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Research paper

Influence of Geodetic Works on the Road Pavement Evenness in the Highways Construction

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Abstract

The regulatory requirements and methods of road pavement evenness monitoring in the highway construction have been considered. The constituents and the marginal error magnitude, which should be taken into account for the highway pavement evenness estimation, have been substantiated. The fixing design schemes and the stringline deviation from the planned position during geodetic placement works on horizontal and inclined sections and vertical curves sections have been defined. The necessary marking points interval of fixing stringline, which ensures the reproduction accuracy in the vertical alignment terrain and necessary surface evenness of highway pavement, has been defined.

Keywords: *highway, geodetic works, crest and sag curves, pavement surface, radius of vertical curve, vertical alignment*

1. Introduction

Evenness of highway pavement is one of the main indicators of the transport and operational highway condition since it determines not only user comfort and movement safety, but also the strength and durability of the entire road structure [1-3].

The term «Evenness of highway pavement» relates primarily to the geometric characteristics of actual vertical alignment, which may have vertical deviations from the design position with wavelengths exceeding 10 m and an amplitude-fluctuation of 5 cm, which in aggregate actually compose the vertical alignment of the road (Fig. 1) and affect the car motion mode and the operation of its engine [4-6].

Fig. 1: Example of vertical alignment

Analysis of theoretical researches and practical recommendations relating to assessment of road pavement evenness shows that unevenness formation starts at vertical alignment designing stage (up to 15 – 20% of road pavement designed evenness indicators), unevenness progress occurs in construction period (reconstruction) during paving operations (including pavement top layer), unevenness accumulation takes place during road exploitation process as a result of transport loadings and climate conditions [7-10]. The most responsible in this respect should be considered the stage of road surface paving, because it is still possible to detect and correct project errors at this time, but it is almost impossible to eliminate the technology violation in the road construction.

In modern road building, self-contained asphalt pavers with an automated control system of working attachment are used for paving operations. Automated control systems designed to receive an even surface of the road pavement in the longitudinal direction with design slopes of the transverse profile.

Key points such asphalt pavers is the automatic longitudinal and transverse profiles constructions relative to the base surface by applied material layer thickness adjusting.

When paving the road base layers and surface for the control taking not actual road subgrade or the existing road surface layer, on which the asphalt paver base mounting moves, but for the base taking special guide, which simulation the even vertical alignment of the road surface. Thus, all possible unevenness of earthwork or of the existing road surface layer, which remained at the time of the new layer paving, will not affect the quality of its surface [11].

For asphalt paver operation as a guide, the steel string apply as a guide, which stretched on the prop with taking a level along the road, or unbendable multiple-seated skis 18-24 m long, which are attached to the asphalt paver and slide along the top of the road subgrade or base pavement.

The type of stringline is selected depending on the presence and nature of the unevenness on the road subgrade surface or existing base layer, which is detected by leveling in interval 5 - 10 m.

In particular, in the presence the unevenness on a base surface with a wavelength of 15-30 m and a depth of 16 mm, it is recommended to use multi-seated skis of 10 m or more as a guide and to use strings [12] as a guide when depths of unevenness is 16 - 50 mm. Typically, the base layers and the lower pavement layers are paving using a stringline, and the upper pavement layers are paving using the multi-seated skis.

The vertical alignment of the highway consists of horizontal and inclined sections which are interconnected by vertical curves sections (Fig. 2).

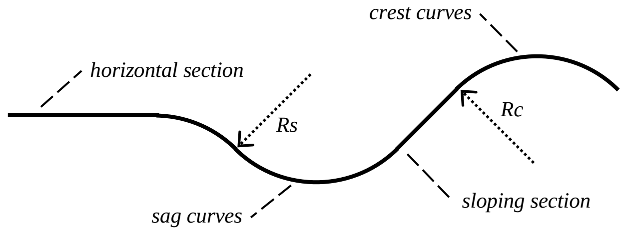

Fig. 2: Scheme of elements of the vertical alignment

According to the requirements (p. 5.2.2, [13]), "the design of the road vertical alignment should be carried out on the basis of the traffic intensity, conditions of safety and comfort of vehicles, taking into account the possibility of road reconstruction…". Requirements for the basic parameters of the vertical alignment elements are given in Table 1.

Table 1: The basic parameters of the vertical alignment elements

Name vertical alignment elements	Parameters
– longitudinal slope	< 30 ‰
– vertical curve radius	
– crests	> 70 000 m
– sags	> 8 000 m
– vertical curve length	
– crests	> 300 m
– sags	> 100 m

In the roads design it is allowed to reduce the normative parameters (see Table 2) to the maximum permissible parameters in accordance with design parameters and design speeds in the case when the terrain conditions and other local conditions are impossible to apply the previous requirements or their implementation leads to significant portions of work.

Table 2: The permissible parameters of the vertical alignment elements

Name elements	Parameters depending on the calculated speed of movement, km/h		
	130	110	90
The minimum longitudinal slope, ‰	40	50	60
The minimum vertical crests curve radius, m	15000	11000	9000
The minimum vertical sags curve radius, m	4400	3200	2100

The question arises about the accuracy of vertical alignment reproduction and the provision of the necessary road pavement evenness in the case when use a steel string as a base surface for the operation of self-contained asphalt pavers with an automated control system of working attachment.

2. Defining the Problem

Elevation marks recommended determining by leveling the vertical alignment for assessment of road pavement evenness in the operational quality control during construction process, replacement work and renovation of the highway according to the requirements [13].

About permissible deviations of measurement road surface elevations is noted in these norms «… not more than 10% of height measurements might have deviations from project values within the limits of ± 20 mm, for the rest of them ± 10 mm» (table 21.1, p. 39 [13]).

Elevation marks recommended to determine by leveling the vertical alignment with interval 5±0,2 m on the sections length not less than 400 m, by which the vertical deviation from the vertical alignment is calculated (p. 5 [14]) for assessment of road pavement evenness in the acceptance quality control during the road construction and road exploitation process using formula (1) according to the requirements [14]

$$\delta h_i = \left| 0{,}5(h_{i-1} + h_{i+1}) - h_i \right| \quad (1)$$

where h_{i-1} , h_{i+1} – relative marks of previous and further profile points (Fig. 3).

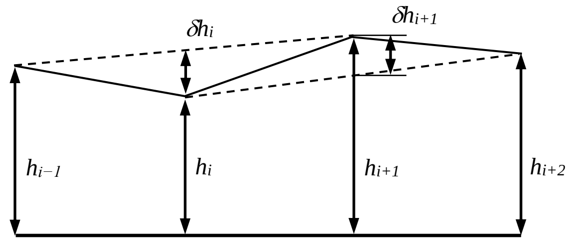

Fig. 3: Scheme for deviation δh_i determination from project line

Stringline is stretches on the prop with taking a level along the road with certain interval for setting out on the terrain vertical alignment during road surface paving.

Road pavement evenness during the road construction works, it is recommended to assess with limiting error $\Delta_{\partial on}$ according to the requirements [11] by the formula:

$$\Delta_{\partial on} = \sqrt{\Delta_g^2 + \Delta_c^2 + \Delta_m^2} \quad (2)$$

where Δ_g, Δ_c, Δ_m – limiting error of geodetic works, building works and building machines works.

Limiting error of geodetic works Δ_g is controlling during performing mark works and it is related with the technical characteristics of the leveler and the correctness of the setting out vertical alignment.

Limiting error of building works Δ_c is controlling during paving the road surface and it is primarily related to the installation and adjustment of a steel stringline.

Limiting error of building machines works Δ_m is determined by the correctness of the setting and mode of the technological transport operation which involved in the road surface paving.

Based on the principle of equal impact [15] limiting error Δ_i of individual component can be defined by the formula:

$$\Delta_i = \frac{\Delta_{\partial on}}{\sqrt{n}} \quad (3)$$

where n – the number of component errors.

If we accept the limiting error of the deviation of the elevations points of the vertical alignment $\Delta_{\partial on}$ = 10 mm (table 21.1, p. 39 [13]), then the individual components according to (3) must be no more than $\Delta_i = 10 / 3^{-1/2} = 5.77$ mm.

Among showed in the formula (2) the components of the limiting error require special attention to geodetic work, because the quality of their implementation depends on the accuracy of vertical alignment setting out.

3. Research results

Horizontal sections

According to [16] stringline is a flexible cord of constant section that under its own weight q in the middle of the span l has sag f (Fig. 4).

$$f = \frac{ql^2}{8N} \quad (4)$$

where q − weight of the cord, kg/m;
l − horizontal span length between supports, m;
N − horizontal tension in the cable, kg.

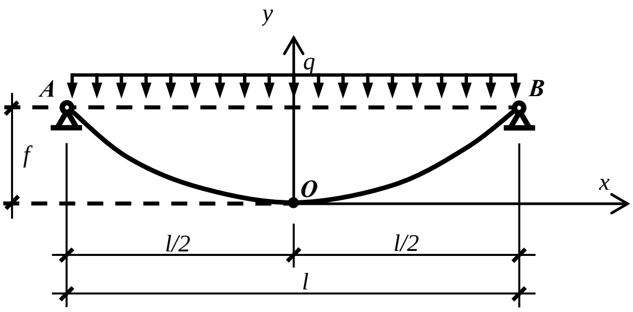

Fig. 4: Calculation scheme for symmetric cord ($H_A = H_B$)

If adjacent points of stringline will be fixed at one level ($H_A = H_B$), during geodetic marking works (Fig. 4), elevation of point in the middle of the span might be calculated by the formula:

$$H_O = H_A - f \quad (5)$$

Altitude levels difference of the vertical alignment control points to vertical alignment, calculated by the formula (1) will make:
− on the prop (is calculated except for the first and last points of fixing the stringline):

$$\delta h_B = \left|\frac{H_O + H_O}{2} - H_B\right| = |H_O - H_B| = |H_O - (H_O + f)| = f \quad (6)$$

− in the middle of the span:

$$\delta h_O = \left|\frac{H_A + H_B}{2} - H_O\right| = |H_A - (H_A - f)| = f \quad (7)$$

Thereby, altitude levels difference may correspond to the value of bending deflection f for all the control points of the vertical alignment.
If taken in calculation that stringline is manufactured of steel cable ∅3,1 mm (mass q = 0,0492 kg/m, cross section area is F = 5,66×10-6 m^2), the span is l = 10 m and tension force is N = 200 kg according to the formula the cable will have bending deflection f equal to:

$$f = \frac{0.0492 \times 10^2}{8 \times 200} = 0.003075 \text{ m} = 3.075 \text{ mm},$$

which does not exceed the value of geodetic works limiting error Δ_i = 5.77 mm.

Assessment of road pavement evenness by the altitude levels difference of the vertical alignment to the vertical alignment in the case of precise fixation of the stringline ($H_A = H_B$= 1.000 m), for the horizontal sections with a length of 100 m are presented in Table 3.

Table 3: The permissible parameters of the vertical alignment elements

Staked location of points PK+, m	Elevation point, H_i, m	Altitude levels difference δh_i, mm	
		Related to adjacent points (DSTU B V.2.3-3-2000)	Related to starting point PK 0+000
0+000	1.000	–	–
0+005	0.997	3.075	3.075
0+010	1.000	3.075	0.000
0+015	0.997	3.075	3.075
0+020	1.000	3.075	0.000
0+025	0.997	3.075	3.075
0+030	1.000	3.075	0.000
0+035	0.997	3.075	3.075
0+040	1.000	3.075	0.000
0+045	0.997	3.075	3.075
0+050	1.000	3.075	0.000
0+055	0.997	3.075	3.075
0+060	1.000	3.075	0.000
0+065	0.997	3.075	3.075
0+070	1.000	3.075	0.000
0+075	0.997	3.075	3.075
0+080	1.000	3.075	0.000
0+085	0.997	3.075	3.075
0+090	1.000	3.075	0.000
0+095	0.997	3.075	3.075
0+100	1.000	–	–
	Average value	3.075	1.538

Results of road pavement evenness assessment in the case of precise fixation of the stringline (Fig. 4) show that, the altitude levels difference of the existing vertical alignment from the vertical alignment are within the acceptable deviations Δ_i = 5.77 mm and have a value of 3.075 mm at each measurement point, according to the first method, and they're only within the span, according to the second method.
If adjacent points of stringline will be fixed at different levels during geodetic marking works (Fig. 5) and cord will be of an asymmetric shape the bending deflection for each point of fixation f_i might be calculated by the formulas:

$$f_1 = \frac{ql^2}{8N} + \frac{Nh^2}{2ql^2} + \frac{h}{2} \quad (8)$$

$$f_2 = \frac{ql^2}{8N} + \frac{Nh^2}{2ql^2} - \frac{h}{2} \quad (9)$$

where h − altitude levels difference of adjacent points (Fig. 5).

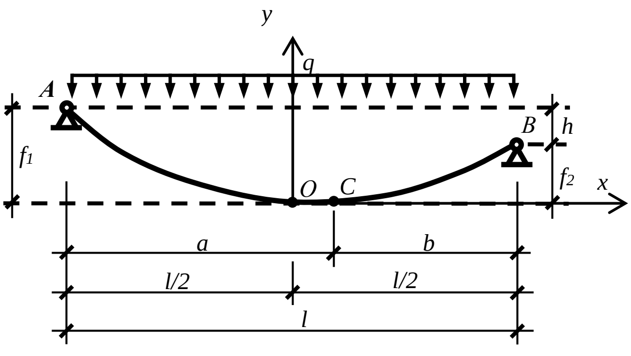

Fig. 5: Calculation scheme for asymmetric cord ($H_A > H_B$)

Elevation of control points relatively A point for the calculation scheme is shown in Fig. 5, and calculated by the formulas:

$$H_B = H_A - h \quad (9)$$

$$H_o = H_A - \frac{ql^2}{8N} \quad (10)$$

Altitude levels difference of the vertical alignment control points to vertical alignment, calculated by the formula (1) will make:

$$\delta h_i = \left| \frac{H_A + H_B}{2} - H_i \right| = \left| \frac{2H_A - h}{2} - H_A + \frac{ql^2}{8N} \right| = \left| \frac{ql^2}{8N} - \frac{h}{2} \right| \quad (11)$$

Assessment of road pavement evenness by the altitude levels difference of the vertical alignment to the vertical alignment in the case of stringline fixation with deviations (H_A = 1.000 m), for the level stretch of road with a length of 100 m are presented in Table 4.

Table 4: The permissible parameters of the vertical alignment elements

Staked location of points PK+, m	Elevation points, H_i, m	Altitude levels difference δh_i, mm	
		Related to adjacent points (DSTU B V.2.3-3-2000)	Related to starting point PK 0+000
0+000	1.000	–	–
0+005	0.997	1.575	3.075
0+010	0.997	0.575	3.000
0+015	0.996	2.075	4.075
0+020	0.999	2.575	1.000
0+025	0.997	2.575	3.075
0+030	1.000	2.075	0.000
0+035	0.999	2.075	1.075
0+040	1.002	3.075	-2.000
0+045	0.999	3.075	1.075
0+050	1.002	2.575	-2.000
0+055	1.000	2.575	0.075
0+060	1.003	3.075	-3.000
0+065	1.000	0.075	0.075
0+070	0.997	1.925	3.000
0+075	0.998	1.075	2.075
0+080	1.001	3.075	-1.000
0+085	0.998	1.575	2.075
0+090	0.998	1.075	2.000
0+095	0.996	2.575	4.075
0+100	0.999	–	1.000
	Average value	2.067	1.938

Results of road pavement evenness assessment in the case of stringline fixation with deviations in the range ±3.075 mm (Fig. 5) show that, the altitude levels difference of the existing vertical alignment from the vertical alignment are within the acceptable deviations, according to the first method, and it has a divergence from -3,000 mm to 4,075 mm, which nevertheless does not exceed the limiting error Δ_i = 5.77 mm, according to the second method.
In general, the results of calculations (see Table 3-4) indicate that in determining the altitude levels difference of the stringline position from the vertical alignment by the method [14] in the case of stringline suspension points are situated at the same level (see Fig. 1), deviations are constant 3.075 mm (average deviation of 3.075 mm), and when stringline suspension points are situated at different levels (see Fig. 2) – vary in the range from 0.075 mm to 3.075 mm (average value 2.067 mm). In determining the altitude levels difference of the stringline position from the vertical alignment relative to the initial point of suspension in the first case (Fig. 1), the values of deviations are 0.000 and 3.075 mm (average deviation of 1.538 mm), in the second case (Fig. 2) – in the range from -3.000 mm to 4.075 mm (average value 1.938 mm).

Inclined sections

To assess the accuracy of geodetic works of the marking design vertical alignment on inclined sections, the second calculation scheme (see Fig. 2) and the formula (11) can be used and taking into account the value of the longitudinal slope.

Vertical curve sections

To assess the accuracy of geodetic works of the marking vertical alignment on the vertical curves, it should be taken into account that points of fixing a stringline split the vertical curve into separate chords, and the stringline between the fixing points will have an asymmetrical sagging from its own weight (see Fig. 6).

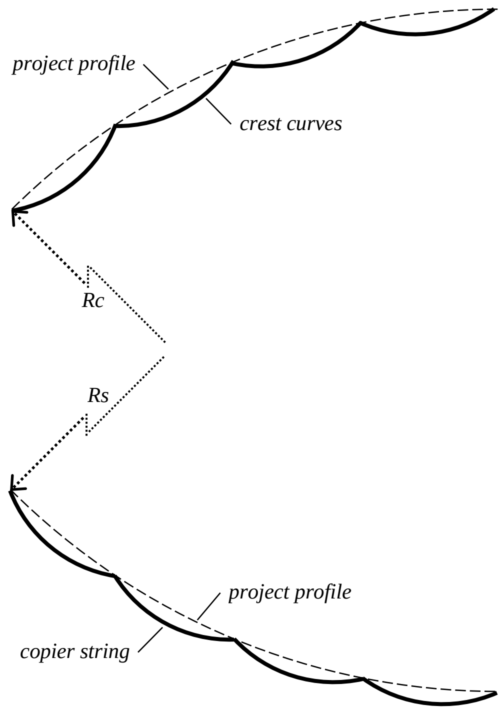

Fig. 6: Scheme of marking the vertical curve of the vertical alignment

Bending deflection f^* of the vertical alignment from the design vertical curve calculated by the formula:

$$f^* = R - (R^2 - 0.025L^2)^{-1/2} \quad (12)$$

where R – radius of vertical curve, m; L – distance between points of fixing a stringline, m.

Calculation of bending deflection f^* with interval siting points of fixing a stringline 5.0, 7.5 m and 10.0 m for crest curve with the recommended [13] radius from 9000 m to 15000 m (see. Table 2) is shown in Fig. 7, and sag curve with radius from 2100 m to 8000 m is shown in Fig. 8.
Results of calculation vertical alignment deviation from the design vertical curves, which are shown in Fig. 7-8, allow drawing the following conclusions:
– on crest curves with radius from 9000 m to 15000 m bending deflection f^* of the vertical alignment from the design vertical curve with interval siting points of fixing a stringline 5.0, 7.5 m and 10.0 m which does not exceed the value of geodetic works limiting error Δ_i = 5.77 mm, therefore the marking of the siting points of fixing a stringline can be performed with interval of 10.0 m;
– on sag curves with radius from 2100 m to 8000 m bending deflection f^* of the vertical alignment from the design vertical curve with interval siting points of fixing a stringline 10.0 m does exceed the value of geodetic works limiting error Δ_i = 5.77 mm, therefore the marking of the siting points of fixing a stringline it is desirable to performe with interval of 5.0 m or 7.5 m;

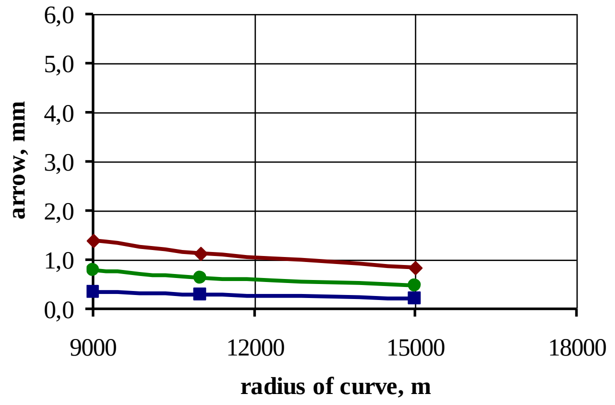

Fig. 7: Longitudinal profile deviation from the design crest curve at the interval of the marking: 5.0 m (square markers); 7.5 m (round markers); 10.0 m (triangular markers)

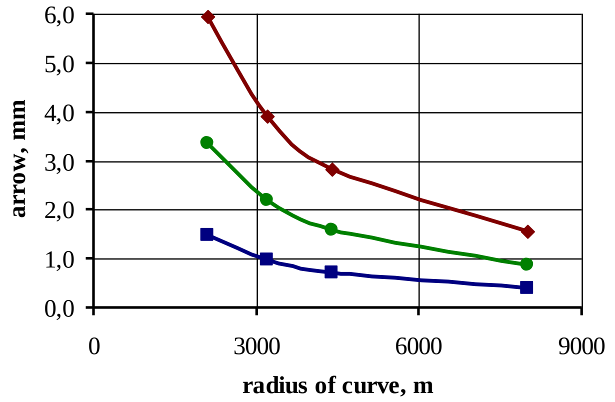

Fig. 8: Longitudinal profile deviation from the design sag curve at the interval of the marking: 5.0 m (square markers); 7.5 m (round markers); 10.0 m (triangular markers)

To assess the accuracy of geodetic works of the marking vertical alignment on the vertical curves, the second calculation scheme (see Fig. 2) and the formula (11) can be used, taking into account the value of the vertical alignment bending deflection from the design vertical curve.

4. Conclusions

The researches of the influence of geodetic works the road pavement evenness in the construction of highway are carried out and indicate that on horizontal and inclined sections the interval of marking points of fixing a stringline, which reproduces in the site the vertical alignment, can take a value of 10.0 m, and in sections of vertical curves, the interval of marking is appropriate to reduce depending on the radius of these curves.

To assess the accuracy of geodetic works of the marking vertical alignment on inclined sections, the second calculation scheme can be used, taking into account the value of the longitudinal slopes on straight sections and radius of vertical curves.

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