Moving underground for urban regeneration – Design challenges and cost assessment for the proposed undergrounding of Poseidonos av.

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Abstract. The evolution in underground construction has led to the development of many large-scale underground projects in which essential infrastructure are placed, and though this facilitating the preservation or even the reclamation of valuable surface space. A part of these underground structures is the subsurface transformation of road networks, aiming either at the better traffic regulation, or at the rehabilitation of the surface urban setting. However, special design requirements are needed along with the accurate costing of the proposed solution that would finally assess the feasibility of the project. The paper deals with the proposed underground relocation of a section of the Poseidonos av., a major coastal highway in Athens, as part of the greater urban regeneration that is going to take place in the Hellinikon area. The design of the 1.47 km underground section is proposed to be implemented as a cut-and-cover top down development that will inflict minimal traffic intervention during construction. Also, all proposed surface arrangements and configurations are presented, designed to ensure efficient transit to all users of the road and the surface area. Finally, the design details are used to draw accurate assessments of the required cost and time of the project that will completely transform the area and actually further boost the integration of the Hellinikon development project in the surrounding area.

1. Introduction

Underground development projects can offer solutions that allow the relocation of unwanted or unnecessary surface functions to a more easily controllable underground setting. This not only minimizes any impacts to the environment but moreover can offer enhanced efficiency in their functions; plus, it can reclaim or preserve valuable surface space for other land use types [1]. Key trends point to the growing recognition of the possibilities offered by underground space for future integrated cities where underground facilities link-up with infrastructure and make city living more sustainable and enjoyable to the citizens [2, 3]. This does not only apply to special underground projects, or land uses that are inflicting serious impacts to the surface environment, but can rather be used in everyday infrastructure like surface road networks [4]. The Big Dig project, the Madrid Calle 30 Project are successful examples of radical change with the underground relocation of surface roads. Nevertheless, besides these mega projects, even small scale and focused interventions can have significant positive effect in the overall setting and functionality of the city.
Underground infrastructure can be developed regardless of surface availability, land uses or topographical constrains, and thus, it can provide uninterrupted by-pass through intersections or other obstacles [1, 5, 6]. In this manner, though the development of road infrastructure the following can be achieved [7]:

- surface area can be reclaimed for the establishment of other uses
- surface road network can be efficiently utilized for direct city needs rerouting all other by-pass traffic underground
- the nuisance from traffic is greatly controlled in the underground sections and has reduced impacts to the urban environment
- travel time and travel cost can be significantly reduced.

This paper is dealing with such a case, where a selected section of Poseidonos avenue, the major highway of Athens, in its coastal front, is proposed to be relocated underground. Of course, main driver for this is the wider interventions that are going to take place in the area of the Hellinikon Metropolitan Project (HMP), a multi-million investment project in a vast area with almost 626 Ha available for the development and hosting of new various uses.

One of the issues that are puzzling all planners is the existence of Poseidonos avenue, a key highway in the area, that runs parallel with the coastal area, isolating the main part of the HMP area from the beach existing on the opposite side of the road, and hence, all other developments that will take place there. In order to bypass this obstacle many design options have been considered, either by the underground relocation of the avenue at different lengths and configurations or by setting up special structures to pass above it.

The analysis presented is aiming at a drastic removal of the surface artery, almost in all its length though the project area. The proposed design is given in detail along with all other concurrent development and road arrangements to ensure efficient transit in all the users of the avenue and the HMP. Finally, the cost of the project is given in a pursue to actively support the decision process to reach the most promising solution to the problem.

2. Current Situation and Proposed Development

2.1. Hellinikon Metropolitan Project and Poseidonos avenue

The former Hellinikon airport is located 8km southwest from the center of Athens and has served for more than 60 years as the major Greek airport and the entrance to Greece. Due to expansion restrictions the site has closed down in 2001 and the new Athens airport has been relocated to the Spata area. The vast area with the exception of some partial use as an Olympic venue has remained undeveloped since, although it is located in one of the most beautiful areas of Athens, right in front of the coastal area, called the Athenian Riviera. The redevelopment of this area has attracted the interest of many stakeholders, but only recently its design and principles have been finalized along with the selection of the company to undertake the endeavor. Nowadays HMP is one of the most ambitious projects in Europe and it includes a diversity of functions and land use types including, housing, commercial and recreational uses along with an area reserved to serve as a metropolitan park, that will eventually transform this brownfield to a modern and thriving urban area [8] (Fig. 1).

Poseidonos avenue is the main coastal highway of Attica, running along all the southern coast of the prefecture, bringing together all the major coastal suburbs from Piraeus until Glyfada, and, from there on to Sounion. In its main part it has 3 lanes per direction, and in certain points a forth one is also present, reaching a total width of 26m to 28m. This highway road literally divides the main development area from the coast, acting as an engineered barrier, making difficult swift passage to the beach front, to the marina and all other facilities that are going to be developed there. Furthermore, it creates nuisance as well as other impacts (e.g. safety issues) to the HMP users. Hence, the planning on how to bypass this obstacle without jeopardizing or interfering with its major transport role or how to integrate the highway into the whole project is the key element that requires rigorous attention.
2.2. Design considerations and proposed solution

The design choices initially proposed by the Greek state and the development company included only partial subsurface relocation of the avenue at certain sections so as to keep cost to a minimum, or to keep a light surface road infrastructure along the axis of the main avenue that is to be relocated beneath street level.

The authors already proposed the complete undergrounding of the avenue having only a single interchange point with the surface road network enabling road connection to the main HMP area [9]. The proposed intervention length is approx. 1.5 km (Fig. 2), and, in this manner a complete and homogenized integration can be achieved between the two areas (main HMP area and coastal front), ensuring unobstructed access between them, while, at the same time, achieving a minimized visual intrusion, noise impacts and nuisance from the traffic. In addition, it achieves a high-speed and modern infrastructure for the drivers, under a constant and uniform environment without multiple surface and underground (on and off) sections, portals, etc., thus minimizing the risk of accidents.

Figure 1. General layout of the HMP development (adapted from [8]).

Figure 2. Proposed development of the tunnel section hosting the relocated Poseidonos avenue [9].
This can be the starting point for the further underground relocation of an additional 1.5 km of the avenue, located in the southern area where a separate residential area has already been developed through the years.

Of course, in order to be fair, the initial proposal from the development company has been made some years back, and now, changes in the HMP project development have been implemented towards a more integral use of the subsurface space for the underground relocation of the Poseidonos avenue. Likewise, the complete undergrounding of the highway is now under serious consideration. The authors aim to be part of this effort and this analysis is to further support this development that will bring on enhanced value to the whole project and its users.

Finally, it should be noted that this analysis is only for the road network, while the already developed tramway, which runs parallel with the avenue, is already sufficiently – or can be further – integrated with the surrounding environment, without the need to be relocated underground.

3. Design of the underground relocation of the Poseidonos avenue

3.1. Geological, geotechnical and hydrogeological characteristics

The geological, geotechnical and hydrogeological conditions of the Hellinikon area are the key factors to mandate design options and special requirements so as to achieve a sound engineered solution that will provide protection to the surface environment minimizing subsidence issues, as well as safe conditions in the users of the underground infrastructure. In the wider area of Hellinikon, typical soil formations are mainly found near surface level in the form of a weathering mantle, alluvial and diluvial formations (clays, sands, gravels, etc.). At greater depths, the formations found are marly limestones, sandstones, as well as Athenian shales. What is of importance though, is the low depth (5-10m below ground level) of a rich aquifer that exists discharging all underground flow from the neighboring mountains into the sea. More specifically, the lithological formations that found in the area are [10]:

- Modern deposits and weathering mantle, covering the majority of the Hellinikon area, consisting by alluvial and dilluvial deposits, as mixed conglomerate, moderately cohesive sands, clays and loose red soils. Their thickness reaches up to 3.5 m.
- Alluvial deposits of streams and torrents. They consist of lenses of moderately cohesive conglomerate alternating with sand-clay materials. Their thickness does not exceed 2.5 m.
- Alternations of lateral ridges, dilluvial deposits and red clays. They consist of non-coherent soil deposits, new and old ridge cones and of dilluvial deposits of red clay, sand and loose breccia.
- Sandstones, marls, conglomerates. The formation consists of alternations of relatively cohesive sandstones, marly sandstones of green-yellow color, marls and conglomerates of medium to high cohesiveness. The thickness of the formation exceeds 70 m.

Through a previously conducted geotechnical investigation campaign [10] a number of boreholes have been developed in the area, mainly showing that in the upper strata, loose alluvial soils, clays and gravels are present while in the lower sections (below 5-6m) a yellow-green marly formation is found. In terms of the main geotechnical properties, for the zone under investigation, namely 2 zones have been considered with respect to the depth, an upper one up to 6m of depth and a lower one. The properties that were taken into account in the analysis for these zones, are given in Table 1.

| Geotechnical Properties | Upper unit (0-6 m) | Lower unit (marl) (6-30 m) |
|-------------------------|-------------------|--------------------------|
| Cohesion c (kPa)        | 12                | 29                       |
| Angle of internal friction φ (°) | 26            | 24                       |
| Specific weight γ (KN/m³) | 18             | 21                       |
| Poisson ratio v         | 0,3               | 0,3                      |
| Young's modulus E (kPa) | 10,000            | 40,000                   |
3.2. Proposed road section, geotechnical design and construction guidelines
The general layout of the underground construction of the highway is already given in Fig. 1. Its total length is 1.47 km, from which, the fully underground section has a length of approximately 1.11 km (ch. 0+180 up to ch. 1+290, black hatch in Fig. 1). The remaining length is comprising the inclined transition sections (blue hatched sections in Fig. 1), each one of which is around 180 m. At the central point of the underground section the development of an interchange is designed so as to allow vehicle access to and from the HMP (Fig. 3).

The maximum depth that the proposed tunnel reaches, is approximately 8.5 m from the existing surface level, with the tunnel structure having a maximum clearance of 5 m. The underground roadways will be consisted by two separate sections, one per direction. Each section has three 3.5 m width traffic lanes, along with a single 0.5 m sidewalk located at the right sidewall at each direction. The same configuration is also present in the inclined transition sections, that is also having a barrier islet to divide the traffic directions. Emergency cross-passages, within the tunnel section, will also be developed at an interval of 250 m.

A local widening of the tunnel cross section is proposed to be developed in the areas near the interchange section where the interconnection of the underground section will be made to the outer environment. At those points an extra lane 4.5 m in width will be developed in each direction that will cater for the acceleration-deceleration lane, so that the vehicles are driven from the surface to the underground section and vice versa smoothly and safely. This section will also function as an emergency escape and U-turn section in case of accidents.

Figure 3. Sketch of the main intersection developed to facilitate access from the underground road section to the HMP.

The construction follows the cut-and-cover principle with the use of pilewalls that will form the initial lateral supporting structure. The top-down construction option is selected over typical cut-and-cover construction in order to maintain the traffic access and avoid inconveniences to neighboring communities during the development phase of the project. Part of the traffic will be rerouted through the Metropolitan Park, during the construction of the project as well.

The construction starts with the development of a series of secant pilewall. These will be developed in the centerline of the axis, as well as to the borderline of the roadway. At first, the centerline piles and the piles in the right section will be bored, while traffic is diverted to the left side of the road. The
Concrete slab at the top of the structure is developed along with its waterproof membrane (PVC) and the excavation progresses from top to bottom. The shotcreting of the area and the installation of ground anchors, will be made next along with the placement of PVC membrane. Concrete works, drainage systems and the development of the pavement is next so as to finish the construction. Traffic is then diverted to the finished underground road section and the development of the left traffic corridor takes place next with the construction advancing in the same order as before. Finally, the surface cover area is restored with the addition of soil cover, plants and paved pedestrian paths. The complete sequencing of the project’s construction phases is illustrated in Fig. 4.

![Figure 4. Construction phases for establishing the underground relocation of the Poseidonos avenue.](image)

The whole development process was modelled in order to assess the stability of the construction. A series of intersecting piles (concrete reinforced and concrete only piles) having a diameter of 1.0m are used to form the pilewall. This option is used to achieve better conditions in terms of the water-tightness of the structure, as the structure is developed partially below water table. They will be bored up to a maximum depth of 12m in the whole length (1,100m), of the in the underground section, while at the transition section their average length is around 8m, ranging from 5m to 12m. The concrete slab that is formed on top of the sections has also a thickness of 1 m. Finally, during the progress of the excavation shotcrete is also used and where needed, and also, a series of 8.5 m long, pre-stressed anchors, will be placed in two rows (upper and lower). The anchors will be placed at a spacing of 1.5 – 2 m between them, having a tension force of 75 KN and 50 KN, for the upper and the lower rows, respectively.
The results of the numerical analysis regarding the modelled construction layout and existing geotechnical setting at the area is performed using Phase2 software package. It is indicated that there will be minimal surface and lateral displacement from the construction activities. The yielding areas of the soil are kept under control, while also, the values of moments, axial and shear forces as imposed to the roof concrete slab and to the pilewall are within the acceptable limits. Figure 5 depicts some screenshots of the results obtained.

![Screenshots of the results obtained](image1)

**Figure 5.** Results of the numerical analysis regarding the proposed construction. (a) values of moments and (b) axial forces in the concrete structure, as well as (c) horizontal and (d) vertical displacements.

Based on the above, it can be deduced that the proposed construction is capable of hosting the traffic without having any impacts to the surface environment. Thus, the final proposed design cross-sections for the undergrounding project are given in Figure 6. This offers the complete undergrounding of the infrastructure and reclaims the majority of the surface space to be developed for recreational and public use (Fig. 7).

![Proposed layout](image2)

**Figure 6.** Proposed layout of the main and the enlarged section of the underground Poseidonos avenue.
4. Cost and scheduling requirements
The cost assessment of the relocation is made through the estimation of the bill of quantities for the project (Table 2) based on the unit values obtained from respective tables published from the Greek General Secretariat for Public Works. In cases of complex or special tasks (relocation of public utility networks, etc.), data was obtained from similar projects in Greece. According to the calculation of the measured quantities, the total cost for the underground development of the Poseidonos avenue is approximately 36.05 million euros (€), before VAT, including the development of the surface works to facilitate the interchange. This sum includes around 10% of the total cost to cover the expenses for unforeseen conditions, as well as a fixed 18% to cover for general contractor's overhead and profit. However, this does not include the cost surface rehabilitation and transformation to host the recreational functions as well as the cost of the E/M installations.

Table 2. Bill of quantities for the proposed undergrounding of the Poseidonos avenue.

| Material / supply/ type         | Unit | Quantity |
|--------------------------------|------|----------|
| Soil material excavation       | m³   | 271.125  |
| Well piles (not reinforced) Φ100 | m    | 32.470   |
| Reinforced well piles Φ100     | m    | 32.545   |
| Reinforced concrete            | m³   | 40.660   |
| Steel reinforcement            | kg   | 9.445.650|
| Pre-stressed Anchors           | m    | 29.380   |

The construction duration of the project is estimated at 32 months, as given in the Gantt chart of Figure 8. Initially, a period of 4 months is foreseen in order to make the relocation of the existing utility network and also the required traffic arrangements. With the completion of the above works, the main construction of the project begins, following the steps already mentioned above, that takes approx. 24 months. The installation of the required E/M equipment (lighting, ventilation, etc.) the safety equipment (firefighting stations, emergency phones, etc.) will be made at that stage along with the traffic signaling. Finally, the surface rehabilitation will be the last part of the works, concluding the project.

5. Conclusions
The development of underground infrastructure can efficiently meet the demands of modern urban areas. Especially in cases where a significant urban regeneration is pursued, the underground relocation of road networks can reclaim valuable surface space and deliver enhanced freedom of chooses to planners to create their vision. This is the case presented in this paper where undergrounding of this major highway has been proved to be a viable option to overcome problems and come up with the integration of the main part of the Hellinikon project with the coastal front. At the same time, besides the minimization of the current seclusion and barrier issues, this development provides zero visual intrusion, and, efficiently tackles traffic noise impacts. Furthermore, it ensures safe, swift and uninterrupted passage though this section towards the southern suburbs of Athens.
The solution developed aims at identifying the design options and to provide a sound and safe construction strategy. Additionally, is serves as the basis to accurately estimate the cost and schedule requirements and thus further improve the decision selection process. It has been found that the design adopted can provide the standards and requirements to facilitate traffic on the one hand and to ensure an optimal performance in terms of stability conditions. The cost of €36 million is certainly a great investment to be made, but can bring over major benefits to the whole Hellinikon development project. Yet, the finalization of the project details can result in having more clear answers in the various construction options, and hence, even be able to further reduce this development cost, further enhancing the attractiveness of the undergrounding project.

References
[1] Kaliampakos D and Benardos A 2008 Underground Space Development: Setting Modern Strategies Proc. Underground Spaces 2008 New Forest UK September 8-10 pp 1-10.
[2] Bobylev N, 2016 Transitions to a High Density Urban Underground Space Procedia Engineering, Volume 165 pp 184-192.
[3] WSP, 2018 Taking UrbanDevelopment Underground - Future-ready solutions for ensuring urban sustainability Report WSP Global Inc.
[4] Godard J P, 2004 Urban Underground Space and Benefits of Going Underground World Tunnel Congress 2004 Singapore 22-27 May 2004
[5] Broere W, 2015 Urban underground space: Solving the problems of today’s cities Tunnelling and Underground Space Technology Volume 55 pp 245-248.
[6] Knorr Skov M, and Olsen T, 2018. Sustainable urban development requires traffic solutions - both underground and above ground, COWI, [available online: https://www.cowi.com/insights/tunnels-and-urban-development, accessed August 2020]
[7] Benardos A, Kazos X, Sotiropoulos N, 2012 Design analysis for the underground relocation of a central road artery in Athens Proc. 13th ACUUS Int. Conf. 7-9 Nov Singapore pp. 557-566
[8] Lamda Development, 2020. The Hellinikon Project, [available online: https://thehellinikon.com/en/, accessed August 2020]
[9] Poulidi F N, 2017 Feasibility assessment of the underground relocation of the poseidonos avenue in the context of the Hellinikon redevelopment project MSc Diploma Thesis NTUA.
[10] Harmanidis F, Siemnos N, Laxanas G, Orfanos V, Bormpolakis G, Zargkoglou K, Gintoni E, and Anastasopoulou S, 2004 Hydrogeological – Borehole campaing of the Olympic 2004 venue – Suggestions for utilisation of hydraulic works, Report, IGME.