TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO

1-B/2016

DOI: 10.4467/2353737XCT.16.055.5404

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THE PROPOSED NEW RAIL ROUTE BETWEEN KRAKÓW AND ZAKOPANE WITH THE USE OF CIVIL ENGINEERING STRUCTURES – TUNNELS

PROPOZYCJA NOWEJ TRASY KOLEJOWEJ KRAKÓW–ZAKOPANE PRZY WYKORZYSTANIU INŻYNIERSKICH OBIEKTÓW BUDOWLANYCH – TUNELI

Abstract

The existing railway from Kraków to Zakopane is characterised by complex horizontal (curves) and vertical (slopes and rises) profiles. Although the railway is attractive to tourists, it is not highly valued by carriers. This article describes a new route with profile modifications. The new route would be possible mainly due to civil engineering structures such as tunnels. It would make it possible to reduce travel time significantly and reduce energy consumption.

Keywords: electric traction, tunnels, railway route profile, energy consumption

Streszczenie

Istniejąca linia kolejowa Kraków–Zakopane charakteryzuje się złożonym profilem poziomym (łuki) i pionowym (spadki i wzniesienia). Pomimo turystycznej atrakcyjności tej linii, jej ocena przez przewoźników nie jest wysoka. W artykule przedstawiono propozycję nowej trasy o skorygowanym profilu. Nowy przebieg trasy uzyskano głównie dzięki inżynierskim obiektom budowlanym – tunelom. Nowa trasa pozwoliłaby na znaczne skrócenie czasu przejazdu i zmniejszenie zużycia energii.

Słowa kluczowe: trakcja elektryczna, tunele, profil trasy kolejowej, zużycie energii

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1. Introduction

In 1884 a local railway connecting Podgórze (today a district of Kraków) with Sucha was built. After the construction of the Chabówka–Zakopane section, the existing Kraków–Zakopane railway was completed in 1899. It is mainly a single-track railway. Electrification of the railway was completed in December 1975. The current 150 km long Kraków–Zakopane route – and the rolling stock used on it – failed to satisfy the passengers' expectations. The route goes around many hills and includes a number of sharp curves. During the construction of the railway embankments, flyovers and tunnels were avoided due to cost savings. As a result, the traction conditions of the route are poor and requires trains to slow down considerably. It is much faster to cover the distance by car, resulting in an enormous amount of traffic congestion on the road from Kraków to Zakopane, especially during summer and winter holidays, as well as during weekends. In periods of heavy traffic, travel time can be extended by as much as 400% over particular stretches of the route, compared to normal conditions. The new route using civil engineering structures (tunnels), as described in this article, could shorten the travel time of trains and reduce energy consumption [1, 2].

1.1. The Proposed New Rail Route from Kraków to Zakopane

The new rail route could significantly reduce the level of traffic on national roads No. 7 and 49 in several sections between Kraków and Zakopane, as well as replace the existing inefficient rail route. Passengers would be able to travel from the capital of Małopolskie Province to Zakopane and other towns located along the new railway much faster than what is currently possible. On weekdays, students and commuters could use a fast and comfortable means of transport instead of a tiring (at high levels of traffic) car drive.

1.2. The New Route and Its Characteristics

The new route would be a fast rail connection from Kraków to Zakopane, passing through Myślenice and Nowy Targ. This connection could be possible by constructing a new railway from Kraków to Chabówka (with the use of tunnels) and modernising the existing railway from Chabówka to Zakopane [3]. Given that the existing railway is to be modernised, then the route is already basically defined and would only need to be changed at the sections which require railway modifications (due to increases in curve radiuses).

1.3. Technical Assumptions for the New Route

Travel time from the Kraków Main Station to Zakopane – approx. 60 min:
at the B-C-D-E section – proposed route – Category M200 (Fig. 1), maximum speed: 200 km/h;
at the E-F section – from Chabówka to Zakopane – Category P120 (Fig. 1), maximum speed: 120 km/h.

The existing route at the E-F section would be modernised in order to meet the requirements of the adopted category. The reason for the speed limit is the short distance between stations. This section of the railway would be a panorama rail route, with the maximum speed of 120 km/h.

1.4. Speed Distribution

While designing the speed distribution for the new railway, the following elements [4, 5, 6] were taken into consideration:
– the maximum speed of passenger trains according to the railway type;
– the maximum speed of freight trains;
– the longitudinal profile of the railway;
– stops for passenger and freight trains.

This route would enable trains to maintain a constant speed over the longest possible sections and allow them to reach the maximum permitted speed for a given railway type across most of its length. It is recommended that the total length of sections with the maximum permitted speed would not be less than [3]:
– 85% of the total railway length for constructed railways;
– 60% of the total railway length for the P120 type modernised railways.

2. The New Route

On the basis of the guidelines [7] for the maximum altitude differences and curve radiuses for each route category, a railway plan [3] was developed.

While designing the new route, the following factors were taken into consideration: housing and industrial density and topography, which greatly influences the technology and cost of railway construction. The starting station of the proposed railway is the Kraków Main Station, and the starting point from Kraków would be the curve of the existing Kraków–Wieliczka railway. The new route was designed based on the available maps (Fig. 1). Altitudinal measurements were conducted using satellite measuring tools, and maps were made available by the Małopolska Infrastruktura Informacji Przestrzennej (Spatial Information Infrastructure of Małopolska) [3], which helped develop elevation profiles along the route.

The Kraków Main Station has been chosen as the destination station for high-speed trains. An integral part of the Kraków–Zakopane railway line project is the construction and connection of the Bieżanów 1 junction with the Kraków Main Station. For this purpose, the existing Kraków–Tarnów railway line will be used, linking with the line in the direction of Wieliczka, then turning south and continuing along a section of this route, at which point the new line bends towards the west, forming the Bieżanów 1 junction, where it ultimately leaves Kraków.

The main obstacles to the construction of the proposed line is the diverse topographical profile within the whole southern part of the Małopolska region. This region is characterised by a number of solitary mountaintops, while the valleys are densely populated and industrialised. The Raba River between Myślenice and Lubień floods in rainy conditions, limiting the use of the land, which is classified as floodplains. (Section D-E) (Fig. 1).

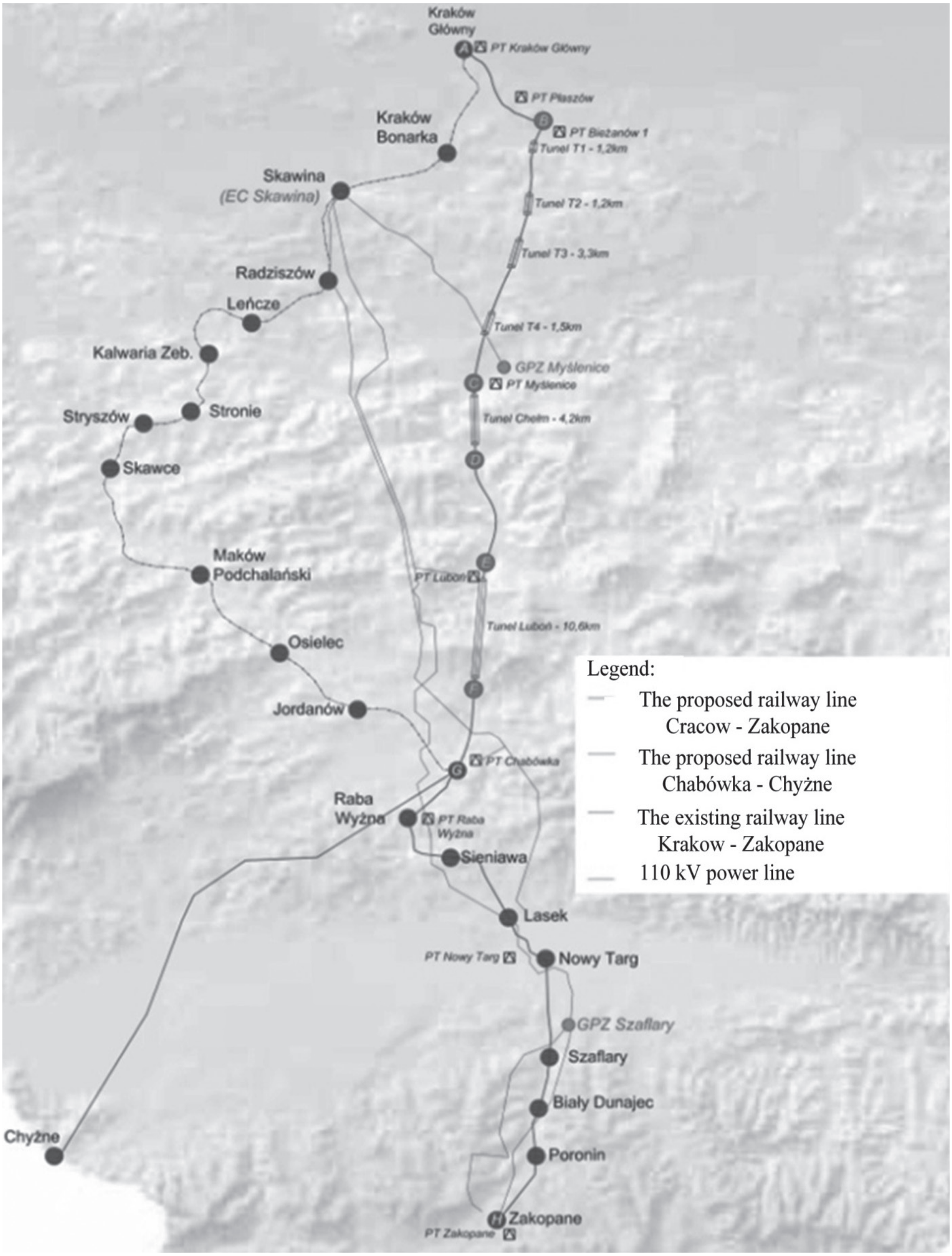

Fig. 1. Map of the new railway route

3. Technical Solutions

On the basis of the aforementioned assumptions and the existing natural obstacles, the construction of 6 new tunnels would be a prerequisite of obtaining the required parameters of the route (curve radiuses and altitudes) with a direct bearing on the maximum train speed. Another important issue would be the necessity of laying tracks on a steel sheet piled embankment, which would also serve as a flood embankment on the east bank of the Raba River along the D-E section (Fig. 2). Such a solution would fulfil the necessary parameters along the upper section and protect the inhabited areas from floods. Additionally, along the D-E section, a road would run parallel to the railway line, providing a connection with the area behind the railway line, because the numerous bridges distributed along the way will have to be removed, as they are obstacles to the newly designed railway line. Along the Chabówka–Zakopane section, due to the densely situated railway stations, the train speed would not exceed 120 km/h. Within the above section, the railway line would be partly modernised to adjust to the parameters, in particular the radiuses of curves according to the technical requirements set by Polskie Linie Kolejowe (Polish Railways) [7].

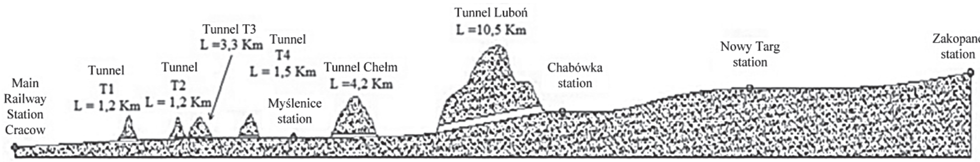

Fig. 2. New route profile

4. Type of Rolling Stock and Traction Assessment – Choice of Rolling Stock

The state-of-the-art three-unit Elf EMU [3] has been chosen for the proposed route in order to achieve much higher speeds than the current rolling stock, as well as significantly shorten travel times.

The minimum capacity of the rolling stock has been established based on the timetables of buses and coaches, which now dominate passenger transport on the Kraków–Zakopane route, and has increased by 50% due to the anticipated increase in demand for rail transport.

Buses leave the Kraków bus station approximately every 15 minutes, taking 30 passengers on average. The travel time is 2.5 h under normal traffic conditions. The train travel time of 60 minutes means that one train with a capacity of 300 passengers can replace seven buses.

5. Routes and Frequencies

It has been assumed that all trains will be operated by multiple units of identical traction characteristics.

In order to optimise transport efficiency, it has been assumed that the following basic routes will be serviced with high frequency:

a) Kraków–Zakopane – all day every 60 minutes alternately with trains (Kraków–Myślenice–Nowy Targ–Zakopane)
b) Zakopane–Kraków – all day every 60 minutes alternately with trains (Zakopane–Nowy Targ–Myślenice–Kraków).

The travel time on the Kraków–Zakopane route has been determined based on the theoretical drives for the assumed timetable speeds, allowing for the following technical provisions (Table 1).

Table 1

Selected travel times for basic routes according to variants

Routes		Current time	Projected time	Train type
Kraków	Zakopane	4:12	0:57	regular
Kraków	Zakopane	3:57	0:50	express

6. Traction Assessment

In order to determine the loading conditions acting on the newly designed railway line, theoretical drives were performed, from which the following parameters were obtained: total energy consumption, specific energy consumption, and results such as the technical speed and total travel time obtained over the course of the assessment of the analysed route for particular types of trainsets.

It was assumed that the drive will be performed twice along the analysed section.

a) the first drive was performed for a three-unit EMU, based on a timetable,
b) the second – return – drive was performed for the same unit,
c) the third drive was performed for a three-unit EMU without stops,
d) the fourth – return – drive was performed for the same unit.

The weight of each unit was increased by the weight of seated passengers, each weighing 80 kg (Table 2).

Table 2

Results of theoretical drive calculations

3-unit ELF EMU Kraków–Myślenice–Chabówka–Zakopane	3-unit ELF EMU Zakopane–Chabówka–Myślenice–Kraków	3-unit ELF EMU express train Kraków–Zakopane	3-unit ELF EMU express train Zakopane–Kraków
$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km
$T = \Sigma\Delta t = 70$ min	$T = \Sigma\Delta t = 66$ min	$T = \Sigma\Delta t = 57$ min	$T = \Sigma\Delta t = 50$ min
$A = U \cdot \Sigma I\Delta t = 1154$ kWh	$A = U \cdot \Sigma I\Delta t = 414$ kWh	$A = U \cdot \Sigma I\Delta t = 1179$ kWh	$A = U \cdot \Sigma I\Delta t = 630$ kWh
$j = \frac{A}{m \cdot s} = 88.53 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 31.75 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 90 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 48 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$
$V_t = \frac{S}{T} = 85.3 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 90.45 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 104.6 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 119.4 \frac{\text{km}}{\text{h}}$

Where: S – distance [km], T – total travel time [min], A – total energy consunption [kWh], j – specific energy consumption $\left[\frac{\text{Wh}}{\text{brtkm}}\right]$, V_t – average speed [km/h].

7. Summary and conclusions

The preliminary analysis suggests that a new Kraków–Zakopane railway connection could be built, which, thanks to modern civil engineering structures such as tunnels, would allow much higher speeds. The article discusses the passenger variant. It was assumed that the line would be operated by three-unit PESA Bydgoszcz ELFs (WE21), for which the results have been presented in this paper.

High-speed railways are characterised by different technical parameters from those of the existing rails and result in specific track requirements, particularly curve radius, longitudinal tilt, and intertrack space.

For these reasons, the costs of construction exceed the corresponding costs of modernisation to the existing railways. On the other hand, the investment would significantly reduce travel times.

The calculation results of theoretical drives for the new railway suggest that the travel time from Kraków to Zakopane would be 57 minutes, with a return journey of only 50 minutes. The difference is attributable to differences in elevation between Kraków and Zakopane, which is about 600 m. The Zakopane-Kraków trains travel downward, encountering less resistance, thereby achieving a maximum speed with reduced energy consumption (Table 2).

By comparison, train travel time from Kraków to Zakopane now is much longer than three hours (Table 1).

This short travel time along this route is possible only if tunnels are constructed. Because of tunnels, the problem of the curve radiuses and steep slopes, which significantly affect train movement, would be eliminated.

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