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METHOD OF PREDICTING THE STRENGTH PARAMETERS OF ROADBED OF SILTY SOILS IN REGIONS I AND II OR ROAD-CLIMATIC ZONES WITH AID OF A COMPUTER

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Hanover, New Hampshire

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13. ABSTRACT

In planning and building the main transport trunk roads in regions I and II of the road-climatic zone, it is necessary to solve the question concerning the opportunity of applying the local cohesive soils for building a roadbed. To facilitate the evaluation of these soils (silty sandy loams and silty loams) and in planning the road designs, the author's method was converted to algorithm, programmed and solved on the Ural-4 computer for more than 150 points in the USSR territory. Averaged parameters for the two soils were established and formulas for transferring from soil moistness to its strength and stress indexes derived. The adoption of the computer into the planning of road designs in the regions of permafrost and severe climate will favor the formulation of planning the highways on a higher scientific level.

14. KEY WORDS

Analysis (Mathematics)	Roadbeds
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NOTICE

METHOD OF PREDICTING THE STRENGTH PARAMETERS OF ROADBED OF SILTY SOILS IN REGIONS I AND II OF ROAD-CLIMATIC ZONES WITH AID OF A COMPUTER

[Trudy Pyatogo Soveshchaniya-Seminara po Obmenu Opytom Stroitel'stva v Surovykh Klimaticheskikh Usloviyakh (Transactions of Fifth Conference-Seminar on Exchange of Construction Experience under Severe Climatic Conditions), Materials of Section on Road-Transport Construction, Vol 7, No 1, Krasnoyarsk, 1968, pp 21-37]

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In planning and building the main transport trunk roads in regions I and II of the road-climatic zones, it is necessary to solve the question concerning the opportunity of applying the local cohesive soils for building a roadbed. The unjustified disregarding of these soils causes an excessively high cost of construction. However, the indiscriminate use of local cohesive soils (usually silty sandy loams and loams) without considering their moisture-conducting properties and the soil-hydrologic conditions can lead to an inadequate strength of road designs and to intolerable values of heaving and settling.

In our reports [2, 3, 12a] and also in the reports compiled by the Omsk branch of Soyuzdornii [12b, 12c, 12d], we have established the principles of evaluating the suitability of the indicated soils for building a roadbed on main highways; we have presented the appropriate formulas and nomograms for calculating the average moistness of roadbed soils in the calculated spring period (W_{sr}^{ves}), the determination of expected heaving (h_o) and settling (S). However practical experience gained in planning has shown that the introduction of the procedures developed is hampered by the formula setup and the unwieldiness of the computation process.

At the present time, we are planning several main transport highways of considerable length (BAM, the Tyumen'-Surgut line, and others) for which the successful solution to the problem of utilizing the local cohesive soils can bring about a considerable savings in government resources. For such extended routes, it will be necessary to perform calculations on predicting the moisture content, strength and deformation-type parameters, heaving and settlement of the roadbed for a large number of design sections. Such work will require considerable time and therefore will not always be carried out. To facilitate the evaluation of the suitability of local cohesive soils in the roadbed and in planning the road designs, the author's method discussed in report [10] was converted to an algorithm, was programmed [See Note] and solved on the Ural-4 computer for more than 150 points in the USSR territory ([Note]: The programming and solution of the problem were performed by V. N. Gladkikh).

In developing the algorithm, we were required to average the characteristics of the soils with the identification of typical differences, since otherwise the number of variants to the problem's solution would have been extremely large. The evaluation of the soils' fittness for building a roadbed was conducted for two standard types of soils, i.e. silty sandy loams and silty loams. The segregation of several standard soil types is typical for all operations with averaged strength and deformation-type parameters of roadbed soils [7, 9].

Based on reports by V. I. Birulya, N. A. Kless [8], N. S. Ivanov [6], V. M. Sidenko [11], Soyuzdornii [9] and the author [2], we succeeded in establishing the averaged parameters listed below for the silty sandy loams and loams and in deriving formulas for transferring from soil moistness to its strength and stress indexes.

$$\frac{W_o}{W_T} = 0.66 \qquad (1)$$

where: W_o and W_T = respectively the optimal moistness at the flow point.

$$\frac{W_{pv}}{W_T} = 0.83 \qquad (2)$$

where: W_{pv} = moistness corresponding to the total moisture capacity at standard (optimal) compactness.

2. $W_h/W_T = 0.34$ (3) - for silty sandy loams.

$W_h/W_T = 0.39$ (4) - for silty loams.

where: W_h = moistness (based on liquid phase) at limit of primary ice separation (at temperature of -0.5 - -1.0°C).

3. $W_{nf}/W_T = 0.25$ (5) - for silty sandy loams;

$W_{nf}/W_T = 0.27$ (6) - for silty loams,

where: W_{nf} = moisture content corresponding to nonfreezing water and temperature -10°C.

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(6) Cold Regions Science and Engineering Monograph 3, Section A2a: Methods of Building on Permanent Snowfields,

(14) CRREL-CRSE-3-A2a AD-681 809
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4. $\gamma_T = 0.53/W_T$ (7) - for silty sandy loams;

$\gamma_T = 0.58/W_T$ (8) - for silty loams,

where: γ_T = weight by volume of skeleton of optimally compacted soil prior to freezing, g/ccm.

5. $E_y = 217/(W_{av}^{spr}/W_T)^{1.74}$ (9) - for the silty sandy loams;

$E_y = 133/(W_{av}^{spr}/W_T)^{2.68}$ (10) - for silty loams,

where: E_y = elastic modulus of soil, kg/cm^2; W^{spr}_{av} = average moistness of roadbed soil in spring in the layer H_a = 50 cm lying directly under the road covering.

6. $C = 0.33 - (W^{spr}_{av}/W_T - 0.56)$ (11) - for silty sandy loams;

$C = 0.041/(W^{spr}_{av}/W_T)^{4.45}$ (12) - for silty loams,

where C = adhesion, kg/cm^2.

7. $\varphi = 16.4/(W^{spr}_{av}/W_T)1.18$ (13) - for silty sandy loams;

$\varphi = 7.76/(W^{spr}_{av}/W_T)^{2.31}$ (14) - for silty loams,

where: φ = angle of internal friction in degrees.

Equations (1) - (8) were utilized in the derivation of the basic formulas presented below, suggested by the author [4, 10] for predicting the average moistness in the limits of the H_a layer and the amount of heaving in the roadbed soil under conditions of the latter's moistening from beneath from the level of ground above-frost or surface water.

For a determination of the average autumn moistness (W^{aut}_{av}) at $T_{oH} < 0.25$:

$$\frac{W_{cp}^{oc} - W_0}{W_{ns} - W_0} = \left(1 + \frac{H_\ell}{H_a}\right) \cdot erfc\left[\left(1 + \frac{H_a}{H_\ell}\right) \cdot \frac{1}{2\sqrt{Fo_H}}\right] + \left(1 - \frac{H_\ell}{H_a}\right) \cdot erfc\left[\left(1 - \frac{H_a}{H_\ell}\right) \cdot \frac{1}{2\sqrt{Fo_H}}\right] + \frac{2\sqrt{Fo_H}}{\sqrt{\pi}} \cdot \frac{H_\ell}{H_a}\left\{exp\left[-\frac{1}{4Fo_H} \cdot \left(1 - \frac{H_a}{H_\ell}\right)^2\right] - exp \cdot \left[-\frac{1}{4Fo_H} \cdot \left(1 + \frac{H_a}{H_\ell}\right)^2\right]\right\} \qquad (15)$$

Also at $T_{OH} \geqslant 0.25$:

$$\frac{W_{cp}^{oc} - W_0}{W_{nB} - W_0} = 1 - \frac{8}{\pi^2}\left(\frac{H_i}{H_a}\right) \cdot \sin\left(\frac{\pi}{2} \cdot \frac{H_a}{H_i}\right) \cdot \exp\left(-\pi^2 \frac{F_{OH}}{4}\right), \tag{16}$$

where: the criterion of autumn moisture accumulations:

$$F_{OH} = \frac{K_1 \cdot \tau_{Bn}}{H_B^2} \tag{17}$$

K_1 = coefficient of soil moisture conductivity determined experimentally [2, 8, 10]; τ_{Bn} = length of moisture buildup period calculated for the zero points and excavations based on the meteorological parameters of the region [3, 4]; H_B = distance from top of roadbed to level of round, above-frost or surface water established during the period of surveying. The reduction in the time period τ_{Bn} for the embankments (as a result of additional evaporation of moisture through the slopes) was considered approximately based on reports [4, 10].

For determining the average moistness of roadbed soil toward the end of winter:

$$W_{cp}^{3.n} = W_n + (W_{cp}^{oc} - W_n) \cdot \frac{\exp(-A^2)}{\sqrt{\pi} A \cdot \operatorname{erfc}(A)};$$

$$A = \frac{\alpha \cdot \sqrt{\tau_{3n}}}{2 H_B \sqrt{F_{OH}}}, \tag{18}$$

where: α = characteristic of freezing rate of road construction determined by heat-engineering calculation according to the method suggested in reports [2, 3, 10].

In developing an algorithm for the problem, we adopted the following standard design of road covering:

a double-layered asphalt-concrete covering 9 cm thick;

an underlying ballast layer 18 cm thick; and

a sandy base with a thickness of 16 cm.

The thermal-physical parameters of the indicated layers having been utilized in calculating α are listed in Table 1.

Table 1

Name of material in layer	Heat conductivity factor λ, kcal/m, °C, hrs	Heat of ice formation, Q, kcal/m^3	Volumetric heat capacity, C, kcal/m^3, °C
Asphalt-concrete	0.60	400	850
Ballast	0.70	2750	350
Sand	1.00	7000	400

For the roadbed soil, the values Q and C were computed with the aid of the known formulas [2, 6, 10] transformed by us in application to the standard parameters (γ_T; W_{nf}) of the silty soils under consideration

$$Q = 44000\,(W_{cp}^{oc}/W_T) - 11500 \tag{19}$$

$$C = 380 + 375\,(W_{cp}^{oc}/W_T) \tag{20}$$

For determining the heat conductivity factor of roadbed soil in a frozen state, based on report [6], we derived the formula:

$$\lambda = 0.3 + 2.5\,(W_{cp}^{oc}/W_T) \tag{21}$$

The parameter for the freezing rate α was computed from the equation:

$$\alpha = \frac{h_{cr} + \left(\sum_{i=1}^{n=3} h_i\right)_{3n}}{\sqrt{\tau}} \tag{22}$$

where: τ = freezing time of soil to depth $h_{cr} + \left(\sum_{i=1}^{n=3} h_i\right)_{3n}$ and in its turn h_{cr} = critical freezing depth of roadbed according to N. A. Puzakov (assumed to equal 120 cm); $\left(\sum_{i=1}^{n=3} h_i\right)_{3n}$ = depth of soil layer equivalent from a heat standpoint to a multi-layered road covering. The determination of $\left(\sum_{i=1}^{n=3} hi\right)_3$ was conducted according to the method of V. V. Dokuchayev [1] from the equation:

$$\left(\sum_{i=1}^{n=3} h_i\right)_{3n} = h_1 \frac{H_{rb}}{H_1} + h_2 \frac{H_{rb}}{H_2} + h_3 \frac{H_{rb}}{H_3} \tag{23}$$

where: H_{rb} = freezing depth of roadbed soil for the entire freezing period (τ_{np}); and H_1, H_2, H_3 = freezing depth of corresponding materials in the layers for this same period with duration τ_{np}.

The values H_{rb}, H_1, H_2 and H_3 were calculated for the Qi, Ci and λi-values corresponding to each material from the relationship validated in report [2]:

$$H_i = \frac{\tau_{np}}{\theta_i + \frac{1}{2} C_i (a\tau_{np}^2 + b\tau_{np})} \cdot \sqrt{\lambda_i \left(\theta_{ib} + \frac{2a\theta_i + b^2 C_i}{3}\tau_{np} + \frac{ab \cdot C_i}{2}\tau_{np}^2 + \frac{a^2 \cdot C_i}{5}\tau_{np}^3\right.} \quad (24)$$

where the climatic factors a and b were established for each point of design from the relationships [2]:

$$a = -\frac{4\,Q_{min}}{\tau_{np}^2}, \quad (25)$$

$$b = \frac{4\,Q_{min}}{\tau_{np}}, \quad (26)$$

and in turn, Q min = the minimal average monthly air temperature during the winter (based on mean many years' weather data).

If during the calculations, the condition

$$h_{kp} + \left(\sum_{i=1}^{n=3} h_i\right)_{3n} \geq H_{3n}, \quad (27)$$

occurred, the α-value was computed from the formula:

$$\alpha = H_{3n} / \sqrt{\tau_{np}} \quad (28)$$

The two-dimensional state of the problem of freezing for embankments (influence of slopes) was considered approximately on the basis of the given reports [1, 4] by multiplying the obtained value of α by the factor 1.1.

For determining the amount of heaving, we utilized the equation:

$$h_o = h\frac{\Gamma_T}{\Delta_o}\left[1{,}09\left(W_{cp}^{3HM} - W_{H3}\right) - \left(W_{n8} - W_{H3}\right)\right] \quad (29)$$

where: h = freezing depth of soil in roadbed determined by heat-engineering calculation, h = h_{cr} or $h = H_{3n} - \left(\sum_{i=1}^{n=3} h_i\right)_{3n}$; $\Delta_{o_{win}}$ = weight of water by volume; W_{av} = average soil moistness in Ha layer toward the end of winter.

Utilizing the equations (1-8), Eqs. (15, 16, 18) and (29) in the algorithm of the problem were reduced to the form:

$$\frac{W_{\text{ср}}^{\text{ос}}}{W_T} = 0{,}56 + 0{,}27 \left\{\left\{\left(1 + \frac{H_в}{H_а}\right) \cdot erfc\left[\left(1 + \frac{H_а}{H_в}\right) \cdot \frac{1}{2\sqrt{F_{он}}}\right] + \left(1 - \frac{H_в}{H_а}\right) \cdot erfc\left[\left(1 - \frac{H_а}{H_в}\right) \cdot \frac{1}{2\sqrt{F_{он}}}\right] + \frac{2\sqrt{F_{он}}}{\sqrt{\pi}} \cdot \frac{H_в}{H_а} \cdot \left\{exp\left[-\frac{1}{4F_{он}}\left(1 - \frac{H_а}{H_в}\right)^2\right] - exp \cdot \left[-\frac{1}{4F_{он}}\left(1 + \frac{H_а}{H_в}\right)^2\right]\right\}\right\}\right\} \tag{30}$$

for $T_{он} \geq 0.25$

$$\frac{W_{\text{ср}}^{\text{ос}}}{W_T} = 0{,}56 + 0{,}27\left[1 - \frac{8}{\pi^2}\left(\frac{H_в}{H_а}\right) Sin\left(\frac{\pi}{2} \cdot \frac{H_а}{H_в}\right) exp\left(-\pi^2 \frac{F_{он}}{4}\right)\right] \tag{31}$$

$$\frac{W_{\text{ср}}^{\text{зим}}}{W_T} = 0{,}34 + \left(\frac{W_{\text{ср}}}{W_T} - 0{,}34\right) \frac{exp(-A^2)}{\sqrt{\pi} \cdot A \cdot erfc(A)} \tag{32}$$

- for silty sandy loams

$$\frac{W_{\text{ср}}^{\text{зим}}}{W_T} = 0{,}39 + \left(\frac{W_{\text{ср}}^{\text{ос}}}{W_T} - 0{,}39\right) \frac{exp(-A^2)}{\sqrt{\pi} \cdot A \cdot erfc(A)} \tag{33}$$

- for silty loams.

$$h_o = \frac{h}{\Delta_o} 0{,}53 \left[1{,}09 \left(\frac{W_{\text{ср}}^{\text{зим}}}{W_T} - 0{,}25\right) - (0{,}33 - 0{,}25)\right] \tag{34}$$

- for silty sandy loams.

$$h_o = \frac{h}{\Delta_o} 0{,}58 \left[1{,}09 \left(\frac{W_{\text{ср}}^{\text{зим}}}{W_T} - 0{,}27\right) - (0{,}83 - 0{,}27)\right] \tag{35}$$

- for silty loams.

The average spring moisture content of roadbed soil was established from the relationship

$$W_{\text{ср}}^{\text{вес}} = W_{\text{ср}}^{\text{зим}} \tag{36}$$

As an example, in Tables 2-3 we have presented the results obtained from solving the problem for two points located in I (Dudinka) and II (Irbit) road-climatic zones.

Table 2.

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (W_{av}^{aut}/W_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (W_{av}^{spr}/W_T): Sandy loams	Relative spring moistness: Loams	Strength parameters, Sandy loams: Moduli (kg/cm^2)	Sandy loams: Interval friction angle, °	Sandy loams: Adhesion (kg/cm^2)	Strength parameters, Loams: Moduli (kg/cm^2)	Loams: Interval friction angle, °	Loams: Adhesion (kg/cm^2)	Heaving h_0 (cm): Sandy loams	Heaving h_0 (cm): Loams	Value of criterion (F_{oh})
				DUDINKA.	Period of fall moisture accumulation - 936 hours. Duration of freezing spell - 6000 hours. Minimal mean monthly temperature - 29.5°C.								
						H_B = 250 cm							
3.34	0.56	3.93	0.62	0.61	493	25	0.27	499	24	0.37	--	--	0.05
6.68	0.58	3.91	0.69	0.67	415	25	0.20	397	28	0.25	--	--	0.10
10.02	0.60	3.88	0.76	0.73	346	23	0.13	306	16	0.16	--	--	0.15
13.35	0.62	3.85	0.84	0.81	97	--	--	238	13	0.11	4	2	0.20
16.69	0.65	3.82	0.93	0.88	83	--	--	187	10	0.07	10	7	0.25
20.03	0.67	3.80	1.00	0.95	72	--	--	51	--	--	15	13	0.30
23.37	0.69	3.79	1.08	1.02	53	--	--	42	--	--	20	18	0.35
26.71	0.70	3.77	1.15	1.09	57	--	--	35	--	--	25	23	0.40
30.05	0.72	3.76	1.22	1.16	51	--	--	30	--	--	30	28	0.45
						H_B = 200 cm							
2.14	0.56	3.93	0.61	0.60	519	30	0.28	531	26	0.41	--	--	0.05
4.27	0.58	3.91	0.66	0.64	449	27	0.23	436	22	0.29	--	--	0.10
6.41	0.60	3.88	0.72	0.70	381	24	0.17	345	18	0.20	--	--	0.15
8.55	0.63	3.85	0.79	0.76	327	22	0.10	277	15	0.14	--	--	0.20
10.68	0.65	3.82	0.86	0.83	94	--	--	223	12	0.10	5	3	0.25
12.82	0.67	3.86	0.92	0.89	83	--	--	185	10	0.07	10	8	0.30
14.96	0.69	3.79	0.99	0.94	74	--	--	52	--	--	14	12	0.35
17.09	0.71	3.77	1.05	1.00	67	--	--	45	--	--	18	16	0.40
19.23	0.72	3.76	1.10	1.05	61	--	--	39	--	--	22	20	0.45
21.37	0.73	3.75	1.16	1.11	56	--	--	34	--	--	26	24	0.50
25.64	0.76	3.73	1.26	1.20	48	--	--	27	--	--	33	32	0.60
						H_B = 150 cm							
1.20	0.56	3.93	0.59	0.58	543	31	0.30	562	27	0.45	--	--	0.05
2.40	0.58	3.90	0.63	0.62	480	28	0.26	471	23	0.34	--	--	0.10
3.61	0.61	3.87	0.69	0.67	417	26	0.20	387	19	0.24	--	--	0.15
4.81	0.63	3.84	0.74	0.72	365	23	0.15	318	16	0.17	--	--	0.20
6.01	0.65	3.82	0.80	0.77	323	21	0.09	265	14	0.13	--	--	0.25
7.21	0.67	3.80	0.85	0.82	97	--	--	225	12	0.10	5	3	0.30
8.41	0.69	3.78	0.90	0.87	88	--	--	195	11	0.08	8	6	0.35
9.62	0.71	3.77	0.94	0.91	80	--	--	57	--	--	11	10	0.40
10.82	0.72	3.76	0.99	0.95	74	--	--	50	--	--	14	13	0.45
12.02	0.74	3.75	1.03	0.99	68	--	--	45	--	--	17	16	0.50

Table 2 (Cont'd).

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (W_{av}^{aut}/W_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (W_{av}^{spr}/W_T) Sandy loams	Relative spring moistness (W_{av}^{spr}/W_T) Loams	Strength parameters, Sandy loams: Moduli (kg/cm^2)	Strength parameters, Sandy loams: Interval friction angle, °	Strength parameters, Sandy loams: Adhesion (kg/cm^2)	Strength parameters, Loams: Moduli (kg/cm^2)	Strength parameters, Loams: Interval friction angle, °	Strength parameters, Loams: Adhesion (kg/cm^2)	Heaving h_o (cm) Sandy loams	Heaving h_o (cm) Loams	Value of criterion (F_{oh})
						H_B = 150 cm (cont'd)							
14.42	0.76	3.73	1.11	1.07	60	--	--	37	--	--	23	22	0.60
16.83	0.77	3.73	1.18	1.13	55	--	--	32	--	--	27	26	0.70
19.23	0.78	3.72	1.24	1.19	50	--	--	8	--	--	31	31	0.80
						H_B = 100 cm							
0.53	0.57	3.92	0.58	0.58	556	31	0.31	578	27	0.47	--	--	0.05
1.07	0.59	3.89	0.62	0.61	499	29	0.27	490	24	0.36	--	--	0.10
1.60	0.62	3.86	0.66	0.65	446	27	0.23	415	21	0.27	--	--	0.15
2.14	0.64	3.83	0.70	0.69	400	25	0.19	355	18	0.21	--	--	0.20
2.67	0.66	3.81	0.74	0.73	363	23	0.15	308	16	0.17	--	--	0.25
3.21	0.68	3.79	0.78	0.77	333	22	0.11	271	14	0.13	--	--	0.30
3.74	0.70	3.78	0.82	0.80	193	--	--	241	13	0.11	2	1	0.35
4.27	0.71	3.77	0.85	0.83	95	--	--	217	12	0.09	5	4	0.40
4.81	0.73	3.75	0.88	0.86	90	--	--	193	11	0.08	7	6	0.45
5.34	0.74	3.74	0.92	0.89	85	--	--	180	10	0.07	9	8	0.50
6.41	0.76	3.75	0.97	0.95	76	--	--	51	--	--	13	12	0.60
7.48	0.78	3.72	1.02	0.99	70	--	--	46	--	--	16	15	0.70
8.55	0.79	3.71	1.06	1.03	66	--	--	41	--	--	19	18	0.80
9.62	0.80	3.71	1.10	1.06	62	--	--	58	--	--	22	21	0.90
10.68	0.80	3.70	1.13	1.10	58	--	--	35	--	--	24	24	1.00
13.35	0.82	3.70	1.20	1.16	52	--	--	30	--	--	29	29	1.25
						H_B = 75 cm							
0.30	0.58	3.90	0.58	0.58	568	31	0.31	584	28	0.48	--	--	0.05
0.60	0.61	3.87	0.63	0.62	491	29	0.26	473	23	0.34	--	--	0.10
0.90	0.63	3.84	0.66	0.66	445	27	0.23	408	20	0.26	--	--	0.15
1.20	0.66	3.82	0.70	0.69	407	25	0.19	359	18	0.21	--	--	0.20
1.50	0.68	3.80	0.73	0.72	376	24	0.16	319	17	0.18	--	--	0.25
1.80	0.69	3.78	0.76	0.75	350	23	0.13	287	15	0.15	--	--	0.30
2.10	0.71	3.77	0.79	0.78	329	22	0.10	261	14	0.13	--	--	0.35
2.40	0.72	3.76	0.81	0.80	103	--	--	240	13	0.11	2	1	0.40
2.70	0.74	3.75	0.84	0.83	98	--	--	221	12	0.10	4	3	0.45
3.00	0.75	3.74	0.87	0.85	93	--	--	205	11	0.08	6	5	0.50
3.61	0.77	3.73	0.91	0.89	85	--	--	180	10	0.07	9	8	0.60
4.21	0.78	3.72	0.94	0.92	81	--	--	55	--	--	11	10	0.70

Table 2 (Cont'd).

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (w_{av}^{aut}/w_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (w_{av}^{spr}/w_T)		Strength parameters						Heaving h_o (cm)		Value of criterion (F_{oh})
					Sandy loams			Loams					
			Sandy loams	Loams	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Sandy loams	Loams	
						H_B = 75 cm (cont'd)							
4.81	0.79	3.71	0.97	0.95	76	--	--	51	--	--	13	13	0.80
5.41	0.80	3.71	1.00	0.98	72	--	--	47	--	--	15	15	0.90
6.01	0.81	3.70	1.03	1.00	69	--	--	44	--	--	17	17	1.00
7.51	0.82	3.70	1.06	1.06	63	--	--	38	--	--	21	21	1.25
9.01	0.82	3.69	1.13	1.10	59	--	--	35	--	--	24	24	1.50
10.52	0.63	3.69	1.17	1.13	55	--	--	32	--	--	26	26	1.72
12.02	0.83	3.69	1.20	1.16	53	--	--	30	--	--	29	29	2.00
						H_B = 50 cm							
0.13	0.63	3.85	0.63	0.63	489	23	0.26	463	23	0.33	--	--	0.05
0.27	0.66	3.82	0.64	0.65	467	28	0.25	429	21	0.29	--	--	0.10
0.40	0.68	3.79	0.69	0.69	412	25	0.20	361	18	0.21	--	--	0.15
0.53	0.70	3.78	0.72	0.72	386	24	0.17	327	17	0.18	--	--	0.20
0.67	0.71	3.77	0.74	0.74	365	23	0.15	302	16	0.16	--	--	0.25
0.80	0.73	3.76	0.76	0.76	349	23	0.13	281	15	0.14	--	--	0.30
0.93	0.74	3.75	0.78	0.78	333	22	0.11	262	14	0.13	--	--	0.35
1.07	0.75	3.74	0.80	0.79	320	21	0.09	247	13	0.11	1	--	0.40
1.20	0.76	3.73	0.82	0.81	103	--	--	234	13	0.10	2	2	0.45
1.34	0.77	3.73	0.83	0.83	99	--	--	221	12	0.10	4	3	0.50
1.60	0.79	3.71	0.96	0.86	93	--	--	202	11	0.08	6	5	0.60
1.87	0.79	3.71	0.88	0.87	90	--	--	193	11	0.08	7	7	0.70
2.14	0.80	3.71	0.90	0.89	87	--	--	182	10	0.07	8	8	0.80
2.40	0.81	3.70	0.92	0.91	84	--	--	58	--	--	9	9	0.90
2.67	0.81	3.70	0.94	0.92	81	--	--	55	--	--	11	11	1.00
3.34	0.82	3.70	0.97	0.95	77	--	--	50	--	--	13	13	1.25
4.01	0.82	3.69	1.00	0.98	73	--	--	47	--	--	15	15	1.50
4.67	0.83	3.69	1.02	1.00	70	--	--	44	--	--	16	16	1.75
5.34	0.83	3.69	1.04	1.02	67	--	--	42	--	--	18	18	2.00
6.6[illegible]	0.83	3.69	1.08	1.06	63	--	--	38	--	--	21	21	2.50
8.01	0.83	3.69	1.12	1.09	60	--	--	35	--	--	23	23	3.00
10.68	0.83	3.69	1.18	1.14	54	--	--	31	--	--	27	27	4.00

Table 3.

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (w_{av}^{aut}/w_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (w_{av}^{spr}/w_T)		Strength parameters						Heaving h_0 (cm)		Value of criterion (F_{oh})
					Sandy loams			Loams					
			Sandy loams	Loams	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Sandy loams	Loams	
IRBIT. Period of fall moisture accumulation - 1992 hours. Duration of freezing spell - 3960 hours. Minimal mean monthly temperature - 16.0°C.													
H_B = 250 cm													
1.57	0.56	3.74	0.60	0.59	531	30	0.29	548	26	0.43	--	--	0.05
3.14	0.58	3.71	0.65	0.63	463	27	0.24	456	22	0.32	--	--	0.10
4.71	0.60	3.68	0.70	0.68	400	25	0.19	368	19	0.22	--	--	0.15
6.28	0.62	3.65	0.77	0.74	345	22	0.12	297	15	0.16	--	--	0.20
7.84	0.65	3.62	0.83	0.80	100	--	--	241	13	0.11	3	1	0.25
9.41	0.67	3.60	0.89	0.86	89	--	--	202	11	0.08	7	6	0.30
10.98	0.69	3.58	0.95	0.91	80	--	--	57	--	--	11	10	0.35
12.55	0.70	3.56	1.00	0.96	72	--	--	49	--	--	15	14	0.40
14.12	0.72	3.55	1.06	1.01	66	--	--	43	--	--	19	17	0.45
15.69	0.73	3.54	1.11	1.06	60	--	--	38	--	--	23	21	0.50
18.83	0.76	3.52	1.20	1.15	52	--	--	31	--	--	29	28	0.60
H_B = [illegible] cm													
1.00	0.56	3.74	0.59	0.58	549	31	0.30	570	27	0.46	--	--	0.05
2.01	0.58	3.71	0.63	0.62	490	28	0.26	486	24	0.35	--	--	0.10
3.01	0.60	3.68	0.68	0.66	427	26	0.21	400	20	0.26	--	--	0.15
4.02	0.63	3.65	0.73	0.71	376	24	0.15	332	17	0.19	--	--	0.20
5.02	0.65	3.62	0.78	0.76	331	22	0.11	276	15	0.14	--	--	0.25
6.02	0.67	3.60	0.83	0.81	99	--	--	234	13	0.11	4	2	0.30
7.03	0.69	3.58	0.88	0.86	90	--	--	202	11	0.08	7	5	0.35
8.03	0.71	3.56	0.93	0.90	82	--	--	177	10	0.07	10	9	0.40
9.04	0.72	3.55	0.97	0.94	76	--	--	52	--	--	13	12	0.45
10.04	0.73	3.54	1.02	0.98	70	--	--	47	--	--	16	15	0.50
12.05	0.76	3.52	1.10	1.05	62	--	--	38	--	--	22	21	0.60
14.06	0.77	3.51	1.16	1.11	56	--	--	33	--	--	26	25	0.70
16.06	0.78	3.50	1.22	1.17	51	--	--	29	--	--	30	29	0.80
H_B 150 cm													
0.56	0.56	3.74	0.58	0.58	563	31	0.31	587	28	0.46	--	--	0.05
1.13	0.58	3.71	0.61	0.61	510	29	0.28	509	25	0.38	--	--	0.10
1.69	0.61	3.67	0.65	0.65	455	27	0.24	430	21	0.29	--	--	0.15

Table 3 (Cont'd).

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (W_{av}^{aut}/W_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (W_{av}^{spr}/W_T)		Strength parameters						Heaving h_o (cm)		Value of criterion (F_{oh})
					Sandy loams			Loams					
			Sandy loams	Loams	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Sandy loams	Loams	
						H_B = 150 cm (cont'd)							
2.26	0.63	3.64	0.70	0.69	405	25	0.19	364	19	0.22	--	--	0.20
2.82	0.65	3.62	0.74	0.75	365	23	0.15	312	16	0.17	--	--	0.25
3.39	0.67	3.59	0.78	0.77	332	22	0.11	272	14	0.13	--	--	0.30
3.95	0.69	3.58	0.82	0.80	102	--	--	240	13	0.11	3	1	0.35
4.52	0.71	3.58	0.86	0.84	95	--	--	214	12	0.09	5	4	0.40
5.08	0.72	3.55	0.90	0.87	88	--	--	192	11	0.08	8	7	0.45
5.65	0.74	3.54	0.93	0.90	82	--	--	174	10	0.06	10	9	0.50
6.78	0.76	3.52	0.99	0.96	74	--	--	49	--	--	14	14	0.60
7.91	0.77	3.51	1.04	1.01	68	--	--	43	--	--	18	17	0.70
9.04	0.78	3.50	1.09	1.05	63	--	--	39	--	--	21	20	0.80
10.17	0.79	3.49	1.13	1.09	59	--	--	35	--	--	24	23	0.90
11.30	0.80	3.49	1.17	1.13	55	--	--	32	--	--	28	26	1.00
14.12	0.81	3.48	1.25	1.20	49	--	--	27	--	--	32	32	1.25
						H_B = 100 cm							
0.25	0.57	3.73	0.56	0.56	598	33	0.33	628	30	0.54	--	--	0.05
0.50	0.59	3.69	0.61	0.60	517	30	0.28	512	25	0.39	--	--	0.10
0.75	0.62	3.68	0.64	0.64	469	28	0.25	443	22	0.30	--	--	0.15
1.00	0.64	3.63	0.68	0.67	427	26	0.21	386	19	0.24	--	--	0.20
1.26	0.66	3.61	0.71	0.70	393	25	0.18	342	18	0.20	--	--	0.25
1.51	0.68	3.59	0.74	0.75	366	23	0.15	307	16	0.16	--	--	0.30
1.76	0.70	3.57	0.77	0.76	341	22	0.12	277	15	0.14	--	--	0.35
2.01	0.71	3.55	0.80	0.79	321	21	0.09	252	13	0.12	1	--	0.40
2.26	0.73	3.54	0.82	0.81	102	--	--	233	13	0.10	3	2	0.45
2.51	0.74	3.53	0.85	0.84	95	--	--	215	12	0.09	5	4	0.50
3.01	0.76	3.52	0.89	0.88	88	--	--	188	10	0.07	8	7	0.60
3.51	0.78	3.51	0.93	0.91	83	--	--	57	--	--	10	10	0.70
4.02	0.79	3.50	0.96	0.94	78	--	--	52	--	--	12	12	0.80
4.52	0.80	3.49	0.99	0.97	74	--	--	48	--	--	14	14	0.90
5.02	0.80	3.49	1.02	0.99	70	--	--	45	--	--	16	16	1.00
6.28	0.82	3.48	1.07	1.04	64	--	--	39	--	--	20	20	1.25
7.53	0.82	3.47	1.12	1.09	60	--	--	36	--	--	23	23	1.50
8.79	0.83	3.47	1.15	1.12	56	--	--	33	--	--	26	25	1.75
10.04	0.83	3.47	1.19	1.15	54	--	--	30	--	--	28	28	2.00
12.55	0.83	3.47	1.25	1.20	49	--	--	27	--	--	32	32	2.50

Table 3(Cont'd).

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (W_{av}^{aut}/W_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (W_{av}^{spr}/W_T)		Strength parameters						Heaving h_0 (cm)		Value of criterion (F_{oh})
					Sandy loams			Loams					
			Sandy loams	Loams	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Sandy loams	Loams	
						H_B = 75 cm							
0.14	0.58	3.71	0.58	0.58	562	31	0.31	576	27	0.47	--	--	0.05
0.28	0.61	3.67	0.61	0.61	518	30	0.28	506	25	0.38	--	--	0.10
0.42	0.63	3.64	0.65	0.65	462	27	0.24	429	21	0.29	--	--	0.15
0.56	0.66	3.61	0.68	0.68	425	26	0.21	381	19	0.24	--	--	0.20
0.71	0.68	3.59	0.71	0.70	397	25	0.18	343	18	0.20	--	--	0.25
0.85	0.69	3.57	0.73	0.73	373	24	0.16	313	16	0.17	--	--	0.30
0.99	0.71	3.56	0.76	0.75	353	23	0.13	288	15	0.15	--	--	0.35
1.12	0.72	3.55	0.78	0.77	337	22	0.11	268	14	0.13	--	--	0.40
1.27	0.74	3.53	0.80	0.79	321	21	0.09	249	13	0.12	1	--	0.45
1.41	0.75	3.53	0.82	0.81	103	--	--	234	13	0.10	3	2	0.50
1.69	0.77	3.51	0.86	0.85	95	--	--	209	11	0.09	5	5	0.60
1.98	0.78	3.51	0.88	0.87	91	--	--	195	11	0.08	7	6	0.70
2.26	0.79	3.50	0.90	0.89	86	--	--	81	10	0.07	8	8	0.80
2.54	0.80	3.49	0.93	0.91	83	--	--	57	--	--	10	10	0.90
2.82	0.81	3.48	0.95	0.93	80	--	--	54	--	--	11	11	1.00
3.53	0.82	3.48	0.99	0.97	74	--	--	48	--	--	14	14	1.25
4.24	0.82	3.47	1.02	1.00	70	--	--	45	--	--	16	16	1.50
4.94	0.83	3.47	1.05	1.03	67	--	--	41	--	--	18	18	1.75
5.65	0.83	3.47	1.07	1.05	64	--	--	39	--	--	20	20	2.00
7.06	0.83	3.47	1.12	1.09	60	--	--	36	--	--	23	23	2.50
8.47	0.83	3.47	1.15	1.12	55	--	--	33	--	--	26	25	3.00
11.30	0.83	3.47	1.22	1.18	51	--	--	28	--	--	30	30	4.00
						H_B = 50 cm							
0.06	0.63	3.64	0.63	0.63	489	28	0.26	463	23	0.33	--	--	0.05
0.13	0.66	3.61	0.66	0.66	453	27	0.23	412	21	0.27	--	--	0.10
0.19	0.68	3.59	0.68	0.68	427	26	0.21	378	19	0.23	--	--	0.15
0.25	0.70	3.57	0.69	0.69	414	25	0.20	359	18	0.21	--	--	0.20
0.31	0.71	3.56	0.72	0.72	383	24	0.17	321	17	0.18	--	--	0.25
0.38	0.73	3.55	0.74	0.74	364	23	0.15	298	16	0.16	--	--	0.30
0.44	0.74	3.53	0.76	0.76	349	23	0.13	279	15	0.14	--	--	0.35
0.50	0.75	3.53	0.78	0.78	336	22	0.11	263	14	0.13	--	--	0.40
0.56	0.76	3.52	0.79	0.79	325	22	0.10	251	13	0.12	--	--	0.45
0.63	0.77	3.51	0.81	0.80	105	--	--	240	13	0.11	2	1	0.50
0.75	0.79	3.50	0.83	0.83	100	--	--	221	12	0.10	4	3	0.60
0.88	0.79	3.50	0.84	0.84	98	--	--	214	12	0.09	4	4	0.70

Table 3 (Cont'd).

Water conductivity factor, K_1 (cm^2/hr)	Relative fall moisture content (W_{av}^{aut}/W_T)	Freezing parameter d ($cm/hr^{0.5}$)	Relative spring moistness (W_{av}^{spr}/W_T)		Strength parameters						Heaving h_0 (cm)		Value of criterion (F_{oh})
					Sandy loams			Loams					
			Sandy loams	Loams	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Moduli (kg/cm^2)	Interval friction angle, °	Adhesion (kg/cm^2)	Sandy loams	Loams	
						H_B = 50 cm							
1.00	0.80	3.49	0.86	0.85	94	--	--	204	11	0.08	5	5	0.80
1.13	0.81	3.48	0.87	0.87	92	--	--	195	11	0.08	6	6	0.90
1.25	0.81	3.48	0.89	0.88	89	--	--	189	10	0.07	7	7	1.00
1.57	0.82	3.48	0.91	0.90	85	--	--	175	10	0.06	9	9	1.25
1.88	0.82	3.47	0.93	0.92	82	--	--	55	--	--	10	10	1.50
2.20	0.83	3.47	0.95	0.94	79	--	--	53	--	--	11	12	1.75
2.51	0.83	3.47	0.96	0.95	77	--	--	51	--	--	12	13	2.00
3.14	0.83	3.47	0.99	0.97	74	--	--	48	--	--	14	14	2.50
3.77	0.83	3.47	1.01	0.99	71	--	--	45	--	--	16	16	3.00
5.02	0.83	3.47	1.06	1.03	65	--	--	41	--	--	19	19	4.00

With the aid of these tables, we easily solve a number of problems which are important for the planning and construction of highways.

1. An evaluation of the suitability of local cohesive soils for building a roadbed, proceeding from an avoidance of inadmissible heaving.

2. Determination of required height of fill based on the same criterion.

3. The establishment of design values for the strength and stress parameters of roadbed soil of the adopted design, required for planning a road covering and calculating the roadbed stability.

4. Prediction of strength and stress parameters of roadbed soil in the existing roads.

5. An estimation of the possible amount of heaving on the existing roads.

6. A determination of soil freezing rate in the roadbed in the interests of organizing operations and utilizing the existing highways.

7. Finding the optimal type of road design.

Let us examine a procedure of solving these problems in the sequence shown in Table 3 for the Irbit Rayon.

1. Let us assume that based on the samples taken during the period of surveys based on the available procedure [10], we have determined the moisture conductivity factor K_1 of silty loam. Its value proved to equal $K_1 = 5.6$ cm^2/hr. In the period of surveys, the mossy-vegetative cover was severely damaged within the limits of the right-of-way. The level of ground water was located at depth $H_{1gw} = 50$ cm from the surface. The intent is to build a roadbed in the embankments with the subsequent construction of light improved covering. We are required to assess the suitability of local soils for building the embankments.

In connection with the planned construction of a light-weight improved covering, the value of total heaving according to N. A. Puzakov [12e] should not exceed 6 cm. Considering each section of Table 3 (at actual H_β-values) by column corresponding to the amount of heaving of embankments made of loam equalling 6 cm, we easily find that the maximally permissible value of K_1 equals 5.59 cm^2/hr for $H_\beta = 150$ cm. Consequently the indicated soils characterizing $K_1 = 5.6$ cm^2/hr can be utilized in a revetment for $H_\beta \geqslant 150$ cm, i.e. at the latter's height $H_{//} \geqslant H_\beta - H_{1gw} = 150 - 50 = 100$ cm.

In the algorithm of the problem, we have adopted the condition of estimating the moisture-conducting properties of soil in the zone by a unified moisture conductivity factor, K_1. Such an assumption, valid for the zero points and excavations, is approximate in application to embankments. For the conditions of the example which is being solved, in connection with the disturbance of the mossy-vegetative cover and the slight depth of soil layer from surface to the LGW (50 cm), its application is also fairly valid especially if we consider the compaction of the soil in the base to the LGW under the effect of the weight of the fill and the passing traffic. For other conditions (having preserved the mossy-vegetative cover and a considerable depth of soil layer from the surface to the LGW or above-frost water), a more precise formulation and solution to the "three-layer" problem has been given in the report by R. Z. Poritskiy [12d]. However, a refinement of the importance of the inaccuracy permitted by us in the one-dimensional "single-layer" problem as compared with the results for the "three-layered" problem is still a question for the future.

The investigations conducted by R. Z. Poritskiy [12d] indicated that the mossy-vegetative layer having been retained in the base decreases the inflow of moisture into the body of the embankment from the cohesive soils. Therefore, the "single-layer" system adopted by us in developing the algorithm in any case conditions the reserve in the quantitative values of the parameters printed on the page of output data (Tables 2-3).

2. The determination of the required height of fill in the example under discussion in essence has already been conducted. (Minimal $H_н$ = 100 cm).

3. The design values of the strength and stress parameters are determined from Table 3 in the following manner:

a) For $H_н = H_в - H_{1gw} = 150 - 50 = 100$ cm

$E_y = 198$ kg/cm^2, $\varphi = 11^\circ$, $C = 0.08$ kg/cm^2

b) For $H_н = H_в - H_{1gw} = 200 - 50 = 150$ cm. The value closest to that established experimentally $K_1 = 5.6$ cm^2/hr is found for the embankments in Table 3 (at $H_в = 200$) $K_1 = 5.52$ cm^2/hr.

From the column corresponding to $K_1 = 5.52$ cm^2/hr, we easily establish that $Ey = 284$ kg/cm^2, $\varphi = 15^\circ$ and $C = 0.14$ kg/cm^2.

As is evident from Table 3, with an embankment of a given height, heaving is absent.

c) For $H_н = H_в - H_{1gw} = 250 - 50 = 200$ cm. Interpolating in Table 3 between the values $K_1 = 5.18$ cm^2/hr and $K_1 = 6.90$ cm^2/hr, we find for $K_1 = 5.60$ cm^2/hr, $Ey = 359$ kg/cm^2, $\varphi = 18^\circ$ and $C = 0.21$ kg/cm^2. As in the previous case, heaving $h_o = 0$.

4 and 5. For predicting the strength and stress parameters of the roadbed and also the heaving values, it is necessary to know:

design of roadbed (excavation, fill); type of soil (sandy loam, loam); distance of bottom of road covering from LGW (H_β); and value for the moisture conductivity factor K_1.

Thus for a road section with a stagnation of surface water, possible during the fall, at the foot of the roadbed built in an embankment with a height of 75 cm of silty sandy loam with $K_1 = 2.50$ cm^2/hr, we find at $H_\beta = 75$ cm·

$E_o = 88$ kg/cm^2 [See Note] and $H_o = 8$ cm ([Note]: In Tables 2-3 in the columns where data are lacking for φ and C, in the column of moduli, we indicate the stress moduli E_o based on the relationship $E_o \cong 1/3$ Ey).

6. Since in the output data, we have the value α, at any time we can easily find freezing depth τ of the roadbed with the aid of relationship following from (22):

$$h_{3n} = \alpha\sqrt{\tau} - \left(\sum_{i=1}^{n} h_i\right)_{3n} \qquad (37)$$

7. The quest for an optimal road design can be conducted based on the method developed by V. M. Sidenko [11], proceeding from providing the minimal overall cost of roadbed and road topping. To a fixed height of embankment H_H (or H_β -value for excavations and zero points), there correspond the actual cost of roadbed (C_{rb}) and the inherent stress and strength parameters which can readily be found from the tables analogous to Tables 2-3. Furthermore, for each magnitude of values H_H or H_β with the aid of the available methods, we determine the design and then the cost of the road covering (C_{rc}). It is evident that we can find the road design for which there will occur min ($C_{rb}+C_{rc}$).

Tables similar to 2-3 have been utilized successfully by the Lengiprotrans.

In planning the roadbed for the permafrost regions, we should remember that the consideration of its strength and stress parameters is inadequate. On the thawing of ice-saturated soils of the base under the fill, additional settlements exceeding those permitted can develop. It is also necessary to check an embankment of planned height (H_H) for subsidence. The latter can be determined on the basis of the available [words illegible] [12a, 12c].

If the anticipated settlement exceeds that permitted, we can increase the height of fill or introduce into the composition of road design the layers of heat-insulation, determined with the aid of tables, similar to 2-3 the new parameters of the roadbed (E_o; Ey; φ; C; H_o); we can also calculate the value for the depth of road covering, and based on a heat-engineering calculation of thawing, we can compute the value for the roadbed settlement. At the present time, this problem, namely calculating the thawing of a multilayered road construction and base with the establishment of the anticipated settlement has also been programmed. The algorithm and the program for the problem envisage an alternate solution to the problem (various layers of the road covering and height of embankment) in each actual example. In addition, on the printout on the output data sheet, there will be shown the heat-physical parameters of the roadbed soil and of all layers in the road covering (λ; C; Q). At the basis of finding λ, we place the theoretical method discussed in report [5] and confirmed experimentally. The primary materials from the calculations on the computer for the thawing and determination of road construction settlements will be presented to the conference in Tyumen'.

The adoption of the computer into the planning of road designs into the regions of permafrost and severe climate will favor the formulation of planning the highways on a higher scientific level.

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