Comparative Evaluation of Alternative Methods for the Construction of Underground Car Parks

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ABSTRACT

The present paper focuses on the comparison between the alternative methods of constructing underground parking spaces. It analyses and compares the “cut-and-cover” method, a most common method for the construction of underground parking stations, with the “room-and-pillar” method originating from the mining sector which also exhibits equally satisfactory results. This evaluation takes into account the applicability of each method in relation to the ground conditions, their ease of use, as well as their performance in terms of financial efficiency during construction. The assessment is made using reference projects as input. More specifically, the construction costs of three underground car-stations, constructed with the “cut-and-cover” method are compared with the construction costs of three other underground car-stations which were designed following the “room-and-pillar” method principles. Their key elements are recognized and major cost components are evaluated in a head to head analysis.

1. IMPORTANCE OF PARKING SPACES – UNDERGROUND CAR PARKS

Car plays an important role to modern societies as it is a comfortable and fast mean of transport. However, its usefulness and service degree depends particularly on the sufficiency of suitable parking spaces. The importance of “parking” is evident from the space that is provided and the time that a car is found parked in relation to the time of its movement. Thus, a passenger car requires a parking area of approximately 25 m², including the essential areas for gaining access and manoeuvres, while the time it remains parked is more than 90% of the total. However, the lack of parking spaces is one of the most significant problems that large urban centres face today. This fact has lead to particularly negative consequences in the life and style of the cities because of the traffic jams and long delays, as well as the environmental pollution. The utilisation of the subsurface with the establishment of underground car parks has been proposed as a measure to alleviate the lack of parking space in urban areas and today, along with the underground transit systems (metros, etc.), can be characterised as the most typical form of underground development (Kaliampakos D., 2003). The advantages that such facilities offer are significant (ITA-WG13, 1995; Sterling, 1997) and their use is widespread. In particular, they contribute to the environmental protection, as valuable surface space can be preserved and the visual annoyance is minimal, assisting in the improvement of the quality of the city life (Tareau, J.P., 1995), and at the same time they can provide a safe environment with high availability since their construction could take place almost anywhere. Nevertheless, underground car parks have to deal with a high construction and service cost, in relation to aboveground solutions, because of the increased need for support, lightning and ventilation. That issue puts forth the necessity to further investigate solutions capable of offering lower costs without on the same time affecting the efficiency of underground car parks.
2. UNDERGROUND CAR PARKS - “CUT-AND-COVER” METHOD

2.1. General outline – Cases examined

This method, which is commonly used for the construction of underground parking areas, is quite flexible and it requires simple mechanical equipment. For the support of the cutting perimetric walls, steel strands or reinforced concrete, or tensile anchors are used. Cut and cover is easily adapted on the loose soil of top layers while in exceptional cases also in hard soil.

In recent years a booming in the development of underground car parks following this method was experienced in Greece and in Athens in particular. In Table 1 the characteristics of three underground garages are presented (J.&P., 2003a,b,c), namely the stations of Paidon Hospital square (Fig. 1a), Rizari street, and finally Kanigos Square (Fig 1b). These car parks are located under public squares, having a total capacity ranging from 500 to 650 parking places, covering a surface of about 17,000 m² allocated in 4-5 floors.

Table 1. Characteristics of underground car parks constructed following the cut-and-cover method.

<table>
<thead>
<tr>
<th>Parking Station</th>
<th>Surface (m²)</th>
<th>Volume (m³)</th>
<th>Floors</th>
<th>Capacity (cars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paidon Hospital Square</td>
<td>17,433</td>
<td>54,764</td>
<td>5</td>
<td>576</td>
</tr>
<tr>
<td>Rizari Street</td>
<td>18,997</td>
<td>56,339</td>
<td>4</td>
<td>664</td>
</tr>
<tr>
<td>Kaniggos Square</td>
<td>15,401</td>
<td>49,283</td>
<td>4</td>
<td>491</td>
</tr>
</tbody>
</table>

Fig. 1. Underground car stations in Athens. (a) Vehicle entry point of the Paidon Hospital Square car park; (b) Ground plan of the car station developed under the Kanigos Square.

2.2. Cost Analysis – Key issues

The cost analysis of the underground car parks are based on the as-build cost data and concern the cost of individual construction phases of the Paidon Hospital Square and Rizari Street stations, as well as the total construction cost of the three stations. Therefore the comparison is aiming not only at providing general cost assumptions but also at identifying key factors which affect the construction process and differentiate the project’s cost.

Table 2. Cost data of the cut-and-cover underground car stations in Athens.

<table>
<thead>
<tr>
<th>Parking Station</th>
<th>Total Cost (x10³ €)</th>
<th>Cost/parking place (€)</th>
<th>Cost/m² (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paidon Hospital Square</td>
<td>5,283</td>
<td>9,170</td>
<td>303</td>
</tr>
<tr>
<td>Rizari Street</td>
<td>4,830</td>
<td>7,275</td>
<td>254</td>
</tr>
<tr>
<td>Kaniggos Square</td>
<td>9,856</td>
<td>20,075</td>
<td>640</td>
</tr>
</tbody>
</table>
Even though there are differentiations between the examined “cut-and-cover” projects, and each car park has unique design features, the expenditure allocation of the construction costs are distributed roughly at the same cost components. Thus, the cost of the concrete works is the most important one, reaching almost to the 30% of the total cost, followed by the electrical and mechanical works (20%). Also, the required support amounts approximately to 10%, whereas the excavation and waterproofing is almost 9% and 5% of the total cost, respectively. In Fig. 2 the major cost components of the examined projects are presented.

Based on the examined data, the factors that play an important role to the total cost are:

- local conditions in the construction area
- geological background and
- excavation depth

The siting of an underground car parking facility has a great effect not only to its utilisation but is also of major importance to its construction cost. As the cut-and-cover method requires the excavation to start from the top and gradually reach to the target depth, in the early stages, it is possible to have precautions to the city life. Thus, the proximity of the construction site to other buildings, nodal points in the city, etc. mandate the establishment of additional measures to alleviate possible consequences. On the other hand, after the construction period a series of parallel work are required to redevelop the original forms or even improve the prevailing conditions.

In the examined cases, the most characteristic examples are the car parks constructed under Kaniggos Square and the Paidon Hospital Square. In the first case, the construction took place in the heart of Athens centre, under both the homonymous square and Akadimias avenue. Thus, a number of parallel works, rerouting of the traffic, pedestrian passages, rearrangement of utility networks, etc. were required along with a complete renovation and landscaping after the construction period. Moreover, in order to minimise the impacts it was decided to divide the construction in many phases, element that affected both the project’s budget and its construction period.

Another important factor is the need for additional support measures so as to ensure that the safety of the surrounding buildings and ensure that ground deformations will be kept at a minimum level. Thus, the design of the support system (piles, diaphragm walls, cable support, etc.) should include the additional loadings, while the installation of steel braces and other support types at the topmost level should be made parallel or before the actual start of the excavation. This was the case in the Paidon Hospital Square car park and is reflected to the extra cost spending in support and concrete works, compared to the case of the Rizari street garage where the structure was built under a public garden.
The geological structure is also of importance, as it affects the excavation and support cost. If the rock has increased strength, more resources should be allocated in the excavation stage, while the support can be simpler and more economical. The geological background of the Paidon Hospital square is constituted by hard red clay, loose soil, conglomerate and gravel, rocks, of low to medium strength and cohesiveness while in the Rizari Street car park, the Athenian Schist prevails as it is characterized by higher strength and cohesiveness, and consists a rocky formation.

Hence, the underground parking area of the Paidon Hospital square presents lower excavation cost in relation to the Rizari Street’s case. This happens not only because of the smaller volume of the first but also because of the fact that the subsoil is constituted by loose soil, low stiffness and cohesion, contrary to the rocky formation of the second region, that is extracted more difficulty. As with support, the opposite stands. The support required for the Rizari Street car park is lighter and of lower cost, whereas in the Paidon square’s case, more material, personnel and labour hours are required.

Finally, the excavation depth is in proportion to the support and the excavation costs. As it increases more difficulties are to be encountered as the mucking of the materials becomes an important cost centre and the support used should be capable of overcoming increased lateral pressures. This has been also the case for the Paidon Square Hospital car park as increased expenses were required to the support system.

3. UNDERGROUND CAR PARKS – “ROOM AND PILLAR” METHOD

3.1. General outline – Cases examined

The room-and-pillar is a typical “open stope” mining method, where only part of the ore/rock is extracted while the rest remains in place in the form of pillars so as to provide natural support of the overburden. The method can be used in horizontal or slightly inclined formations, located in low to medium depth and are characterised of high to medium strength. The approach of this method for the creation of void space is different than mining. More specifically, instead of designing the exploitation scheme with a view to extract as much rock as possible and achieve the highest recovery ratio, the project’s design aims at providing adequate space to serve the needs of a typical parking facility, without compromising the safety of the site.

The data provided regarding the construction cost of the underground parking places is relied on three specific cases (Table 3), the construction of which is proposed to take place by using the principles of the room-and-pillar method (Christopoulos, 2003; Dimitroukas et al.,2003; Kaliampakos et al., 2005).

Table 3. Characteristics of underground car parking stations designed with the room and pillar method.

<table>
<thead>
<tr>
<th>Parking Station</th>
<th>Surface (m²)</th>
<th>Volume (m³)</th>
<th>Floors</th>
<th>Capacity (cars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agia Paraskevi</td>
<td>13,248</td>
<td>66,240</td>
<td>1</td>
<td>360</td>
</tr>
<tr>
<td>Tourkovounia</td>
<td>11,319</td>
<td>45,276</td>
<td>1</td>
<td>346</td>
</tr>
<tr>
<td>Katehaki Bus depot</td>
<td>59,917</td>
<td>479,336</td>
<td>1</td>
<td>284 (buses)</td>
</tr>
</tbody>
</table>

The first two car parks have a capacity of around 360 parking places, while the third is designed to host the depot of the public bus company of Athens, with a capacity of 284 busses. All of those facilities are designed within limestone formations of good to medium strength and the rock will be extracted using blasting agents. Moreover, the facilities are developed in a single floor space.

3.2. Cost Analysis

In the cost analysis of the selected projects, two major cost components can be discerned; the excavation cost and the development cost. The first incorporates all the necessary operations for the creation of the void space (excavation, mucking, support, etc.), while the second includes all the
required works to develop and transform the site into a fully working underground car parking facility (mechanical installations, waterproofing, pavements, etc.). The cost data is presented in Table 4.

<table>
<thead>
<tr>
<th>Parking Station</th>
<th>Total Cost (x10^3 €)</th>
<th>Cost/parking place (€)</th>
<th>Cost/m² (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agia Paraskevi</td>
<td>1,353</td>
<td>3,760</td>
<td>102</td>
</tr>
<tr>
<td>Tourkovounia</td>
<td>3,067</td>
<td>8,865</td>
<td>297</td>
</tr>
<tr>
<td>Katehaki Bus depot</td>
<td>3,667</td>
<td>12,910</td>
<td>61</td>
</tr>
</tbody>
</table>

It should also be noted that the excavation cost takes into account the income gained from the sale of the extracted raw materials which could be used as aggregates. The impact of such decision is of extreme importance, as for example, with a no sale option, the cost for the Agia Paraskevi case would be approximately at 170 €/m².

To understand the differentiation in the cost figures, the case of the Agia Paraskevi car park will be used as a base example. This garage is constructed in a hilly environment allowing for the minimisation of the access tunnels. The Tourkovounia car park has almost the same characteristics, nevertheless its siting requires a number of parallel works to be completed so as to become attractive to the end users. Thus, a series of access tunnels is required, along with the construction of an inclined shaft, in which a shuttle funicular lift will allow easy passage to the city’s centre. Nevertheless, the total cost of these works is extremely high, estimated at approximately 2 million €, increasing the total cost per parking place from 2,900 € to 8,865 €.

Another issue that plays an important role is the size of the garage itself and more specifically the height. This can be shown by examining the Katehaki bus depot case, the main difference of which lies on its preferred dimensions. As it should facilitate buses, its dimensions are increased allowing for the creation of economies of scale. Furthermore, it allows for the development of a bench type operation where the excavation of the lower part could be made using vertical blastholes, and thus achieving higher productivity rates, which are reflected to the decrease of the construction cost.

4. DISCUSSION – CONCLUSIONS

The development of car parks underground is an efficient method of overcoming surface space constrains and provide at the same time an efficient way to facilitate the parking needs in modern cities. Each one of the construction method that was examined in this paper has its own unique features and characteristics. The cut-and-cover method is most efficient in soils or soft ground conditions and when multi level structures are to be constructed, whereas the room and pillar method presents significant advantages in cases of rock formations and suitable geomorphologic setting.

The cost analysis however indicates that the room and pillar method offers a considerable reduction in the total cost (Fig. 3).

![Fig. 3. Comparison of total construction cost (€/m²) of underground car parks constructed with the “cut-and-cover” and “room-and-pillar” methods.](image-url)
The cost per square meter is at least 3 times lower in the room and pillar cases than of the cut-and-cover ones. This differentiation in the total cost is due to two main reasons; the revenues from the aggregate sales and the absence of major support systems and concrete works in the very form of the room and pillar facility, as the pillars themselves constitute the structural elements that offer the natural support. Consequently, the selection of the room-and-pillar construction scheme can be proved most efficient in terms of financial results and can become the standard construction method, particularly in cases of special projects and where the feasibility of creating an underground car park is marginal or questioned.

REFERENCES