. Concreting is done from bottom to top, therefor the bentonitic mud is recovered. ^[2]

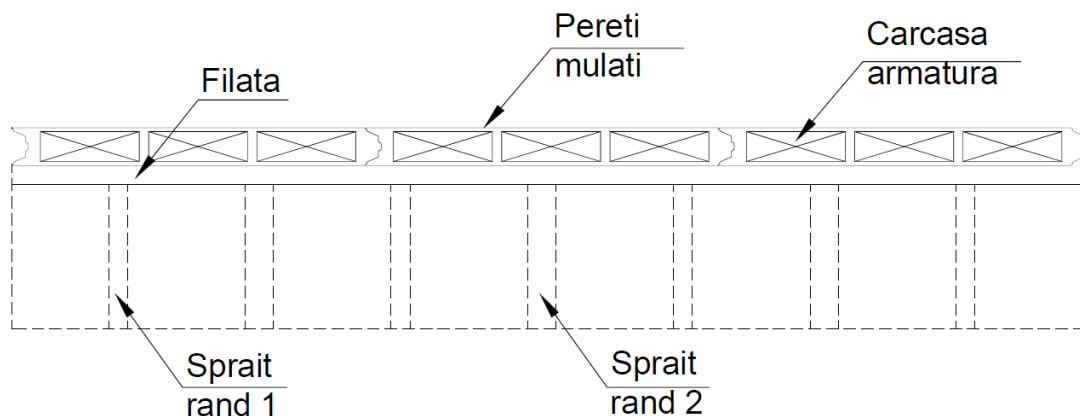


Fig. 11. Plan view – molded walls support ^[2]

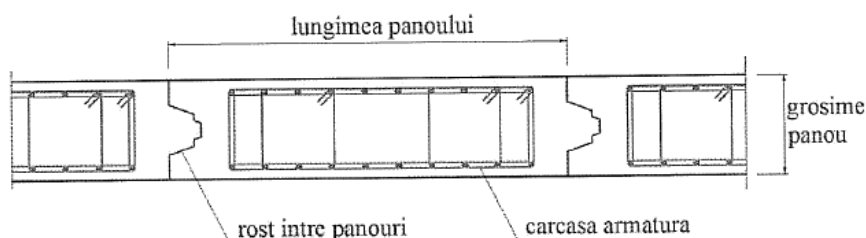


Fig. 12. Panels from molded walls ^[5]

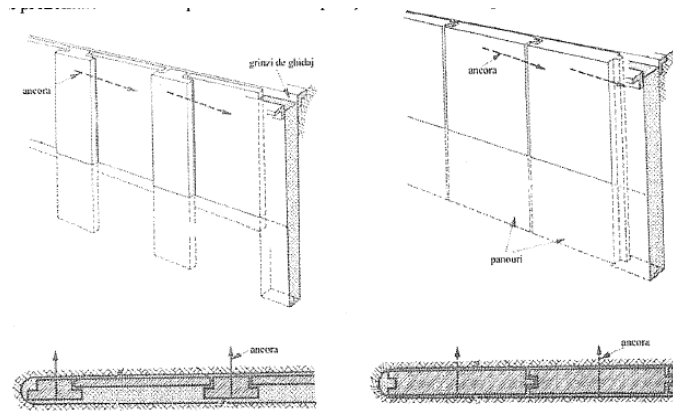


Fig. 13. Prefabricated molded walls ^[5]

Constructive types of the cross section of a Cut and Cover tunnel can have different configurations:

❖ Circular cross section

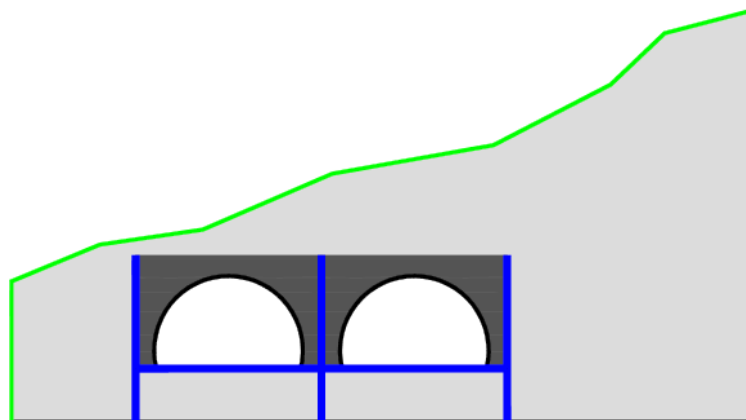


Fig. 14. Circular cross section

❖ Coffered cross section

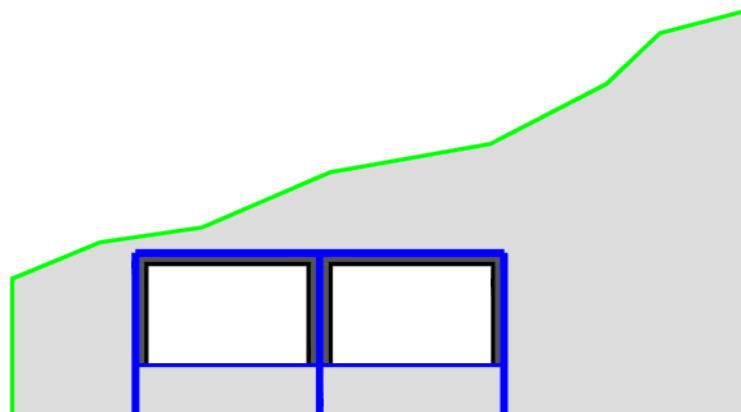


Fig. 15. Coffered cross section

Curently in Romania there is a series of constructions executed or in execution using Cut and Cover method, being a method used for all ways of communication: subway, railway and road.

Railway Turdas tunnel has a length of 780 m, on a local variant of the railway Coslariu – Simeria, railway section between Vintu de Jos – Simeria, accomplished inside of rehabilitation of the line for the train traffic of maximum speed of 160km/h for passengers trains and 120km/h for freight trains. Execution method is Cut and Cover imposed by geotechnical and geological conditions, together with maximum covering about 14.00 m. Cross section was established in concordance with the adopted method and is composed from:^[6]

- primary support, composed by molded walls of 80 cm thicknees and variable lengths between 20.0 and 23.00 m;
- inner lining made from reinforced concrete of 60 cm thickness, with a invert at the lower part of 1.00 m thickness and foundations of 1.60 m thickness.

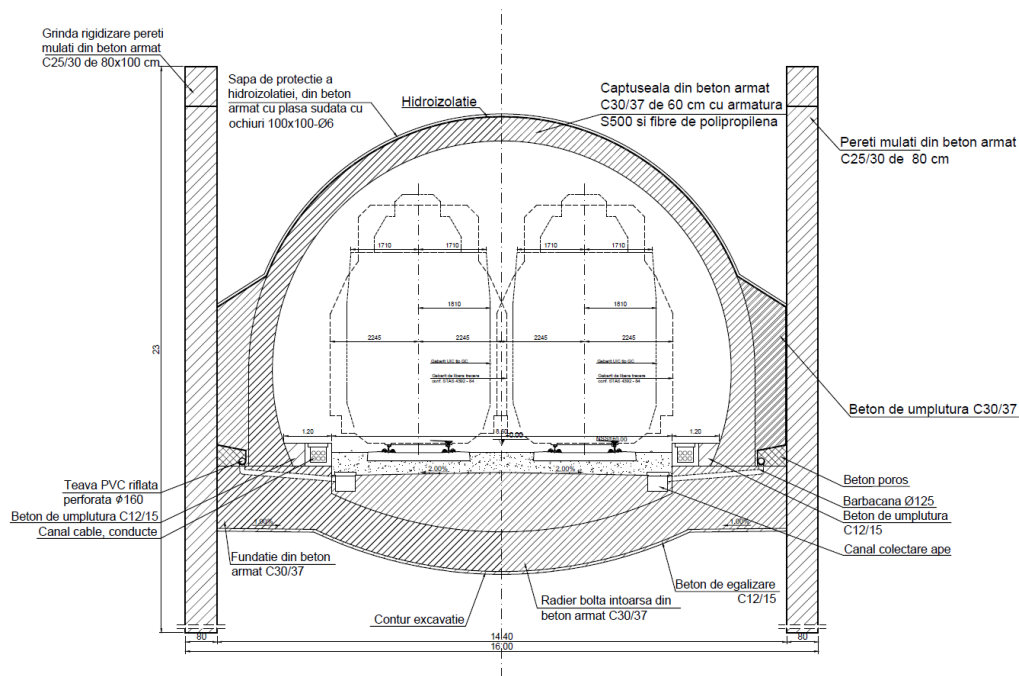


Fig. 16. Turdas tunnel cross section ^[6]

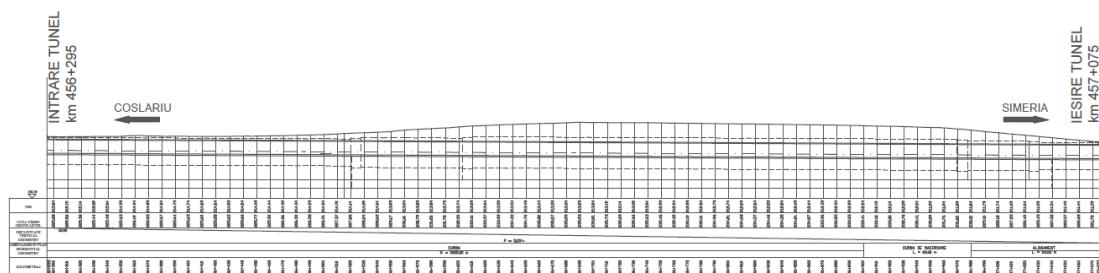


Fig. 17. Longitudinal profile ^[6]

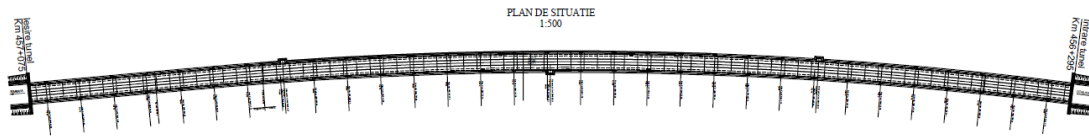


Fig. 18. Plan view ^[6]

Execution tehnology used for the construction of Turdas tunnel: ^[6]

- realizing of excavation in steps until the execution platform level of the molded walls;
- realizing of technological roads so that the drilling installation of the molded walls can stand and trucks can evacuate the soil;
- excavation of soil, the reinforcement and concreting the molded walls;
- excavation of soil between the molded walls until the first row level of struts;
- mounting the first row of struts;
- further excavation until second level of struts;
- mounting the second row of struts;
- further excavation until inferior level of invert;
- casting the equalizing concrete;
- mounting the invert reinforcement and concreting;
- realization of the waterproofing;
- reinforcement and concreting on right legs area;
- removal of the second row of struts;
- realizing the tunnel arch;
- realizing of the tunnel waterproofing on the arch area and the protection;
- removal of the first row of struts;
- realizing the filling of soil until the superior level of molded walls;
- realizing of the filling in steps until initial level of the ground.

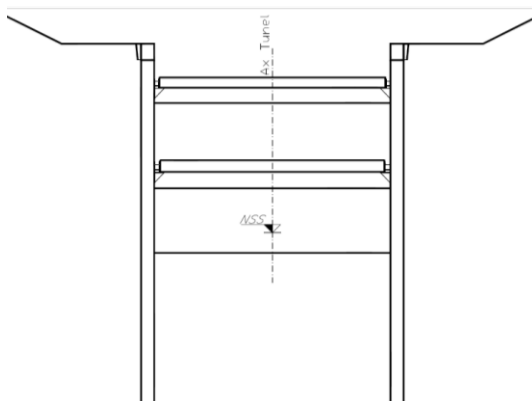


Fig. 19. Excavation ^[6]

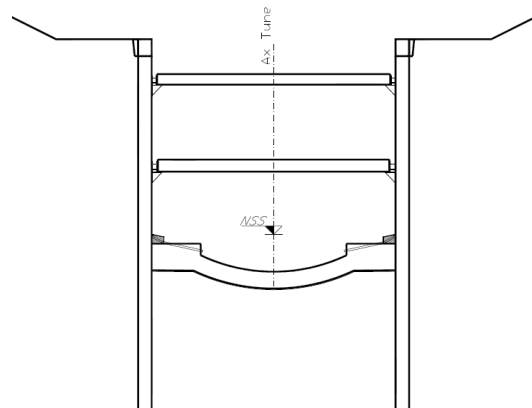


Fig. 20. Pouring the invert and foundations ^[6]

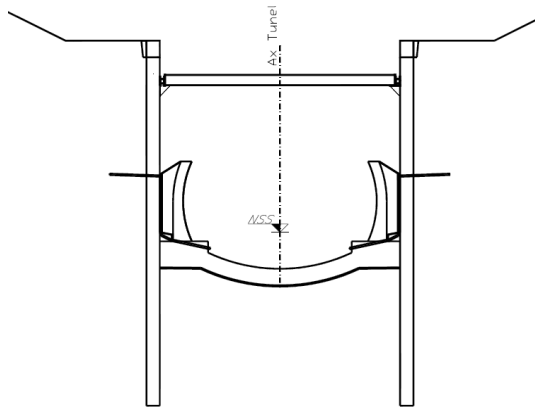


Fig. 21. Realizing the right foot^[6]

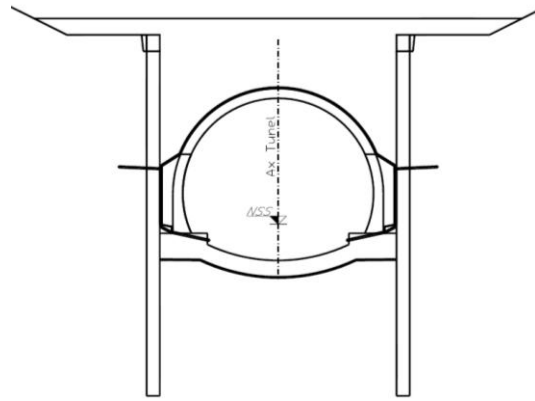


Fig. 22. Realizing the arch and the filling^[6]

Road passages from Bucharest are executed with Cut and Cover method:



Fig. 23. Băneasa passage (tunnel)

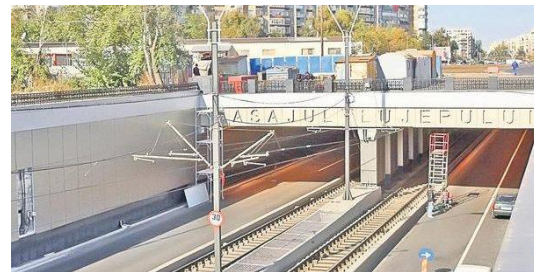


Fig. 24. Lujerului passage (tunnel)

1.2. Tunnel executed from surface using Cover and Cut method – tunnel executed in partial open trench

Cover and Cut method was originally used for the construction of low depth underground structures, in crowded urban areas, where interruption of circulation on long period of time was not a solution. ^[2]

The steps for the Cover and Cut method involves: the execution of the pretranch in order to reach the quota of execution of the future support system; the execution of the support system capable to take the push given by the ground – this system is part of the definitive resistance structure; realization of the concrete slab/floor and also the cooperation between support system and concrete slab – this slab is part of the definitive resistance structure; execution of the waterproofing on the concrete slab area and bringing the field at the initial condition; execution of the excavation under the concrete slab in steps, until invert quota; execution of the invert; execution of the waterproofing and inner lining. ^[2]

The use of the Cover and Cut method is specific and recommended for urban areas, where interruption of circulation and extremely limited space does not allow the use of another surface execution method.

For the extraurban areas, in highway projects or railway is recommended the use of the method when coverage is small and when are slopes instability situations or when sloping the shore is impossible.

Depending on the covering, Cover and Cut method can have two solutions:

- a. Slab/floor type, when the covering is small;

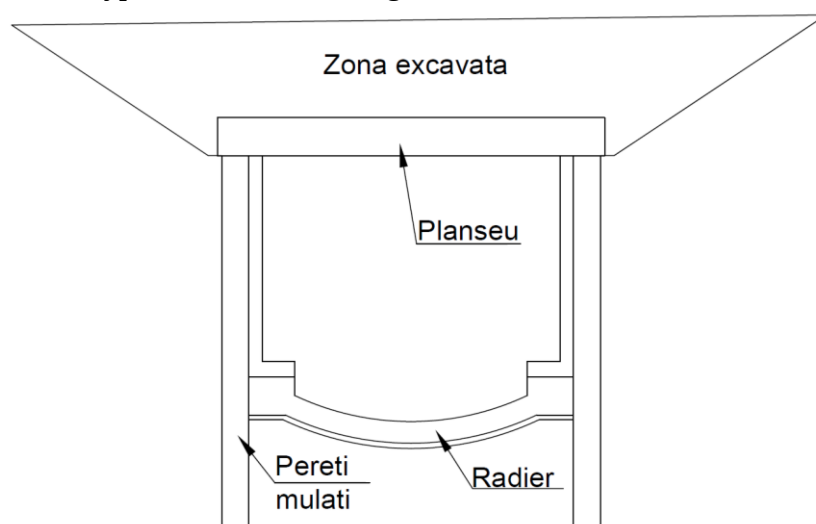


Fig. 25. Slab/Floor type cross section ^[2]

- b. Arch type, when the covering is big.

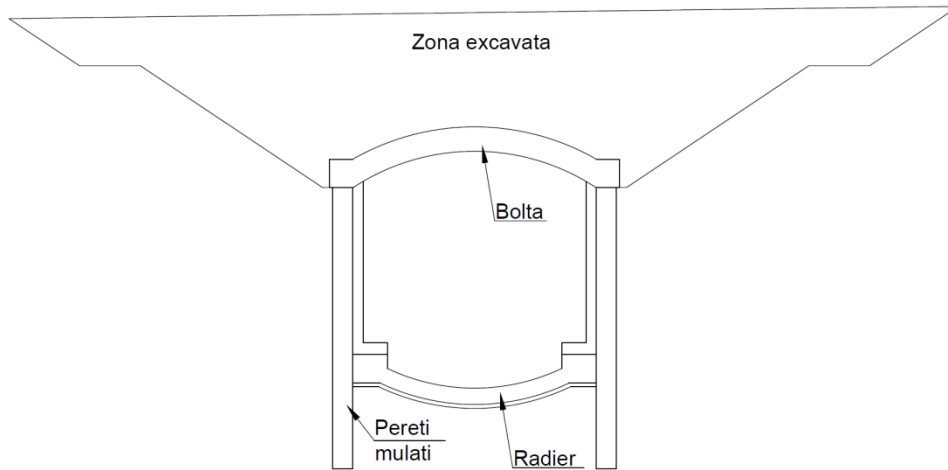


Fig. 26. Archtype cross section ^[2]

Constructive types of the cross section of a Cover and Cut tunnel can have different configurations:

- ❖ Circular cross section

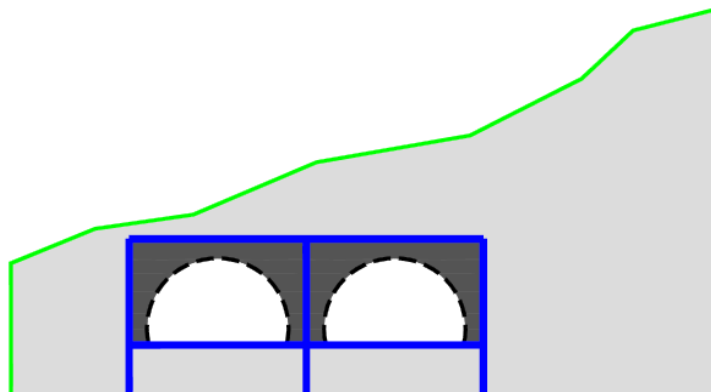


Fig. 27. Circular cross section

- ❖ Coffered cross section

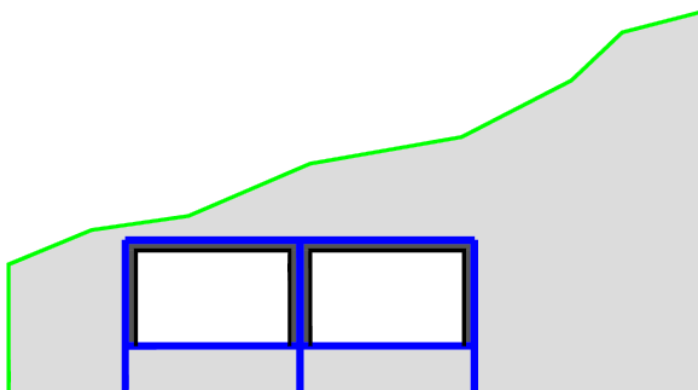


Fig. 28. Coffered cross section

Cover and Cut method offers the possibility of execution of the excavation and the tunnel lining in the hardest conditions and reaching the rock layer at a higher depth. As steps of execution this can be illustrated so: ^[2]

- step 1 – excavation until the execution level of support system;
- step 2 – execution of the support system;
- step 3 – execution of the arch;
- step 4 – bringing the field at the initial state;
- step 5 – excavation in steps under the arch until the invert level;
- step 6 – execution of the invert and the inner lining.

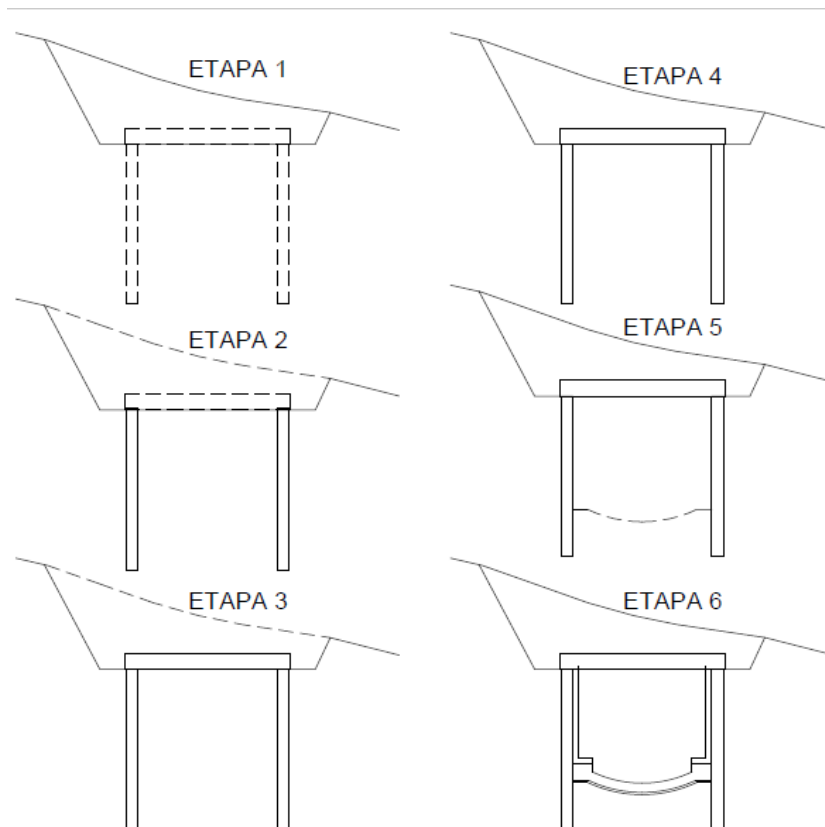


Fig. 29. Stages of constructions of a Cover and Cut tunnel^[2]

Currently in Romania there is a series of construction in execution or executed using Cover and Cut method, being a method used for all ways of communication: subway, railway and road.

First construction made in Romania through Cover and Cut surface execution method is the railway tunnel on the Albeni – Alunu railway line, of 45.00 m length, which is crossing the Coal Road.



Fig. 32. Academia Militară station, M5, Bucharest

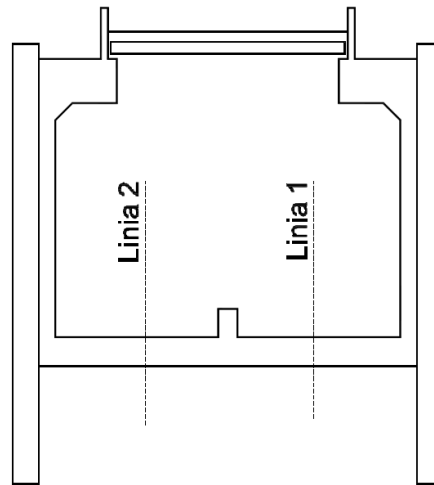


Fig. 33. Cross section between Valea Ialomiței and Romancierilor station, M5, Bucharest

The newest road tunnel, put into operation is the Sacel tunnel, on the fourth section of the highway Sibiu – Orastie, with 340 m length, being executed through „Cover and Cut” method.

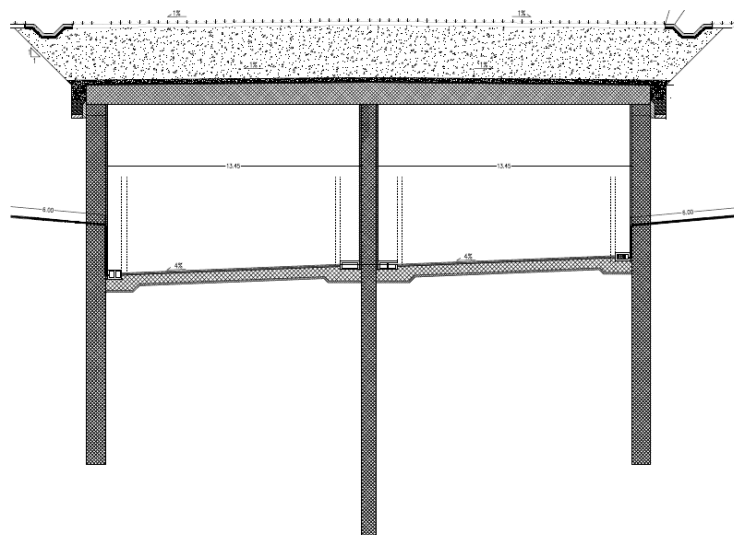


Fig. 34. Cross section – Sacel tunnel, A1, Sibiu – Orăștie



Fig. 35. Sacel tunnel, A1, Sibiu – Orăștie ^[9]

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