Early Application of Underground Funicular 'Tunnel' in Istanbul

Eren Kayaoğlu[1], Adem Candaş[1], Y.Ziya Kocabal[1], C.Erdem İmrak[1,2]
[1]ITU. Faculty of Mechanical Engineering, 34437, Istanbul, Turkey
[2]Chairman of Safety, Environment & Education Committee, AYSAD

Key Words: Istanbul, Tunnel, funicular, underground.

ABSTRACT

Tünel is a short underground funicular with two stations, connecting the quarters of Karaköy (Galata) and Beyoğlu (Pera) and located at the northern shore of the Golden Horn in Istanbul. Tünel is the second-oldest subterranean urban rail line in the world, after the London Underground. It was originally conceived by Eugène-Henri Gavand in 1867 and opened for service on January 17, 1875. In this study, Tünel and its history and working principle are expressed and the crucial components and mechanisms are explained in details.

1. INTRODUCTION

Tünel (means tunnel in English) is the shortest way between Galata and Beyoğlu (also known as Pera) where are the oldest districts of, Istanbul (Figure 1). It is the second subway of the world -after London Subway- inherited from the Ottoman Empire decree by Sultan Abdulaziz to the modern Turkey. French engineer Eugène-Henri Gavand came to Istanbul as a tourist in 1867 and released that the people are climbing the slope of Yüksekkaldırım. A railway project between Galata, the banking center, and Beyoğlu, the center of social life, might be great and profitable. After long negotiations, his project was accepted by Sultan Abdulaziz and he took the privilege of construction the first subway of İstanbul. So, Tünel was constructed by hundreds and opened with a magnificent ceremony. Now, it is one of the historic and symbolic attraction points of the city.

Figure 1. The bird eye view of the Tünel, located between Karaköy and Beyoğlu

2. HISTORY

The first railway line in the modern sense was designed between Liverpool and Manchester by the British engineer George Stephenson in 1830. Although railways are mainly used for transportation at the long distances, some ideas were developed in the cities in the form of trams. Because installation of tram railways is quite difficult especially in dens areas of the large cities, a new transportation form has emerged by installing rails to the tunnels opened under the ground and operating trains on such rails, which is called “metropolitan railways”, “metro”, or “subway”. The first subway was built in 1863, between Farrington Street and Bishop Road in London and it was 6 km long. In the first subway, the cars were pulled by a steam locomotive.

Year 1869 might be considered as a turning point in Istanbul’s public transportation. Because, in this year, concessions for three important aspects of public transportation were granted, which can be called 3 Ts, and their contracts were signed. These 3 Ts are Train, Tram and Tunnel. Their common connotation is an indication of the importance given to the modern transportation in those years. With the works started and commissioning new transportation vehicles, Istanbul’s visage has changed and such chance affected social life (Acar et al., 2013)

Eugène-Henri Gavand visited Istanbul in 1867 and observed that large number of people walked between Karaköy and Beyoğlu, which were two major centers of Istanbul. Galata (Karaköy) was an important financial and commercial center, while Beyoğlu was a lively and attractive leisure destination. When people want to get to Karaköy from Beyoğlu, or vice versa, they should have taken Yüksekkaldırım Road (Figure 2), which interconnects those places. The people walking here easily got tired because Yüksekkaldırım was too steep and neglected and it was not suitable for pedestrians and transportation.

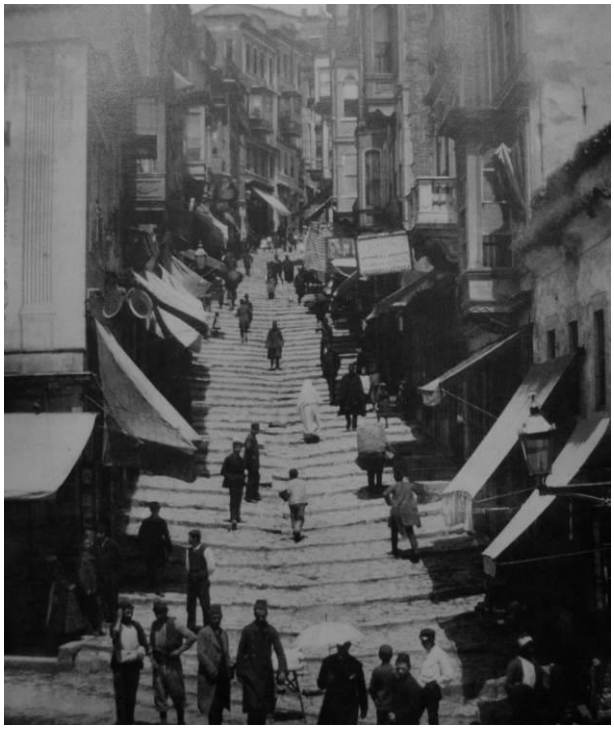

Figure 2. Yüksekkaldırım Road in 1890 (Engin, 2011)

Approximately 40,000 people were walking between these lively centers (Gavand, 1876). Yüksekkaldırım couldn't handle such traffic. First of all, a considerable inclination of 24% existed and the width of the street was only six meters. In some places, it even dropped to four meters. Walking in such conditions was quite difficult and exhaustive. Gavand thought that the construction of an underground railway, in the form of lift between Karaköy and Beyoğlu would provide people transport easily. It would be constructed to a point as close as to Galata Bridge. Beyoğlu Station would be constructed right across from Galata Dervish Hall and next to Teke Cemetery.

The project presented by Gavand was discussed in Council of State and the concession was given by decree dated June 10, 1869. Later, the contract and the specifications regarding the construction of Tünel were signed by the Minister of Public Works Davud Paşa and the concession holder Eugène-Henri Gavand on November 6, 1869. Accordingly, the matters regarding the realization of the project would be as follows (Acar et al., 2013):

- Eugène-Henri Gavand, undertakes to construct the railway, which is the subject of this contract, without any cash assistance from Ottoman Empire, assuming all losses and damages, and to comply with the terms and conditions of the contract regarding the construction and operation of the railway.
- While the concession holder is at liberty to take necessary financial measures to supply the capital required to realize this undertaking, he cannot issue share when unless company management is established and the articles of incorporation is approved by the government.
- The concession holder undertakes to complete the construction within 30 months after the contract is approved.
- The railway will consist of two lines, total width shall be 7.7 meters and the width of each railway shall be 1.44 meters.
- All required land to construct the stations at the entry and exit shall be purchased and paid by the concession holder.
- The engines that will pull the railroad cars shall be of highest quality and the concessions, presented by the government, regarding their usage and placing filters to remove the smoke.
- The concession holder shall give 1.5% of the revenue to the government. For the buildings and shops included in the railway structure, the concession holder shall pay taxes like other building owners.
- The concession period is 42 years. Ottoman Empire shall have the right and authority to purchase the railway, any time after 15 years of the approval date of the contract.
- The concession holder shall be subject to current and future Ottoman Empire laws. All disputes between the parties shall be solved by Council of State.

Tünel opening ceremony was held on January 17, 1875. Many statesmen participated in the ceremony. However, absence of Gavand immediately stood out. He was the originator of the project and he almost performed the construction alone. It was understood that he resented to be stayed out when he would reap the benefits of his efforts.

The next day, Tünel was presented to the service of the public. The average trip duration was 2.5 minutes. The fees were as follows: First class one-way ticket was 2 kurus, return ticket 3 kurus, second class one-way ticket was 1 kurus, and return

ticket 1.5 kurus. A special 20 return ticket was 50 kurus for first class and 25 kurus for second class. Children under five would not be charged, the military personnel and officials would pay half the fee. In addition, for animals and carriages, a special tariff was provided. Tünel attracted the attention of the people from the day it was opened. Within 14 days, from January 18 to January 31, transporting 75,000 passengers was an indication of public attention. The number of passengers would increase in time. 111,000 passengers in February and 127,000 passengers were transported in April. When the company reduced the ticket prices, the number of passengers reached to 225,000 in June. Meanwhile the total cost of Tünel was 4,125,554 francs.

3. SURROUNDING AND ARCHITECTURAL CHRACTERISTICS

Suriçi is a term used for the place that the early city is founded at 7th century BC. Karaköy district is near the Suriçi and these two historical areas are split by the Golden Horn. Beyoğlu side of the Tünel is the end of the İstiklal Street and also known as “Tünel Square”. Metrohan (Figure 3) is the building on Beyoğlu Station of Tünel which provides the transportation between Karaköy and Beyoğlu. It was built between Erkan-ı Harp St. and Ilk Belediye St. in Beyoğlu district. The construction plan of Tünel, Tünel route, buildings and machinery drawings have been published by Eugène-Henri Gavand in Paris in 1876. According to the Tünel project drawings, the station building on Beyoğlu side was a 4-storey building including the ground floor. On the 5th floor, forming the terrace, a small hut and a two-storey tower was located.

Figure 3. Metrohan, Beyoğlu Station of Tünel

4. WORKING PRINCIPLE AND TECHNICAL PROPERTIES

The length of Tünel is 550.80 m, width is 6.70 m and the height is 4.90 m. The length of the railway inside is 626 m. It was first built as double track railway. The profile of the railway is not flat (Figure 4). There is a light ramp at Karaköy side. The reason for this is, cars to gain sufficient speed in order to overcome the next ramp. This image serves as a parabolic railway line. There is a 10-20 mm/m slope at Karaköy side. This slope increases and reaches to 149 mm/m. It remains constant until Tünel exit for 90 meters. Then, with a slight decrease in slope, it reaches to Beyoğlu Station with 139 mm/m. The railway is 1.15 meter above sea level at Karaköy Station. The railway is 62.70 meter above sea level at Beyoğlu Station.

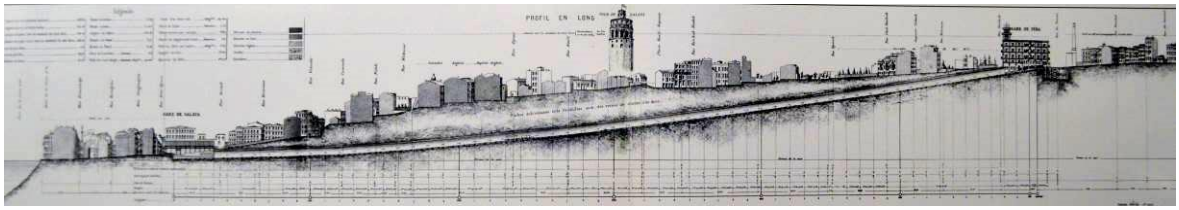

Figure 4. Tünel Project (Gavand 1876)

There were two reasons to build the railway in parabolic way. The first reason was to ensure to have a thick earth between Tünel's upper level and the houses on the ground (Figure 5). Galata Tower's location with respect to the tunnel can be seen in this figure. On the other hand the upper sectional view represents the Beyoğlu Station, the lower sectional views represent sections of the tunnel descending through sea level.

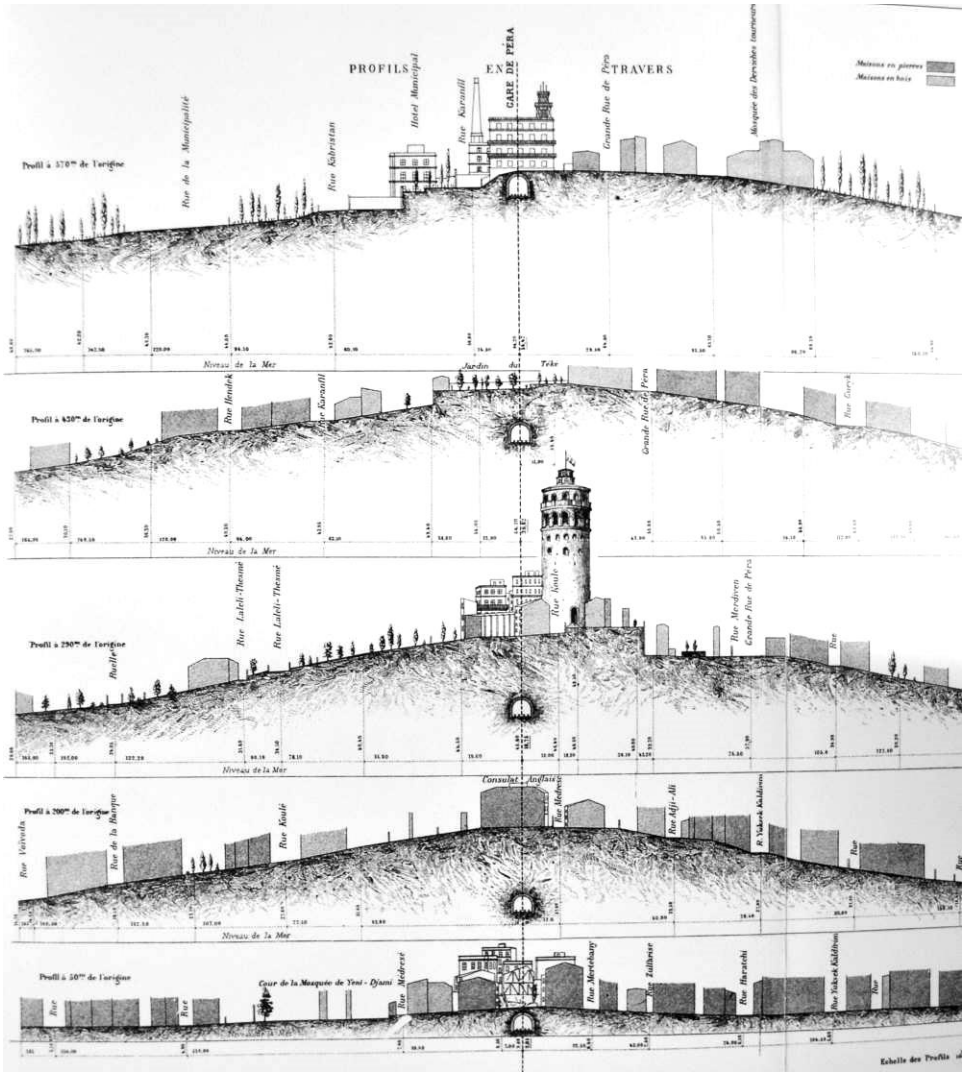

Figure 5. Longitudinal cross sectional views of Tünel (Gavand 1876)

Secondly, due to the high slope at Beyoğlu side, to ensure the cars pulled each other by the ropes, to move without requiring fully the steam power (Figure 6). Cars are hauled by a rope and driven by an engine located at one of the two terminals

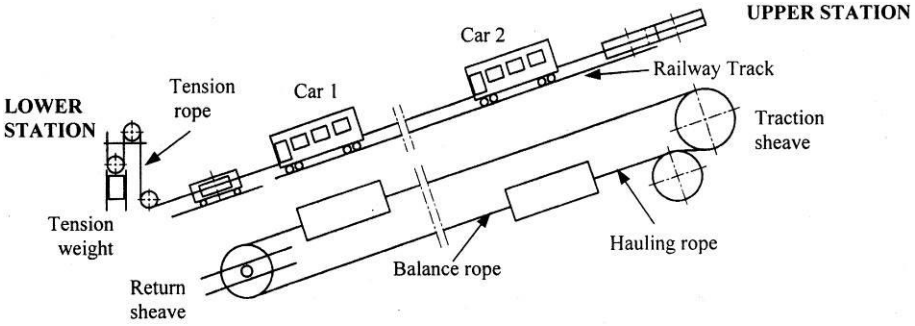

Figure 6. Overall configuration of Tünel (Imrak and Ozkırım 2002)

The cars operated on the same track, without changing lines and pulled by separate flat cables (Figure 7). Each train consists of two cars. A dual brake system was installed on each car. They are driven by a fixed steam engine until 1968, located on Beyoğlu Station.

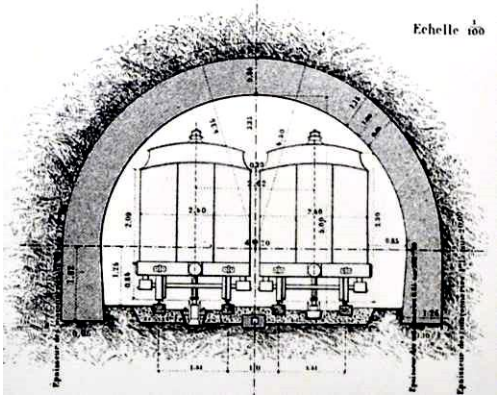

Figure 7. Sectional view of the tunnel (Gavand 1876)

The driving gear of Tünel was powered by two steam engines of 150 HP each (Figure 8). Tünel was closed in 1968 for electrification and renewal works and the new system of Tünel was reopened in 1971 (Engin 2000).

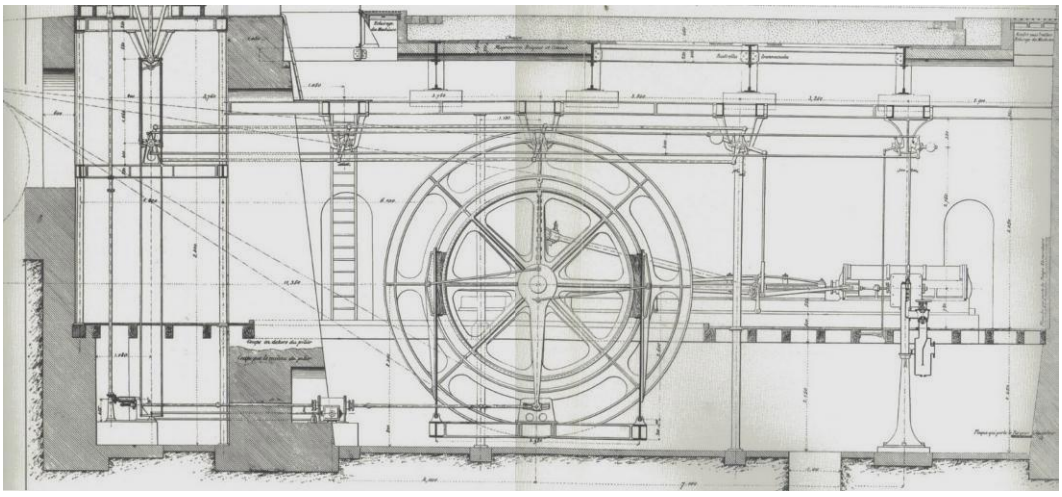

Figure 8. Traction sheave and steam engine (Gavand 1876)

5. COMPARING OF STEAM TÜNEL AND ELECTRIC TÜNEL

Nowadays the trains in the historical funicular tunnel are powered by electricity. Tünel's working principles can be examined in two period (Table 1).

Table 1. Comparing of steam Tünel and electric Tünel

The Steam Tünel (1875-1968)	The Electric Tünel (1971-2014)
Cars operate on the same track by coming and going constantly without changing lines.	Except the meeting point in the middle of the line, the rail was transformed into one line (Figure 8)
Because the passengers use the same entry and exit points, only one side doors of the cars are opened.	The passengers enter to the cars from right side in Karaköy and leave from the left side in Istiklal St. (Beyoğlu).
Each train consists of two wooden cars (Figure 9). Second class carriage trips are made on the front car, and there is a platform for carrying belongings, animals and carts in this car. Rear car is reserved only for passengers. Second class seats are made of wood, first class seats have cushions.	There are two metal cars. These cars moving in opposite direction. No class separation.
It is operated by steam engine.	It is operated by electric engine.

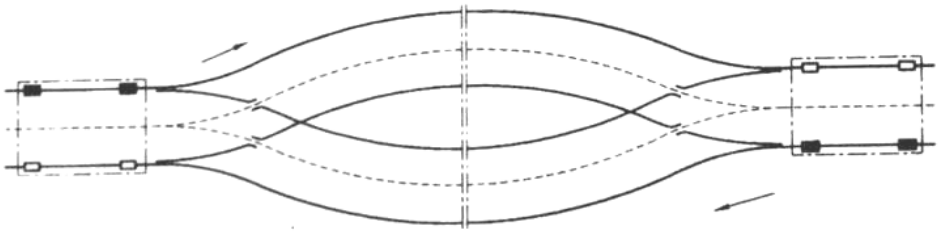

Figure 8. Operating cars on the same railway (Imrak and Ozkırım 2002)

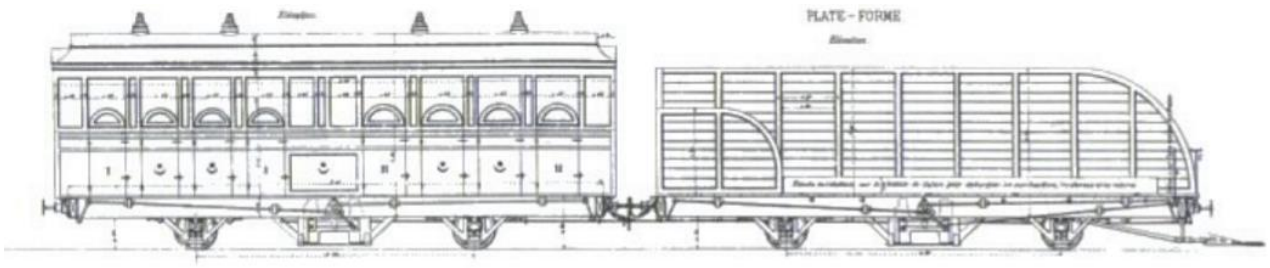

Figure 9. Rear and front cars (Gavand 1876)

In the 1950's the cars in Tünel were wooden. To comply with requirements of modern technology, it was decided to renovate Tünel in 1968. Renovated Tünel was running on rubber tires and metal cars (Figure 10).

Figure 10. Wooden car in 1950 and metal car in 2014

The modern Tünel's technical characteristics can be seen at Table 2.

Table 2. Technical Characteristics of Tünel (İmrak and Özkırım, 2002)

The length of tunnel: 574 m	Number of cars: 2
Track length: 626 m	Car weight: 22 tons (empty 34 tons (full)
Elevation between stations: 51 m	Car length: 16 m
Average track incline: 10%	Normal waiting time 3.5 mins
Maximum load per car: 170 passengers	Traveling time: 1.5 mins
Handling capacity per hour: 3,500 passengers	Maximum speed: 8.33 m/s (22 km/h)
Daily handling capacity: 15,000 passengers	Minimum operating speed: 1.5 m/s
Annual handling capacity: 1,000,000 passengers	Driving sheave diameter: 3.5 m
Main engine: 350 HP	Hauling rope diameter: 30 mm
Stand-by diesel engine: 250 HP	Tension weight: 33 tons

6. CONCLUSION

This paper briefly presents the history and technical properties of Tünel. It has been working since 1876. It was designed and constructed by Eugène-Henri Gavand decree by Sultan Abdulaziz.

Today Tünel is operating between Karaköy and Beyoğlu. After the renovation between 1968-1971 it became very modern and vibrations and noises caused by iron wheels are not experienced anymore.

Tünel is not only the world's second subway but also it is the first of the modern funiculars. It is hoped that in the near future a variety of new transport systems as an outgrowth of the funiculars will be developed and become widespread for short-range transport.

ACKNOWLEDGEMENT

Financial support for this work is gratefully acknowledged from AYSAD and Central Anatolian Exporters Union.

REFERENCES

Acar, F., Engin, V., Kargı, H. (2013). *The World's Second Subway in the Memory of Tünel's 138th Anniversary*, *Tünel Tanıtım Broşürü İETT*, İstanbul.

Engin, V. (2000). *Tünel, Simurg Publ*., İstanbul.

Engin, V. (2011). *İstanbul Tüneli, Tunnel de Constantinople, Yeditepe Publ*., İstanbul. (Gavand 1876 - In Turkish)

Gavand, E.H. (1876). *Chemin de fer Metropolitan de Constaninople au Chemin de fer Souterrain de Galata Pera dit Tunnel de Constantinople*, Paris.

Imrak, C.E., Özkırım, M. (2002). *Funicular Systems and Early Application in İstanbul, Elevator Technology 12, Proc. of ELEVCON'2002*, pp.151-160.

BIOGRAPHICAL DETAIL

Eren KAYAOĞLU has been employed as a research assistant in Istanbul Technical University (ITU) since 2007. Mr. Kayaoğlu received the BSc degree in Mechanical Engineering from Yıldız Technical University in 2004 and MSc degree in Mechanical Design from ITU in 2009. He has carried out research into PhD thesis. He is also a Member of Chamber of Mechanical Engineers in Istanbul, Turkey

Adem CANDAŞ has been employed as a research assistant in Istanbul Technical University (ITU). Mr. Candas received the BSc degree in Mechanical Engineering from ITU in 2010 and and MSc degree in Mechanical Design from ITU in 2009 carried out research into PhD thesis.

C.Erdem IMRAK has been employed as a fulltime Professor in Istanbul Technical University (ITU). Dr. Imrak received the BSc, MSc, and PhD degrees in Mechanical Engineering from ITU in 1990, 1992 and 1996 respectively. He has carried out research into materials handling and especially lift systems. Currently his activities include: a Member of the IAEE; a Member of the OIPEEC, a Member of Chamber of Mechanical Engineers in Turkey; a Member of Steering & Consulting Committee of Asansör Dunyası Magazine and a Member of International Committee of Elevatori and Rapporteur from Turkey.

Yusuf Z. Kocabal has been employed as a lecturer in Istanbul Technical University (ITU) since 1984. Mr. Kocabal received the BSc degree in Technical Education from Marmara University. He is also the chairman of the sport committee and the chief executive lecturer of technical drawing lessons in ITU Faculty of Mechanical Engineering.