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Assessing and Analysing the Potential of Urban Subsoil: A Case Study of Rabat, Morocco

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Abstract — *The development of urban areas is characterized by significant growth and urban expansion, which leads to the appearance of satellite towns, also known as dormitory towns. In order to reduce this speed of horizontal urban expansion, it was wise to think about the use of urban subsoil, which leads to the improvement of urban planning in the form of vertical construction. Apart from the fact that this approach proves to be surrounded by several constraints of a geological, hydrogeological, geotechnical, and socio-economic nature, the volume and potential value will also have to be assessed before proceeding with this type of construction. In this sense, the different factors influencing the use of urban subsoil, as well as the methods for analyzing the potential of urban subsoil, on a theoretical basis, will be shown* **-** *in order to better utilize it. Accordingly, the case study of Rabat's city, the capital of Morocco, will be considered. The project consists of building a two-level underground car park near a historic earthen wall. In order to assess the possibility of this type of excavation, it was more appropriate to carry out recognition trials and other stability tests. Subsequently, it was evaluated using the principle of the observational method to find out how the frequency of the excavation machines affects the stability of the surrounding wall. As a result, the frequency of the vibrations generated by the excavation machines had to be adopted using a geophone during the construction and commissioning phase of the car park.*

Keywords — *urban subsoil, cities extension, geotechnical studies, construction planning, urban development plan.*

I. INTRODUCTION

Urban development recognizes significant growth in view of human reproduction and development, and also immigration to urban centers away from the countryside. The number of people living in urban areas is increasing dramatically at a steady pace. New inhabitants, new houses, and therefore new buildings and facilities for this new urban population. Indeed, this growth manifests itself in the form of lateral extension. Surface construction is extended horizontally towards the city limits. The horizontal extension of the cities has led to the appearance of satellite cities, also called dormitory towns, which do not promote the development of the conurbations. In the end, after several decades, each city will be glued to its neighbor, with no more surface space for building or development.

In order to prevent this from happening one day, it is time to look for other alternatives. Demographic change and immigration to urban centers will not stop overnight. These are difficult constraints to manage and control. High-rise construction is necessary in order to preserve green spaces and agricultural areas in the face of this population density and also lack of building space [3,10,11,12]. It made sense to think about exploiting the urban subsoil to transform the current horizontal construction to another in height. In this case, the development and planning of vertical cities will be addressed.

In theory, this seems feasible, except that in practice, this type of exploitation is conditioned by a number of factors that limit this type of practice. In terms of feasibility, the exploitation of the urban subsoil is framed by several criteria which differ from one country to another. Criteria are related to the presence of underground water tables, historical underground sites, or the presence of undeveloped minerals and mines. From a technical point of view, vertical construction is linked by the nature of the soil and the level of the substratum.

The objective of this work is, therefore, to study all these constraints which limit the exploitation of the urban subsoil, whatever their nature. The recognition of these constraints will make it possible to quantify what will later be called the potential of the urban subsoil.

In this article, the name of the high-rise building or the vertical development of urban areas characterizes, in particular, the deep construction and the exploitation of the urban underground.

On the basis of current examples and an extensive literature search, it has been found that the potential

The use of the urban subsoil depends on several factors. These factors have been classified into two classes: the first one will be called the class of indirect causes, and the second one the class of direct causes.

The indirect causes will group together the limits of socio-economic feasibility. The direct causes, on the other hand, will group together all the factors of a technical nature. The limits of the technical feasibility of digging at the urban level will be detailed.

A. Historical context

The use of the urban subsoil is limited by several socio-economic factors. Indeed, the typology of the exploitation of these subsoils differs from one country to another over time. At the beginning of the 20th century,

the use of underground excavation was limited to rail transport projects, as in the case of the city of Tokyo in 1920 [9], which were accompanied by underground crosswalks and the presence of a few shops.
The Parisian subsoil is occupied by the density of various networks and those from the 20th century onwards, such as water, electricity, gas, sewers, to which telecommunication networks are added from the 21st century onwards. Towards the end of the 1980s, the foundations of Parisian buildings occupied about 50% of the city's subsoil [14] (fig.1).

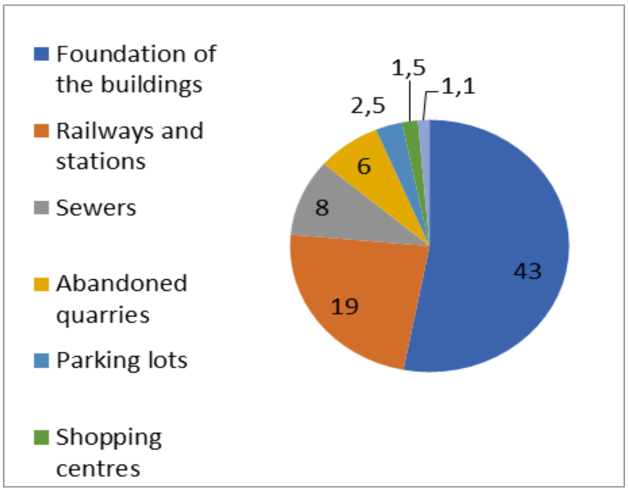

Fig 1.The volume of use of the Parisian basement as a percentage in 1980 [14]

B. Indirect causes of the urban subsoil use limit

The underground space is rich in resources that can be shown as advantages in terms of exploitation. These resources are composed of the space present in the urban subsoil, groundwater water, equipment, and geothermal energy, which will be called temperature, to put it simply [11, 5]. But several intersecting factors limit the development of excavations and the occupation of the urban subsoil. Let's start with the state of this subsoil and, in particular, its temperature. This is almost constant and tolerable, so it can be seen as an advantage rather than a disadvantage in terms of lower energy costs. Except for the gain in terms of air-conditioning, it will be wasted in terms of lighting, air renewal, or groundwater pumping.
There is also, as an indirect factor, the congestion of agglomerations. Indeed, digging tunnels and underpasses for vehicles will not solve the overflow of vehicles in the long term. Congestion and traffic jams at peak car times will increase over time. Therefore, it makes sense to consider building crosswalks as well as vehicular crossings to relieve traffic congestion. These pedestrian underpasses will be less expensive than vehicle underpasses due to the shallow depth of excavation and the geological nature of the site. Furthermore, this type of construction will be maintained in the long term as it has the possibility of co-financing or total private financing, exploiting the area as an economic zone by introducing small and large businesses [16].

Regulations may disadvantage this type of excavation. Indeed, the ownership of the subsoil depends on one country to another. Other laws indirectly limit underground exploitation, such as the law of water, the law of groundwater preservation, or the law of mining management.

C. Direct causes of the urban subsoil use limit

The so-called direct factors are of a technical nature. They are related to the geological, hydrogeological, and geotechnical nature of the project site, the constraints of adjacency, or the risk of non- earthquake protection. The latter is illustrated in the case of the Kobe earthquake in Japan in 1995, where 10% of the underground constructions were ruined [17].

The geological, geotechnical, and hydrogeological nature of the land blocks this type of exploitation in the sense that the poor quality of the soil requires the use of several very expensive technical resources to reinforce it. Obviously, if this type of underground exploitation requires several high-risk, low-profit reinforcement tools, the choice will be quickly made, i.e., to abandon vertical construction for horizontal construction. For example, if it was planned to build a tourist complex on the banks of a river with several levels above and below ground.

First of all, it is necessary to think about lowering the water table during the construction period. There are sites in the middle of a swampy area. It is also necessary to study the quality of the soil or the foundation if it is rigid or flexible enough to support the load of the future construction. The aim of any A profitable project is to find solutions to these constraints at the lowest cost. If this is going to be done at a very high cost, it would be better to opt for another type of construction.

Moreover, the joint ownership of buildings remains the most difficult problem to solve. Such is the case of the construction of the Oudayas tunnel in Rabat, Morocco. This tunnel was designed to relieve the city's dense traffic. The central section is trenched under part of the 17th century Oudayas monument. The implementation was rather critical from the outset. In order to see the possibility of digging under this historical monument, core drill holes were made at the level of the wall and the ground. As a result, the historic site rests on superficial and deep foundations as well as buttresses placed in places on the riverside. The goal was, therefore, to protect this monument from differential settlement caused by the digging of this part of the tunnel. In this sense, the lining was in two phases: the first, called provisional, consisted of installing micro piles under the foundations, holding them together by U-shaped metal beams, and then proceeding with block excavation (Fig. 2). The second, called definitive, consists in transferring loads of the structure onto a foundation slab which is at the same time the tunnel cover slab.

Fig 2. Illustration of the provisional phase (A) and the final state (B) of the tunnel [20, 21].

This classification of direct and indirect issues limiting the exploitation of the urban subsoil remains relative and specific to the authors. What may appear to be an advantage to one may be seen as an inconvenience to another. Daoust-Hébert Maxime illustrates this perspective by the example of the development of highways by exploiting the underground space. This seems advantageous in an environmental approach in terms of reducing noise pollution and gas emissions, as it seems disadvantageous in the sense that the evolution of the highway network threatens the use of public transport. In other words, the more highways there are, the more vehicles use them and therefore the more gas emissions, which is bad for the environment [5].

Apart from the factors that limit the exploitation of the urban subsoil, the lack of planning, disorder, and anarchy prevent the development of the subsoil. The failure or absence of underground mapping causes a lot of damage, especially when it comes to underground networks and wires. It is therefore impossible to know what type of intervention to carry out: dig carefully to find out what infrastructure is hidden in the subsoil or call in other geophysical instrumentation for identification purposes. During the construction of the foundations below a height of 30 meters in the Mecidiyeköy district of Istanbul, Turkey, pipes were driven into and then pierced the tunnel shaft that encased the metro. This damaged two carriages, the tunnel, and the foundations of the car parks of the buildings that were at shallow depth [2]. This accident was due to the ignorance of the infrastructure and the lack of underground mapping.

II. MATERIALS AND METHODS

This project involves the redevelopment of the Bab Lhad square, located in the center of Rabat, the capital of Morocco, and the construction of an underground parking lot composed of two basements(Fig.3.) This car park is an essential part of the development of the city of Rabat. This new infrastructure, intended to increase the parking supply in the city center, is part of the integrated program for the development of the capital called "Rabat City of Light, Moroccan Capital of Culture". The city of Rabat also has other underground car parks in the city center, such as the Bab Laalou and Bab Chellah car parks. The aim is, therefore, to apply the method of quantifying the potential of this subsoil which is the subject of this project. The project site was called Bab Lhed Square in the form of a large pedestrian area adjacent to the great wall of Bab Lhed dating from the 12th century, which is considered a historical heritage of this city. The redevelopment of this square consists of keeping this pedestrian space while occupying the underside as a car park. Economically, this project will be profitable for all parties. The car park will be guarded and maintained by a private company, but there will also be no more parking crisis, especially on working days and weekends. All that remains is to manage the technical feasibility of this project.

In this sense, a geotechnical campaign was launched. The result is that the soil has good mechanical characteristics. Indeed, the sandstone layer had been Found at 3.50 m/TN and the earthworks were planned in the order of 7.90m/TN [7]. The stability did not pose any problem with regard to the slope that will be realized. The geological and geotechnical nature of the site did not constitute a limit to the use of this subsoil.

Fig 3. Project site for the construction of the underground parking lot at Bab Lhad Square

The excavation work for this future parking lot requires the use of several machines, notably jackhammers, rock breakers, mechanical shovels, and excavators.

All these machines generate continuous vibrations when they are in operation [1]. These vibrations can, in turn, cause several damages to the stability of the foundation of the wall that is located near this site. The presence of this wall constitutes, in fact, a limiting factor for the excavation works of this project (Fig.4). The goal is then to potentiate the realization of these structures, then into the rest of the structure. In the case of this wall built on rammed earth in the 12th century, several damages can be perpetuated following this wave propagation. Indeed, the vibrations can generate soil settlements, liquefaction, slope failures [14], or even introduce fatigue, also called dynamic fatigue [8,13]. At the level of the structure, vibrations can develop new cracks or promote the development of cracks already opened as well as the displacement or the fall of some elements of this structure.

A. Define the wave frequency, its method of measurement, and metrology

In order to evaluate the impact of vibrations on the surrounding wall, it is first necessary to materialize them. A vibration is characterized by its frequency, and its amplitude is also called its speed [19]. The interest is thus to fix the maximum frequency and speed, allowing the stability of the wall. To do this, it was necessary to carry out vibratory measurements. At the level of the circular of 23/07/86, two methods of quantification of mechanical vibrations were represented [4]. The finite analysis method will have proceeded in this case of study. First of all, it is necessary to define the initial conditions of the structure before proceeding to its analysis; in particular, it is necessary to define the corresponding field of application, the effects of vibrations on the structure, as well as the category of the source.

Project in this case of the figure. It is therefore vibrations in order to limit their impact on the stability of the wall [6].

TABLE I
CONSTRUCTION CLASSIFICATION OF THE CASE STUDY FOLLOWING THE FINE ANALYSIS METHOD

Field of application	Effects of vibrations		Source Category
	Direct	Indirect	
Old buildings and structures [4]	Cracks in the wall (due to resonance or pulse repetition [4])	Densification of the soil	Continuous source

Fig 4. Distance between the Bab Lhad wall and the place where the parking lot was built.

Excavation or even demolition machines generate continuous vibrations over time, contrary to impulse vibration sources, such as explosive blasting, for example [15]. From their sources, the waves propagate towards the foundations of the adjacent From the classification of the constructions by the method of fine analysis, represented at the level of the circular of 23/07/86, it was deduced (Table.1) that the site of study is classified in class 11 with mention Cf relating to the type of foundations as well as the nature of the ground [4].

In order to measure the frequency and amplitude of the vibrations emitted by mechanical machines, three geophones were set up. The geophones have a natural frequency of 1 Hz and are able to detect even frequencies not felt by humans.

The orientation of the geophones was in the direction of the construction. The first geophone will Be named "Sensor 1" and will be placed on the ground near the mechanical equipment for which their impacts are being looked at, notably the rock breaker and the jackhammer. The second and third geophone will be placed at the level of the wall.

Of course, measurements will be made when the machines are not in operation for comparative purposes.

III. RESULTS

Given that each sensor has three measurement axes (two horizontal and one vertical), the sensor gives. As a result, the maximum speed on one of the axes of vibration emission. Vmax will be noted as the maximum vibration speed on the axeman designating the axis on which the maximum speed was detected.

The following table summarizes the results obtained.

TABLE II

SUMMARY OF RESULTS FROM GEOPHONE 1

Maximum vibration speed in road traffic, excluding machinery operation in mm/s	Machines operating on the study site around the Bab Lhad wall	
	Maximum vibration speed in mm/s	Type of machine
Between 0.5 and 1.92	0,05	Jackhammer
	0,13	Rock breaker

For the rock breeze, the maximum speed obtained by sensor 1 was between 1.4 and 2.4 mm/s. At sensor 3, the velocity did not exceed the value of 0.13 mm/s (Fig.5).

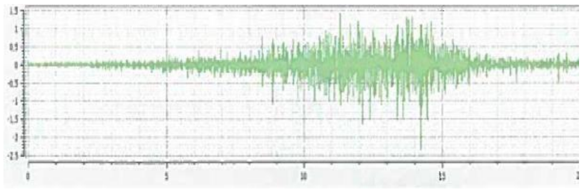

Fig 5. Example of the results obtained at sensor 1 regarding the vibratory mode of the rock breaker

In the case of the jackhammer, the maximum speed obtained by sensor 1 was between 0.73 and 2.56 mm/s. At sensor 3, the speed did not exceed the value of 0.05 mm/s (Fig. 6).

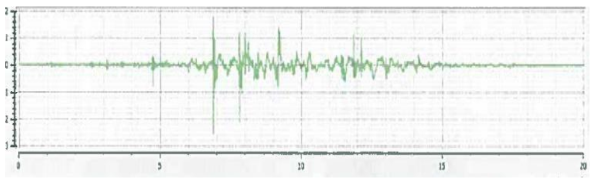

Fig 6. Example of the results obtained at sensor 1 regarding the vibration mode of the jackhammer

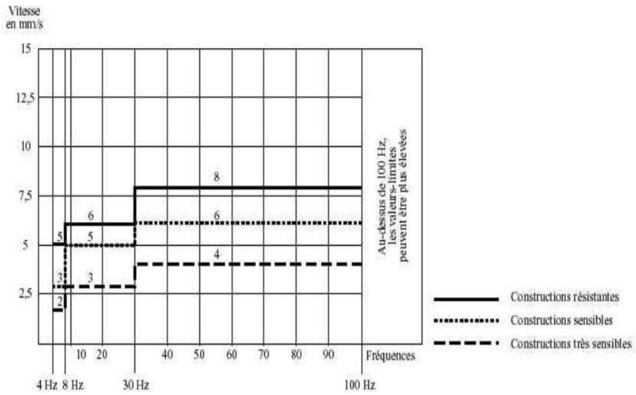

Fig 7. Limiting values of the particular velocity as a function of the observed frequency in the case of continuous or similar vibrations [4].

Since the wall is part of the very sensitive constructions according to the classification of the circular of 23/07/86 as well as article 22 of the decree of 22 September 1994, the observed values do not exceed the threshold of the frequency- velocity couples are shown in Fig. 7.

Whether it is the rock breaker or the jackhammer, their two respective maximum speeds do not exceed the maximum speed of vibrations generated by road traffic outside the operation of the machines. The measurements made on this site show that the use of machinery is not likely to disturb the base and structure of the wall of Bab Lhad built with rammed earth. The excavation works using this type of machines can take place without any limit or constraint of this type.

However, it is imperative to check the frequency of the vibrations of the machines by a geophone all along the earthwork and especially those induced by the earth-moving machines at the sandstone level.

Comforting the wall by other methods will be destructive to the aesthetics of the city's heritage. This solution of checking frequencies as the earthwork progresses is more practical and judicious with regard to the type of construction of a cultural and historical nature.

IV. DISCUSSION

The exploitation of the urban subsoil does not stop at managing the technical constraints. With the advancement of research and science, it is possible to overcome this technical limitation. Nevertheless, the search for these limits must be carried out in the preliminary phase during the study of each project before starting the work. In the case of the Bab Lhad car park in Rabat, the protection of the historical heritage has been positioned as a primary and major objective of the urban management of the capital. The idea of an underground car park in the heart of the old medina of Rabat was born following the congestion of this space after the extension of the 2nd line of the Rabat tramway.

In this case study, the operation of this site could be limited by the vibrations generated by the digging machines. However, the experiment was carried out on each machine separately. The question now is, what would be the case if there was a cumulative vibration? Indeed, when several machines are started, which is the case on the construction site, the vibration level remains the same as the one previously evaluated. The vibration frequency does not tend to double. For this last hypothesis to occur, the machines must generate the same type of vibrations at the same frequency and speed while having the vibratory waves in phase. Such a coincidence is rare or even non-existent.

The technical rules will only limit the risks of construction defects. It is necessary to think rather of introducing rules and development plans related only to the exploitation of the urban subsoil. These rules must include environmental protection during the construction phase as well as during the commissioning phase. Environmental protection is essential from the moment of excavation (e.g., management of excavation waste, its disposal, transport, and recycling where possible) to the moment of commissioning, i.e., everything related to stormwater management, air conditioning maintenance, etc.

In addition to the protection of the environment, the protection of individuals against aggression and refraction is necessary. A developed basement, whether it is an underground pedestrian passage, an underground car park, a public transport station, or even a shopping center, must be equipped with surveillance equipment, permanent lighting (especially in underground pedestrian passages), and the surveillance and human intervention of security agencies or others. Without this, the project will be subject to vandalism, homelessness, and aggression as it is not protected. This will result in a project that is bound to fall into disrepair. A waste of an important investment that will be abandoned because of a lack of surveillance.

Future regulations must include long-term designs. An example is the Bab Lhad square. This square used to be a tourist area with a few fountains (Fig.8), which were later demolished and replaced by a simple pedestrian square without fountains this time. Subsequently, in 2017, it was decided to redesign the square for the third time after the construction of this car park with 500 parking spaces. All of this redevelopment of this space was done in a period of about 10 years. Does the question then arise as to why the car park project was not designed at the time of the first redevelopment? The need for Rabat city center for the 500 parking spaces offered by this car park today is the same as it was 10 years ago. The aim is then to study the profitability of the project beforehand in relation to its lifespan and its role in urban development.

Fig.8 First redevelopment of Bab Lhad Square [22]

The exploitation of the urban subsoil should then follow a precise protocol that also takes into account the economic perceptions which follow this occupation: maintenance, success, and sustainability of the project, development, and reproduction. It would be absurd to build shopping centers in the underground of a city where the climatic conditions do not require such a costly investment compared to the construction of shopping centers on the surface.

It is, therefore, necessary to take an interest in the planning and organization of the underground space in the long term, starting by thinking about its management and distribution. Indeed, the distribution of the underground space must be tuned to the movement, dynamism, and mobility in this space. In other words, the more populated, dense, and frequented the space is, the closer it should be to the surface. Such is the example of the Carré Eden shopping center in Marrakech (Morocco), where the first level of the basement is dedicated to a large surface, then the other two to parking lots. The levels near the surface must be dedicated to theaters, cinemas, large surface and libraries, the medium depths to parking lots, warehouses, cooling rooms, etc. then the extreme depths to mines, nuclear power Plants, sensitive laboratories, and other similar activities. The goal is to plunge and hide all utility services (networks, sewers, etc.) in the urban underground to leave room for fluidity and life on the surface of the cities.

Evaluating the potential of the urban subsoil will allow not only it's planning but also its management against its waste and disorder. It is, therefore, time to consider the need for studies of urban underground development plans specific to the characteristics and technical and economic conditions of each city in the world.

V. CONCLUSION

The exploitation of the urban subsoil depends on its geological and technical potential in the first place and its socio-economic potential in the second place. The typology of this exploitation also influences the choice of the excavation site.

The construction in height, more exactly in-depth in this article, allows avoiding the birth of satellite cities and the protection of green spaces as well as agricultural environments. But also, thanks to precise planning, this approach will allow promoting the urbanism and the planning of the cities by exploiting the underground space in the burial of the inconvenient infrastructures while taking advantage of the geothermal characteristics of this space in terms of energy-saving, notably the heating and the air conditioning.

The exploitation of the urban subsoil constitutes the future of modern cities, provided that this exploitation is oriented and studied on the basis of master plans and urban planning studies.

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