

Improvement of Characteristics of the Railway Direction Kharkiv-Dnipro with the Purpose of Introducing the high-speed Passenger Traffic

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Abstract. The high efficiency of high-speed rail transport contributes to its development both in the service sectors and in the construction of devices for servicing high-speed trains, in particular, track development. At the same time, it is necessary to take into account the obvious problems that accompany the process of reconstruction of railways during the transition to high-speed passenger traffic. Among them, the presence of small radii of circular curves, an insufficient length of straight inserts and transition curves should be noted. In this paper, it is proposed to consider small-radius curves located close to each other as one common module when reconstructing railways with the aim of introducing high-speed passenger traffic. The implementation of this approach will allow solving one of the main problems - straightening of the railway section. This will increase the speed of passenger trains and reduce travel time by reducing the length of the route. The article deals with the task of reconstruction of modules consisting of three adjacent curves, which occur when improving the characteristics of the plan of the Kharkiv-Dnipro railway direction.

1 Introduction

In [1] it is noted that the activity of the railway transport, as part of the Ukrainian unified transport system, contributes to the normal functioning of all sectors of the economy and the strengthening of the defense capabilities of the country, which are important factors in joining the European Union. Modern tendencies in the market of transport services for passenger transportation lead to a reduction of the role of railways and an increase in the importance of road and air transport. Therefore, certain measures should be taken in order to increase the attractiveness of rail passenger traffic by introducing high-speed highways. It is these measures that enable the railway industry to maintain and effectively use existing technical capacity for structural changes in technology and to maintain competitive advantages over other modes of transport.

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At the same time, the transition to high-speed passenger traffic is associated with a number of problems, the main of which is the task of rebuilding the railway plan, and in the first place, increasing the radii of circular curves to 1200 and more meters, the extension of straight inserts and transitional curves. Domestic and foreign science of the railway industry paid enough attention to these issues, but now life is putting forward new and more stringent requirements.

2 Formulation of the problem

According to [2], the practice of designing and reconstructing a railway plan shows that rearrangements are for the most part single-curved small radius, while complex divisions consisting of two, three, and four adjacent curves remain in the same form as they do not exist. rather vivid and accessible methods of their reconstruction.

However, under very difficult plan conditions, the reconstruction of blocks containing three or more curves becomes complicated and extremely expensive, especially since the reconstruction works are carried out on the operating line and it becomes expedient to consider variants of radical straightening of the route at a sufficiently long distance, which allows to improve not only the parameters of the plan, but also the operational parameters of the site by reducing its length.

3 Recent research and publications analysis

Historically, a number of calculation methods have been developed when solving problems of reconstruction of a plan. The most perfect one is method of normal lines [1], which has found only a limited application by virtue of known difficulties. Approximate evolvent methods have been widespread.

With the introduction of computer technology the most widespread methods were obtained using rectangular coordinates, free from imperfections of evolvent methods. There are two classes of tasks for the reconstruction of the plan: bringing the plan to the correct geometric outline; reconstruction of the plan in order to improve its characteristics (increasing the radius of circular curves, increasing the lengths of transition curves, increasing the lengths of direct inserts between adjacent curves). The tasks for the reconstruction of the plan are considered in the work [3]. In total six types of tasks have been analyzed. The main disadvantage of this method is the complexity; in addition, the application of the method of angular diagrams deliberately brings a certain error to the result. Also, the disadvantages include the fact that only two adjacent curves have been considered, while in practice, often there are problems of reconstruction of a section containing more than two curves. It should also be noted that these objectives did not directly aim at increasing the radii of circular curves, which became relevant nowadays when the introduction of high-speed passenger trains became an urgent task. In the work [4] the nine design tasks, as well as the task of calculating landslides and project interchanges have been described. Relatively simple cases have been considered. These tasks are focused on the use of computers. Here the problem of increasing the radius of circular curves is not set. The reconstruction problem in relation to two adjacent curves is considered. Improving the characteristics of the plan requires consideration of tasks that include the reconstruction of complex plan districts, which consist of not only two, but also three or more adjacent curves. Therefore, there is a need to develop new methods of reconstruction of the existing position of the complex plan.

4 The selection of unresolved parts of the general problem

As shown by the analysis of some of the executed reconstruction projects, as a rule, designers are limited to the restructuring of single circular curves, rarely considering two, and almost do not touch cases with three or more adjacent curves.

5 The purpose of the article

The purpose of the article is to reconstruct modules consisting of three adjacent curves that take place while improving the characteristics of Kharkiv-Dnipro railway plan, which, according to the work, provides for the introduction of high-speed passenger traffic.

6 Statement of the main research material

The main disadvantages of the technical equipment of this section, which do not allow to increase the speed of passenger trains up to 160 km/h, are: curves of small radius, the presence of turnouts in curves, worn top structure of the track, emergency condition of a number of artificial structures, narrow interlayers and platforms on separate points, "sick" earthworks, large number of crossings, insufficient technical equipment of a number of stations. After eliminating the disadvantages in this direction, it is possible to significantly increase the speed of passenger trains (up to 160 km/h), and reduce the time of travel. The determination of the cost of reconstruction and construction of a new recaptured section at the comparative stage should be carried out on the following indicators: earthworks, upper structure of the track, electrification and man-made structures. Table 1 shows the cost indicators of the main components during the reconstruction of the site and the construction of a new track.

Table 1. The components of construction cost in the reconstruction and construction of a new site.

The components of the construction cost	Reconstruction of the site	The construction of a new site
Earth works	$L_r q'_a \gamma$	$L_b q''_a$
Upper structure of the track	$L_r a_{us}$	$L_{us} a_t$
Electrification	$L_r a_e$	$L_b a_e$
Artificial structures	$L_r q'_a \delta$	$L_b q''_a \delta$

The table shows the unit values, which depend on the length of the section – a_{us} , a_e , δ , and also γ – is the coefficient, which takes into account the increase in the cost of construction works on the reconstruction of the route with the continuous movement of trains. The presented expenses for the construction of a new decoiled area will amount to thousands UAH.

$$E_b = L_b a_b + L_b (\alpha N e + k) \frac{1}{E}, \quad (1)$$

L_σ – length of the ordered section, km;

a_σ – cost of construction of one kilometer of the decoiled site, thousand UAH/km;

α – coefficient taking into account the uniform distribution of the traffic flow by directions;

N – the number of trains in the freight direction, thousand trains per year;

e – cost of one train-km, thousand UAH;

k – the cost of maintaining permanent devices, thousand UAH/km per year;

E – discount rate.

At the same time, at a known fraction of the length of the section to be reconstructed under high-speed traffic, the costs of reconstruction of the line, (thousand UAH), from the total length of the existing route (λ) are given as follows

$$E_r = \lambda L_e a_r + L_e (\alpha N e + k) \frac{1}{E}, \quad (2)$$

L_e – length of the existing area, km;

a_r – cost of reconstruction of one kilometer, thousand UAH/km;

It is advisable to direct the route, provided that $E_r > E_b$ when the specific length of the reconstruction sites is equal to

$$\lambda \geq \frac{L_b a_b + c \Delta L}{L_e a_r}, \quad (3)$$

c – operating costs per kilometer, thousand UAH/km;

ΔL – shortening the length of the existing area when the route is adjusted, km.

From formula (3) it is obvious that λ depends, first of all, on the lengths of the existing and new stations.

The key factor when introducing high-speed passenger traffic is the duration of the trip. When aligning the route, the gain in time (Δt) may be more significant than while reconstructing the line plan.

The gain in time can be found using the following formula, min.

$$\Delta t = 60 \cdot \left(\frac{L_e}{V_e} - \frac{L_e - \Delta L}{V_b} \right), \quad (4)$$

V_e, V_b – respectively the speed at the existing and the decoiled section, km/h;

The analysis of the main technical characteristics of the Kharkiv-Dnipro line showed that with an increase in the speed of passenger trains up to 160 km/h, it is necessary to reconstruct the plan in order to increase the radius and the lengths of straight inserts. For the indicated site, three variants were designed: East, West and Global. The main features of the options are presented in Table 2.

Table 2. The main characteristics of the station variants that decoil.

Characteristics	Options for sites that decoil		
	Global	Eastern	Western
Line plan:			
- radius, m	2000	2000	2000
- sum of angles rotation, degrees	75	156	135
Longitudinal profile:			
- length of sites	0	1600	0
- length of sections with guide slope, m	11800	3600	4000
The volume of earthworks, thousand m ³	4553,94	652,72	301,62

The next step is to conduct a feasibility study of the options for rectification based on the above criteria. Substituting the corresponding values in the expression (1), and then in the formula (2) for all three variants, we obtain that according to the construction cost

criterion and the difference in length it is expedient to align the route with the Western variant. The results of calculated costs are given in Table 3.

Table 3. The costs are for the reconstruction of the current plan and for the rectification options.

The improvement of the parameters of the current plan	Value of reduced costs, ths. UAH
Option of reconstruction	251852.34
Eastern version of rectification	152043.71
Western version of rectification	102691.26
Global version of rectification	325362.18

According to the results of Table 3, it can be said that the alignment of the route along the Eastern and Western variants requires less costs than the reconstruction of complex lines of the line plan for the introduction of high-speed trains. So, after the comparative analysis, we can say that from the considered variants of the alignment the most expedient to realization is the Western one. At the previous stage, it satisfies all the criteria. It was this variant of rectification that was used in the reconstruction of the block of curves on Merefa – Vodolaga running line. This running line requires the solution to the problem of the reconstruction of a block of three closely spaced curves with insufficient values of radii. In order to increase the speed of passenger trains, it is necessary to increase the radius (R_r) and the value of the direct insertion between the curves (d_r). Next, for finding the values of the normal, the analytical model of the plan was used.

To determine the values of the displacement between the project and the existing plan for the purpose of comparison, the method of the angular diagrams is used. To compare the results of calculating the values of normal lines obtained by the method of the angular diagrams and using the analytical model of the plan, a joint displacement graph was constructed. The graph has shown that the application of the method of the angular diagrams does not always allow accurate determination of the values of normal (Figure 1).

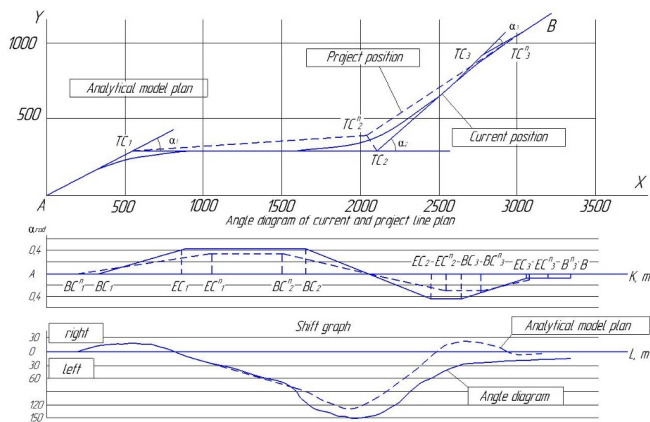


Fig. 1. The analytical plan model and angle chart method, shift graph.

The main component for determining capital investments is the cost of earthworks. The determination of the excavation volume on the basis of a digital model of relief was carried out on the pickets in widths from the condition of constant height of the mound. The calculation of the volume of the required soil itself was carried out using the Simpson

formula. For the construction of the mound of the project line 23 thousand m³ will be required. Performance data includes: reduction of speed limit; line shortening; cutting of running time. In order to determine the performance, the following traction calculations for Merefá – Vodolaga running line for the freight and passenger traffic were made, taking into account the limit on this curve (85 km/h) and after lifting it. The results are presented in Table 4.

Table 4. The results of the traction calculations for Merefá – Vodolaga running line

Characteristics	Restricted				Without restriction			
	passenger		freight		passenger		freight	
	forth	back	forth	back	forth	back	forth	back
R_m , MJ	1953	2012	4583	4667	2072	2181	4751	4797
R_r , MJ	1965	2000	4629	4620	2085	2168	4800	4748
t , min	14.3	14.4	18.5	18.6	13.8	13.5	17.6	17.6
ΣR_m , MJ	3965		9250		4253		9548	
ΣR_r , MJ	3965		9249		4253		9548	
Σt , min	28.7		37.1		27.3		35.2	

The difference between the parameters of the mechanical work (R_m), the resistance forces (R_r) and the running time for passenger and freight traffic are given in Table 5.

Table 5. The difference between the traction calculations.

Traction calculation indices	Passenger service	Freight service
R_m , MJ	288	298
R_r , MJ	288	299
t , min	1.4	1.9

7 Conclusions

Consequently, the above studies convincingly show that when the length of the running line is reduced after the reconstruction of only one module on $\Delta L = 79.09$ m and the speed limit on the section of the module is eliminated, i.e. reconstructed, the traveling time of passenger trains will be reduced by 1.4 minutes, and freight by 1.9 minutes.

References

1. M. Y. Kutsenko, O. A. Dudin, G. V. Pakhar, O. M. Danilenko, O. M. Dubina. Information and control systems on the railway transport, 5, 55–59, (2018)
2. O.Ohar, O.Rozsokha, M. Kutsenko, Y. Smachilo, Eastern-European journal of enterprise technologies, **3-90**, 48-57, (2017.)
3. I. V. Turbin, A. V. Gavrilencov, I. I. Kantor. *Izyskaniya i proyektirovaniye zheleznykh dorog*. Moscow: Transport, 479, (1989)
4. G. Z. Wertsman and A. P. Volodinю. *Proyektirovaniye vtorykh puteyю*. Moscow: Transport, 359, (1970)
5. P. Ferreira, R. Maciel, J. Estaire, M. Rodriguez-Plaza. Structure and Infrastructure Engineering, **15.1**, 1 – 13, (2019)
6. Y.-Z. Zhou, L.-J.Chen, C. Gao. Bridge Construction. **48.5**, 11 – 15 (2018).