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Sustainability and Functionality of Railway Network and its Connecting Facilities in Kosovo

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Abstract

The railway network presents a special communication function, which keeps humanity closer. The first developments of the railway network in Kosovo date back to 1874, when the first train entered this area from Thessaloniki through Skopje. This paper aims to provide some data generated during the year 2020 regarding the railway network in Kosovo and its connecting facilities. Construction of railway lines, stations, tunnels, bridges, watersheds, protective walls, and canals for surface water drainage has an average lifespan of 92 years. The total length of the railway network is 336.68 km, in which are built 23 tunnels with a total length of 9789.5 m. 26.1% of them are of medium depth, while 73.9% are of shallow depth from the ground surface. 66.07% of the railway lines are active, while 33.42% are non-functional.

Keywords: Railway Network; Kosovo; Stations; Sustainable Railway Infrastructure; Tunnels.

1. Introduction

To recognize and understand the development and importance of the railway network in Kosovo, it is necessary to consider its historical circumstances. It has been over 147 years since the first construction of the railway, which connected the southern part with the northern part of Kosovo, and those creating connections with two important capitals, Skopje (North Macedonia) and Thessaloniki (Greece). The greatest development of the railway network and the associated facilities in Kosovo occurred from 1926 to 1960/1963. On this railway network, there are several facilities like stations, bridges, tunnels, canals, protective walls, watersheds, etc. Stations are places where vehicles stop and depart, making a round trip to transport passengers and goods. There are main and secondary stations in the railway network. Figure 1 shows the types of stations according to the architecture of their construction. They represent a very characteristic feature in the country's architectural and cultural identity [1, 2]. Although most of them are severely damaged, the historical value of the station buildings cannot be ignored. They imprint the historical and cultural memory of a place, and people repay that prosperous era with new vitality [3, 4].

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Figure 1. Types of stations in terms of architecture

Bridges are engineering facilities for crossing roads into rivers, valleys, or large slippery areas. Each bridge consists of supports and an aerial part, which is placed between the supports where it transmits the load of the bridge itself and the moving vehicles [5, 6]. Its purpose is to connect two points at the shortest possible distance. Four types of bridges are identified on the railway lines (Figure 2). There are a total of 115 bridges with a length of 2.988m [7].



Figure 2. Types of bridges

Tunnels are underground engineering facilities that are located inside a rock massif [5]. A tunnel is a road that opens underground by piercing a mountain or a hill to pass by train or vehicle. Tunnels belong to the group of underground engineering facilities with a length much greater than their height and width. Tunnels, depending on the geological conditions of the region, may have different positions towards the geological structure. The tunnels under the railway tracks are built at an altitude of 331 to 654 m, with an average height of 501 m. The shape of tunnels that have been identified in Kosovo is a horseshoe shape (Figure 3), with a height of 6 m and a width of 2.60 m.



Figure 3. Tunnels shape

Watersheds are the places where water passes under the railway. The shape, dimensions, and building materials depend on the size of the catchment that carries water to the railway. During the research, we identified different types of watersheds in the railway network of Kosovo (Figure 4).

Protective walls are engineering structures built to prevent landslides. There are several of those engineering works on Kosovo's railways, which are built of rock material, but there are also concrete protective walls (Figure 5).



Figure.4. Watersheds shape



Figure 5. Types of protective walls

Canals are engineering facilities that aim to remove surface water that comes in the direction of the railway. They are made of concrete, with different shapes and dimensions (e.g. $L_1 = 50 \text{ cm} \times L_2 = 40 \text{ cm}, h = 30 \text{ cm}$; $L_1 = 50 \text{ cm} \times L_2 = 30 \text{ cm}, h = 30 \text{ cm}$) depending on the amount of water, respectively of the hydrological parameters of the area through, which pass the railway trail. This research identified only one form of canals, with different dimensions (Figure 6).



Figure 6. Types of channels

2. Geological Construction

The Çikatovo-Drenas tunnel is built on the Lower-Middle Triassic limestone "cT₁₋₂" represented by meta-carbonate rocks-marbles, calcareous schists. The Baica-Terdevc-Drenas tunnel is built on the rock formations of the Drin-Ivanica element, Maastrichtian floor "sKmD" represented by sandstone, siltstone, marlstone (flysch). Gexhë tunnel in the formations of the Pashtrik Cretaceous, Coniacian-Maastrichtian floor is represented by limestone, marlstone, and calcarenite with chert "Kcn-mP". Tunnels Dresnik i Ulët-Klina and Pogragja-Toplan-Klina are built in formations Ks-mG, Pagarusha Cretaceous Maastrichtian floor, Santonian-Maastrichtian floor, thin-bedded limestone with chert (Ks-mG). Tunnels Ujëmirë-Klina and Ujëmirë I-Klina are built in the rock formations of the Drin-Ivanica element Maastrichtian floor represented by flysch (sandstone, siltstone, marlstone-flysch "sKmD" [8, 9].

The tunnel of Prishtina is built in the rock formations of the central area of Vardar Coniacian-Maastrichtian floor represented by limestone, marlstone, chert, calcarenite, partly conglomerate (calcareous flysch) "IkcN-mC". Podujeva tunnel is built in the rock formations of the central area of Vardar Barremian-Aptian floor represented by sandstone, siltstone, conglomerate, partly marlstone (flysch) "Kb-ac" [10]. The Vllaq Tunnel is built in the rock formations Jurassic Magmatic Event Middle-Upper Jurassic floor represented by serpentinite. The Jellova tunnel is built on the rock formations of the Jurassic Magmatic Event Middle-Upper Jurassic floor represented by serpentinite "SJ_{2,3}". Tunnels Ballaban and Kulla (Banjska) are built on the rock formations of the Jurassic Magmatic Event Middle-Upper Jurassic floor represented by peridotite, dunite, and partlyserpentinized "σJ_{2,3}".

The Pridvorci-Zveçan tunnel is built in rock formations of the Jurassic Magmatic Event Middle-Upper Jurassic floor represented by basalt "βJ₂₋₃". The Tvergjane-Leposavic tunnel is built in rock formations of the External Vardar Zone of the Coniacian-Maastrichtian floor represented by sandstone, siltstone, conglomerate, marlstone, limestone "SKcn-mE". The Jerinje e Poshtme-Plavkovë tunnel is built in rock formations of the Cenozoic Magmatic Event Oligocene-Pliocene floor represented by "αEo-Nm" [11]. The Kaçanik i Vjetër-Stagovë tunnel is built in rock formations of the External Vardar Zone, the Coniacian-Maastrichtian floor represented by limestone, marlstone, siltstone (calcareous flysch) "fyKcn-mE". The Runjevo-Kaçanik tunnel is built in Lower Palaeozoic rock formations "cPz1" represented by marble, then in slabs represented by biotite gneiss, leptinitic gneiss "gPz1". Tunnel Gajre I is built in Paleozoic "mPz1" formations biotite muscovite schist. Tunnels Gajre II, III, IV, V are built in Paleozoic formations represented by biotite gneiss, leptinitic gneiss "gPz1" [9].

2.1. Study Area

The Republic of Kosovo is located in Southeastern part of Europe; it belongs to the countries of the Western Balkans. It extends in latitude from 41°50'58" to 43°15'42" and east longitude from 20°01'02" to 21°48'02" (Figure 7).

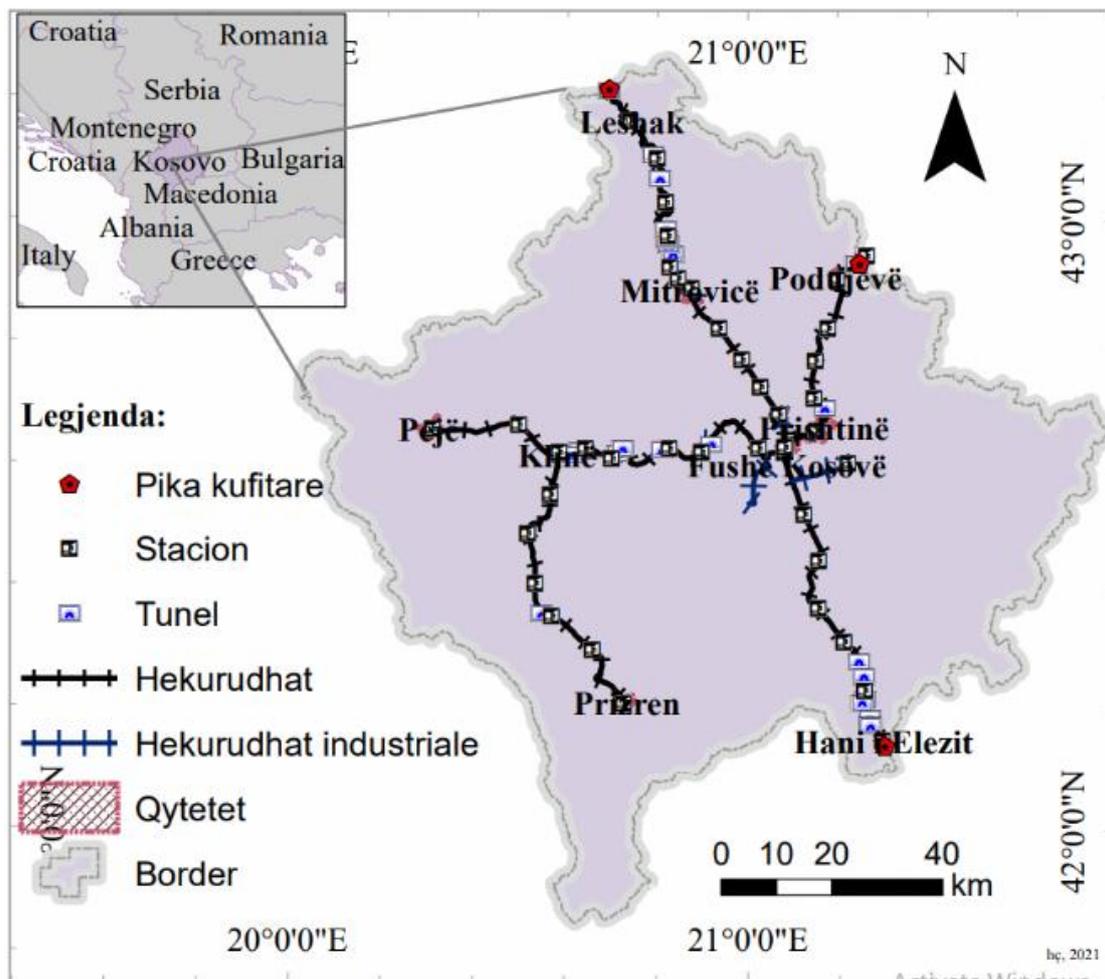


Figure 7. Map of study area

3. Research Methodology

The research methodology is based on two phases: the first phase of field research work and the second phase of office work (in figure 8 is shown in more extended form). Field research was carried out in different monthly stages during the year 2020. The following tools were used for field research: meter tape, GPS-Garmin, camera, notes from the field. The following working materials were used to achieve the goals of this paper: topographic maps of the territory of the Republic of Kosovo at a scale of 1:25000 [12], geological maps (1:100000 and 1:200000), satellite images from Google Earth, Arc Map v.10.1, Excel and field research visits. Topographic maps are georeferenced, and then the digitization of the railway network presented with line geometry is performed. Point and line geometry is used for the digitization of tunnels; polygon geometry is used for cities, while point and polygon geometry is used for stations, all in vector format.

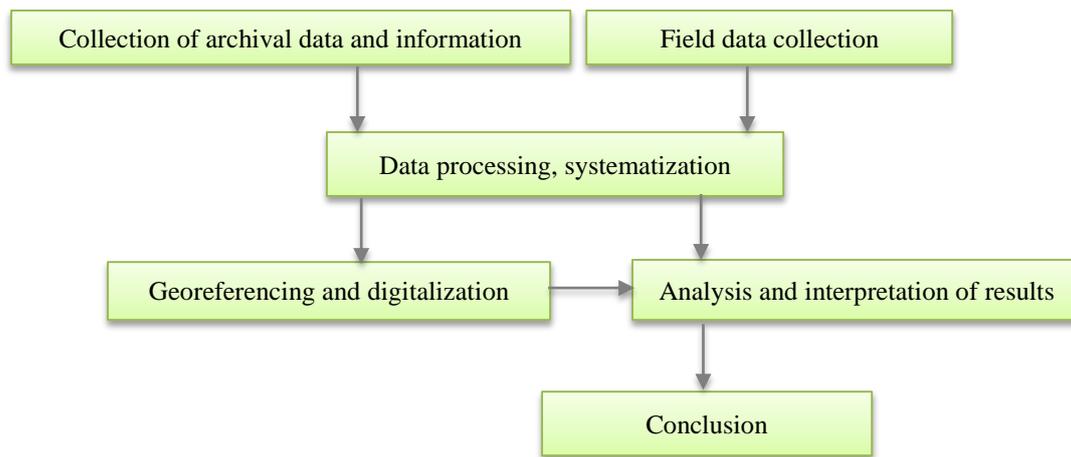


Figure 8. Flowchart of work methodology

4. Results and Discussions

The greatest development of the railway network and the associated engineering facilities in this area occurred from 1926 to 1960/1963. The data highlighted in this study (Table 1) shows that the total length of the network railway for general transport is 336.68 km, of which, functional length is 237.34 km, while 99.34 km is not functional. The longest railway line is Hani i Elezit-Fushë Kosovë-Mitrovica 98.25 km, then Klinë-Prizren 58.74 km.

Table 1. Railway lines for general transport

No.	Railway line	Length (km)	Construction date	Lifespan (years)	Current status
1	Hani i Elezit-Fushë Kosovë-Mitrovicë	98.25	xx.xx.1874	147	Good (functional)
2	Mitrovicë-Leshak	41.94	12.02.1931	90	Good (functional)
3	Leshak-Jarinje (Pllavkovë)	9.32	12.02.1931	90	Good (functional)
4	Fushë Kosovë-Prishtinë	6.65	09.07.1934	87	Good (functional)
5	Prishtinë-Podujevë (Merdar)	40.60	07.07.1948	73	Not good (non-functional)
6	Fushë Kosovë-Klinë-Pejë	81.18	12.07.1926	95	Good (functional)
7	Klinë-Prizren	58.74	xx.05.'60-'63	61	Not good (non-functional)
Overall Length		336.68	Average	91.86	

Engineering facilities, according to their longevity and importance, are divided into five categories (Table 2) [5]:

Table 2. Lifespan of construction engineering facilities

Category	Engineering Facility	Lifespan (years)	Kosovo Railway Network
Out of category	Monuments, Museums, Power Stations, etc.	Over 100	
I	Hydropower facilities, railways, central state capital buildings, large industrial buildings	Over 60	Kosovo railways and tunnels
II	Factories and plants, communal facilities, simple buildings	Over 40	
III	Light facilities, massive residential constructions, etc.	Under 40	
IV	Temporary facilities	Less than 10	

Based on the categories, lifespan, and construction engineering facility (Table 2), it results that the railway network and its accompanying facilities enter into the first category. Referring to this categorization, it is noticed that all railway segments have survived the time in terms of their sustainability and functionality. Assessed from their lifespan, respectively years of construction, it results that the railway line Hani i Elezit-Fushë Kosovë-Mitrovicë has 147 years (Table 1) since the time it was built and is still functional, although, in recent years several projects have been developed for its repair (reconstruction) (funding from European Union).

Railway lines for industrial transport - the research showed that 49.56 km of railway networks are built for industrial transport purposes in Kosovo (Table 3). The longest line (13.89 km) of the industrial railway is the one that connects the Mining and Magnesite Industry "Golesh" with the railway station Bardh i Madh. This railway line is used today by the NewCo Enterprise "Feronikeli" for the transport of nickel-iron from the mine "Gllavica" in Medveca-Lipjan, while the line from the mine "Gllavica" to the mine "Golesh" is not functional.

Table 3. Industrial railway lines

No.	Name of Railway Line	Length (m)	Percentage (%)
1	Fabrika e këpucëve	588.76	1.19
2	Fabrikapërpunimin e metaleve	597.40	1.20
3	Remontiitrenave	1943.80	3.92
4	Fabrika e sheqerit	810.02	1.63
5	Miniera e Goleshitdheminiera e Hekur Nikelit	13688.36	27.60
6	Fabrika e tekstilitKosova	1382.49	2.79
7	TrafoZhitkocv	435.91	0.88
8	FabrikaTrepça	677.66	1.37
9	FabrikaTrepça (Metalurgjia)	4518.86	9.11
10	Fabrika e PaimeveVodicë	3537.81	7.13
11	TermocentraliKosova "A"	3499.99	7.06
12	MinieraKizhnicë	12481.31	25.16
13	MinieraKizhnicë	522.22	1.05
14	Fabrika e vajit (M.Z)	424.22	0.86
15	St. Drenas-Shkriorja e Feronikelit	4491.18	9.05
Total		49599.99	100.00

The research reveals that in the entire railway network of Kosovo, there are 23 tunnels with a total length of 9789.5 m (Table 4).

Table 4. Characteristic data of tunnels

No.	Name of the tunnel /Location/	Direction	Coordinates		L _{md} Z (m)	Length (m)
			N	E		
1	Ujë Mirë-Klinë	Entrance (direction from Fushë Kosovë	42° 37' 25"	20° 42' 47"	490	200
		Exit (direction Peja)	42 37 20	20 42 47	487	
2	Ujë Mirë I-Klinë	Entrance (direction from Fushë Kosovë	42 37 46	20 43 39	508	134
		Exit (direction Peja)	42 37 48	20 43 24	504	
3	Baicë-Terdevc-Drenas	Entrance (direction from Fushë Kosovë	42 37 47	20 48 56	654	1065
		Exit (direction Peja)	42 37 30	20 48 16	649	
4	Çikatovë-Drenas	Entrance (direction from Fushë Kosovë	42 38 21	20 55 12	586	316
		Exit (direction Peja)	42 38 12	20 55 06	585	
5	Prishtinë	Entrance (direction from Fushë Kosovë	42 41 31	21 10 25	642	1593
		Exit (direction Podujevë)	42 42 09	21 09 36	626	
6	Merdar-Podujevë	Entrance (direction from Fushë Kosovë	42 55 51	21 13 50	624	1690
		Exit (direction Serbia)	42 56 09	21 14 59	621	
7	Pogragjë-Toplan-Klinë	Entrance (direction from Fushë Kosovë	42 37 38	20 38 03	510	412
		Exit (direction Peja)	42 37 33	20 37 34	438	
8	Dresnik i Ulët-Klinë	Entrance (direction from Fushë Kosovë	42 37 10	20 36 50	435	402
		Exit (direction Peja)	42 37 13	20 36 34	434	
9	Gexhë-Rahovec	Entrance (direction from Fushë Kosovë	42 21 38	20 32 38	336	715
		Exit (direction Prizren)	42 21 26	20 33 03	331	
10	Stagovë-Kaçanik	Entrance (direction from Fushë Kosovë	42 16 50	21 14 35	529	178
		Exit (direction North Macedonia)	42 16 47	21 14 33	525	
11	Runjevë-Kaçanik	Entrance (direction from Fushë Kosovë	42 15 23	21 15 12	526	205
		Exit (direction North Macedonia)	42 15 20	21 15 14	515	
12	Kaçanik I (Gajre I)	Entrance (direction from Fushë Kosovë	42 11 14	21 15 58	448	88.27
		Exit (direction North Macedonia)	42 11 12	21 15 57	444	
13	Kaçanik II (Gajre II)	Entrance (direction from Fushë Kosovë	42 13 04	21 15 24	484	100
		Exit (direction North Macedonia)	42 13 02	21 15 22	484	

14	Kačanik III (Gajre III)	Entrance (direction from Fushë Kosovë	42° 12' 50"	21° 15' 01"	490	215
		Exit (direction North Macedonia)	42 12 44	21 14 58	484	
15	Kačanik IV (Gajre IV)	Entrance (direction from Fushë Kosovë	42 10 41	21 15 52	430	338
		Exit (direction North Macedonia)	42 10 34	21 15 58	426	
16	Kačanik V (Gajre V)	Entrance (direction from Fushë Kosovë	42 10 30	21 16 03	413	114
		Exit (direction North Macedonia)	42 10 28	21 16 08	415	
17	Vllaq-Zveçan	Entrance (direction from Mitrovica)	42 56 55	20 50 04	510	227
		Exit (direction Serbia)	42 57 02	20 50 03	512	
18	Jallovë-Zveçan	Entrance (direction from Mitrovica)	42 57 48	20 49 31	510	327
		Exit (direction Serbia)	42 57 54	20 49 20	516	
19	Ballaban-Zveçan	Entrance (direction from Mitrovica)	42 58 16	20 49 08	502	200
		Exit (direction Serbia)	42 58 22	20 49 09	508	
20	Kulle (Banjska) Zveçan	Entrance (direction from Mitrovica)	42 59 14	20 49 02	517	579
		Exit (direction Serbia)	42 59 31	20 49 00	511	
21	Pridvorci-Zveçan	Entrance (direction from Mitrovica)	43 04 24	20 48 17	479	76
		Exit (direction Serbia)	43 04 24	20 48 20	476	
22	Tvergjanë-Leposaviq	Entrance (direction from Mitrovica)	43 06 41	20 47 24	475	287
		Exit (direction Serbia)	43 06 50	20 47 23	464	
23	Jerinje e Poshtme-Pllavkovë	Entrance (direction from Mitrovica)	43 12 56	20 41 28	432	350
		Exit (direction Serbia)	43° 13' 08"	20° 41' 30"	435	

The largest number of tunnels is in the railway line Fushë Kosovë-Hani i Elezit, a total of 7 tunnels with a length of 1216.5 m, and Mitrovicë-Jarinje, a total of 7 tunnels with a length of 2046 m. The third line in a row is Fushë Kosovë-Klina in which are 6 tunnels with a total length of 2529 m (Table 5). From table 5 it can be seen that although in the line Prishtina-Podujeva there are only 2 tunnels, this line dominates in terms of the length, with a total length of 3283 m or with 33.53% of the length of all tunnels in the railway network of Kosovo. The highest percentage in terms of the number of tunnels is the lines Fushë Kosovë-Hani i Elezit and Mitrovicë-Jarinje (Pllavkovë) with 20.90% (Table 5). The tunnels on the railway track are built at an altitude of 331 m (exit of the Gexhë tunnel) to 654 m (entrance to the Baica-Terdevc tunnel) with an average height of 501 m. The shortest tunnel 76m is in the locality Pridvorce, while the longest 1,690 m is in the locality Merdar, while the average length of the tunnels is 426 m (Table 1). The shape of the portals is mainly in the shape of a horseshoe, with a height of 6m and a width of 260 m at the end, 290 m in the middle. The material, which is used for the tunnel portal cladding (entrance and exit) is rock. The dimensions of the rock blocks which are used for masonry range from 35, 40 to 85 cm. They were carved in certain parts before being placed.

Table 5. Number of tunnels in the Kosovo railway network

No.	Railway line	Number of tunnels	Percentage (%)	Length (m)	Percentage (%)
1	Fushë Kosovë-Hani i Elezit (Bllacë)	7	30.43	1216.7	12.43
2	Mitrovicë-Jarinje (Pllavkovë)	7	30.43	2046	20.90
3	Fushë Kosovë-Klinë	6	26.09	2529	25.83
4	Prishtinë-Podujevë (Merdar)	2	8.70	3283	33.54
5	Klinë-Prizren	1	4.35	715	7.30
Total		23	100.00	9789.7	100.00

According to the standard GN206 [13] (Table 6), it results that the tunnels in the railway network of Kosovo are divided into two groups. In the first group belongs the tunnels with short length and in the second one those with medium length. 90.5% of tunnels in the railway network of Kosovo are of medium length.

Table 6. Division of tunnels by length

Rank according to GN206	Length	Number of tunnels by length in the Kosovo railway network	Percentage (%)
Very short	up to 50 m	0	0
Short	50-100 m	2	9.52
Medium	500-2200 m	19	90.5
Long	2200-4000 m	0	0
Very long	above 4000 m	0	0

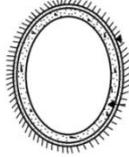
Referring to the division of tunnels according to depth from the ground surface [5], the research shows that 6 tunnels use 26.1% of them have average depth and 17 tunnels or 73.9% of them have shallow below (Table 7).

Table 7. Division of tunnels by depth

No.	Rank	Depth of railway tunnels in Kosovo from the ground surface (from the highest quota)	Percentage (%)
1	Very deep over 300 m	0	0
2	Depth 100-300 m	0	0
3	Average 50-100 m	6	26.1
4	Shallow below 50 m	17	73.9
Total		23	100

Other engineering facilities like bridges, watersheds, protective walls, and water drainage canals are also constructed of environmental material combined with sand and river gravel for the preparation of mortar as the connecting elements of masonry. Seven shapes of tunnel opening are known (Table 8) [14, 15]. The selection of the shape of the tunnel, its position, lifespan, etc., depends on the geological conditions of the region, the position of the geological structure, and the purpose of its use (transport [16], hydrotechnical [17], municipal [18], mining [19]). This research shows that the shape of the tunnel on the Kosovo railways is horseshoe shaped and partly segmental.

Table 8. Geometric shapes of tunnels

No.	Shape	Description	Tunnel shape on Kosovo Railways	Scheme
1	Polycentric	This tunnel shape has a number of centers and provides a sufficient flat base for traffic movement.	There is no	
2	Circular	Circular tunnels are used to carry water under pressure. These are not appropriate for traffic tunnels because more filling is needed to make the base flat.	There is no	
3	Rectangular	For pedestrian traffic, rectangular shapes of tunnels are appropriate. These types of tunnels are not suitable to resist external pressure due to their rectangular shape and these are not in use these days.	There is no	
4	Egg-shaped	This tunnel shape has a number of centers and radius length. These are suitable as sewer tunnels to carry sewage water.	There is no	
5	Horseshoe	Horseshoe tunnel shape is a combined shape of arches and circular tunnel. These types of tunnels shape are quite popular.	Form of the tunnel in Kosovo	
6	Elliptical	For carrying water, elliptical-shaped tunnels are appropriate. These are suitable in softer material. For better resistance to external pressure, the major axis of this tunnel is maintained vertically.	There is no	
7	Segmental	Segmental tunnels are suitable for traffic tunnels. It is a section with an arched roof and straight sides. These are generally used for subways or navigation tunnels.	Form of the tunnel in Kosovo	

5. Conclusion

The railway network presents a special communication function. In Kosovo, it has a history of over 147 years. On this railway network, there are several engineering facilities like stations, bridges, tunnels, watersheds, canals, etc. Their size and construction depend on the circumstances of the time of their construction, as well as the material used for their construction. The geological construction through which the tunnels are built is diverse and includes geological formations of different ages and floors. The total length of the railway network for general transport is 336.68 km, of which functional lengths are 237.34 km, while 99.34 km are not functional. The railway network for industrial transport has a length of 49.56 km. The lifespan of the railway network and the engineering facilities on it is over 90 years. The research revealed that in the entire railway network of Kosovo, there are 23 tunnels with a total length of 9789.5 m. 90.5% of the tunnels are medium-length tunnels. According to the results from the depth of the ground, 73.9% of them have an average depth. The tunnels on the railways in Kosovo have a horseshoe shape. Ancillary facilities like stations, bridges, canals, protective walls, watersheds, etc., are of different shapes and dimensions. From 1963 until nowadays, no new construction has been made in this network, except some projects for the repair (funding of the European Union) of a segment in the railway line Hani i Elezit-Fushë Kosovë-Mitrovica. Based on the research, it is concluded that in this railway network, intervention is required through a deeper analysis supported by technical analysis, laboratory analysis, etc., to bring to the standard state of operation the entire network and the engineering facilities attached to it.

6. Declarations

6.1. Author Contributions

Conceptualization, H.Ç. and B.J.; writing—original draft preparation, H.Ç. and B.J.; writing—review and editing, H.Ç. and B.J. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

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6.5. Institutional Review Board Statement

Not applicable.

6.6. Informed Consent Statement

Not applicable.

6.7. Declaration of Competing Interest

The authors declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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