The tunnels of Egnatia Highway. Experiences in managing construction

Οι σήραγγες της Εγνατίας Οδού. Εμπειρίες από την διαχείριση της κατασκευής τους.

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ABSTRACT: The paper deals with the construction management organisation of the Egnatia tunnels for the implementation of the design and the efficient progress of the excavation. A case history of a tunnel in complex geology and difficult ground illustrates such a management, where reliable monitoring allowed modifications resulting in significant cost saving in the running construction contract and time gain.

ΠΕΡΙΛΗΨΗ: Η εργασία αναφέρεται στην οργάνωση της διαχείρισης της κατασκευής των σηράγγων της Εγνατίας Οδού για τον έλεγχο της εφαρμογής της μελέτης υποστήριξης και την αποτελεσματική εξέλιξη της εκσκαφής. Περιγράφεται η περίπτωση σήραγγας σε σύνθετη γεωλογία και ασθενείς βραχόμαζες όπου η διαχείριση αυτή, βασισμένη σε ιδιαίτερα αξιόπιστη ενόργανη παρακολούθηση, οδήγησε σε σημαντικό περιορισμό του κόστους της τρέχουσας σύμβασης και εξίσου σημαντικό κέρδος χρόνου.

1. INTRODUCTION

The Egnatia highway is one of the major road infrastructure works currently being constructed in Europe. The project estimated total budget for the completion of the axis as a high-standard motorway of continuous high speed traffic flow is €5,4 bn, VAT included. When complete, the Egnatia highway will have a total of 73 road tunnels of an overall combined length of 100Km. Their construction cost-including all E&M systems-amounts to 35% of the total estimated construction cost.

The majority are bored tunnels, while a few of them are built by the cut-and-cover method. 15 of these tunnels are classed as long, with lengths ranging from 800m to 4,6Km. All tunnels are twin-bore ones. Each traffic direction is carried through passages between the tunnel bores in case of a fire emergency. Special emphasis is laid on the installation of a high standard monitoring and control system, which will ensure the safe operation of tunnels.

Tunnelling conditions range from relatively straightforward to extremely difficult, when weak rock masses have suffered from excessive alpine tectonic compression, mainly in the mountainous western part of the project (Marinos V., Aggistalis G. & Kazilis N., 2004). Design methods vary from simple to mainly numerical. In the cases of severe face instability 3-D approaches were necessary to simulate the rock failure processes ahead of the advancing face (Rawlings C.G., Kazilis N., et al., 2001).

The method of excavation involves large faces (top heading and bench and in few cases full-face excavation) with a temporary or a final invert in difficult ground. Face instability was faced by a forepole umbrella and fibre-glass anchors. The average construction cost, of a long road tunnel with full electromechanical systems, calculated on the basis of the pricelist policy implemented by Egnatia Odos A.E., varies from €8.000 per linear metre in good geotechnical conditions to €35.000 in extremely poor geotechnical conditions (data from 2003,). For shorter tunnels the average construction cost is in the neighbourhood of €10.200 per linear metre.

Given the difficult and complex geological conditions in a number of tunnels the management of the construction and particularly the optimisation with the appropriate, where necessary, modifications of the design have a decisive role in the production of the projects in cost saving and time gain.

2. CONSTRUCTION METHODS

The predominant construction method used for the mountainous tunnels of the Egnatia motorway, is conventional, using drill and blast, hydraulic hammers and mechanical excavators (table 1).

Table 1. Applied excavation method as a percentage of the overall length of tunnels
Πίνακας 1: Μέθοδοι εκσκαφής σε ποσοστό επί του συνολικού μήκους της σήραγγας.

EXCAVATION METHOD	PERCENTAGE (% OF TOTAL LENGTH OF TUNNELS)
Drill and Blast	50
Drill and Blast in combination with Hydraulic Hammers	25
Mechanical Excavators	25

The reasons for a conventional method preference are,

(a) The length of single bore is long enough only in few cases.
(b) The geological - geotechnical conditions: highly tectonized formations and continuous alternations of weak to strong rock masses require an easily adaptable construction method.
(c) The cost of investment by constructors in comparison with construction contract values.
(d) The existing experience of Greek contractors.

There is only one case, at S1 tunnel in Veria - Lefkopetra region, where a roadheader was used to excavate the second bore. This method was selected in order to avoid disturbance to the adjacent finished tunnel, which was already in operation.

The major effort of Egnatia Odos AE's (EOAE's) Construction Management (CM) systems is to strictly control the proposed construction method of the design, with the excavation and primary support categories carried out on site. This is critical in order to avoid potential claims and to strengthen the case for EOAE's committee in the case of a dispute regarding the excavation and primary support class to be applied. The Technical Specification requires a detailed construction methodology to be submitted by the Contractor and approved by EOAE, prior to any activity on site. In particular, for the drill and blast application, a complete design must be prepared. This design is subjected to modifications based on the results of the first twenty blast operations and only then is finally approved by EOAE. Hence, the critical indices are determined, related to blastholes burden, control blasting characteristics, detonation types and delays, types of explosives and specific charges. Based on the actual conditions, minor modifications may be required to accommodate safe working environment and production rates.

The tunnel section, having an area ranging from 110m^2 to 150m^2 depending on the excavation and support category, is excavated in stages (top heading and bench/invert), in line with the rockmass conditions and the overburden. The majority of the primary support categories can be divided in five main groups (table 2). Primary support measures are fully detailed for dimensions in the final design. Based on our current experience, it has been found that the more flexibility the design has in specific issues, the better are the financial and production results that can be achieved. Therefore, EOAE decided to divide the support measures, for each support category into two sub-categories: "Sub-category 1" that cannot be changed and "Sub-category 2" for which decisions have to be taken on site by evaluating the rockmass conditions and the monitoring data, generally following principles of the Observational Method.

Hence, "Sub-category 1" includes:

(1) Shotcrete thickness,
(2) Rockbolts,
(3) Steel ribs.

and "Sub-category 2" includes:

(4) Excavation face support (shotcrete thickness, number of rockbolts),
(5) Pre-reinforcement elements (number of spiles or forepoles),
(6) Invert and foundation improvements (need for temporary invert, number of micropiles).

This discrimination for the elements (4), (5) and (6) has been proved from the past experience, as these elements have a big cost, delaying the production cycle and can only be specified on the base of the actual conditions.

3. CONSTRUCTION MANAGEMENT ORGANISATION

In 2002, evaluation of the experience gained by EOAE from the construction of more than 56Km of tunnels, led to the modification of the tunnels' construction management system and the introduction of the site based Tunnel Support Team (TST) (Figure 1). The TST's main role can be categorised in the following three subjects:

a. Following and checking the correct application of the final designs.
b. Initiating, managing and checking design modifications based on observations principles and monitoring data.
c. Establishing clear, timely and synchronous communication and information lines between the Client's services (General Management, Technical Directorate, Project Managers and Supervision) and the Contractor.

Table 2. Primary support categories and measures
Πίνακας 2: Κατηγορίες και μέτρα προσωρινής υποστήριξης

PRIMARY SUPPORT CATEGORY	SHOTCRETE (1)	ROCKBOLTS (2)	STEEL RIBS GIRDERS (3)	FACE SUPPORT (4)	PRE-REINFORCEMENT (5)	INVERT AND FOUNDATION IMPROVEMENTS (6)
A	✓	✓	×	×	×	×
B	✓	✓	✓	×	×	×
C	✓	✓	✓	✓	×	×
D	✓	✓	✓	✓	✓	✓
E	✓	✓	✓	✓	✓	✓

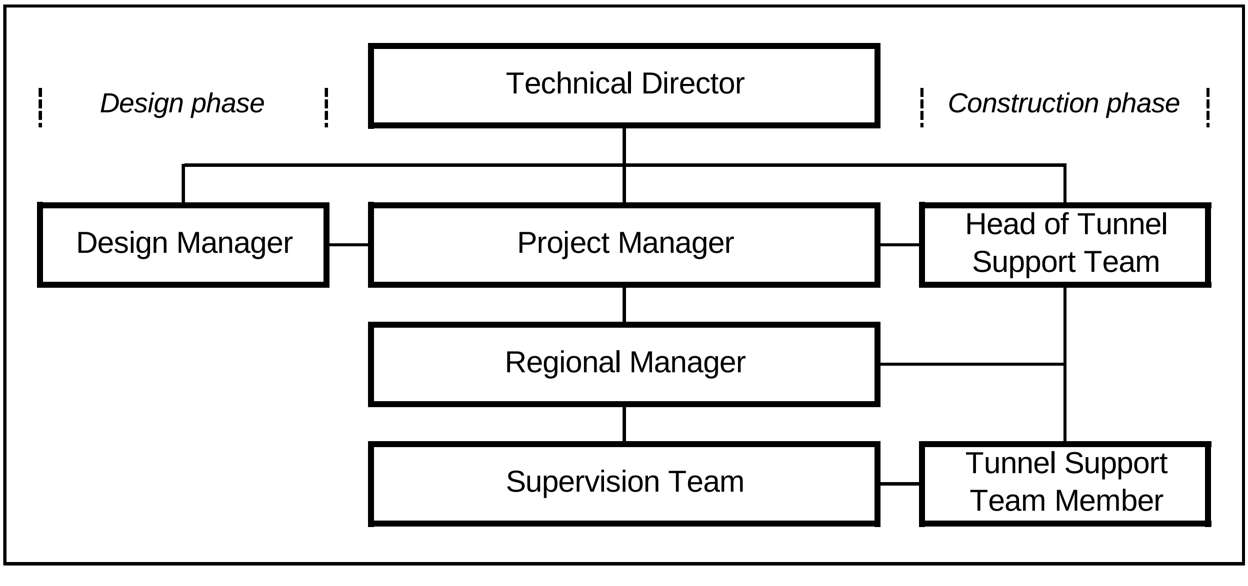

Figure 1. Construction management organization
Σχήμα 1. Οργάνωση της διαχείρισης της κατασκευής

In addition, EOAE implemented the following methods and procedures:

(a) Application of the Observational Method. In the critical projects, the designer or the design checker is nominated as 'Designer on site', and is incorporated into the supervision organization. In these cases, based on the observations and the monitoring data and under the management of the TST, he prepares all of the required modifications or adaptations of the design to conform to the actual geotechnical conditions. For minor cases, where the integrity of the design is not affected, this role is carried out by the TST, having the approval of the designer, the design checker, or the Panel of Experts as necessary.

(b) Establishment of supervision teams to follow up the complete construction cycle of each tunnel (continuous supervision).

(c) Outsourcing to apply or to establish an appropriate monitoring system.

(d) Outsourcing to apply or to establish an appropriate system to observe the basic tunnel geometrical indices (excavation profiles, shotcrete profile, and final lining margin).

The results of this structure seem to be quite encouraging, with significant improvements recorded for finances and production in all cases and in particular for the critical underground projects.

4. CASE STUDY - ANILIO TUNNEL – SECTION 3.3

Anilio tunnel is located in the west part of Egnatia highway. It is a 2,2Km long tunnel and its maximum overburden is 260m. The anticipated formation was flysch. (see figure 2) and more particular:

(a) medium to thick bedded sandstones with siltstones intercalations,

(b) thin to medium bedded siltstones with sandstones intercalations,

(c) alternations of thin to medium bedded sandstones and siltstones,

(d) tectonic mélange of highly folded siltstones intercalated by sandstones and mylonites in a chaotic structure.

These units are thrusted sections from major folds as the whole area has suffered severe tectonic action. The original geotechnical characterization of these unities is presented in table 3.

Table 3. Anilio Tunnel. Original characterization of the anticipated formations
Πίνακας 3: Σήραγγα Ανηλίου. Αρχικός χαρακτηρισμός των αναμενόμενων σχηματισμών

Unity	GSI	σ_{ci} (MPa)
a	50	50
b	35	25
c	30	6
d	20	2.5

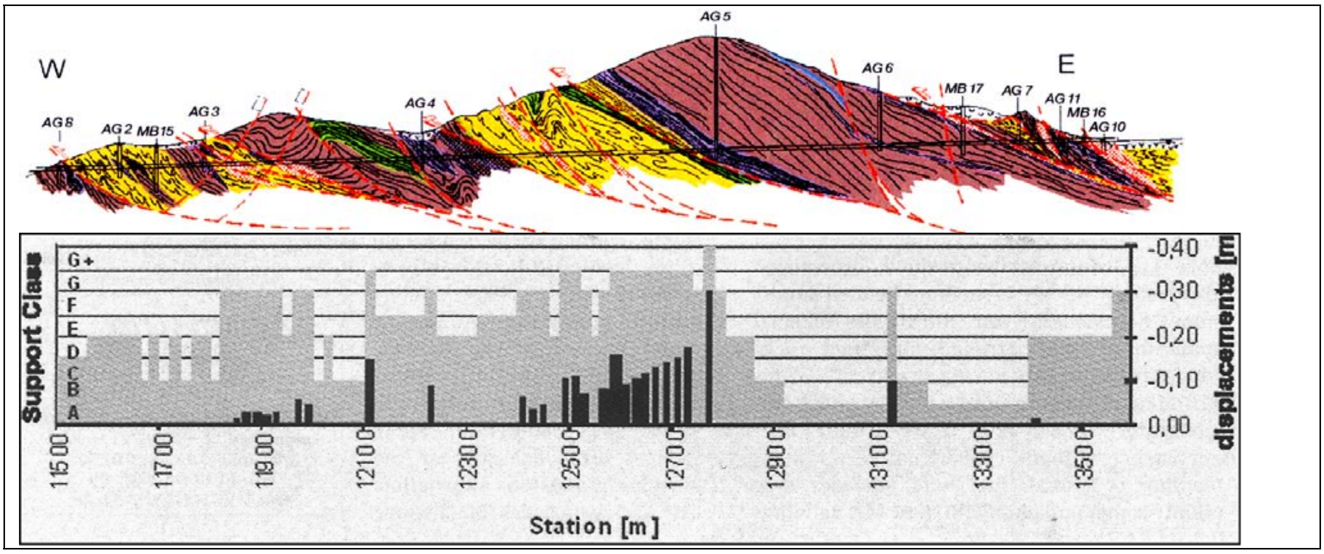

Figure 2. Longitudinal section of Anilio tunnel (from the design; Geology from Mourtzas N & Sotiropoulos E. 1999; support & expected displacements from Schubert W & Riedmueler G 2000)
Σχήμα 2. Μηκοτομή σήραγγας Ανηλίου, από τον μελετητή (Γεωλογία από Μουρτζάς Ν. & Σωτηρόπουλος Ε., 1999, υποστήριξη και παραμορφώσεις από Schubert W & Riedmueler G 2000)

Stability problems arose at the start of the construction. In the exit portal of the tunnel a slide was triggered during the open excavations (figure 3), which resulted in a severe modification of the original design.

Figure 3. Landslide in the exit portal of Anilio tunnel
Σχήμα 3. Κατολίσθηση στο στόμιο εξόδου της σήραγγας Ανηλίου

The excavation and primary support categories of the final design were of a wide variety to cover all of the anticipated rockmasses. Nevertheless, for the longest part of the tunnel, heavy support categories were described including, in addition to shotcrete, steel ribs and rockbolts, the use of forepoles, spiles, fiberglass anchors and sealing shotcrete on the excavation faces, micropiles and the construction of both temporary and permanent invert. Furthermore, two special excavation and primary support categories were designed to apply in the tectonic mélange which was expected to be met in the area of highest overburden. For these sections, sliding girders and shotcrete were specified to accommodate displacements of up to 40cm in squeezing conditions.

Underground works of the first phase started in the autumn of 2001 with good performance. The rockmass revealed better characteristics from those predicted and the resultant tunnel behavior deviated from that assumed. For example, the flysch was never categorized at less than 25 on the GSI basis and the monitored deformations were in the order of 3cm – 4cm except for a limited tunnel section where they reached 12cm. For this case, additional long rockbolts were installed and the movement ceased. It was found that the original design was so rigid that it did not allow modifications, even where all observational monitoring data showed otherwise. Consequently, EOAE initiated a review of the design, which led to a decrease of the overall cost by 15% and a shortening of the time schedule by 3 - 4 months. The major modification items, which resulted in 50% of the cost savings, were as follows:

(a) Decreasing of the number of the forepoles (from 52 down to 26).

(b) Decreasing or even eliminating the use of micropiles.

(c) Decreasing the length of the rockbolts (from 9m down to 6m).

At that time EOAE assigned the 3D monitoring program of Anilio tunnel to an independent specialist (GEODATA GmbH). The results of the monitoring proved that, whilst it was provided in the original design, construction of the final invert was not necessary for a significant length of 600m. This generated the remaining 50% of the cost saving.

Based on all of the above, and with input from the TST and the Design Checker, the excavation and primary support categories of the final design were thus modified. Three new support categories were provided, including one for the squeezing material. The main target was to create a flexible design, easy to apply, which would be considered on the principles of the Observational Method. Hence, clear decision criteria were established for the characterization of the rockmass as well as for the evaluation of the monitoring data. The Design Checker was appointed as ‘Designer on Site’, and as a member of the classification committee. For the collection of data prior to the excavation, especially in the potential ‘squeezing’ zones, probe drilling was routinely executed (see figures 4 and 5).

In this way, further modifications for some excavation and primary support categories were feasible, focused mainly on a longer excavation step (from 1m to 1.3m - 1.5m). Indicatively, the modifications of the heavy category G are presented in table 5. Excavation faces of Anilio tunnel are presented in figures 6 and 7. (Category G is defined by the designer beyond the consideration of table 2).

Figure 4. Good quality flysch (claystones, siltstones and sandstones alterations)
Σχήμα 4. Καλής ποιότητας φλύσχης (αργιλόλιθοι, ιλυόλιθος, ψαμμίτης σε εναλλαγή)

Figure 5. Poor quality flysch (alterations of claystones and siltstones with sandstones intercalations)
Σχήμα 5. Πτωχής ποιότητας φλύσχης (εναλλαγές αργιλικών σχιστολίθων και ιλυολίθων με παρεμβολές ψαμμιτών)

Table 5. Applied modifications in the original category G
Πίνακας 5: Αλλαγές και προσαρμογές της αρχικής κατηγορίας υποστήριξης G

ITEM	G CATEGORY	G$^-$ CATEGORY (G minus)	G$^=$ CATEGORY (G minus minus)
Forepoles	52	25	21
Micropiles	Yes	No	No
Rockbolts	9 m long self-drilling in sidewalls	9 m long self-drilling in sidewalls	6 m long - 32mm grouted rebar in walls and Swellex in crown
Ribs/Girders	HEB 160 at 1 m spacing	HEB 160 at 1 m spacing	HEB 160 at 1.3 m spacing
Shotcrete	30 cm	30 cm	30 cm
Inverts	Yes	If required	If required
Face reinforcement	26 Grouted fiberglass + 5cm shotcrete	20 Grouted fiberglass + 5cm shotcrete	Grouted fiberglass (if required) + 5cm shotcrete
Heading advance	1 m	1 m	1.3 m
Bench advance	2 m	2 m	2.6 m

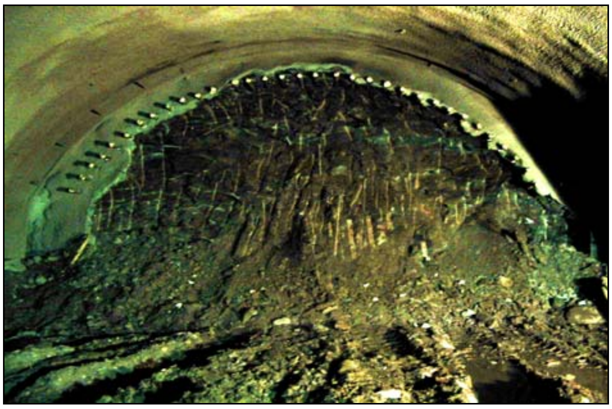

Figure 6. Typical excavation face
Σχήμα 6. Τυπική όψη μετώπου

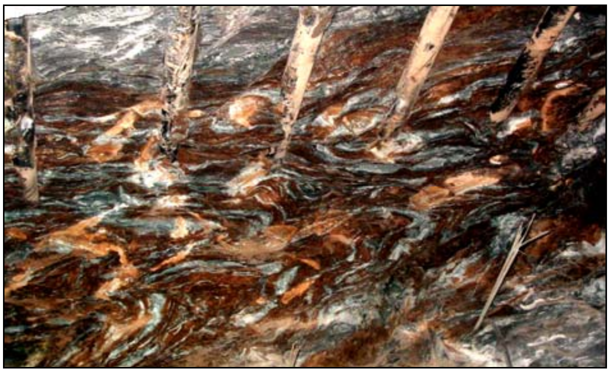

Figure 7. Anilio tunnel. Poor quality flysch (right bore at chainage 12+579)
Σχήμα 7. Σήραγγα Ανηλίου. Πτωχή ποιότητα φλύσχη στο μέτωπο (δεξιός κλάδος στη χ.θ. 12+579)

Careful monitoring of deformations was carried out and the anticipated strongly converging material in terms of 'squeezing' behaviour was never experienced being probably restricted and confined at the tunnel level. The longitudinal evolution of the displacements along the left bore in the highest overburden area, are presented in Figure 8. Left bore of Anilio tunnel broke through in November of 2005, while the right bore broke through a month later. The cost saving of these modifications in the running construction contract is anticipated to be in the order 35% of the original cost estimation, with a time gain of more than 12 months.

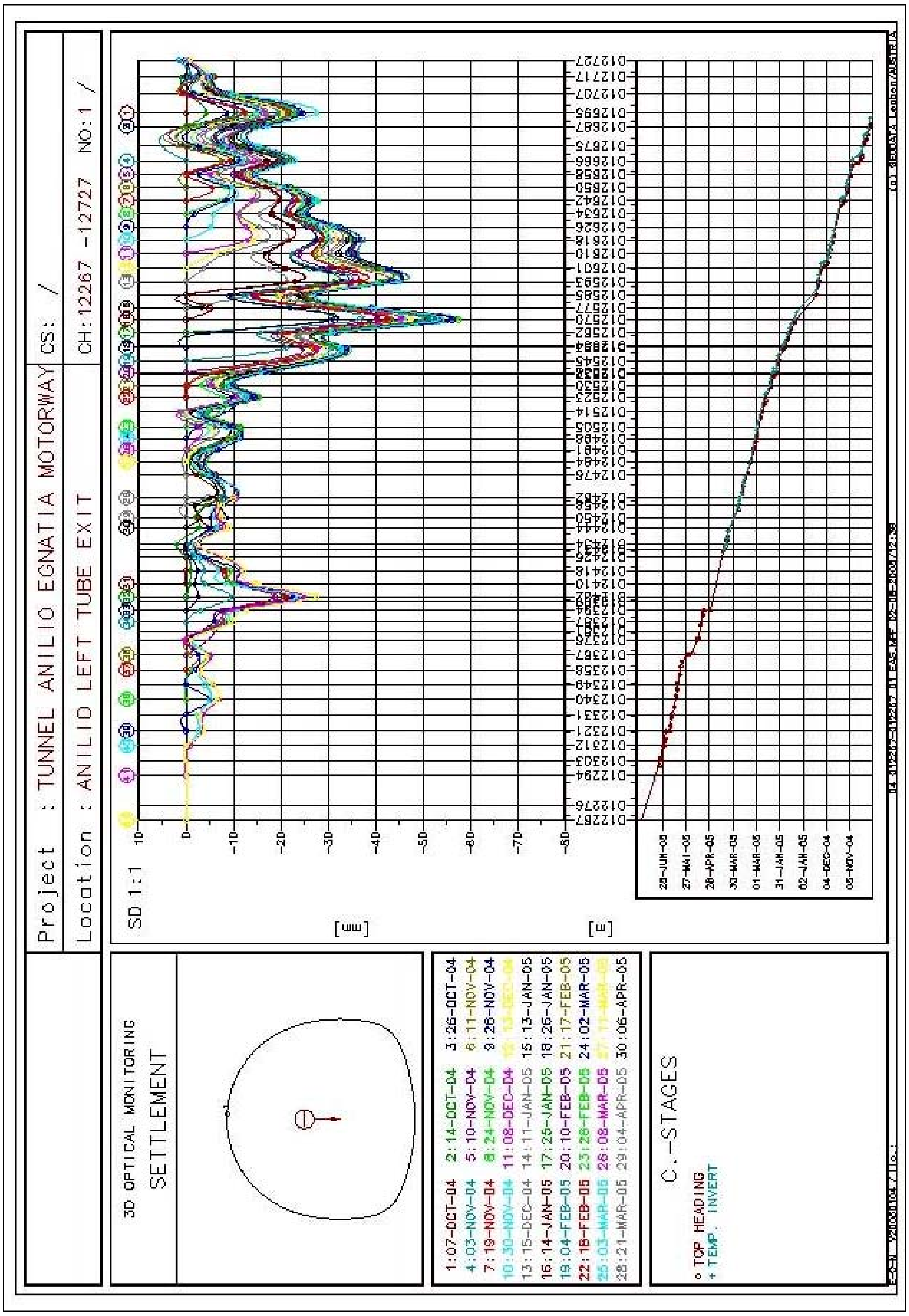

Figure 8. Anilio tunnel. Longitudinal evolution of the crowns' vertical displacement along the left tunnel tube
Σχήμα 8. Σήραγγα Ανηλίου. Κατά μήκος εξέλιξη των κατακόρυφων μετακινήσεων στην στέψη στον αριστερό κλάδο.

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