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# DESIGN OF ENGINEERING STRUCTURES AND CONSTRUCTION OF A REGIONALLY BRANCHED HIGHWAY COMPLEX

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**Abstract:** The article examines the issues of design and construction of engineering structures of regionally branched highways. Special attention is paid to route selection, geometric parameters of roads, and the application of geodetic and tacheometric methods in engineering surveys. The classification of highways, key regulatory requirements, and methods of detailed route layout are analyzed. The obtained results contribute to improving the accuracy of design solutions and ensuring safe and efficient operation of highways.

**Key words:** highways, route design, engineering structures, geodetic surveys, tacheometric survey, geometric parameters, traffic safety.

**Annotatsiya:** Mazkur maqolada hududiy jihatdan tarmoqlangan avtomobil yo'llarining muhandislik inshootlarini loyihalash va qurish bilan bog'liq masalalar ko'rib chiqiladi. Yo'nalishni tanlash, avtomobil yo'llarining geometrik parametrlari hamda muhandislik izlanishlarida geodezik va taxeometrik usullardan foydalanishga alohida e'tibor qaratilgan. Avtomobil yo'llarining tasnifi, asosiy normativ talablar hamda yo'nalishni batafsil belgilash usullari tahlil qilingan. Olingan natijalar loyihaviy yechimlar aniqligini oshirishga va avtomobil yo'llarining xavfsiz hamda samarali ekspluatatsiyasini ta'minlashga xizmat qiladi.

**Kalit so'zlar:** avtomobil yo'llari, yo'nalishni loyihalash, muhandislik inshootlari, geodezik izlanishlar, taxeometrik suratga olish, geometrik parametrlar, harakat xavfsizligi.

**Аннотация:** В статье рассматриваются вопросы проектирования и строительства инженерных сооружений регионально разветвлённых автомобильных дорог. Особое внимание уделено выбору трассы, геометрическим параметрам дороги, а также применению геодезических и тахеометрических методов при инженерных изысканиях. Приведены классификация автомобильных дорог, основные нормативные требования и методы детальной разбивки трассы. Полученные результаты позволяют повысить точность проектных решений и обеспечить безопасность и эффективность эксплуатации автомобильных дорог.

**Ключевые слова:** автомобильные дороги, проектирование трассы, инженерные сооружения, геодезические изыскания, тахеометрическая съёмка, геометрические параметры, безопасность движения.

## INTRODUCTION

Modern highways are complex engineering structures. They must ensure the movement of vehicle flows at high speeds. Roads are designed and built in such a way that vehicles can fully realize their technical capabilities, so that skidding and overturning do not threaten vehicles on curves, ascents, and descents. Throughout the year, the road must be durable and withstand dynamic loads and weather conditions. The growth of road

transport, its cost, the conditions for organizing transportation, and ensuring traffic safety largely depend on the development and condition of the road network. When driving on poor-quality roads, speed decreases, fuel consumption increases, transportation costs rise, and, moreover, the number of traffic accidents increases and vehicle wear intensifies. On a well-designed and properly constructed road with a hard and even surface, a vehicle can develop higher speeds and carry loads corresponding to its maximum payload capacity. Thus, the importance of highways under modern living conditions is increasing significantly, and the better the technical condition of roads, the more fully and economically road transport is utilized. These operational features must be taken into account by designers, builders, and maintenance personnel, who are obliged to ensure normal year-round road service over a long period. For this purpose, it is necessary to create a surveying framework for setting out all elements of the highway in the field, to calculate the volumes of earthworks during the construction of embankment structures for roads, and to select a rational route alignment.

Highways in Uzbekistan have enormous socio-economic significance. Their role increased particularly in the second half of the twentieth century due to the mass motorization of the national economy, associated with the emergence of new industrial sectors in the regional economies and the overall socio-economic development of the country. The degree of development of the road network largely determined issues of transport accessibility of provinces and regions across the vast country. The military-strategic position of the state depended on the condition and intensity of the development of road communications. Therefore, road construction became of decisive importance in the formation and development of large territorial-industrial complexes and in solving the strategic socio-economic objectives of the state. The construction of highways was especially important for those regions of the country where large-scale construction projects related to the establishment of new enterprises, as well as the construction of new cities, were underway, since ensuring uninterrupted supply of all necessary resources at such major facilities is simply impossible without a developed road infrastructure. In this regard, the Fergana region serves as a good example of road network development, associated with the commencement of construction of large plants and other industrial facilities, ranging from oil refineries to automobile manufacturing enterprises. Establishing a well-developed system of highways was absolutely essential.

## REVIEW OF LITERATURE ON THE SUBJECT

Issues related to the design and construction of engineering structures for regionally branched highway networks have been widely studied by both domestic and foreign scholars. These studies are aimed at improving the technical condition of road infrastructure, optimizing design processes, and ensuring traffic safety.

In the works of Yakubov M.S., Turaev Sh.Sh., and Zikraev A.A., the factors for improving the system of design and construction of engineering structures within regionally branched highway networks are analyzed. The authors substantiate the need to enhance the efficiency of design solutions with due consideration of territorial characteristics and technical and economic indicators. This approach is directly related to the issues addressed in the article concerning route selection and the justification of its geometric parameters.

In the studies by Norinov M.U. and Zikraev A.A., special attention is paid to modeling road facility design processes based on artificial intelligence technologies and real-time systems. The authors demonstrate that the application of digital technologies makes it possible to increase calculation accuracy and optimize decision-making processes in design. This approach serves as an important theoretical basis for improving geodetic measurements and routing processes discussed in the article.

In the works of Zikraev A.A., the importance of highway route selection, justification of geometric elements, and compliance with regulatory requirements in design is emphasized. The principles proposed by the author theoretically strengthen the solutions presented in the article, particularly with regard to determining the plan elements and longitudinal profile of the route.

Among foreign researchers, the Russian scholar V.G. Babkov should be noted, whose works examine in detail the issues of selecting geometric parameters of highways and ensuring traffic safety. In turn, the British researcher R. Lamm and his co-authors substantiate the importance of aligning road alignment elements with driver perception and accounting for ergonomic factors in highway design. These scientific principles theoretically confirm the requirements for route smoothness and traffic safety discussed in this article.

## RESEARCH METHODOLOGY

Highways are capital-intensive facilities; therefore, road design must be aimed at achieving high operational performance with minimal construction costs. When selecting design alternatives, priority should be given to those that ensure traffic safety at design speeds, as well as a long service life of the roadbed, pavement structure, and engineering structures. A properly prepared design must ensure: (a) compliance of the road's

operational indicators with the specified requirements; (b) stability and strength of road structures; (c) minimum construction cost; and (d) completion of construction within the specified time frame. Such a division of the design process is usually adopted for convenience of study and organization. Surveys and road design should not be considered as separate processes. In fact, surveys constitute an essential part and the initial stage of design, since, first, during surveys the main design issues are resolved on site, such as the alignment of the route in plan and profile and the placement of road structures; second, surveys provide the data necessary for design development. Highways are classified into three types: (a) motorways; (b) expressways; and (c) conventional roads. Each type has its own capacity, reliability, and service life, all of which must be taken into account and thoroughly analyzed during the design process. In addition, during design works it is important to consider the climatic zone of construction, the categories of connecting roads, traffic intensity, and other factors.

The selection of the route alignment between specified points depends on the road category, terrain, soil-geological, and hydrological conditions. It is not always possible to lay a road along the shortest distance between given points. Ravines, rivers, and wetlands often have to be bypassed, resulting in an elongated alignment laid out as a broken line. At locations where the alignment direction changes in order to bypass obstacles, a turning angle is formed. As a result, the route represents a combination of straight sections of varying lengths connected by smooth curves. To preserve the surrounding landscape during road construction, the principles of landscape design are applied. The dimensions of the geometric elements of the road are determined in relation to the terrain features. Landscape road design ensures compliance with environmental protection and land-use regulations. Road design solutions must ensure: (a) organized, safe, convenient, and comfortable traffic flow at design speeds; (b) uniform driving conditions and compliance with the principle of visual guidance for drivers; (c) convenient and safe placement of junctions and intersections; (d) adequate tire adhesion to the roadway surface; appropriate road equipment, including protective road facilities; and (e) the necessary buildings and structures for road and motor transport services, among others. When selecting route alternatives and road structure designs, in addition to technical and economic indicators, the degree of environmental impact during both the construction and operation phases, as well as the integration of the road with the landscape, should be considered. Land allocated for the construction of highways and road structures generally consists of areas unsuitable for agriculture. Allocation of land from forest fund areas is primarily carried out using non-forested land or areas covered with shrubs and low-value vegetation. The allocation and withdrawal of land for the construction, reconstruction, or repair of highways and road structures are carried out in accordance with procedures established by law. When highways, bridge crossings, and other road structures are located on water bodies and coastal zones, additional mandatory approvals are required from authorities responsible for water use regulation and protection, as well as from agencies overseeing fishery protection and sanitary supervision.

## ANALYSIS AND RESULTS

The minimum number of survey control points depending on the survey scale is given below:

Survey scale: 1:500, 1:1000, 1:2000, 1:5000.

Minimum number of survey points:

– per 1 km<sup>2</sup>: 142, 80, 50, 22;

– per one map sheet: 9, 20, 50, 89.

Survey control points are usually placed on elevated areas with good visibility. The distances between survey points should not exceed 350 m and should not be less than 50 m. In exceptional cases, the minimum distance between survey control points may be reduced to 20 m, provided that the theodolite is centered on a pencil inserted in place of the removed peg and sighting is carried out not on a ranging pole but directly on the peg.

The alignment of a linear structure is used as survey control (Figure 1) in the following cases:

- during surveys of road corridor strips for the design of surface drainage systems;
- for office-based route alignment on complex terrain sections;
- in areas with complex engineering and geological conditions;
- during surveys for the design of small engineering structures;
- for the design of at-grade intersections and junctions of highways, etc.

The route is also often used as part of a survey control network of another type.

P1, P2 are points of the geodetic network;

t I – St VIII are survey points;

Vug1 – Vug3 are the vertices of route deflection angles (Figure 1).

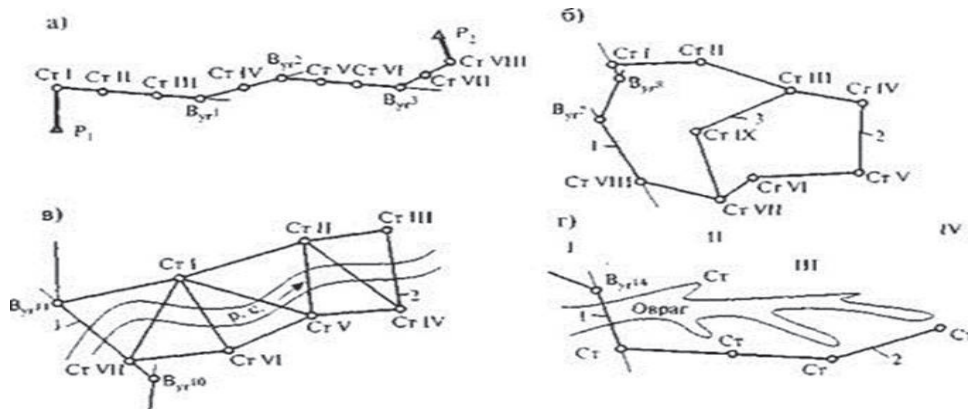


Figure 1. Survey control of a linear object (hanging traverse)

The establishment of survey control points is initially carried out using wooden markers and ground points, with a nail driven into the center of each point, above which the theodolite is centered with an accuracy of  $\pm 0.5$  cm. For high-importance surveys over large areas, where the survey points must be preserved, they are fixed using standard wooden or reinforced-concrete posts. On the front face of the markers and fixing posts, the abbreviated name of the organization conducting the survey, the survey point number, and the year of the survey are indicated.

A highway cross-section consists of the carriageway, shoulders, slopes, and ditches. The width of the carriageway may range from 6 to 15 m depending on the road category. To strengthen the carriageway, shoulders with a width of 2 to 3.75 m are constructed on both sides. Slopes adjoin the shoulders. The line separating the shoulders from the slopes is called the edge of the roadbed. Design elevations are given along this edge in the longitudinal profile. The route is understood as the spatial position of the longitudinal axis of the designed linear structure, coordinated with the terrain. When selecting the optimal variant of a terrain section, the route must meet the following conditions:

- ensure construction and reliable operation of the linear structure with the specified characteristics;
- comply with the constraints imposed by design standards;
- have technical and economic indicators that optimize the value of a numerical efficiency criterion.

As a result of office-based route alignment, a route plan (the projection of the route onto a horizontal plane) and a longitudinal profile (a vertical section along the route axis) are obtained. On the plan, the route consists of straight sections connected to each other by circular curves (Figure 2).

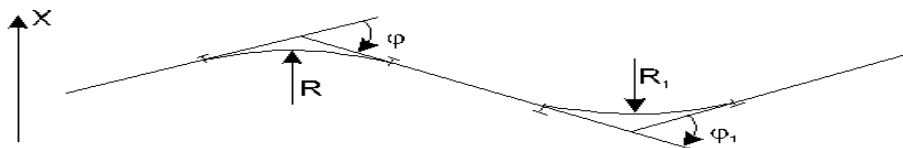


Figure 2. Route alignment in plan

Highways are classified into the following groups:

a) Roads of national importance connect the capitals of republics, major industrial and cultural centers, as well as the capital with major centers of neighboring states. These roads are characterized by the highest level of technical standards. Roads of republican importance connect the main administrative, cultural, and economic centers of republics and regions with the republican capital and with each other.

b) Roads of local importance are subdivided into regional roads, district roads, and economic or departmental roads. Departmental roads are intended to provide connections between collective farms, state farms, and industrial plants. Local roads serve individual economic entities and departments. Roads and streets within populated areas are used for transport connections within settlement boundaries. Some of these roads and streets may also serve transit traffic.

According to their technical level, highways are divided into five categories (SNiP H-D.5-72). The classification is based on the national economic significance of roads, daily traffic intensity or annual freight load, and other indicators. The road categories are as follows:

Categories I-II are national and republican motorways connecting the most important economic regions of the country and major centers. On Category I roads, daily traffic intensity exceeds 6,000 vehicles, with a basic design speed of 150 km/h; they have four or more traffic lanes with a median separating opposite traffic

directions. On Category II roads, daily traffic intensity ranges from 3,000 to 6,000 vehicles, with a design speed of 120 km/h and two traffic lanes.

Category III roads are of republican and regional importance, with traffic intensity of 1,000–3,000 vehicles per day and a basic design speed of 100 km/h.

Categories IV–V roads are local roads with low traffic intensity and basic design speeds of 80–60 km/h.

The main requirement imposed on road alignments is smoothness and safety of movement at specified speeds. In this regard, maximum ruling gradients and minimum curve radii are strictly regulated for highways and railways (Table 1). On curves with small radii, the maximum permissible gradient is eased (reduced). On railways, this easing of the gradient, expressed in fractions, is determined by the formula:

$$\Delta i = (12.2\varphi^\circ) \quad (1)$$

where  $\varphi^\circ$  and  $K$  are the deflection angle in degrees and the curve length in meters, respectively. Since

$$K = R\varphi_{\text{rad}} = \frac{R\varphi^\circ}{p^\circ}, \quad \text{where } R \text{ is the curve radius in meters and } p^\circ \text{ is the radian expressed in degrees}$$

(57.3°), then:

$$\Delta i = \frac{12.2p^\circ}{R} = \frac{700}{R} \quad (2)$$

For example, with a ruling gradient  $i_p = 20\%$ , the maximum permissible gradient on a curve with radius  $R = 700$  m is:

$$i = i_p - \Delta i = 20 - (700 \div 700) = 19\% \quad (3)$$

For public highways, the width of the carriageway and the roadbed is established depending on the road category and the design traffic intensity in accordance with SNiP 2.05.02-85. The slope steepness of embankments up to 3 m in height on Category I–III roads, with embankment heights up to 2 m, should not be steeper than 1:3. Areas for stations and passing loops, as well as large track yards, are usually located on straight horizontal sections, and only under difficult conditions is it permitted to place passing loops and intermediate stations on sections with gradients not exceeding 20‰. In such cases, curves must face the same direction, and the curve radii must be at least 1,000 m for main roads and 600 m for local lines (Table 1, 2).

Table 1. Road Categories and Main Design Parameters

#### Highways

Parameter	Category I	Category II	Category III	Category IV	Category V
Maximum longitudinal gradient (‰)	30	40	50	60	70
Minimum horizontal curve radius (m)	1000	600	400	250	125
Minimum vertical curve radius – convex (m)	25,000	15,000	10,000	5,000	2,500
Minimum vertical curve radius – concave (m)	8,000	5,000	3,000	2,000	1,500

#### Railways

Parameter	Category I	Category II	Category III
Ruling gradient (‰)	15	15	20
Maximum horizontal curve radius (m)	4,000	4,000	4,000
Minimum recommended horizontal curve radius (m)	1,200	800	600
Recommended vertical curve radius (m)	10,000	10,000	–

Table 2. Main Parameters of the Carriageway and Roadbed of Highways

Indicator	I-a	I-b	II	III	IV	V
Number of traffic lanes	4 / 6 / 8	4 / 6 / 8	2	2	2	1
Lane width (m)	3.75	3.75	3.75	3.5	3.0	–
Carriageway width (m)	15 / 22.5 / 30	15 / 22.5	7.5	7.0	6.0	4.5
Shoulder width (m)	3.75	3.75	3.75	2.5	2.0	1.75
Minimum median width (m)	6	5	–	–	–	–
Roadbed width (m)	28.5 / 36 / 43.5	27.5 / 35	15	12	10	8

A route alignment is defined as the axis of a designed linear structure, designated and fixed on the ground or plotted on a map, photoplan, or digital terrain model. The main elements of a route are the plan—its projection onto a horizontal plane—and the longitudinal and cross profiles, which are vertical sections along and across the designed line of the structure. Route staking-out begins with its main points, which include the beginning and end of the route, vertices of deflection angles, and points of intersection with the axes of various structures. After the main points are set out, a theodolite traverse is laid along the route, which is divided into 20-meter segments using pickets. The beginning of the route is marked by picket number 0, so that the number of each picket indicates the number of twenty-meter segments from the start of the route. Characteristic terrain points encountered between pickets are marked with plus points, which indicate the distance to the nearest rear picket, for example, PK 0 + 19.0. Plus points are intended to refine the terrain representation between pickets (Figure 3).

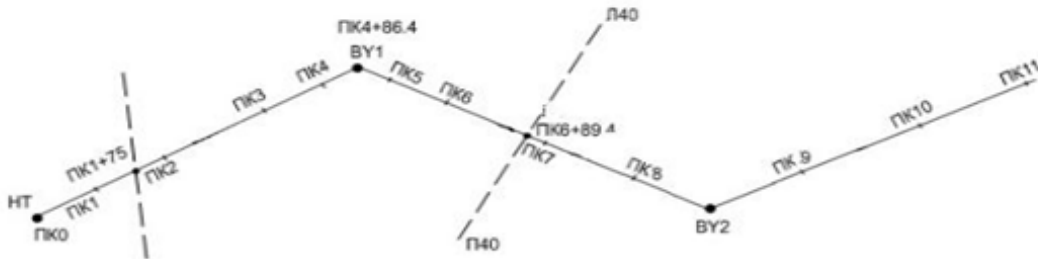


Figure 3. Route staking-out plan

During the construction of linear structures in curved sections, a detailed setting-out is carried out. This setting-out can be performed using three methods:

- the rectangular coordinate method;
- the polar method;
- the method of extended chords.

In this study, the detailed setting-out of the curve was performed using the extended chord method. Detailed setting-out of horizontal circular curves under constrained terrain conditions may also be carried out using rectangular coordinates  $X_i$  and  $Y_i$  measured from the chords. The values are calculated using the following formulas:

1. By assigning a chord length of 5 m, the offset is determined as:

$$y = \frac{b^2}{2R}; d = 2y = \frac{b^2}{R} \quad (1)$$

$$a = \frac{b^2}{R} \quad (2) \quad \text{where } b = 5 \text{ m is the adopted chord length.}$$

2. The number of points is determined using the formula (Figure 4):

$$N = \frac{R}{5} \quad (3); \quad X_i = R \sin \alpha \quad (4); \quad Y_i = 2R \sin^2 \frac{\alpha}{2} \quad (5)$$

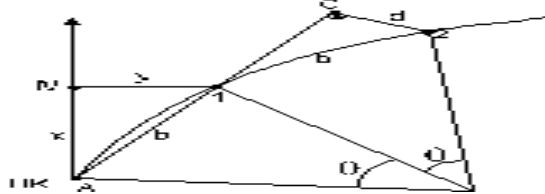


Figure 4. Setting-out of horizontal circular curves using extended chords

Using the calculated offset value  $a$ , all points of the curve are set out except for the first point. The first point is determined using rectangular coordinates  $x = b$  and  $y = a/2$ .

$$N = \frac{128.22}{5} = 26, y = \frac{5^2}{2 \times 150} = 0.08, a = \frac{5^2}{150} = 0.16, d = 2 \times 0.08 = 0.16$$

$$X = 150 \times \sin 1^\circ 54' 8'', Y = 2 \times 150 \times \sin^2 0^\circ 57' 90'' = 0.08$$

## CONCLUSIONS AND SUGGESTIONS

Based on the constructed cross-sections, the volume of earthworks for the roadbed was calculated. The successful operation of road transport, in addition to technical and organizational aspects of transportation, largely depends on the condition of highways and their technical parameters. Steep gradients and sharp curves reduce vehicle speed and payload capacity. Surface irregularities, potholes, and ruts not only reduce speeds and loads but also cause premature vehicle wear. Highways represent a complex system of engineering structures designed to ensure continuous, convenient, and safe vehicle movement under design loads and established speeds. The condition parameters of road elements and road structures determine the overall technical level of the highway.

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