

## **Preliminary geotechnical planning for the installation of a heavy and restructured collective transport system in Sfax, Tunisia**

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## Abstract

Sfax represents one of the most spread out cities in Tunisia, covering a surface area of 220 km<sup>2</sup> that englobes a half million urban dwellers. The service quality of the existing public transport system is perceived to deteriorate, registering reduced travel frequency rates ranging between 15 and 60 minutes. The actual urban transport network prevalent in the city of Sfax is marked with remarkable saturation. As a remedy to this situation, the authorities have reconsidered the need to provide a rather competitive public transport system through introducing the tram, as a new transport means. The conducted pre-feasibility studies have provided us with preliminary knowledge as to the appropriate transport corridor for paving the way for the tram line. Accordingly, and for an effective accommodation of the transmission line, the trace must meet certain imposed technical constraints. To this end, an efficient geometric study need be conducted, whereby, a convenient feasibility map for inserting the first tram into Sfax transport network could be effectively drawn. In this respect, the authorities must consider the creation of a mass transport system that breaks away with the traditional modes, such as air mode. The mission accorded to the pre-project geotechnical study team is aimed to recognize the mechanical characteristics of the soil. Seven zone is identified in the geotechnical results.

**Key words:** Urban transport; public transport; Geometric study; geotechnical; isovalue map

## Introduction

The enlargement of the city of Sfax has ensued a significant spreading of its urban surface and extension of the urbanization limits. This extension process has culminated in a remarkable extension of the transport network, accompanied with a notice able distancing of the residential dwelling zones from the employment areas. Urban sprawl is manifested in a considerable increase in daily travel and itineraries. This mobility is predominantly maintained by private means of transport, particularly the private car, which covered a rate of 60% of the entire transport system in 2009, to the detriment of public transport that covered just 20% over the same period (Bennasr, 2003). It is actually the high demand for travel, coupled with a chronic failure of the public transport system, that stand as the main reasons leading citizens to use their proper means of transport (Taxis, motorcycles and private cars) rather than the public means of transport (80% versus 20 % in 2012). Ever since the 1980s, the modal split of trips in Sfax has tended towards the generalization of the private car. The latter, which used to meet 21% of travel offers in 1986, witnessed its share increase to 35% in 1989, 38% in 1996 to reach 42% in 2003 (Daoud, 2013). Inversely, however, the service quality of the existing public transport is marked with a noticeable deterioration, registering a significant reduction in the travel-frequency intervals from 15 to 60 minutes. Traffic congestion, mainly during peak hours (morning, noon and evening), is generated mainly by the intense concentration of administrative and service activities along the highways. It is aggravated by the blatant lack of parking spaces and facilities, along with the failure met in carrying out the envisaged interchanges' schemes (Hagui and Tlili, 2014). Today the urban transport network has reached its capacity saturation limits. Simultaneously, intensified traffic has increased levels of air pollutants, particularly around the city center. Indeed, total emissions across the Greater Sfax area reached an amount of 5.2 million tonnes of CO<sub>2</sub> in 2010. The transport sector alone has contributed 54% of the total CO<sub>2</sub> emissions. The city of Sfax is continuously undergoing a non-stop sustained urban growth regarding which the public authorities often stand still. As a matter of fact, the authorities must act urgently to face the overall increase in transport and travel demand, which continues to grow even faster than the actual transport supply witnessed development (Cascetta, 2001). The extension and intensification procedures of the conventional road networks (greater vehicle capacity, higher frequency, etc.) are often opted for as solutions, but the rate of growth is such that these measures may prove inadequate. As a remedy to this situation, the authorities have decided to

set up a rather more competitive public transport. They are faced with the need to establish a strong image and a break away with the existing modes and schemes, by promoting a modal shift from the private vehicle towards a more effectively competitive public transport system (An, 2011). This introducing may to a result to increasing the congestion not to minimize the congestion. In France, heavy public transport lines meet a high demand for travel but they more broadly serve as a lever for the planning policies on the one hand at the overall level of the urban area, and on the other hand at the local level, around the stations (Calvert and Snelder, 2017). On one hand, long-term habitat localization strategies, and changes in lifestyle and mobility can change the balances and travel needs, on the other hand, they can be influenced by transport policy

## 2. Littérature review

The population growth rates in the municipalities of Sfax city between 2004 and 2014 ranged from 0.22% to 2.29%., The population in the Sfax city area in 2014 reached 515,725 (INS 2004 a, INS 2014a), and in 2019 it reached 536,952 (INS, 2021).

In the city of Sfax, car ownership per household recorded a significant growth rate of 3.91% between the year 2004, with 54,009, and the year 2014, with 61,356 (INS, 2004b, INS, 2014b), reaching 74,290 in 2019 (INS, 2021). Travel in the city of Sfax reached 92,560 in 2004 and 1,134,279 in 2009. It reached 1,719,810 in 2019, with an average annual growth rate (AAGR) of 4.25% (Figure 1).

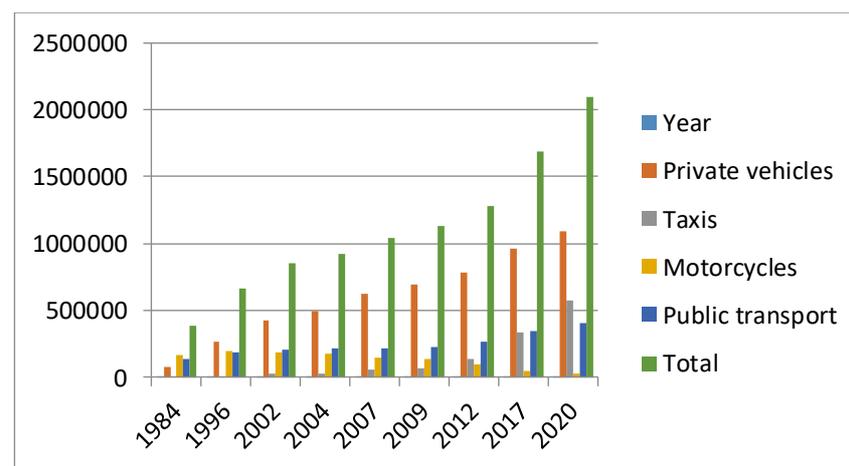


Figure 1. Travels in the city of Sfax

The authorities need a strong image that breaks with the existing modes to encourage modal shift. The public transport project in Sfax includes 2 tramway lines and 3 BRT lines for a total

of 70 km. The entire project costs nearly 2,800 million DT and would be implemented in stages from 2022 to 2030.

Let's take the example of Algiers and Rabat, which are developing new heavy modes. For the Algiers tram, eight years passed between the start of the project and its partial commissioning (Reynaud, 2008), due to difficulties with land acquisition and the diversion of road networks. This maturation period is comparable to that of tramway projects carried out in France. It includes discussions between institutional actors, between the project owner and the network administrator, and all the adjustments on technical design details for affecting the platform and the public spaces from facade to facade. In the case of Rabat, the project presentation notice clearly identifies the positive ecological impacts of the tramway system. In terms of the environment (Fouchard, 2012), it is a transport mode that produces 95% less CO (carbon monoxide), 90% less VOCs (volatile organic compounds), and about 50% less CO<sub>2</sub> (carbon dioxide) and NO<sub>x</sub> (nitrogen oxide) than private vehicles (Chakroborty and Das 2012), as well as mitigating noise pollution and providing landscaping improvements.

First of all, transport has been primarily evaluated in terms of movement. Today, it is increasingly assessed in terms of mobility with accessibility. Dedicated lane public transport systems are less polluting and less noisy than more conventional public transport modes, since they are often electric vehicles, and should furthermore promote environmental improvement (Rivoire, 2008).

In the comparison between BRT (Bus Rapid Transit) and tramway, the tramway ensures a better allocation of road space, which is well accepted by the public, and is less affected by various disruption's types (Morin, 2005): deliveries, priority and reckless traffic, parking, providing it with greater regularity, one of the key requirements for passengers.

The Nice tramway consists of a 9 km line. Initially designed to carry 40,000 passengers per day, it now carries more than 80,000 passengers per day (Millet, 2016).

The road infrastructure of Sfax is a legacy from the 1960s and 1970s, when space was dedicated to private cars (Ayedi and Hammemi, 2015). Sfax's transport network has reached its capacity limits. Its roadways are so attractive to traffic that increasing their flow is not enough to prevent congestion (Daoud, 2013).

Our study is mainly based on the design assumptions of the feasibility studies for the first tramway network installed in Sfax (Systra, 2009). In order to obtain an overall picture of

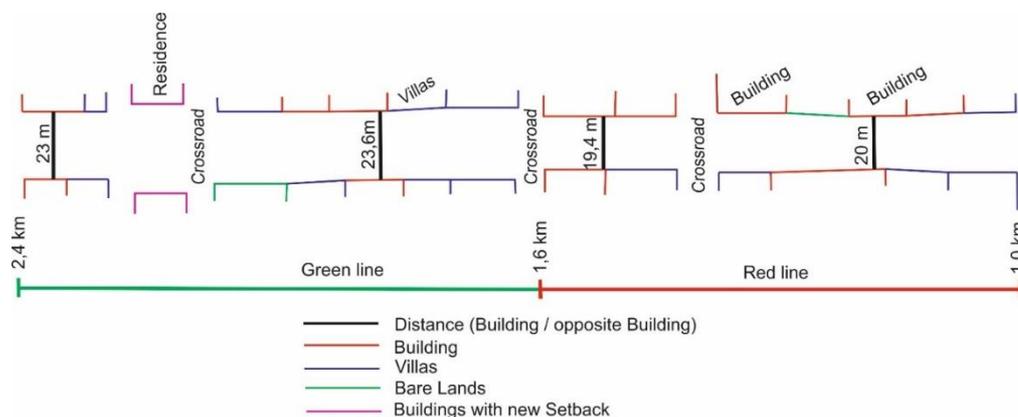
tramway practices in urban areas, various standards and references have been identified and consulted (Elleuch and Rouis, 2018). To define the geometric design parameters used, the city's usual practices regarding road and pedestrian arrangements must be taken into account (Certu, 2013).

Regarding the geometric elements composing the roadway profile, basic values have been established. These values can meet a set of safety and operational constraints and are adapted to the challenging context of the tramway project (Collet, 2009).

### 3. Feasibility study relevant to integrating the tramway into the Sfax Road Network:

#### 3.1. Characteristics of the Sfax road network

The city's road network involves mainly thirteen radial lines, six among them are regional (the Gremda, Menzel Chaker, Gabes, Tunis, Mahdia and Airport roads), and seven are local (the Sidi Mansour, El Ain, Lafran, Saltenia, Mharza, Soukra and Teniour roads) (Ayadi and Hammemi, 2015). These roads, all converging towards the city center, are laid out as 2x2 lanes up to km 11, on a entirely bi-directional carriage way. The road network also encloses six bypasses, or intersection routes, commonly dubbed 'rings' or 'ring roads' (the Martyrs Avenue, Majida Boulila Avenue, Ring road n°5, Ring road PK4 (or the Bourguiba Ring road), Ring road km 4, and Ring road km11) ensuring lateral traffic exchanges.



**Figure 2**Methodology adopted for the geometric study

May be the question that causes the greatest trouble is that of the tram platform installation, which requires deep reflection on the distribution of users across the public space (Tian et al, 2016). The layout of the transmission line, location of the relating platform and distribution of the public space different users must conveniently fit everyone's proper expectations, while respecting the applicable technical standards and accurately determining the roads' minimal

width (Figure 2). The tramline layout should be designed by accounting primarily for the road width and distribution of the existing buildings (Systra, 2009).

### 3.2. Parameter's of the city's geometric and design

The tramway insertion is conceived to rest on an exclusive implementation design through a hierarchization of the roadway (Osman and Ishak, 2017). Accordingly, the passage priority is allotted to the tramway at the level of crossings, along with the development of inter-modality scheme, whereby, the relations between (Car/Collective Transport (CT)) or (CT/TC) or (CT/Mild modes) are safe as possible (Prasetijo et al., 2017). As regards the axial insertion, it consists in installing the two traffic lanes on either side of the tramway lane, as the most favourable transit solution, thus, all interactions with right-turn vehicles are eliminated (Courtois and Dobruszkes, 2008).

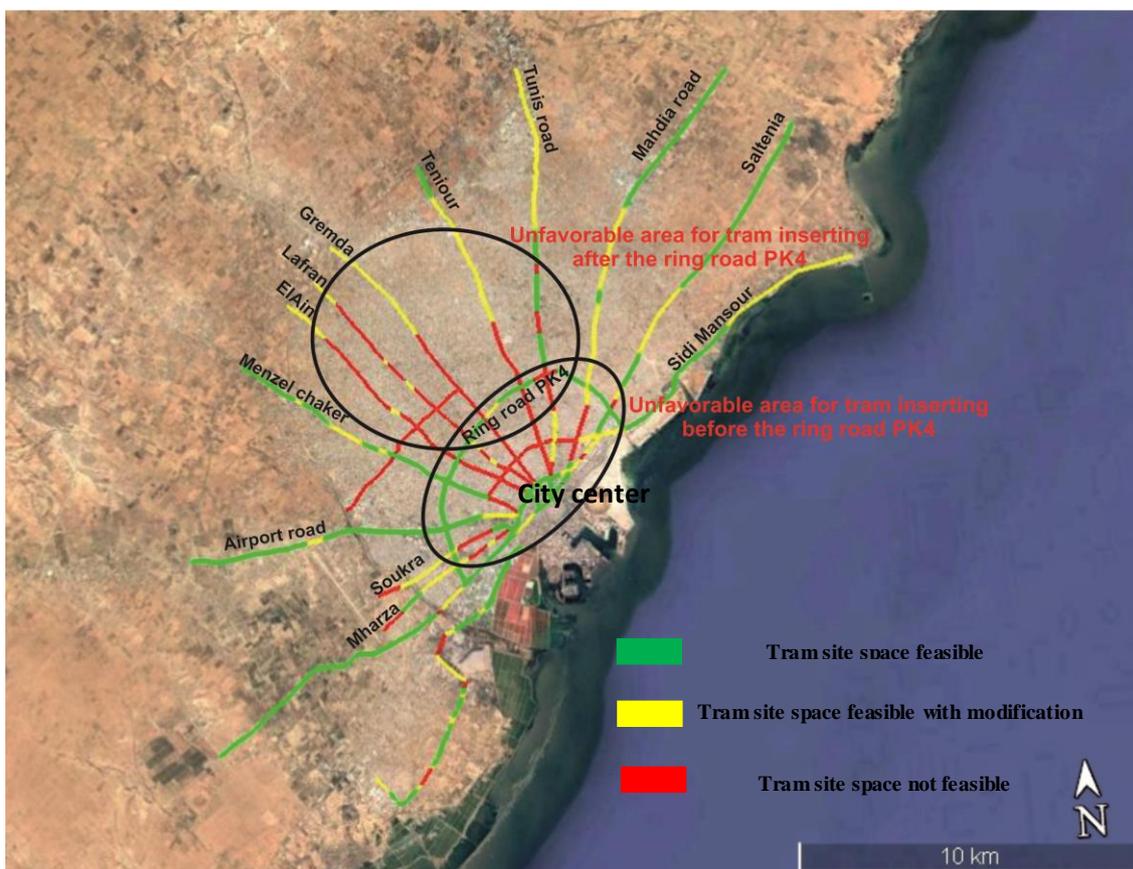
The introduction of the tram must be coupled with comprehensive road development, traffic and parking measures and regulations (Balay, 2009). Therefore, the pre-feasibility studies should allow for an easy recognition of the transport corridor, wherein, the line should fall and be traced. It is also worth considering that the tram to use is of minimum size of 2.3 m. As regards the stations, the side platforms are of a length of 35 meters, with ramps sloping to 5% at maximum, at the end of the platform, to allow access for wheelchairs and people with reduced mobility (Guerrieri, 2018). The platforms' width ranges from three to four meters, depending on the expected attendance and geometry of the site.

The tram must be liable to conversion into a special accessible crossing site. It is a vehicular space dedicated to the circulation or passage of trams, separated from the automobile lanes by a continuous 20 cm wide white strip (Systra, 2009). It is also allows access and crossing by other vehicles to bypass an obstacle on the roadway or to allow riverside access (Maurya et al., 2016).

In an urbanized environment, land constraints usually entail the construction of a narrower roadway. In this case, the traffic lanes' width turns out to be reduced to 3.25 meters per lane, to ensure a convenient crossing and safety to all modes and users (Systra, 2009). Actually, the city's radial lines constitute an important traffic artery with 2x2 lanes. They cross a heterogeneous urban fabric including individual and collective housing, along with a diversity of private and public facilities (such as schools, shops, groceries, factories etc.) (Ayadi and Hammami, 2015). The predominance of the car is remarkably strong, in this context, particularly with the availability of two unmarked parking lines. The minimum recommended

width for the vehicles' parking is 2m, while the minimum width recommended for the sidewalk is 1.5m (Specht et al, 2017).

The installation of a double-track tram on an axial site gives rise to two traffic lanes: one right-of-way traffic lane to the right of the tramway, along another left one. To this end, the road need be no less than 20 m in width. Tramway traffic in a protected site must be in the same direction of the adjacent tramway-traffic lane, for any physical separation to be avoided (block, barrier, edge, parking strip, green berm, etc.), thereby, reducing the road width (Elleuch and Rouis, 2017). At the level of intersections, the tram development criteria should include the introduction of light signaling at intersections, granting passage to the tram, whenever road crossing is simultaneously prohibited (Labbouz, 2008).



**Figure 3.** Geometric feasibility map of the tram network in Sfax

Accordingly with the figure 2 and 3, the red sections turn out to display a width separating opposed buildings that is too inferior to the recommended roadway width (<20 m) (Elleuch and Rouis, 2017). Regarding the yellow sections, they exhibit a width separating two opposite buildings exceeding the recommended roadway width (>20m). As for the green sections, they

display a width range separating opposite buildings that exceeds the recommended roadway width at the stations levels (>21m) (Elleuch and Rouis, 2017).

#### **4. Implementation of a structuring public transport system**

##### **4.1. Criteria for choosing a heavy public transportation system**

Despite the existence of a technical framework and objective technical criteria to help choose the mode, transport projects do not necessarily follow a linear process (Moumouni, 2013). Decisions can be largely influenced by the political context. A transport project indeed relies on strong political will (Appert, 2005). The service level measures the amount of scheduled service, that is, the resources implemented, notably by the network operator, to ensure the service. Service quality measures the gap between the scheduled service and the service actually provided (punctuality, adherence to timetables, cleanliness, etc.) with reference to the "Service Quality" standard EN13816.

The concept of "High-Level Service Public Transport" aims to best meet demand with regard to four main criteria, with a requirement for quality of service (An, 2011): Frequency, operating hours, commercial speed, regularity. In addition to these main criteria, comfort and accessibility for all users, including the most vulnerable, are also considered.

In the city of Sfax, a tramway installation will be implemented on a traversable, and axial site (Elleuch and Rouis, 2018). The integration of the tramway alongside existing modes of transport and pedestrians can lead to many problems. The commercial speed can be affected by surrounding traffic, resulting in congestion of the trams themselves (Cascetta, 2001). Considering a frequency of 2 to 6 minutes, the commercial speed ( $V_c$ ) should have a value of 20 km/h.

An in-depth analysis of the quality of the tramway network in the city of Sfax would allow us to assume that it is inevitably an infrastructure shared with other modes of transport. Indeed, it is in this context that the present study sought to determine the commercial speeds of public transport on the road network of Sfax (Elleuch et al, 2019).

The average commercial speed associated with the Sfax road network is of a rate of 13.8 km / h (Elleuch et al., 2019). By means of example, the Teniour, the Gremda and the El Ain roads generally display commercial speeds of less than 12 km / h during peak hours, while the Tunis and the Soukra roads turn out to exhibit commercial speeds of 13 km / h (table 1).

**Table1. Minimal commercial speed at peak hours (km /h)**

Roads	Minimal commercial speed at peak hours (km/h)
Sidi Mansour	18
Saltenia	13.23
Mahdia	13.46
Tunis road	13.74
Teniour	10.2
Gremda	11.24
Lafran	13.33
El Ain	11.73
Menzel Chaker	14.64
Airport road	12.27
Soukra	13
Mharza	12.4
Gabes	17.05
Av.MajidaBoulila	8.83
Ring Road PK4	16
Ring Road km4	23
Average	13.88

#### 4.1.1. Comparative study of the three rail modes

The choice of a transportation system is based on, on the one hand, a long-term prospective vision of the city area and its transportation network, and on the other hand, on an assessment of the opportunities and constraints of the territory (Joly, 2012). It is a key factor in territorial planning policy, urban densification, and in transport and mobility policy as a whole. An efficient transportation system must be able to meet the identified demand (service issues, expected ridership) and ensure the desired level of service (in terms of operation, quality of service, image, etc.) (Prasetijo et al, 2017). In order to confirm the choice of the most appropriate transportation system for the main public transport network of the City of Sfax, a

comparative analysis of the three rail modes is carried out: underground metro, monorail, tramway.

The cost of public transportation systems represents a significant investment for local authorities, both at the time of implementation (investment cost) and in the long term (table 2) the investment cost is between 45 to 70 \$ per km for the monorail insertion (Fattah et al, 2017). From a technical and cost perspective, the best choice for the city of Sfax could be a heavy transport system that the monorail example. Among the models, examples include: Bombardier's 'Innovia 300,' Hitachi's 'Daegu Urban,' and Siemens' 'H-Bahn.'

The monorail generally runs on elevated structures, which allows it to bypass road traffic constraints and have no interaction with other modes of transport, cyclists, or pedestrians. The stations are built as structures, usually equipped with elevators or escalators. It is a system broadly similar to the elevated metro, but it requires a smaller footprint due to the guidance system using a single central rail, typically made of concrete or steel beam (Fattah et al, 2017).

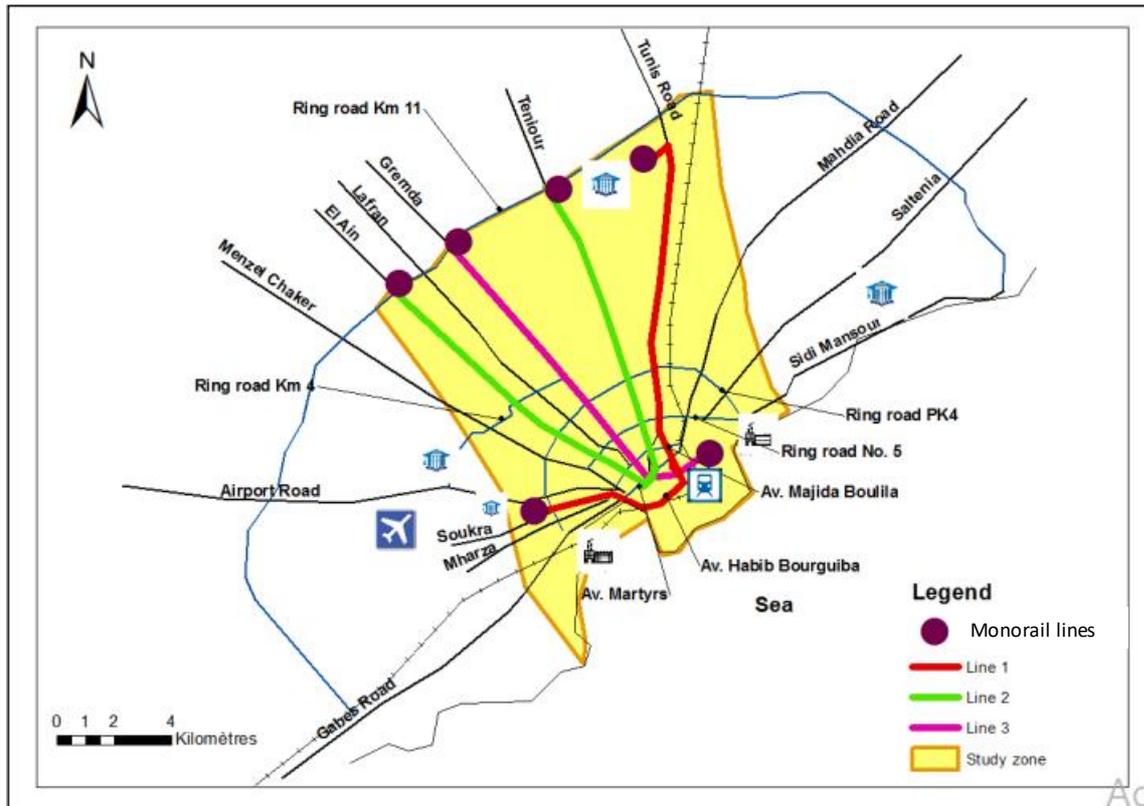
Table 2. Comparative study of the three rail modes

	Tramway	Monorail	Underground Metro
Site / Traffic	Own or shared	No interaction with traffic	No interaction with traffic
Maximum slope	7-8%	7- 8%	4 à 10%
Radius of curvature	25 m	45 m	>200m
Distance between stations	400 à 500 m	500 à 800	800 à 1000
Fréquency	3 minutes per direction	1.5 minutes per direction	1.5 minutes per direction
Capacity	Entre 2600 et 6000 passengers per hour	4000 à 30000 passengers per hour	20000 à 40000 passengers per hour

	per direction	per direction	per direction
Commercial speed	18 – 20 km/h	25 à 40km/h	25 à 50 km /h
Rolling stock (RS) cost	3 à 6 M \$ par train	3 à 4 M \$ per car	6 à 12 M \$ par train
RS lifespan	25 à 40 ans	30 à 40 ans	40 ans
Investment cost	25 à 45 M\$ par km	45 à 70 M\$ par km	100 à 200 M\$ /km
Operating and maintenance costs	10 à 15 \$/ Vehicles Km/an (veh.km/an)	6 à 16 \$ / (Vehi.km/ an)	11 à 17 \$/ Veh.km/ an

According to many structures, the metro system is consistently characterized by a fully dedicated infrastructure, such as the underground example (table 2). This infrastructure, which can be described as sealed (Tian et al., 2016), prevents any intrusion onto the tracks and is not subject to the uncertainties of road traffic, thereby allowing the system to reach very high capacities (up to 40,000 people per hour per direction) (table 2). The downside of this advantage is the high civil engineering cost. Underground sections require a number of facilities to comply with the safety standards and regulations applicable to tunnels (smoke extraction, fire evacuation, etc.).

Three lines are chosen for the public transport structured (Figure 4): Line one is (Soukra–Tunis Roads), Line two is (Teniour – El Ain roads), line three is Gremda road. Sidi Mansour and Airport road can contain a tramway lines structure.



**Figure 4 Identification of the study area**

As part of the heavy public transport line construction project, engineers specialists must take into account, at the preliminary stage of geological and geotechnical conditions in order to know and understand the different zones and the different risks during construction (Osman et al 2017). The pre-project geotechnical study mission includes the adaptation study for the heavy public transport system and the principle of foundation of the various structures (Buildings (building of maintenance, operating building, etc.), substation, engineering structures, etc.) (Prasetijo et al 2017).

#### **4.2. Geological and climati context**

In general, the region of Sfax displays a little diversified geological structure. The geological outcrops are essentially quaternary, followed by tertiary outcrops, specifically, the Miocene and Pliocene (Ben Akacha, 2001). Actually, the Mio-Pliocene reaches a total thickness of 170 m at the Sainte Juliette borehole (Amouri, 1998). The region's predominant climate is semi-arid (Bennaser, 2003).

According to the Sfax-El Maou based weather station, the rainfall average proves to be noticeably low. Indeed, the region is characterized with low annual rainfall average. For instance, this rate did not exceed the rate of 136.4 mm in the year 2012 (Missaoui et al.,

2013). In Sfax, the rain patterns exhibit the same characteristics as those displayed by the Mediterranean franche, marked with very irregular rainfalls, limited to few number of days. The city of Sfax exhibits the thermal temperature characteristics marked with a high number of sunshine hours per year, which culminated in a peak of 185.2 hours over the period (2008 - 2012) (Daoud, 2013).

Indeed, the average annual temperature keeps increasing and could exceed the average of 20° C (in the year 2012). The ratio of the hottest month (August 29.2 ° C) to the coldest mont (January 11.8 ° C) is 2.5 times.

### 4.3. Geotechnical characteristic of the study

#### 4.3.1. Pinpointing the best mechanical characteristics displaying sites

Concerning the mechanical characteristics of the soil, they were obtained by means of pressure-meter surveys.

The purpose of administering the pressure-meter test consists in determining the soil as well as the settlements bearing and endurance capacity, to choose the suitably fit type of foundation (Mestouri and Lamarat, 2014). The pressuremeter soundings would serve to determine the pressure-meter modulus and the limit pressures corresponding to the sites' resistance limit. This study is part of a geotechnical campaign executed by architectural and expert design offices. It consists in implementing 94 pressure-meter survey points at different depths (10m to 25m) (Table (a), table (b), table (c)).

Table 2 (a): Geographical coordinates of pressure-meter survey points

<b>Pressur – meter survey point</b>	<b>Latitude (Decimal degrees)</b>	<b>Longitude (Decimal degrees)</b>
El Ain km 8,5	N 34,792	E 10,684
Lafran km 8,5	N 34,797	E 10,693
Gremda km 9	N 34,805	E 10,703
El Ain km 8,5	N 34,792	E 10,684
Gremda km 6,5	N 34,787	E 10,719
Teniour km 7	N 34,8	E 10,741
Tunis km 7	N 34,805	E 10,755

Table 2 (b): Geographical coordinates of pressure-meter survey points

<b>Pressur – meter survey point</b>	<b>Latitude (degrés)</b>	<b>Longitude (degrés)</b>
Lafran km 5	N 34,774	E 10,715
Gremda km 5	N 34,777	E 10,726
Tunis km 6	N 34,799	E 10,76
Aéroport km 8	N 34,731	E 10,673
El Ain km 4,2	N 34,761	E 10,718
Lafran km 4	N 34,765	E 10,725
Bouzayen	N 34,771	E 10,745
Tenieur km 4	N 34,776	E 10,748
Tunis km 4	N 34,778	E 10,76
Mahdia km 6	N 34,787	E 10,779
El Ain km 3,5	N 34,754	E 10,726
Gremda km 3	N 34,762	E 10,74
Tenieur km 3	N 34,769	E 10,752
Tunis km 3,5	N 34,774	E 10,761
Lafran km 2	N 34,752	E 10,738
Gremda km 2	N 34,755	E 10,746
Tenieur km 2	N 34,758	E 10,755
Aéroport km 3	N 34,733	E 10,726
Menzel Chaker km 1,5	N 34,741	E 10,737
El Ain km 1,5	N 34,744	E 10,745
Lafran km 1,5	N 34,747	E 10,747
Tenieur km 1	N 34,75	E 10,758
Tunis km 1,5	N 34,752	E 10,761
Mahdia km 2	N 34,758	E 10,771
Saltenia km 4	N 34,767	E 10,785
Saltenia km 1	N 34,76	E 10,78
Sidi Mansour km 6	N 34,775	E 10,812
Mharza km 3	N 34,724	E 10,729
Soukra km 1	N 34,732	E 10,742
‘Nasria’	N 34,739	E 10,754

Table 2 (c): Geographical coordinates of pressure-meter survey points

<b>Pressur – meter survey point</b>	<b>Latitude (degrés)</b>	<b>Longitude (degrés)</b>
Sidi Mansour km 0,5	N 34,751	E 10,775
Gabès km 3	N 34,711	E 10,725
Gabès km 1,5	N 34,727	E 10,743
Gabès km 1	N 34,728	E 10,747
‘Rue Annaba’	N 34,731	E 10,749
‘Rue d'Algérie’	N 34,732	E 10,755
‘ 18 Janvier’	N 34,733	E 10,757
Building ‘Sourd’	N 34,727	E 10,751
‘CRDA’	N 34,729	E 10,758
‘Building ‘Beb Bhar’	N 34,731	E 10,76
‘La gare’	N 34,735	E 10,766
‘Marché de gros’	N 34,716	E 10,736
Gabès km 5	N 34,696	E 10,716
Gabès km 7	N 34,687	E 10,706

The pressure-meter sounding studies, carried out across the study area, turned out to demonstrate results that are predominantly inconsistent from the mechanical characteristics’ perspective (Moumouni, 2013). According to the limit pressures and the pressure modulus related isovalue maps, one could well note that there exist seven zones displaying different geotechnical characteristics (Figures 5, 6, 7, 8).

Zone 1: the soil mechanical characteristics prove to be good starting from the second meter. The limit pressures are discovered to exceed 23.5 bars, while the pressure modulus are above 200 bars. The  $E / P_l$  ratio turns out to vary between 10 and 18. The soil lithology is mainly composed of fine beige to yellowish silty sands, from 2 to 15 meters deep (Figure 5 and 7).

As for Zone 2: the soil mechanical characteristics are discovered to be good starting from the third meter until the drilling end. The limit pressures appear to exceed 23.5 bars and the pressure modulus are superior to 200 bars (Figure 5 and 7). The  $E / P_l$  ratio proves to vary



between 10 and 20. The lithology of the ground is mainly composed of a layer of silty tuffaceous sands from 3 to 7 m deep and a layer of clayey sands from 7 to 11 m deep.

Regarding Zone 3, the soil mechanical characteristics are discovered to be good starting from the fourth meter until the drilling end. The limit pressures prove to exceed 19 bars and the pressure modulus are above 200 bars. The  $E / P_l$  ratio appears to vary between 10 and 22. The soil lithology is mainly composed of a layer of sandy clay from 3 to 6 meters deep and a layer of clayey sand from 6 to 12 meters deep.

Concerning Zone 4: the soil mechanical characteristics prove to display good conditions starting from the seventh meter until the drilling end. The limit pressures turn out to exceed 19 bars, while the pressure modulus exceed 200 bars. The  $E / P_l$  ratio displays a variation between 14 and 23 (Figure 5 and 7). The lithology of the ground is mainly composed of a layer of clayey sands from 2 to 7 meters deep and a layer of compact clays from 7 to 15 meters deep.

As regards Zone 5, the soil mechanical characteristics are discovered to be good starting from the eighth meter until the drilling end. The limit pressures turn out to vary between 19 and 32 bars, with pressure modulus exceeding 200 bars. The  $E / P_l$  ratio is discovered to vary between 10 and 23. The soil lithology consists of 2 to 5 meters of sandy clay, and from 5 meters deep, reddish clayey sand.

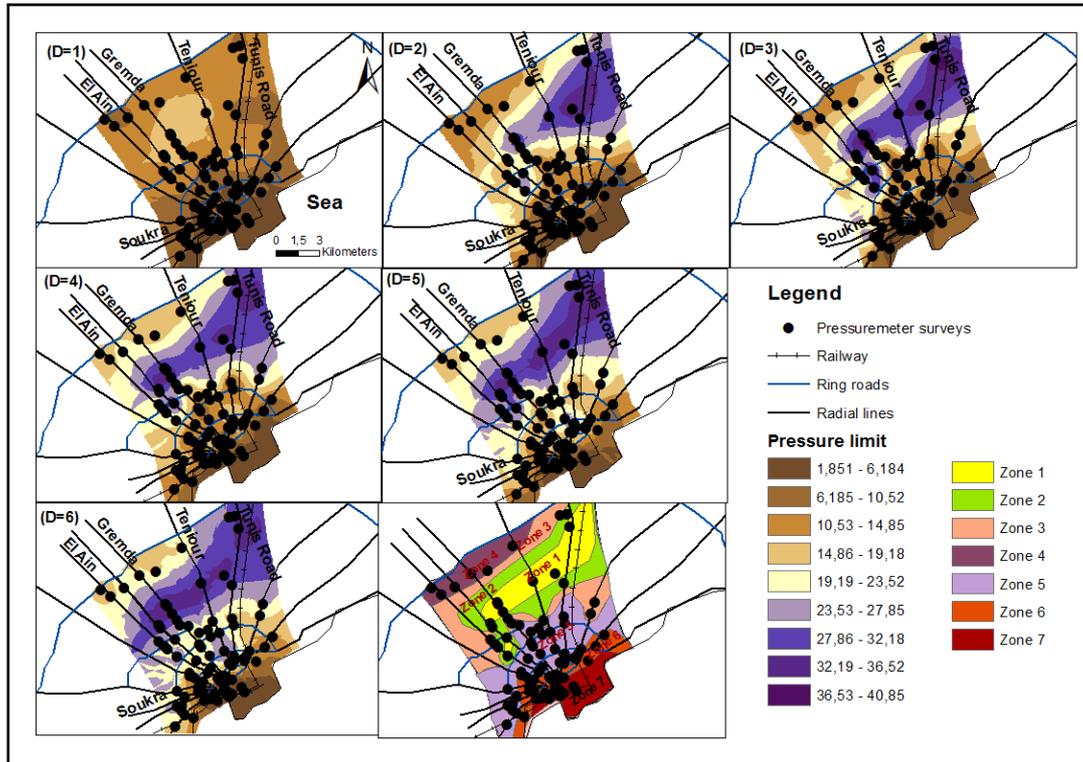


Figure 5. Pressure limits isovalue maps of embedding levels 1, 2, 3, 4, 5 and 6m

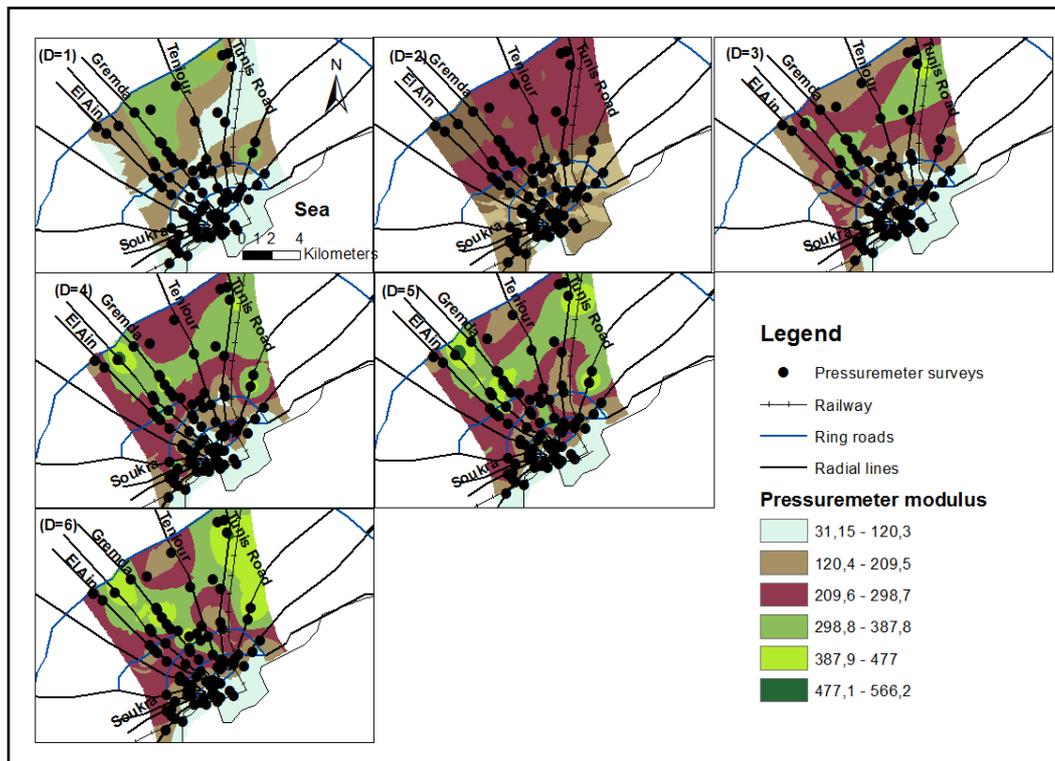


Figure 6. Pressuremeter modulus isovalue maps of embedding levels 1, 2, 3, 4, 5 and 6m

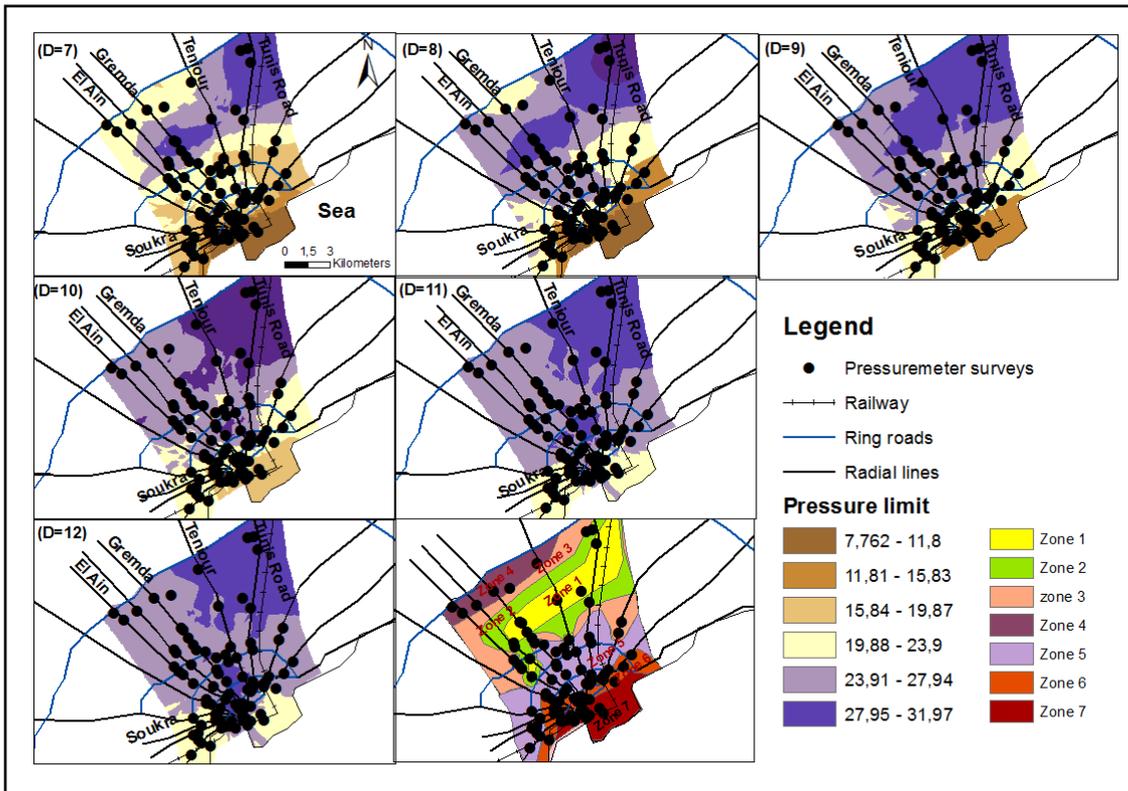


Figure 7. Pressure limits isovalue maps of embedding levels 7,8,9,10,11 and 12 m

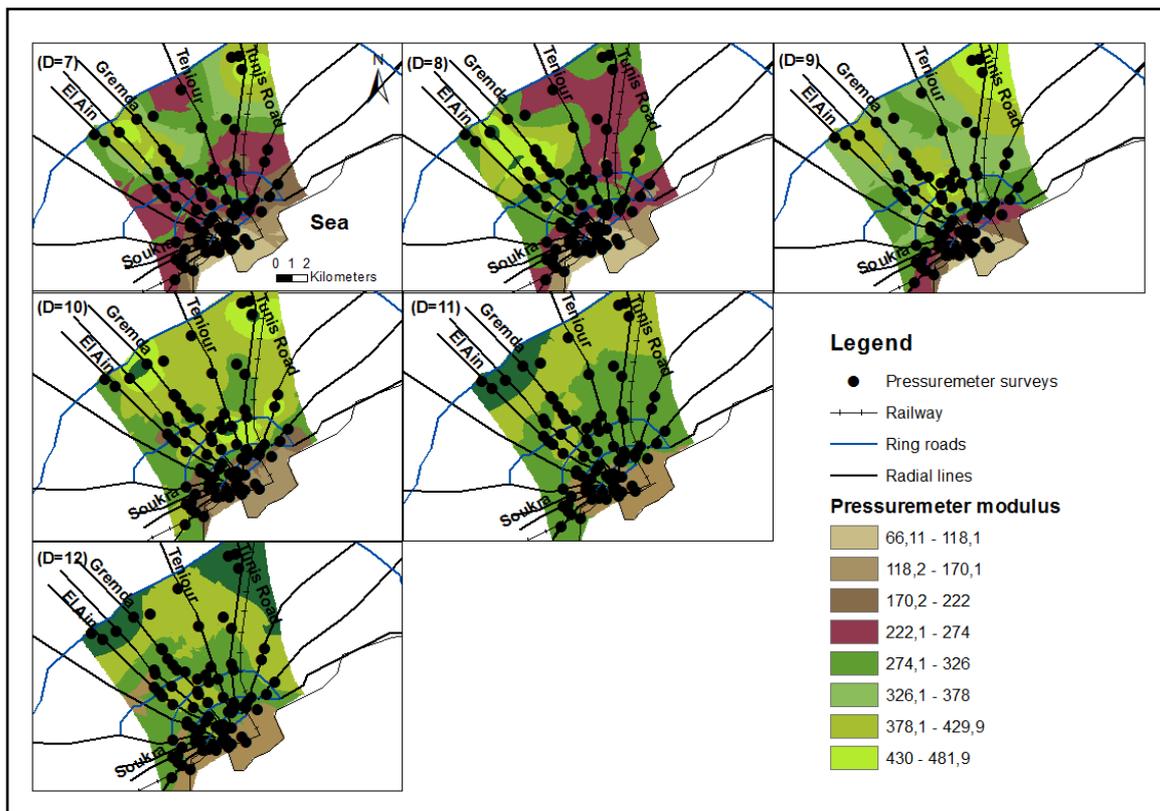


Figure 8. Pressuremeter modulus isovalue maps of embedding levels 7, 8, 9, 10, 11 and 12m

With respect to Zone 6, the soil mechanical characteristics turn out to be good starting from the ninth meter until the drilling end. The limit pressures are discovered to exceed 19 bars, with pressure modulus surpassing 220 bars. The E / Pl ratio scores a variation between 10 and 18 (Figure 5, 6, 7, and 8). At the Sidi Mansour km 0.5 level (N 34.751, E 10.775), the ground lithology is mainly composed of a layer of fine shelly tuffaceous sands, 2 to 9 m deep. At the Soukra km 1 level (N 34.732, E 10.74), the ground lithology is mainly composed of a layer of yellowish fine to medium sands, 2 to 9 m deep.

Finally, Zone 7 proves to exhibit good soil mechanical characteristics starting from the eleventh meter until the drilling end. The limit pressures turn out to exceed 19 bars, with pressure modulus being superior to 170 bars (Figure 5, 6, 7 and 8). This area constitutes the city center of Sfax. Starting from a depth of 2 meters of fine to medium shelly silty clay sand.

#### **4.3.2.A study of the soil bearing capacity based on pressure-meter experiments**

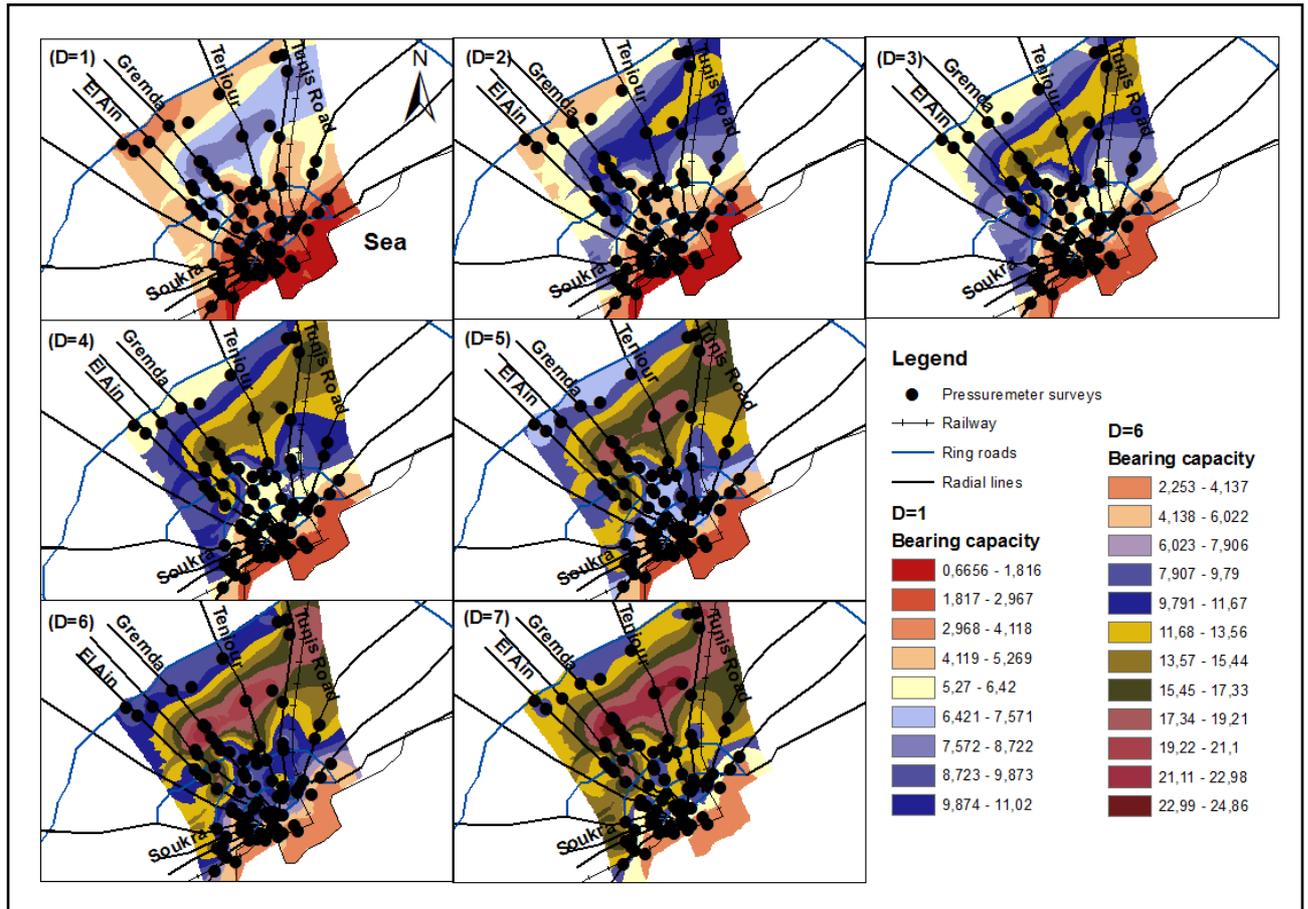
The foundation is the component of a structure that transfers the loads applied to the building (the weight of the building, normal and accidental loads) to the supporting ground.

The soil bearing capacity is directly linked per the rupture characteristic measured in the soil in place (Baud and Gambin, 2011): the pressure limit for the pressuremeter. For the pressuremeter test, Fascicule 62 (NF P94-261) defines the basic formula for the bearing capacity of shallow foundations (For  $D / B < 4$ : case of shallow foundations. With D: the base depth of the foundation relative to the natural terrain and B: the width or diameter of the foundation).

$$q_l = K_p * P_{le}^* + q_0$$

$q_l$ : Ultimate bearing capacity;  $q_0$ : Overburden pressure;  $P_{le}^*$ : Minimum equivalent limit pressure of the soil under the foundation.

$$P_{le}^* = \sqrt[7]{P'(-3R) * P'(-2R) * P'(-R) * P'(0) * P'(R) * P'(2R) * P'(3R)}$$



**Figure 9.** Bearing capacity isovalue maps of embedding levels 1, 2, 3, 4, 5, 6, 7 m for (2R=2m)

Avec: R: Foundation Half width; Pl': net limit pressure; Kp: bearing capacity factor depends on the foundation geometry, the equivalent embedment depth De and the soil type. The soil in the study area can be classified in categories I and II using the table established by L.C.P.C. This factor varies from 0.8 to 1.1 for category I soil and from 0.8 to 1.3 for category II soil.

Equivalent embedment depth De: the calculation of the pressuremeter bearing capacity factor kp requires prior evaluation of the equivalent embedment depth of the foundation calculated using the following equation:

$$De = \frac{1}{Pl^*} \int_0^D Pl^*(z) dz$$

The allowable bearing capacity is given by the following formula:  $qa = \frac{Kp \cdot Pl^*}{3} + q_0$

In the present study, the allowable bearing capacity of the soil is established according to a square isolated footings ( $2R = 2m$ ,  $2R = 2.5m$  and  $2R = 3m$ ) (Table 1), for embedding levels ( $D = 1, D = 2, D = 3, D = 4, D = 5, D = 6, D = 7$ ) where ( $D / B < 4$ ) (Figure 8).

**Table 1** Example of the allowable bearing capacity calculation results for embedding ( $D = 1$ )

Road	Kilometers (Km)	SP	D = 1m		
			Bearingcapacity (bars)		
			Square isolatedfooting (2R)		
			2R= 2 m	2R= 2,5 m	2R= 3m
Tunis Road	1,5	SP1	3,85	3,88	3,94
		SP2	3,69	3,79	3,97
		SP3	3,96	3,99	4,18

According to figure 9: computation results and the isovalue maps of bearing capacities, established in relation to the footings' dimensions and the embedding level relevant to the various pressure-meter soundings, one could well deduce the persistence of five distinguish able zones, specifically (Figure 9): Zone 1: is characterized with a bearing capacity exceeding 7 bars, it is a risk-free zone and the surface foundation proves best to adopt. Regarding Zones 2 and 3, they prove to display a bearing capacity exceeding 5 bars; they are risk-free zones and surface foundation is best fit. With respect to Zones 4 and 5, where the bearing capacity proves to exceed 4 bars starting from 2 m (marked with a non-coherent ground and good compactness), they are risk-free zones, with surface foundation being the best fit option. As to Zone 6, and for the first 4 meters of embedding, the bearing capacity of the soil turns out to vary between 2 and 4 bars (displaying a non-coherent terrain ground with medium compactness). On exceeding 4 meters, the ground bearing capacity is discovered to exceed the level of 4 bars; Zone 7: regarding the first six meters of installation, the zone appears to display a low bearing capacity ranging between 0.66 and 4 bars. Above six meters, the load-bearing capacity proves to increase (exceeding 2 bars), but the soil remains unable to sustain heavy-duty structures. Hence, deep foundation turns out to be the best installation option fit for this area.

### 4.3.3. Pressuremeter based settlement study

Taking into account the bearing capacities that prove to vary from one point to another, the settlement level was calculated with respect to the good mechanical characteristics displaying zones, namely, zone 1, zone 2, zone 3, zone 4, zone 5 and zone 6. Zone 7 was excluded because it is characterized with poor mechanical parameters necessitating the implementation of a deep foundation structure. Therefore, the computation of this area relevant settlement turns out to be useless (Menard and Rousseau, 1962).

Settlement is calculated by the following formula (Menard and Rousseau, 1962):  $S = S_c + S_d$

$S_c$  present the spherical settlement  $S_c = \left( \frac{\alpha}{4,5E_c} \right) * P * \lambda_c * R$

$S_d$  present the deviatoric settlement  $S_d = \frac{1,33}{3E_d} * p * R_0 * \left( \lambda_d * \frac{R}{R_0} \right)^\alpha$

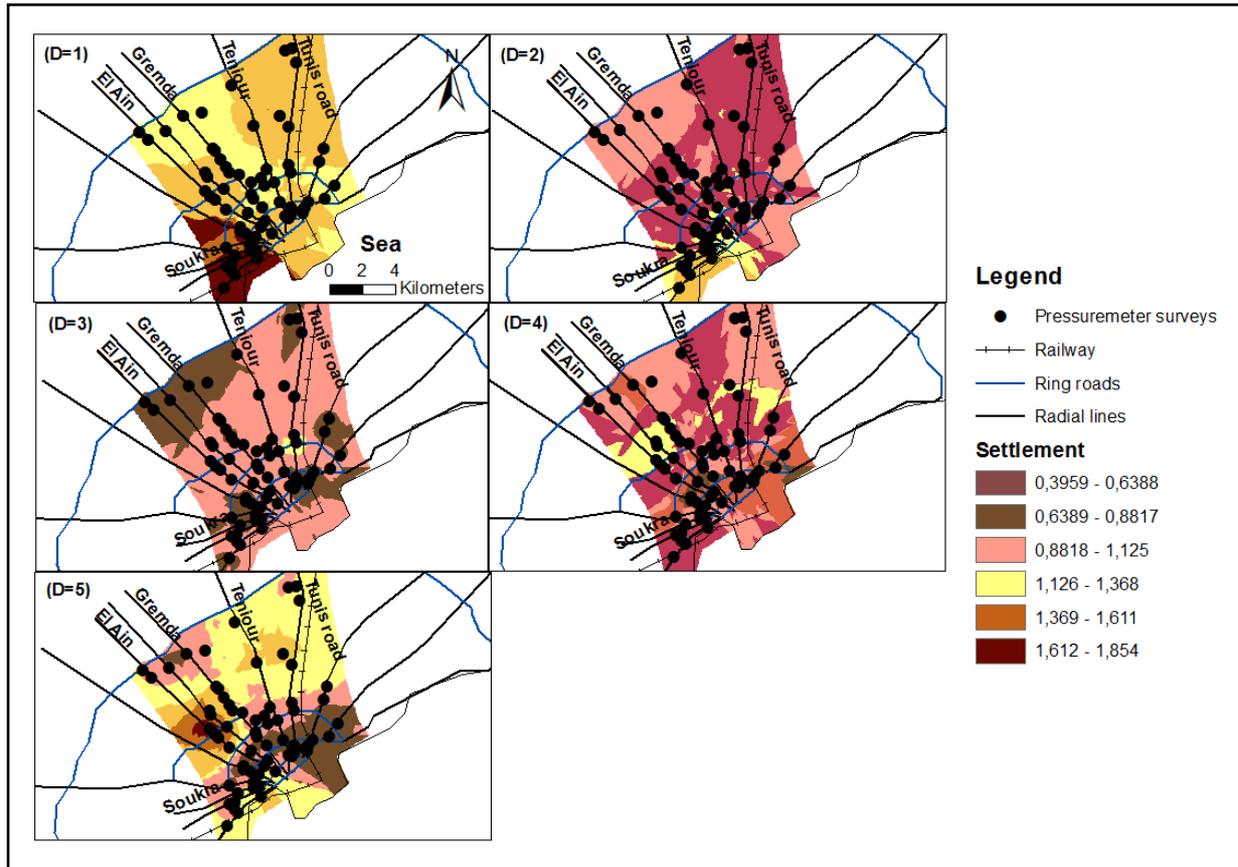
Avec:  $E_d$  et  $E_c$ : equivalent pressuremeter modulus in the spherical (volumetric deformations) and deviatoric (shear deformations) zones respectively. They are calculated as follows: Such as:  $E_c = E_1$ : pressure modulus of the soil between 0 and  $-R$  under the large concrete base ( $R =$  half-width);  $E_d$ : pressuremeter module linked to the module of the land sections located between the seat level and  $-16 R$  under the large concrete base, such as:

$$4/E_d = (1/E_1) + 1/(0,85 * E_2) + 1/E_{3/4/5} + 1/(2,5 * E_{3/4/5}) + 1/(2,5 * E_{6/7/5}) + 1/(2,5 * E_{9 \text{ to } 16})$$

Or  $3,6/E_B = (1/E_1) + 1/(0,85 * E_2) + 1/E_{3/4/5} + 1/(2,5 * E_{6/7/8})$

$P$ : foundation pressure, en bars;  $\alpha$ : structure coefficient, generally evaluated from the ratio of pressuremeter modulus to limit pressure;  $R_0 =$  reference length = 30 cm;  $\lambda_c$  et  $\lambda_d$ : shape coefficients, a function of the length and width of the foundation.

According to the figure 10, Thus, based on the reached calculation results as well as the settlements' isovalue maps, established according to a square insulated sole concerning the various pressure-meter surveys, it is worth noting that the settlement for a recess of 1 and 2 m proves to exceed 1 cm (Table 2).



**Figure 10.** Settlement isovalue maps of embedding levels 1, 2, 3, 4, 5m for (2R=2m)

**Table 2.** Example of the settlement calculation results for embedding (D = 1)

Road	Kilometers( Km)	SP	D = 1 m		
			Settlement (cm)		
			Square isolatedfootings (2R)		
			2R= 2 m	2R= 2,5 m	2R= 3m
Tunis road	1,5	SP1	1,03	1,17	1,37
		SP2	1,00	1,16	1,50
		SP3	1,16	1,30	1,55

As for the 3 m installation case, the settlement is discovered to be inferior to 1 cm. Beyond 3 m deep, one could well note that the settlement proves to be weak (Figure 9).

## **Conclusion :**

The objective of a transit system project lies mainly in meeting the ridership demand, through the setting up of an effective transport system, incorporating a fast, frequent, and comfortable road network (Munafo et al., 2012). The urban integration of the tramway system is defined according to a set of relevant criteria that need be fulfilled (Sharma, 2016), designed with the rolling-stock recommendations and communal rehabilitation planning provided technical data. Accordingly, the transport line layout and platform location (whether axial or lateral), along with the distribution of the public space different users must meet public expectations as much as possible (Labbouz, 2008), complying with the relevant technical and economic standards. The public transit does not constitute the exclusive user of public space, other users of this space must be accounted for determining the minimum roadway width requirements (Courtois and Dobruszkes, 2008). In fact, heavy transport systems, and the relevant selection criteria, need be assessed at the level of the entire city and country context they are expected to develop (Collet, 2009). In this context, and on taking the example of the least convenient lines for the installation, the underground metro could still provide rather enhanced effective services in terms of frequency, speed and regularity (Fattah et al., 2017). It is worth highlighting, that this particular mode of transport is not without high implementation costs. Indeed, its cost would amount roughly to five times higher than the light rail. On the other hand, the infrastructure of a monorail (an elevated, single-rail guided mode of transport) turns out to be less space consuming. Moreover, the nuisance brought about by the monorail installation work would certainly be milder and less intense than that associated with a tramway installation, due mainly to the relatively quick installation of the piles.

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