The “Cut-and-Cover” and “Cover-and-Cut” Techniques in Highway Engineering

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ABSTRACT

The “Cut and Cover” and “Cover and Cut” methods are advanced engineering techniques for tunnel construction in urban and interurban areas. Initially meant for subway tunneling, the “Cut and Cover” method has been lately adopted in motorway projects to deal with small-depth road tunnels and local environmental constraints. The main concept of the method consists of full-length or sequential excavation along the road segment and subsequent construction of the tunnel bore. Following drainage and waterproofing measures, backfilling requires a well-monitored construction process, adequately defined in terms of equipment and quality control. Environmental issues, such as planting and seeding, constitute the final stage, complemented, eventually, by reconstruction of the secondary road network upslope.

The “Cover and Cut” method for tunnel construction was originally developed for urban subway structures where the least possible disruption of traffic is required. In motorway construction projects, road designers prescribe the method for underground structures to efficiently face major issues of instability. At a first stage, a shallow excavation and grading is performed, followed by the construction of a sub-soil concrete “vault”. This vault acting as a retaining structure provides full protection to the main excavation activities below carried out by conventional drilling and hauling equipment. The tunnel bore construction constitutes the final stage of the technique. In this paper, an overview of both methods is presented illustrating main features, advantages and field of application. Relevant environmental and geotechnical issues are displayed and fundamental elements of the design process are addressed. Representative sketches of the construction stage are given as well as an outline of a number of case studies in major motorway construction projects.

GENERAL LAYOUT

The “cut and cover” and the “cover and cut” are two techniques for tunnel construction in highway engineering. The “**Cut and Cover**” method has been used for a long time in urban subway construction but also in interurban transportation projects, in the construction of relatively short and shallow highway and railway tunnels. Lately, the method has been adequately adapted to facilitate construction of tunnel portals.

The basic concept of the method is to excavate a trench or a cut which must be roofed over and to concrete a tunnel in situ covered subsequently with fill material.

This technique involves stepped excavation and implementation of support either by means of temporary walls and bracing systems so as to support the slopes of the excavation. In cases of extremely adverse geotechnical conditions, pre-strengthening might be necessary in order to minimize or avoid stability problems during the excavation phase. Therefore, sheet piles or "Berliner walls" have become common practice in "cut and cover" construction. Once the foundation level has been reached, concreting of the tunnel commences, to be followed by waterproofing and placement of backfill.

The "**Cover and Cut**" method was originally developed for construction of shallow underground structures in congested urban areas, where open excavation techniques would cause significant disruption to traffic. The fundamental concept of the method comprises a first stage of constructing the "cover", an earth retaining concrete shell, followed by the second stage, the "cutting" operation, representing the main excavating activities under the previously constructed "cover". These retaining effects in road tunnel engineering are established by concrete vaults, providing safe cover to excavating activities underneath.

In urban areas, the traffic disruption criterion is decisive and dictates use of the "Cover and Cut" method, whenever conventional tunneling methods (TBM or other) are not applicable. Conversely, in rural areas, it is mostly the landslide risk that leads to the solution of the "cover and cut" technique. In rare cases, buildings, installations and natural obstacles in the vicinity of the greater area of the intended excavation activities prescribe application of this method instead of the ordinary "non-retained" excavation operations.

THE "CUT AND COVER" CONSTRUCTION PROCESS

The "cut and cover" technique is a simple construction method widely applied in both urban and rural tunneling projects. The main prerequisites for application of the method are the dominance of soft or weak ground conditions and/or low overburden.

The "cut and cover" method consists of excavating an open cut by applying, practically, technical means identical to the traditional excavation process and by constructing a single or twin tunnel lining under ordinary building engineering conditions. Once the cast-in-place concrete structure finished and particular waterproofing and drainage measures taken, fill operations are carried out, usually, up to the initial ground level. Caution at the compaction process during the construction of the first inferior soil layers is necessary, since heavy vibrating rollers risk provoking distress to the tunnel structure. Utilities and local transportation network are subsequently restored and multiple environmental rehabilitation actions are performed.

Tunneling in rural areas, either for highway or railway projects, is expected to involve the use of the "cut and cover" method in cases where a cut along the alignment is to be carried out in weak material and/or in areas with a potential for landslide development no matter whether new or recurring. Therefore, in some cases of poor ground conditions, it is slope instability that calls for application of the method. It can be asserted that modification of the alignment in case of geotechnical instability might be more effective and time saving alternative. There are, however, cases, especially in mountainous terrains with high relief and stability problems, where realigning part or all of a project is not a realistic option.

In rural engineering projects, the "cut and cover" tunnels are constructed using open excavation methods to form the cut section required. In areas where shaping of a slope to the soil intrinsic properties tackles to space constraints, additional measures to reduce the area of operations must be taken. Moderately unfavorable ground conditions are handled by means of ground anchors, drilled and stressed in the course of the excavation process (Fig.1).

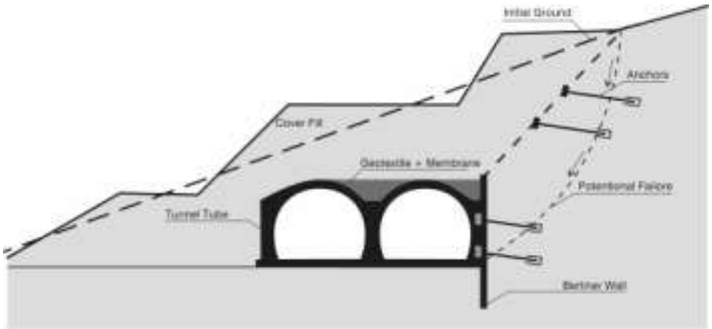

Figure 1: "Cut and Cover" tunnel along an unstable cut slope.

Frequently, a sheet pile combined with heavy anchoring or a Berliner wall may be necessary to provide lateral retaining to a vertical excavation. Subsurface drainage measures are often required to ensure slope stability of the provisional cutting. Excavated material is usually used as cover fill but borrow-pit gravel may be laid in limited quantities as well. Backfilling must be considered not only as an environment restoration process but as a stabilizing action establishing also permanent equilibrium underground.

A specific application of the "Cut and Cover" method is encountered at tunnel portals where current earth retaining methods applied during construction are not sufficient to face small-scale and well-defined instability problems. The geotechnical concern of the "Cut and Cover" approach is to provide safe entrance to the underground project during construction and full geotechnical stability during operation. Preservation of the environment, reduced effort in lining construction and safe geotechnical conditions are the main advantages of the technique. More specifically, the "cut and cover" method is feasible and beneficial when:

• Initiation of underground excavation in weak formations with low overburden might trigger instability above the openings

• Structurally controlled wedge sliding or rock falls above the portals are expected regardless of rock mass quality

• Lateral slides due to unfavourable orientation of discontinuities and/or poor geotechnical conditions are possible.

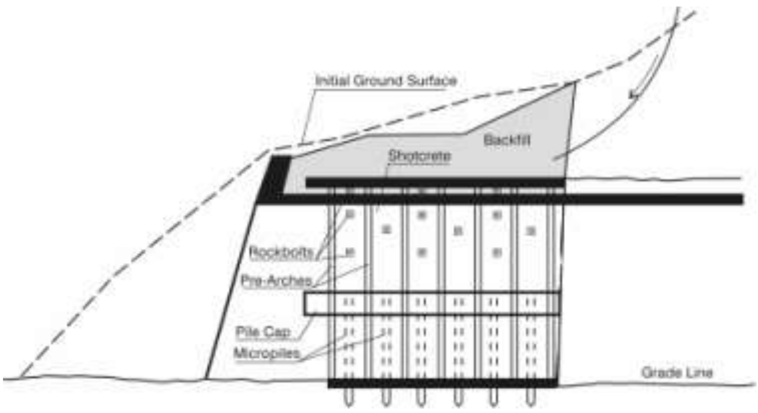

Figure 2: Use of the "cut and cover" method for safe initiation of underground excavation.

Construction of a tunnel portal using the "Cut and Cover" method is a two-fold project. The temporarily supported "cut" is constructed prior to underground excavations, while the permanent structure is constructed along with the final lining of the tunnel. The temporary “cut” consists of an excavation retained by a series of steel beams (pre-arches) in the “top heading” usually founded on a reinforced concrete spread footing which might also act as a pile cap if a series of piles is needed for foundation purposes (Fig.2). The length of the “pre-arched” section depends on the geotechnical conditions and the extent of the anticipated instabilities. The pre-arched section is shotcreted and sometimes bolted and can be partially covered to maximize stability. The final “Cut and Cover” shell is an extension of the final lining below the pre-arched area and usually extends beyond the pre-arches. In cases of minor instability, the length of the “Cut and Cover” segment of the tunnel ranges between 12 and 20m.

THE “COVER AND CUT” TECHNIQUE

The main field of application of the “Cover and Cut” method is the construction of underground structures in urban trafficked areas. Although it seems that lately the direct subsurface drilling (TBM) method prevails in subway or underpass construction, in some cases, especially for shallow excavation purposes, the “Cover and Cut” method may prove more effective.

On the other hand, in motorway projects, tunnel engineering is likely to use the “Cover and Cut” method in cases of instability of earth slopes at portals. Commonly, tunnel portals are constructed in weathered and fractured rock requiring special provisions for support and protection.

In these cases, an extended “non-retained” excavation (no retaining measures during excavation) may activate instability and would prove to be inapplicable (Fig. 3). The most well known construction technique the “Cut and Cover” method can be applied in tunnel portals when soil instability problems are limited and well defined. This technique for tunnel portals is slightly different from the non-retained excavation technique in that, due to more extended earthwork operations, lateral retaining wing walls or braced excavation walls may be necessary and backfilling over the portal is always foreseen.

When the risk of surface slides, rockfalls or deep landslides is significant, the “Cut and Cover” method is not suitable for application. The excavation zone must be reduced to the strict minimum and fully supported to facilitate the required earthwork operations.

These requirements are achieved by adopting the “cover and cut” method, which provides full earth retaining concrete shell for each tunnel bore (in case of twin tunnels) before cutting. This protective shell consists of drilled and cast-in-place piles supporting a quasi-horizontal slab which is then cast on the ground surface and tied to the piles, in a way to form the covering vault. Excavation under this protective concrete shell is similar to excavation in a suitably lined tunnel and absolutely safe.

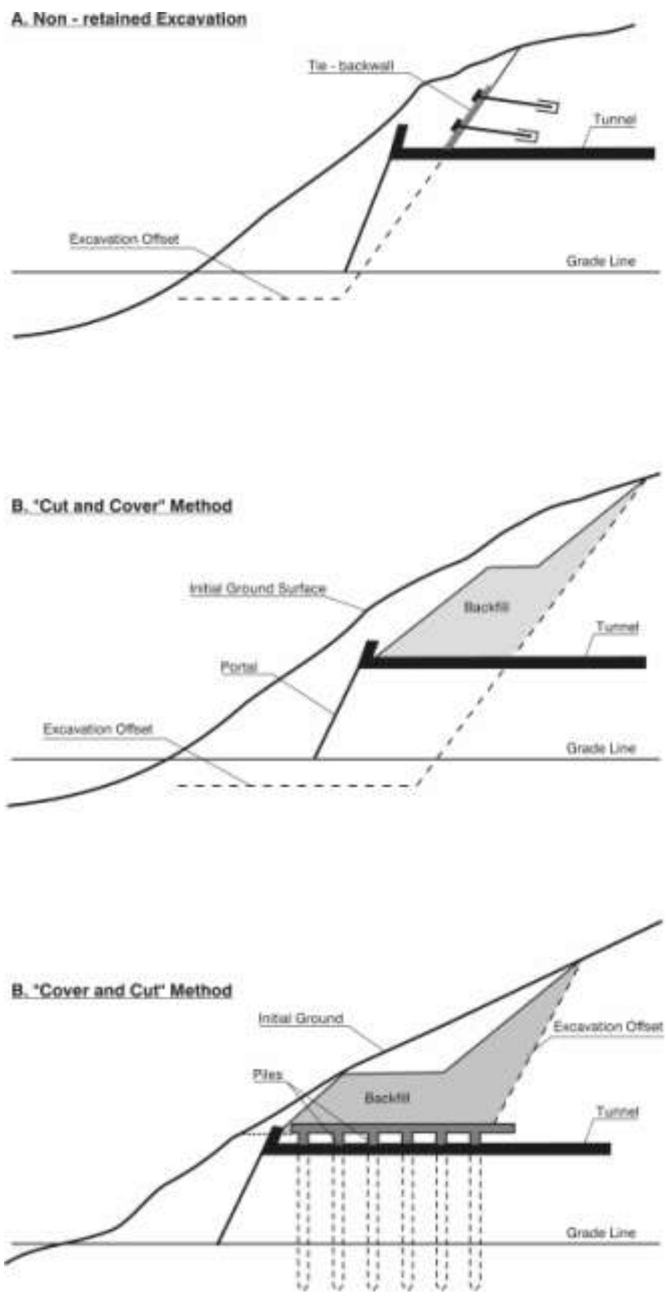

Figure 3: Methods of Construction for Tunnel Portals

The “Cover and Cut” method for construction of tunnel portals is preferred to any other similar technique when:

- Risk of rockfalls or surface slides in a direction parallel to the road alignment is significant (Figure 4).
- Risk of deep slides in the transverse direction is significant.
- Risk of deep landslide, due to extended excavation in the transverse (perpendicular to the road alignment) direction is significant (Figure 4).
- Extended open excavation is obstructed by existing installations / facilities or prohibited by ecological constraints.

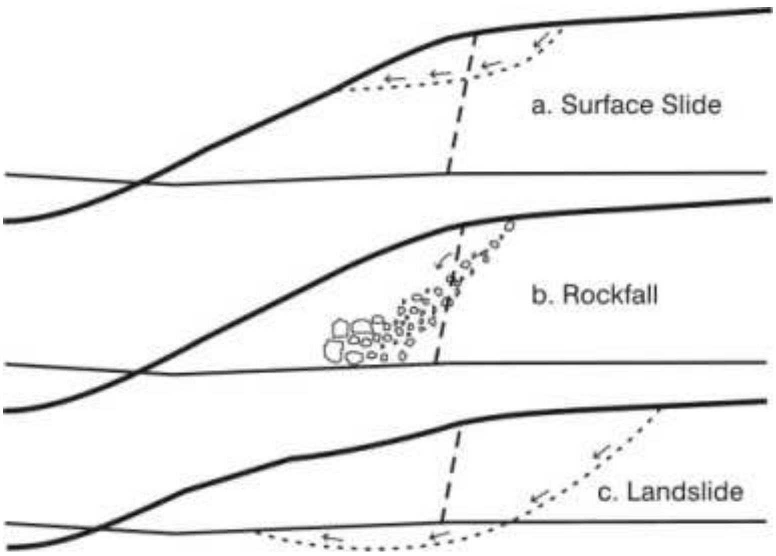

Figure 4: Risk of Failures at Tunnel Portals

The fundamental concept of the method consists of minimizing the extent of the non-retained cutting and providing full cover to the tunnel bore underneath. The first stage of the open excavation downward stops at a level much higher than the one foreseen for the non-retained excavation (Fig.5) thus reducing risk of instability. In the longitudinal direction, the method is applied as long as the unstable soil formations or conditions extend.

The construction process comprises six distinct stages, including earthwork operations, drilling and casting of piles, slab construction, earth removal and backfilling (Fig.5):

Stage I: Preliminary excavation and grading is performed. The ground level is adjusted in a way to permit access and movement of equipment for pile drilling and slab construction. In several cases, earth filling may be locally required to provide a uniform horizontal ground surface. Pile heads must be at the same level to be tied by a horizontal head beam.

Stage II: One row of piles on either side of the tunnel section are drilled and cast-in-place. Spacing of piles is usually equal to 2D, where D is the pile diameter.

Stage III: At stage III the head beams and the covering slab are constructed.

Stage IV: At stage IV the “underneath” excavation is performed absolutely protected by the piles / slab concrete shell. Fiber – shotcrete is spread over the rock surface at inter-spaces between piles.

Stage V: At stage V the inner lining of the tunnel is constructed.

Stage VI: Backfilling operations are usually carried out at stage VI either for environmental or for network restoration reasons.

In highway engineering, the “Cover and Cut” method is applied to the construction of tunnel linings or tunnel portals instead of the “Cut and Cover” technique whenever the extent of the weathered, fractured and unstable rock materials is large and the failure risk significant. Compared to the “Cut and Cover” technique, the method offers the possibility to perform excavation and concrete lining under most adverse conditions and to reach downward the solid rock substratum at a greater depth.

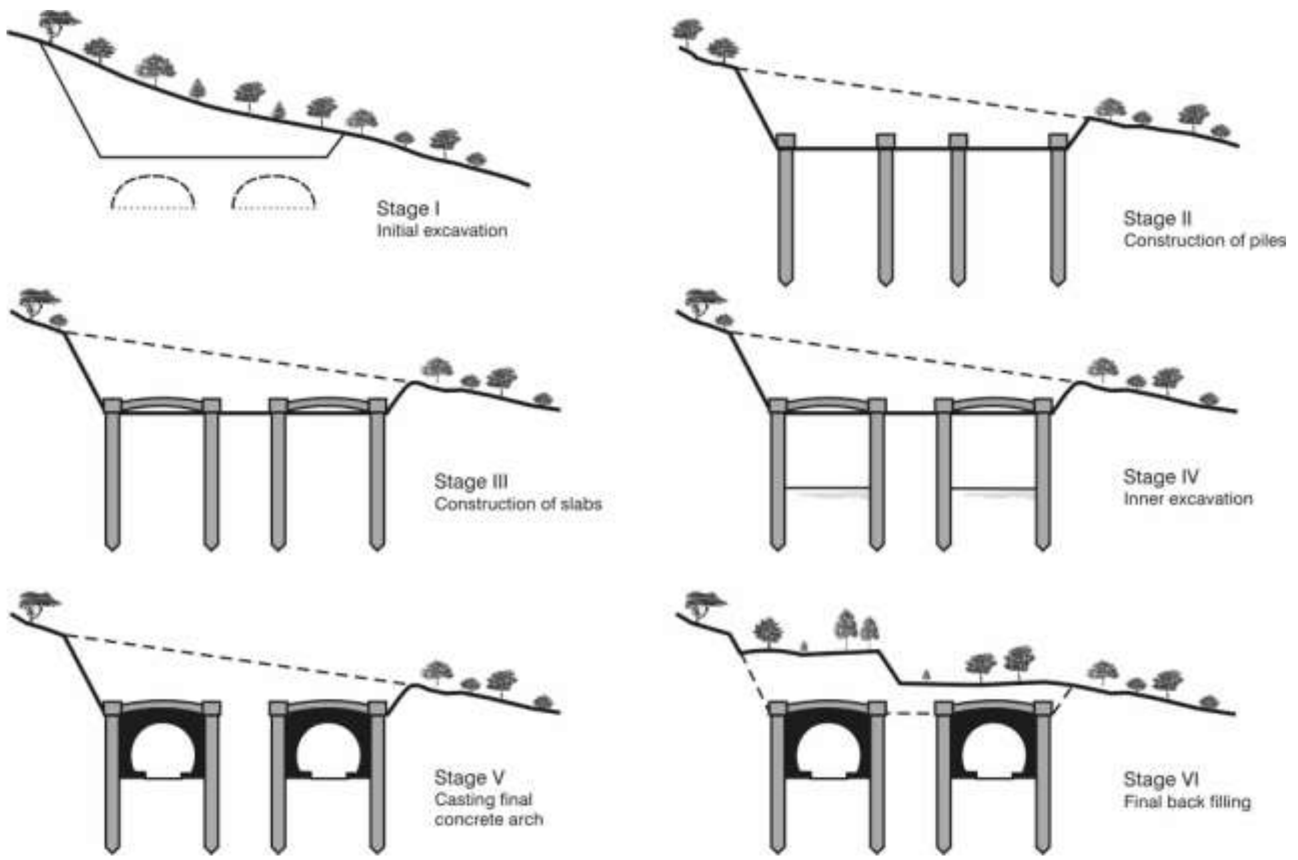

Figure 5: Construction Stages for “cover and cut” method

DESIGN

“Cut and Cover” Design Process

As is true with every tunnelling project, a set of studies is necessary to ensure the safe construction and operation of a “Cut and Cover” tunnel, such as environmental impact assessment, geotechnical study, excavation and support design, structural and static study, final lining design, M/E design etc.

The **geotechnical study** is immensely important as it evaluates the fundamental input for the static calculation of the tunnel. Based upon in situ and laboratory tests, the earth mass parameters are determined, namely apparent weight, groundwater table, friction angle, cohesion and vertical loads at the foundation level. Additionally, the study addresses the slope stability and earth retaining issues, as the “cut and cover” method is, in essence, an open cut engineering case. Thus, the slope stability is checked against potential failures (planar slides, circular slides, wedge detachment) and the necessary support measures are designed in order to satisfy the two criteria for a successful open cut stability, that is, an adequate factor of safety and controlled creep deformations. The main precursor of ground loosening and lateral yield of the abrupt cut faces is the time lapse between excavation and application of earth retaining measures. Lateral yield would cause ground movement around the cut and would evidently increase the sliding risk. It should be noted that in the case of “Cut and Cover” tunnels where slopes and cuts are temporary, the proposed measures aim at providing an acceptable factor of safety for short term stability, presuming, however, the most adverse geotechnical conditions.

The **static analysis of the tunnel** lining takes into account various permanent loads such as weight of concrete lining, apparent earth weight, creep stresses, dehydration shrinkage, hydrostatic pressures, additional loads, such as temperature gradients and temperature variations, and special dynamic loads such as explosions and earthquakes.

The main loads exerted on the tunnel lining are the cover fill weight ($\gamma \times h$) and the lateral earth pressures ($K_0 \times \gamma \times h$) where γ is the apparent earth weight, h is the height of the design earth column and K_0 is the coefficient of lateral earth pressure at rest. The lateral earth pressure is usually approached by a trapezoidal distribution envelope with increasing values from top to bottom. This distribution, however, should be considered as apparent envelope since the actual pressure distribution is a function of the construction sequence and the relative rigidity of ribs(curved parts) and posts(vertical parts) of the concrete structure. The state of stresses on the tunnel bore depends on the physical properties of the soil material (homogeneity, grain size for soils, presence of water) and the characteristics of the concrete lining.

Calculation of stresses on the structure is performed by means of special finite element modelling allowing for full loading conditions at the operational stage. The tunnel structure is represented by a three-pillar frame founded on elastic soil. Modelling of soil foundation which undergoes elastic strains under the fill loading is limited to a finite number of springs since no additional settlement or risk of underground failure should be expected. The back fill material is simulated by conventional triangular or quadrilateral elements. Commonly, plane strain conditions are assumed to apply to a representative section integrated into the numerical computations.

"Cover and Cut" Design Characteristics

In order to simplify analytical computations, two distinct stages of "Cover and Cut" construction and respective loading schemes are considered. At stage A, the piles are drilled and cast-in-place and then the covering slab is constructed on the prepared ground surface. Negligible loading is exerted, at this stage, on the piles or the slab (Figure 6a). Earth removal below the covering shell takes place using conventional excavation methods followed by the final tunnel lining, the overall procedure constituting stage B.

The overall stability of the piles, the pivot point and the length of embedment are assessed through a conventional analysis of active and passive stress distribution on the piles (Figure 6b). Earth pressure on the piles is determined with regards to the shear strength characteristics of the surrounding soil and rock formations. This state of stresses corresponding to stage B governs the design of the "piles – head beam – slab" structure. For pile design purposes, earth pressure at rest is assumed to apply along the external side of each pile row, instead of active pressure, to account for safety throughout the numerical computations.

Usually a safety factor of 1.3-1.5 is applied to the analysis of the required embedment depth. Current safety factors for the design of piles, SF=1.5 for static loading and SF=1.2 for seismic loading are integrated in the design procedure in terms of allowable stresses.

Frequently, low shear strength must be expected along surface strata around the portal area justifying the use of the "Cover and Cut" method. Numerical resolution at Stage B is accomplished by means of adequate software programs for both static and dynamic loads.

In cases of twin tunnels, the depth of embedment varies from 1/3 to 1/2 of the total pile length, depending on the rock mass characteristics. Covering slabs, for twin motorway tunnels, usually have a span of 11.50 – 13.00m.

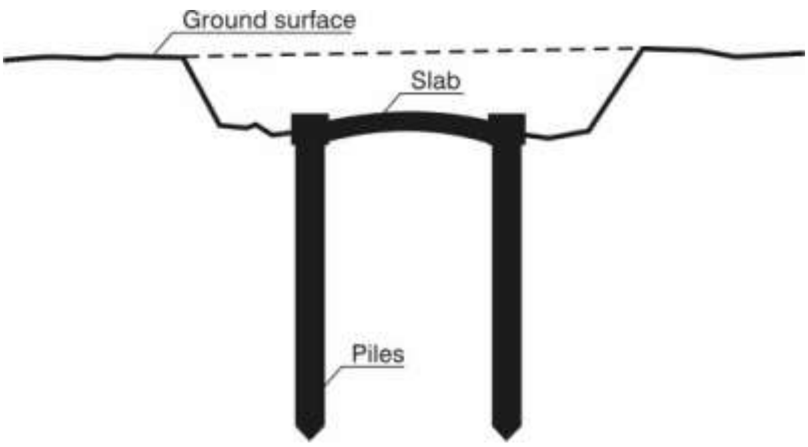

Figure 6.a: Zero Stress Stage (Stage A)

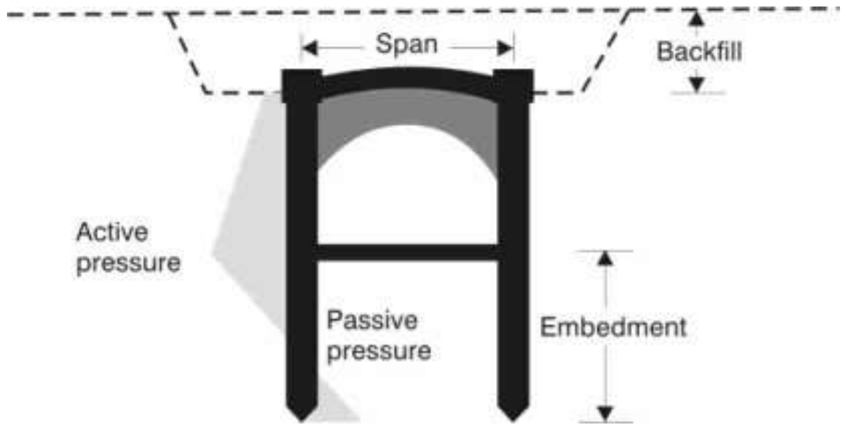

Figure 6.b.: Structure under Loading (Stage B)

FIELD OF APPLICATION

The “Cut and Cover” and the “Cover and Cut” methods are tunnel construction techniques applied to urban and interurban road engineering. In fact, these construction methods are “intermediate” techniques between the tunnel option meant for a “deep” route profile and the open cutting meant for a “shallow” route profile.

It is well known that a tunnel option is a relatively costly solution reserved to cases of deep overburden and sensitive environment. On the contrary, a traditional open cutting is a low-cost technique which significantly affects the environment. The two “C&C” methods are recommended for application in case of intermediate overburden depth and fairly sensitive environment. The general conditions of application for each technique are summarized in Table 1.

Table 1: Field of Application of “C&C” methods in primary network.

Conditions	Open Cutting	Cut & Cover	Cover & Cut	Drill & Blast Tunnel
Cutting or Tunnel length	Unlimited	Limited, L<300m	Short, L<150m	Significant , L>150m
Depth of Grade Line	Limited, H<30m	Intermediate H<50m	Small, H<15m	Great H>30m
Environm ent	Indifferent Context	Fairly Sensitive Areas	Sensitive Areas	Highly Sensitive Areas
Geology	Soils, Gravels, Soft Rock	Soils, Gravels, Soft Rock	Loose Sands, Unstable Soils	Soft and Hard Rock

The “Cut and Cover” method is preferred to the traditional open excavation leading to cutting sections for reasons of environmental protection and geotechnical stability. Restoration of existing transverse local networks may also be a reason to apply the technique despite the tunnel construction cost.

With regard to the environmental impact, the two "C&C" methods lie between the infinitesimal effects of a tunnel construction and the detrimental effects of the open cutting. The "Cover and Cut" technique is even less damaging since only shallow grading operations are executed in view of the covering shell construction.

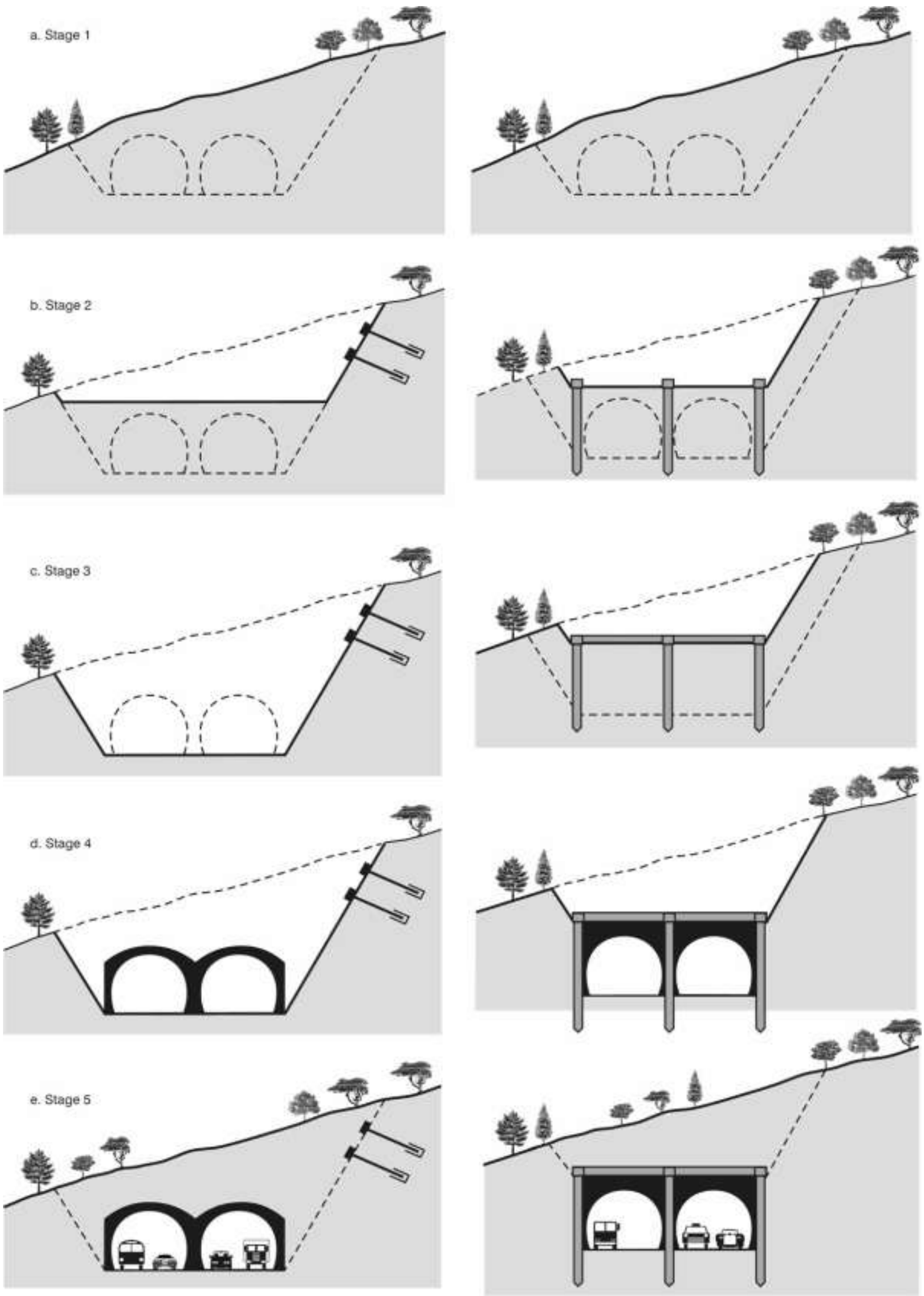

Figure 7: Stages of Construction for the "C&C Techniques (cut and cover on left, cover and cut on right)

In conclusion, the “Cut and Cover” method is usually applied in Highway Engineering (Fig.7), in case of:

- Limited depth (<50m) of grade line in environmentally sensitive areas, instead of open cuttings
- Limited depth of grade line in areas where local networks and facilities may only be provisionally relocated, instead of open cuttings
- Adverse geotechnical conditions, faults and loose materials, instead of short-length D&B tunnels

Similarly, the “Cover and Cut” method is recommended for application (Figure 7), in case of:

- Shallow overburden in highly sensitive environment instead of “cut and cover” or open cutting
- Shallow overburden combined with networks, utilities and facilities which cannot be relocated or removed, instead of “cut and cover” or open cutting
- Great risk for failures related to excavation operations, instead of “cut and cover”

CASE STUDIES

The “Cut and Cover” #1 tunnel

As mentioned earlier, the “Cut and Cover” method can be applied in major motorway projects cross-cutting mountainous areas. The Σ1 tunnel of the Egnatia Motorway in Epirus (Figure 8) is a typical case illustrating the use of the technique.

The tunnel was constructed as a twin-tube tunnel having a length of 270m. This part of the Egnatia Motorway crosses an extensive overthrust zone characterized by extremely weak material and highly unstable conditions. The material consists of heavily sheared slickenside siltstone, almost at the threshold of schistosity, with sandstone fragments of various size which do not contribute to the overall stability of the rock mass. The alignment runs along a series of secondary landslides, some of them with recent incidents of activation, where a thorough geotechnical investigation, including installation of inclinometers, evidenced the potential for further destabilization. Shifting the alignment upslope to avoid broader scale destabilization resulted in the choice of a “Cut and Cover” solution.

The tunnel was constructed at an overburden depth of 35m and was founded upon a 1m thick mat foundation. Minimum thickness of the tunnel lining at the crown is 0.8m while the outer walls and the mid-wall have a thickness of 1.1m and 1.24m respectively.

The slope was shaped in form of a vertical cut supported by a “Berliner wall” sequentially constructed along with the downward progress of the excavation operations.

Figure 8: “Cut and Cover” tunnel

a) Construction of the “cut and cover” walls. To the left, the upper part of the “Berliner wall” is still visible.

b) View of the portal of the “cut and cover” tunnel where the openings, the backfill and the wingwalls can be seen

The wall consists of a series of D=45cm concrete piles, bearing a double U220 steel beam reinforcement. Piles are spaced at 1.5m and embedded at a depth of 3.5m below the foundation level. Excavation proceeded from top to bottom with a step of 2m and further support was provided by installation of pre-stressed anchors and passive self-drilling rock bolts. The pre-stressed anchors of monobar type, 21-24m long, 10m grouting length and 33.3tn service load were installed in the two upper rows with a 2m longitudinal spacing while the self-drilling anchors were installed in four rows with a length ranging from 9 to 18m and a service load of 15tn.

Throughout construction, groundwater control in the uphill cut slope was accomplished by drilling drainage holes and by interposing drainage trenches on the slope benches. For purposes of permanent drainage, the tunnel was “enveloped” in a permeable layer of coarse sand and gravel with a minimum thickness of 0.5m drained by perforated PVC pipes placed along the outer walls of the tunnel (Ø200mm along the left wall and Ø400mm along the right one). A separation geotextile was placed between the cover fill and the drainage layer to preclude fine material clogging of the drainage layer. The crown and the walls were waterproofed by placement of watertight membrane covered by two geotextile fabrics.

The “Cover and Cut” portal of the T6 tunnel

The “Cover and Cut” method was applied in specific cases for the construction of tunnel portals along the Egnatia Motorway. In 2002, at the eastern portal of the T6 Tunnel (Figure 9), in Epirus, the method was used to facilitate construction through weak flysch materials.

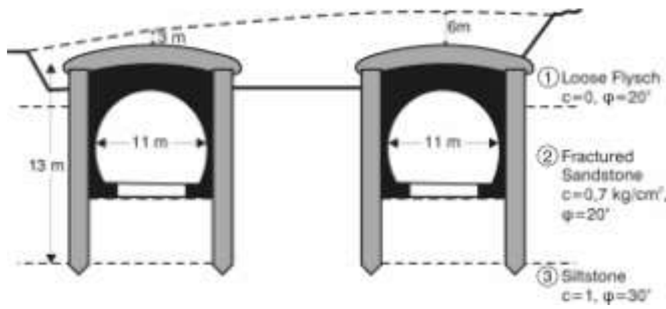

Figure 9: Construction of "Cover and Cut" Portal

The geotechnical study reported a loose surface formation varying in depth from 5 to 8 meters, lying upon fractured sandstone of low strength to a depth of 12-15m. The underlying stronger bedrock consisted of a slightly weathered siltstone of medium strength.

The construction, preceded by shallow excavation (to a depth of 3-6 meters), took place in stages as previously described. Piles of D=1.20m were constructed to a depth of 13m. The depth of embedment was 470m. and the thickness of the covering slab varied from 0.80 to 1.80m. The final lining was carried out after excavation under the protective covering vault.

The T105 "Cover and Cut" Tunnel Lining

The non-retained excavation of a cut section (h = 10-20m), at a road segment of the motorway in Eastern Macedonia (near Amphipolis), was disrupted by an extended landslide in loose silt upslope. Fractured gneiss (GN) and marbles (MR) constituted the bedrock materials.

During the early stages of the excavation process upslope and before attaining the upper bench, a landslide took place along the whole road segment (Fig.10). The failure occurred when the toe of the loose formation was struck and removed. The excavation process was halted and the open cutting option was abandoned in favour of a 150m long tunnel by use of the "cover and cut" method.

Piles of 80cm diameter were used at a spacing of 100cm. The pile length was 14.10m and the depth of embedment was 6.60m. Special drainage and surfacing measures were taken at the inter-space between piles. Piles and covering slab were cast-in-place after an initial grading. Excavation of 3-6 meters in depth but also sparse fill operations were performed in order to provide a leveled surface suitable for movement of drilling and casting equipment. The tunnel lining was cast after excavation under the protective concrete shell. Backfill above the protective slab was placed at the end of the construction stage followed by environment restoration measures.

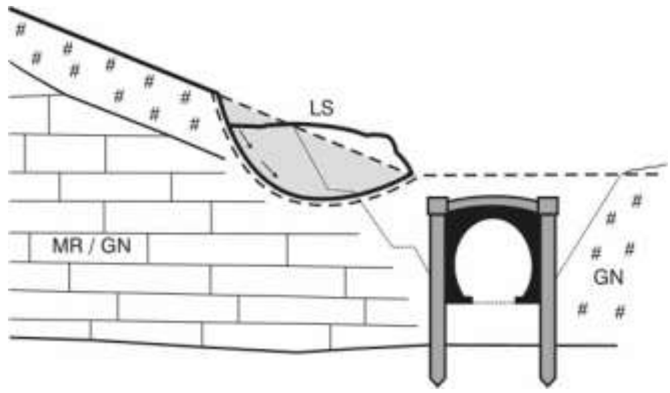

Figure 10: Geotechnical Instability Upslope.

OVERVIEW AND CONCLUSIONS

Cut-and-Cover tunneling is a very useful method for shallow tunnels in adverse ground conditions, in both urban and rural areas. In rural areas the technique is applied whenever environmental constraints require avoidance of open cuts or aesthetic degradation. The main advantages of the method can be recapped as following:

"Cut and Cover" technique allows safe initiation and completion of highway tunnels as well as safe work progress in unstable weak ground in rural projects.

The technique may be applied in form of sequential construction in case of most adverse geotechnical conditions.

Although the applicability of the method is reduced in case of deep overburden and the construction cost increases significantly, new technologies in trenching and earth retaining nowadays allow the use of "Cut and Cover" technique at great depths and very close to, or even under, existing tall buildings.

Tunnel portals are very often sensitive areas for excavation, since the constitutive rock material is likely to be weathered and quite unstable. Serious problems of instability, identified and quantified by geotechnical investigation, cannot be handled through the common excavation procedure or by the "Cut and Cover" technique. When the landslide risk cannot be accurately assessed in extent, direction and severity, a more effective and reduced-risk method is required.

The solution is provided by the **Cover and Cut** method establishing full protection during the construction and the operation stage. The method is characterized by rapidity and accuracy and may be applied to short-length segment (usually 10–20 m) at tunnel entrances.

In all case studies in highway engineering, the technique proved to be safe and efficient. Stability problems were adequately handled and the duration of the construction stage was hardly affected. Nevertheless, in highway construction, where the "cost" factor is of critical importance, the method should be limited to cases of serious rock fall and landslide risk.

Indeed, since the method prescribes a "double concrete lining", the construction cost is relatively high compared to the respective budget figures of the conventional methods. This is certainly a drawback but it is rather of secondary importance if the application is of limited extent which is the case of tunnel portals. On the other hand, when the method is preferred to the current "non-retained excavation" for full tunnel construction, it is certain that efficiency in managing geotechnical problems joins economy and environment preservation through a rather simple and safe construction process.

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