

COMPUTER TECHNIQUE IN RAILWAY CONSTRUCTION AND OPERATION

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I. Overall statement of the problem

From among the transportation systems it is the rail transportation whose operation is the most suitable for central controlling, mechanization and automation. Explanation for this may be that in contradistinction to the other branches of transportation, the track, yard equipment and other service installations, rolling stock (tractive and hauled vehicles), maintenance and repair plants, etc. are managed centrally, their construction, operation and maintenance may be integrated into a uniform technical process, positively affected by the scheduled rail traffic and its character of mass transportation. The keen competition developed in recent decades between rail and highway required exact computations to determine the economy of these significant branches of land transportation which, in turn, need the application of modern cybernetic means. At the same time it can be stated that, due to the extraordinarily intricate and varied railway operation, to the numerous factors affecting rail service — which, in their combined effect, are of random character and of wide scatter — the estimate of the demand on transportation may only be carried out on the basis of the theory of probability.

Thus, it is seen that the introduction of up-to-date computer technique in all of the fields of railway operation became an immediate necessity. Just like in other fields of production, the first phase of computerization has ended at a number of foreign railways where the economic motivation of the adoption of computers was the economy in clerical staff. To-day, the computers are wanted for the research of the optimum solutions of engineering and economic problems. To this end, civil engineers have first of all to computerize the planning of railway operation processes and engineering planning work of track and yard construction.

The international organization of the railways UIC endeavours to summarize the results obtained in this field by the world's railways. To-day, already numerous programs have been developed in all fields of railway operation. Some examples of problems solved and programs established at the railways

of the Soviet Union, U.S.A. and Japan, interesting first of all civil engineers, will be presented below:

- A model simulating the bottlenecks of an existing marshalling yard, of help to decide whether a new yard should be built or the existing one reconstructed.
- Checking the route for loads out of gauge.
- Bridge loading program for determining the stresses caused by overload running at different speeds, and if necessary, for designing a bypass.
- Computation of train performances of trains of arbitrary sets on different sections of railway lines.
- Permeability of single-track lines, simulation model of C.T.C.
- Simulation of time tables.
- Simulation model for planning and operating marshalling yards.
- Program for the analysis of economical effects of closing secondary lines of light traffic.
- Computer processing of data recorded by track-recording coach and scheduling the track maintenance works.

2. Research work at the Department of Railway Construction

In the research work aiming at the adoption of computers in railway operation, the Department of Railway Construction participated already in 1966 by working out the problem: "Computerization of designing track structures". For several years, the Department processed records of the track-recording coaches by computer, then simulated the operation of hump yards, designed railway track profiles in connection with optimization of running times of trains.

Though not too many programs have been developed at the Department, some of them merit to be mentioned for their subject and professional value, even on an international level. Also simulation programs of significant span have been run on computers of middle and low capacity. These research investigations were carried out in close co-operation with the Design Bureau of the Hungarian State Railways; the first steps in this direction were made with the assistance of the Department Working Team of the Hungarian Academy of Sciences. Later on this work has been extended to the solution of actual problems on assignment by the Ministry of Transport and Communication and the Underground Railways of Budapest.

It is to be noticed that, following the development of the first programs, the relevant work of the Department has been extended to the university teaching, and the computerized planning has been incorporated in the subjects

“Railway Construction”, “Railway Operation” based on the instruction of computer technique at the Faculty of Civil Engineering.

The students in Highway and Railway Construction solve some details of railway planning problems — calculation of formation volumes, track structures, computation of running times of trains — on the computer of the Faculty and in diploma projects, an increasing emphasis has been laid on the development of computer programs.

3. Examples of computerized problems

In the following, some problems of major significance in the field of railway construction will be presented in order to demonstrate the use of the computer. In the following, computing problems developed at the Department of Railway Construction of the Technical University, Budapest, will be described, concerning

1. computer design of tracing railway lines in the horizontal plane,
2. determination of profiles of railway lines and the volume of earthwork,
3. tracing underground railway lines.

3.1. Computer design of tracing railway lines in the horizontal plane

Designing railway lines is carried out by making use of the methods of analytic geometry, familiar in surveying practice.

On the basis line defined by points A_1 and A_2 given as starting data, let us measure the defining distances u_1 and v_1 of point E_1 of the track axis (Fig. 1).

Let us calculate the bearing $\delta_{A_1A_2}$; in its knowledge, the co-ordinates of point E_1 can be determined:

$$Y_{E_1} = Y_{A_1} + u_1 * \sin(\delta_{A_1A_2}) + v_1 * \cos(\delta_{A_1A_2})$$

$$X_{E_1} = X_{A_1} + u_1 * \cos(\delta_{A_1A_2}) - v_1 * \sin(\delta_{A_1A_2}).$$

From the pairs of points E , the bearings of the tangents can be determined. The intersections of the tangents give the vertices of the curves. For their determination, the method of intersection has been programmed. As given points E_2 and E_3 nearer to the vertex S are selected. The intersection of the tangents of given bearings laid through these points is vertex S .

The direction of the curve (right or left curve) will be established in advance for the data input from the graphic plan.

Subsequently, the computer designs the standard clothoid easement curve on the basis of the programmed instructions according to the MÁV D. 21 specification. In case of long transition curves the exact formulae are used.

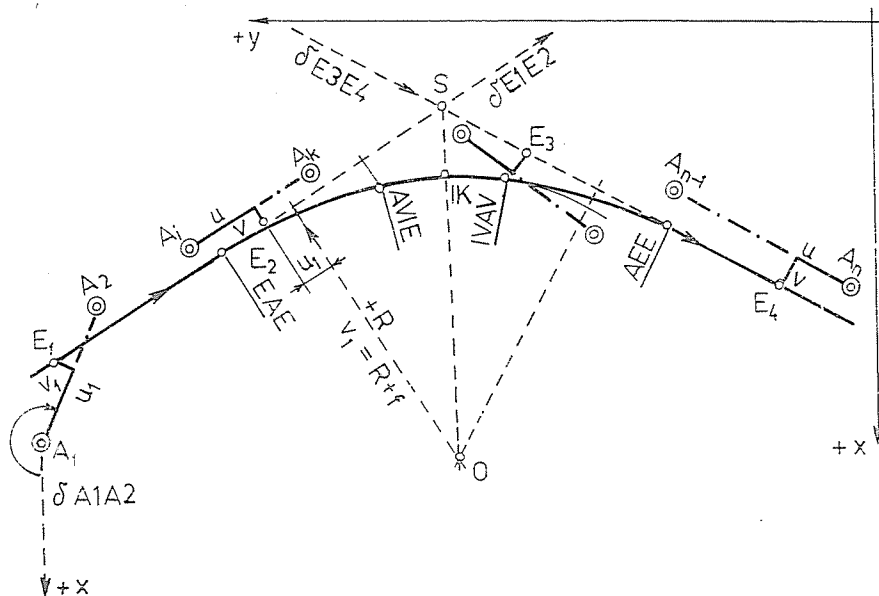


Fig. 1. General scheme of the problem of line stationing

The length of the tangent distance from the vertex to commencement and termination points of the easement curve is calculated according to the following formula:

$$TH = (R + f) * \tan \frac{\alpha}{2} + x_0.$$

To compute the length of the pure circular curve of the same radius, the formula $R \cdot \text{arc}(\alpha - 2\tau)$ will be used; the full length of the curve is obtained by adding the length $2L$ to the former value.

In the following, the computer outputs — according to the program — are the co-ordinates of the essential points of the curve in the basic system. These essential points are: commencement and termination of the easement curves at both ends of the circular curve and the mid-point of the curve. In determining these points, the computer previously defines also the co-ordinates of the centre of the curve.

$$YO = Y_{E_2} + u_1 * \sin(\delta_{E_1 E_2}) + v_1 * \cos(\delta_{E_1 E_2})$$

$$XO = X_{E_2} + u_1 * \cos(\delta_{E_1 E_2}) - v_1 * \sin(\delta_{E_1 E_2})$$

where

$$u_1 = \overline{E_2 S} - (R + f) * \tan \frac{\alpha}{2}$$

and

$$v_1 = R + f.$$

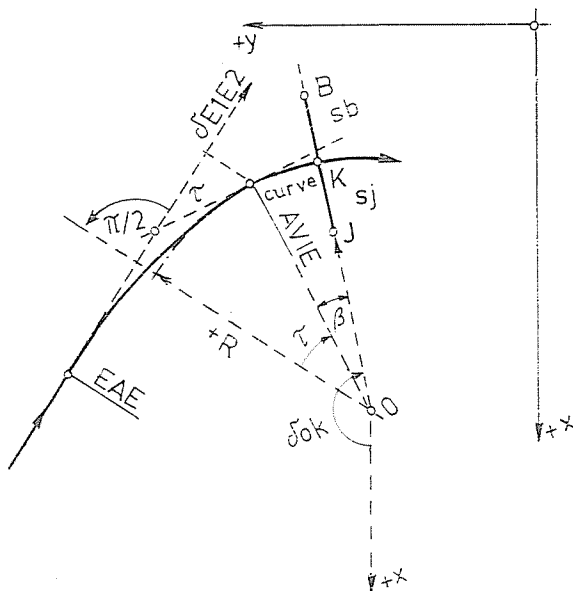


Fig. 2. Computation scheme for point K on the curve

The computation will be carried out in a similar way also from the tangent E_3E_4 . Thus, the co-ordinates of the centre are checked by computing from both tangents, and only an error less than 1 cm is permitted.

The essential points of the pure circular curve including those of the commencement and termination of the easement curve as well as the mid-point of the curve will be computed with the help of polar co-ordinates, the origin being the centre of the curve (Fig. 2).

The formulae for midpoint K, involved in Fig. 2, are:

$$\delta_{OK} = \delta_{E_1E_2} - \pi/2 + \tau + \beta$$

(curve value being predeterminable, depending on the planned density of curve points),

$$YK = YO + R * \sin (\delta_{OK})$$

$$XK = XO + R * \cos (\delta_{OK}) .$$

The same formulae are applied for the determination of monuments B and J from their known distances sb and sj. The only difference is that R will be replaced by $R - sj$ and $R + sb$, respectively.

The details of the easement curve are computed by starting at the commencement of the easement curve as basic point, and from the tangent as basic direction by the method of peripheral angles.

In this case, the peripheral angle σ and its threefold, the tangent angle should always be calculated. Namely for all of the details of the line, the fixed points normal to the tangent should also be computed (Fig. 3).

Point K is computed from the point of commencement of the easement curve EAE :

$$\text{arc } \sigma = 0.16667 \dots * \frac{l^2}{RL},$$

wherein l means the distance of point K from the commencement of the easement curve measured along the curve.

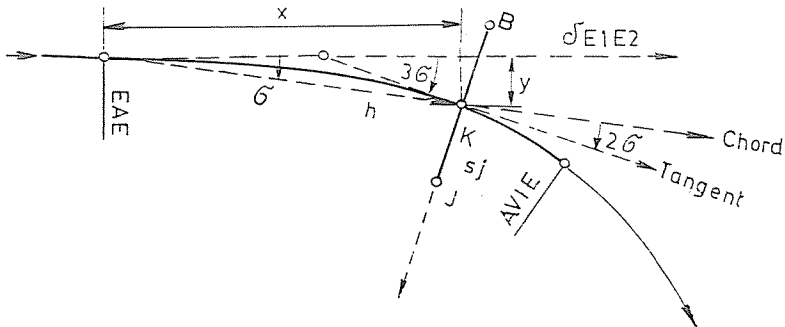


Fig. 3. Computation scheme for point K on the easement curve

According to the MÁV D. 21 Specification, if $l \geq 0.75 L$, then the co-ordinates x, y of the detail point should be computed with respect to the tangent. From them the length of chord h from EAE to K will be determined. The co-ordinates of point K in Fig. 3 are obtained by making use of the formulae:

$$YK = YEAE + h * \sin (\delta_{E_1E_2} + \sigma)$$

$$XK = XEAE + h * \cos (\delta_{E_1E_2} + \sigma).$$

For $l < 0.75 L$ the substitution $h = l$ is permissible.

The bearing of the tangent is simple to determine, as shown in Fig. 3; for example, the co-ordinates of fixed point J are:

$$YJ = YK + sj * \cos (\delta_{E_1E_2} + 3\sigma)$$

$$XJ = XK - sj * \sin (\delta_{E_1E_2} + 3\sigma).$$

In developing the program it should be taken into account that the computer is working with radians.

In calculating the details of the circular curve, the central angle also

defines the direction of the cross-section by starting at the centre of the circle, therefore the knowledge of the bearing of the tangent is here unnecessary.

Points are laid out at intervals of 50 m, starting at the given point E_1 along the tangent.

The computer finds the segment of 50 or 100 m as the first step, and proceeds by equal intervals to the cross-section predetermined as the input. Then it changes interval. Entering the curve entrains another change of interval, of course so that the defined points include also round stations. Thus, intervals should be selected as integral divisions of 100 m (50, 25, 20, 10, 5). Leaving the curve, the computer changes back to the interval given for the tangent, and lays out the points up to the last given point E .

For computing the station points and fixed points of the line, a GIER—ALGOL program has been developed. On this basis, the GIER computer prints a table listing the station points of the line, the co-ordinates Y and X of the details in the given system of co-ordinates, as well as a limit point or monument to the right and left of these details each, which define the direction of the cross-section and, at the same time, the width of the area to the left and to the right to be evaluated, in this order.

In general, planning of flatland railway lines is treated, thus it is assumed that the alignment can be laid out by interposed tangents. The curve program was developed accordingly.

The basic map of the desired scale is generally available from photogrammetric surveys. This involves appropriate amount of triangulation or traversing points, with co-ordinates also available in the selected system.

Thus, the *process of planning* is as follows:

1. The designing engineer draws the varieties of alignment on the basic map.

2. For laying out the intermediate tangents, he selects two points for each of them, and graphically measures their offsets to the tangents defined by the two basis points.

3. Then, he determines the radius R of the curve to be laid between the tangents, and in case of a curve with easement curves, the constant C of the easement curve.

A positive sign is attributed to the radius of a curve directed to the right and a negative one to that directed to the left.

4. The designer defines the station of the point determining the commencement tangent, and graphically prepares the kilometrage of the line variation with the help of a scale.

5. He prepares a list containing the distances between the given cross-sections both along the tangents and curves. He defines the width for the evaluation of the soil cross-section in meters.

6. Finally, the designer puts the input data on the data sheet.

3.2 *Computer determination of the railway-line profiles and the amount of earthwork*

Computation process of line location in the vertical plane. In planning the section of a line in the vertical plane, i.e. its profile, besides the actual planning work, the designer has to work out numerous details considered as tiresome calculation routine work. Such are, for example, calculation of the rail head elevation, of the height data of embankments and of depths of cuttings, etc.

Computing the profile starts by graphically determining the points of gradient change. For sake of simplicity, the changes of gradient rounded to tenths of per mil should be assigned to round hectometer or ten meter stations. If no peculiar restraints exist then the defined points of gradient change may be given by their stations and elevations above the basic plane.

However, in practice, certain elevation restraints often require the line profile to be led through so-called bench marks. This may be the case with engineering structures, level crossings, etc. where the line has to be led exactly through these points or with a tolerance of plus or minus a few centimetres, depending on the type of restriction.

Therefore, the computer program has been developed in such a way that within each section of uniform gradient, the planned profile of the line can be fixed or checked by a height mark each.

The computer program of the written profile of the line has been established in the GIER—ALGOL language.

On the basis of the computer program, first the distances between the given gradient change points, the differences in elevation and from these, the gradients of each section are output. Then, sections between two successive points are examined for the existence of a bench mark. These datum marks are given by their numeral, their level referred to the standard datum, as well as by the absolute value of the tolerance (in meters). The elevation of the rail head, its difference in elevation and the fixed point are computed and compared to the permissible error. If it is greater than permitted then the previously graphically found gradient is shifted parallelly and placed on the given bench mark, the preceding or the subsequent section is cut, the new stations of gradient change computed, and in the following, these are also taken into account.

The vertical curves, elevation of the rail head in the curve, are computed as shown in Fig. 4.

If the cross-section investigated lies in the vertical curve, then the rail-head elevation should be determined by taking the alleviating curve into account. The correction in elevation may be either positive or negative. This should be marked in graphical design by a positive or negative sign before

the value of the radius of the vertical curve. The value R of the radius is positive if the centre of the vertical curve is above the profile and negative if it is below it. The length T of the tangent is calculated by the customary formula:

$$T = \frac{R}{2} * \frac{e_2 - e_1}{1000}.$$

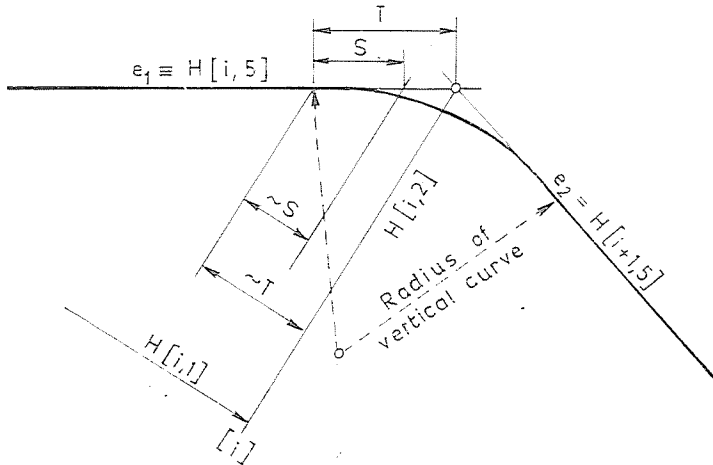


Fig. 4. Computation of alleviation of change of gradient

The familiar parabolic formula of correction is:

$$y = \frac{x^2}{2R}.$$

As a matter of fact, the program is meant to produce all data needed for the determination of the profile. According to that said above, the stations of the breaks in the profile, their elevation — omitting the terrain data —, and therefrom the actual gradients in per mil and the lengths of sections of uniform gradient have been computed. For each break in the profile the lengths of the tangents to the vertical curves and the offsets y have been found.

Thus, the gradients of the profile are at disposal. On the lower part of the drawing of the profile the station, elevation and level of the rail head are represented. The first two are input data, the third will be determined by the computer from the corrected elevation data. The embankment height or cutting depth data are obtained by deducing the total thickness of the ballast and of an eventual sub-ballast layer.

Computation of the cross-sectional areas

In practice, a wide variety of cross-section forms may occur. The program can manage any realistic case. Besides, the program was to be developed so as to hint the designer in special cases to check the objectionable cross-section. Therefore the cross-sectional areas are not immediately followed by computing the volume but the designer first checks the indicated special cross-section and designs a convenient solution. Subsequently, after applying the corrections on the cross-section, the volume is determined by the computer. The process of computation is seen in Fig. 5.

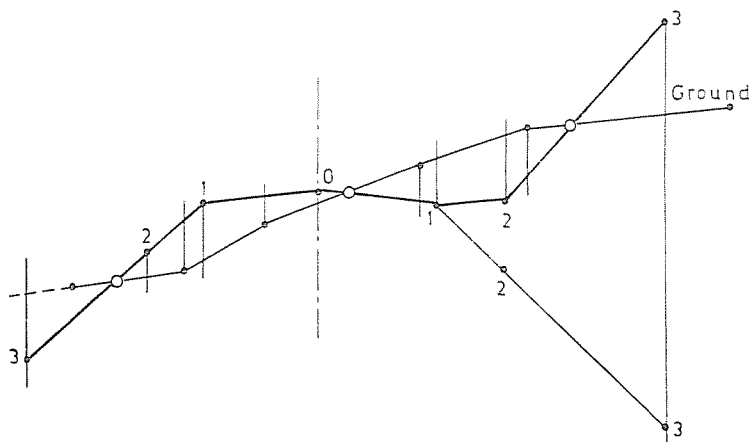


Fig. 5. Diagram of the general cross-section

In the figure, the essential points of the standard cross-section are numbered on the profile drawn in heavier line. Vertical lines are drawn through each of the break points dividing the area into lamellae for computing the cross-sectional area. In computer treatment, only a part of the area of an embankment and of a cutting are represented for each cross-section. If several parts of area of the same type occur in the same cross-section, then they are added and treated together.

The distance of the extreme terrain point in the left-hand-side of the figure to the centre line of the track is shorter than that of point 3 of the embankment. In such a case, the computer extrapolates the terrain elevation in the vertical line through point 3 from the two extreme terrain points.

The points of intersection of the standard cross-section and the soil surface are output by the computer; the numerals of these points also are printed out.

In the case of Fig. 5, in the column of INTERSECTIONS the No. 3 appears.

For more than three intersections, the cross-section will consist of more than two separate parts of area.

The computer may not sense but one intersection point, such as in the case of Fig. 6.

In this case, the computer finds the terrain to be still higher at the right side, along the vertical line of the extreme point 3 of the cross-section, therefore it would be advisable to line the cutting with a revetment wall. The area of the cutting will be computed up to the vertical line of point 3, at the same time, column RIGHT of the data sheet indicates REVETMENT WALL, to call the attention to this particular case.

Also the left side of the cross-section will be checked in the same way and in such instances, the designation SUSTAINING WALL, similar to that of the figure above, will appear in column LEFT.

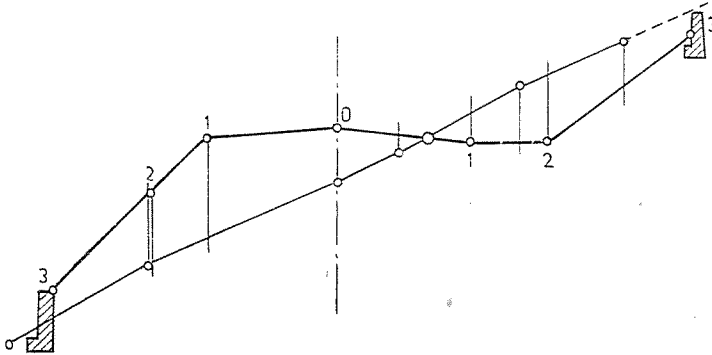


Fig. 6. Interpretation of sustaining and revetment wall marks

In computing the earth mass, the volume of the drain ditches will be treated separately. Namely, this mass of earth will only be excavated after the cross-section of the cutting has been made by the machines. This kind of earthwork requires both accurate marking-out and implementing, therefore, its unit costs also are higher.

The computation system of the program is an intricate one because it takes into account every possible variation. The basic formulae are, of course, simple; only a wide variety of logical analyses makes the program long and complex.

This sequence of computations should, however, only be pursued for cross-sections of complicated form. In normal cases, the desired output is furnished in a short run.

In determining the cross-sectional area, the numerical values for the cross-sectional areas are joined by other hints in the data sheet. A mark at the number of intersections may hint to the fact that in the computation the cross-section investigated had to be closed by a vertical line, passing through the extreme point of the cross-section, and simulating a sustaining wall or a revetment wall. In such cases, the cross-section should be investigated for the

possibility of an eventual area reduction by means of an engineering structure, sustaining or revetment wall, or in case of a slope, by means of a steeper lining.

Computation of the earth mass

It is a much simpler problem to compute the earthwork volume. Remind, however, that the program does not involve the volume of the transition bodies between embankment and cutting. Accordingly, cross-sections should be assigned at spacings to allow for this neglect.

Average areas given on the familiar forms for earthwork volume calculation are computed, and the sum of two adjacent section areas is multiplied by the half spacing.

In developing the program, also the effect of compaction of the embankment has been allowed for. Transverse and longitudinal hauling of soil are computed as usual. Longitudinal haulings are continuously summarized over a continuous section, simplifying the computation of mass equalization, determination of mass gravity centres.

The coefficient of compaction should be given, similarly to that for the cross-section, together with the numeral of the valid boundary cross-section.

The computation joins that of the cross-sectional areas, but here is a possibility for eventual modifications on the tape of outputs containing the station numbers, areas of embankments and cuttings, to be used as input tape for cubing.

3.3 Analysis of the trace of an underground railway line

This problem arises from the impossibility of driving ahead a tunnel as designed and staked, with a perfect accuracy, either in the vertical or in the horizontal sense. Checking measurements establish the vertical and horizontal deviations from the design direction and the needed corrections. Thus, the real centre line of the tunnel does not coincide with the designed axis, but is rather a helical curve with lesser or greater construction and measurement errors.

After the construction of a longer or shorter section of the tunnel, the design centre line of the track will be staked both vertically and horizontally and the essential points of the tunnel referred to.

The reinforced concrete block wall in Fig. 7 indicates all location values of the section. The centre of the measuring system is assumed at 1700 mm over the plane laid on the rail heads vertically in the design centre line of the track, and in curves, shifted by a length e .

Because of its reinforced concrete block construction, the wall of the tunnel is considered as a *hinged ring*. For defining the position of the hinges,

the distance of all measurable hinges to the origin of the reference system is determined. In the measurements, the ends of two adjacent blocks may exhibit derivations of a few millimeters; in such cases their arithmetic mean is taken into account.

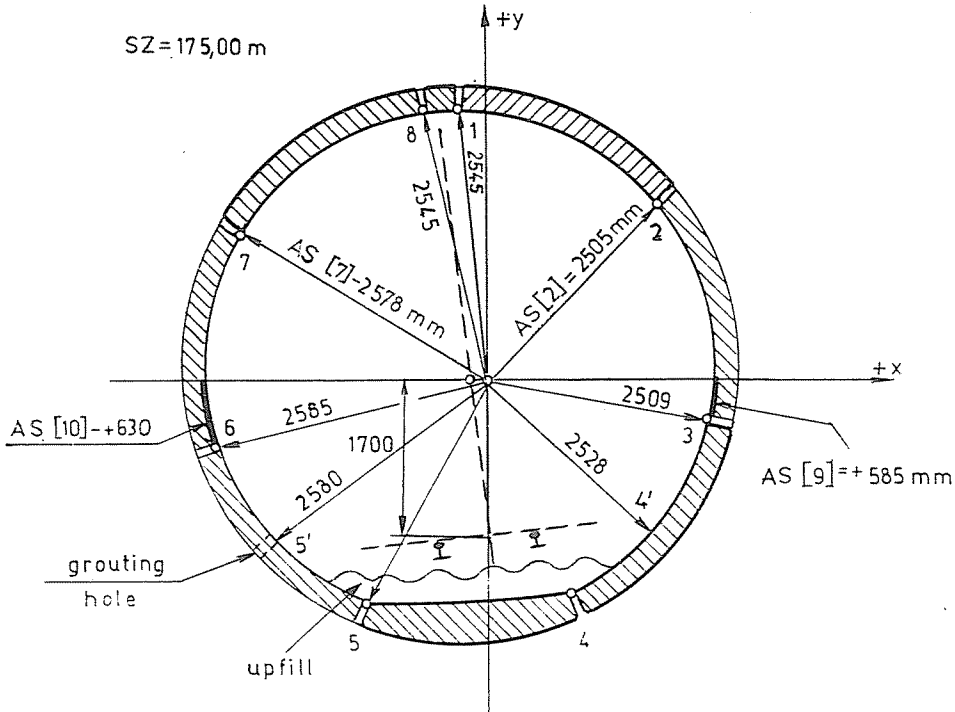


Fig. 7. Measuring of tunnel cross-section constructed of r.c. blocks

No bearings at the hinges are measured, while to fix the directions of the hinges, the distance to the horizontal of hinges 3 and 6 are always measured. These values are affected by sign; curve lengths are positive if *measured downwards from the horizontal x-axis*, else they are negative.

In surveying the cross-section, location of lower hinges 4 and 5 (Fig. 7), is inhibited by the upfill. Instead, the distance of the grouting holes 4' and 5' to the origin of the reference system is measured, and in the program the actual position of hinges 4 and 5 is referred to that of hinges 6 and 3.

The vehicle gauge of the underground railway line of Budapest is specified in the Design Principles of the Underground Railways, and so are formulae for the basic gauge dimensions in tangents affected by various superelevations and in vertical equalizing curves.

In the followings, selection and analysis of only five design points on the outline of the cross-section will be sufficient. The position of the lower essential points may vary according to the location of the third rail.

In checking, the polar data of the measured tunnel cross-section are plotted in the system of co-ordinates of survey.

Starting at hinge 3, the positions of hinges 2 and 1, further lower, the position of hinge 4 will be determined. The left-hand-side of the cross-section will be calculated in a similar way, starting at hinge 6. There are two alternatives for checking the reliability of the measurements. In case of a hinged structure, the measured and calculated distances between hinges 1 and 8, as well as between hinges 4 and 5 can be compared. For a deviation greater than 40 mm, the computer program causes an error signal to appear on the console typewriter indicating the sign-affected value of the coarse error, making a repeated measurement imperative at the tested cross-section.

In knowing the co-ordinates of the essential points of the clearance plotted in the survey system of co-ordinates, the distance of these points to the wall plane of the tunnel may be determined. The cross-section with a theoretical radius of 2550 mm will be deformed to a certain degree during construction. Consequently, the arc centres of the reinforced concrete blocks do not coincide. Thus, the polar distance between the wall and the gauge points is determined from the theoretical centre of the sector containing that point.

In Fig. 8 the *interpretation of the distances* calculated in the checking test is seen. In this example, gauge point 1 is in the safety region, thus, it appears with *negative sign* in the data sheet. The numerical values of the distances with the appropriate sign are as follows (Fig. 8):

P	TAV	ERY	ERX	EFY	EVX
1	-73	-51	53	-107	104

Obviously, in the case where the gauge point is in the safety region or even inside the tunnel wall — i.e. the sense of the shift points to the centre of the sector — the sign of TAV is *negative*. Otherwise, the computed distance has, as a matter of course, a positive sign.

The distances ERY and ERX are the components of the radial distance TAV with the *right sign* in respect to the *system of co-ordinates*.

EFY means the vertical distance — i.e. in the Y -direction — of gauge point P to the safety region; the meaning of EVX is the same but in the horizontal sense. In case of protrusion, these values correspond to the *required shifts*, in the opposite case to the *permissible ones*.

To determine these shift values, the program implies the analytic solution of the intersection point of straight lines and circular arc. The proper signs of the roots are defined by preliminary logic investigation.

The computerization offers all informations to the designing engineer necessary to correct the deficient section. Repeating the check with the modified trace substituted, in the TAV column no negative values appear if the correction was right.

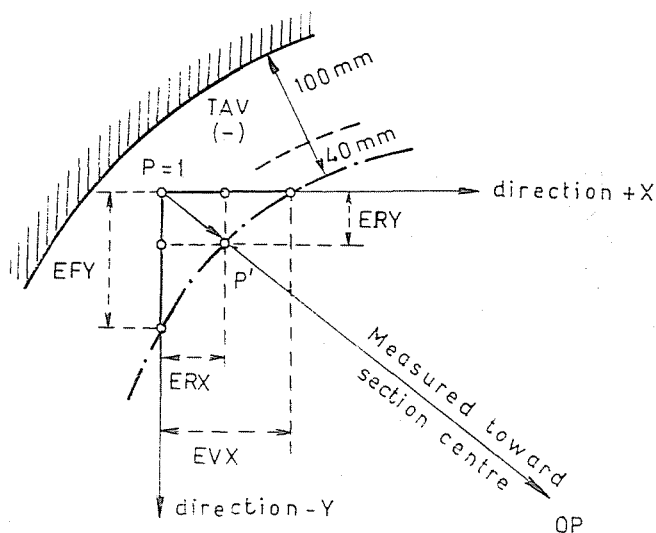


Fig. 8. Interpretation of data in the data sheet

The necessary and permissible shifts are well illustrated by the method of representation in Fig. 9.

In the figure, the positions of the five essential gauge points are distorted. Drawing the forms belonging to the five design gauge points shifted to the centre according to Fig. 9 results in the area of possible shifts.

Now, the diagrams of the *vertical* and *horizontal shifts* for the tunnel section in question are drawn according to the checking program.

In the diagram of the *vertical shifts* the necessary and permissible shifts in direction *y* are represented. Magnitudes of the critical vertical shifts *permissible* in each cross-section or, for a protruding gauge point, of the *necessary* shifts are represented true to sign to adequately selected longitudinal and vertical scales.

In Fig. 10 the *necessary and permissible horizontal shifts* are shown.

In the tunnel section already constructed, the position of the new centre line of the track, best fitted to the cross-sections, will be defined applying vertical and horizontal shift diagrams.

First, it should be ascertained whether a trace with unobstructed clearance can be found by modifying the line profile alone.

The *diagram of the horizontal shifts* (Fig. 10) is likely of help in determining the new centre line of the track, involving lateral shift values meeting shift requirements for obtaining the new centre line, although keeping within the permissible limits.

Computed lateral shift magnitudes (dash-and-dot line in Fig. 10) are compiled in a correction list. Running the *corrected computer program* with

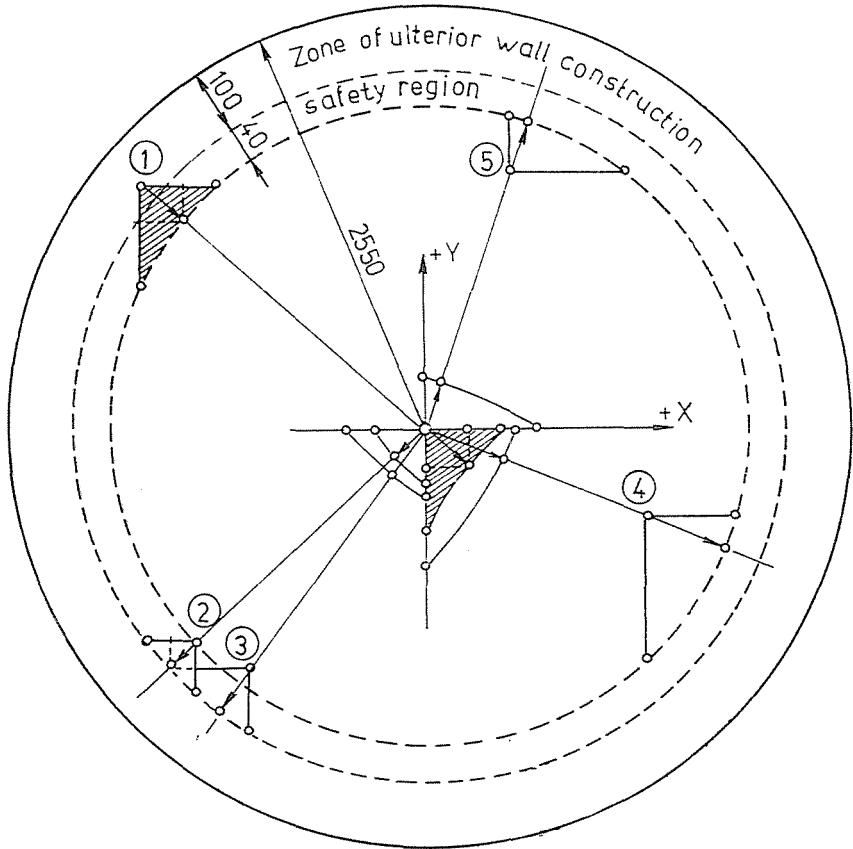


Fig. 9. Illustration of required and permissible shifts

its implication, the data sheet will not contain protrusions of negative sign any more.

It is to be noticed that besides the representation shown in the foregoing, also the method of angular representation can be applied, in more complicated cases, to define the values of shifting the track centre-line.

Namely, the appropriate reference line of the diagram of shifts for the curve correction by the method of angular representation offers a possibility for realizing curvature conditions up to requirements.

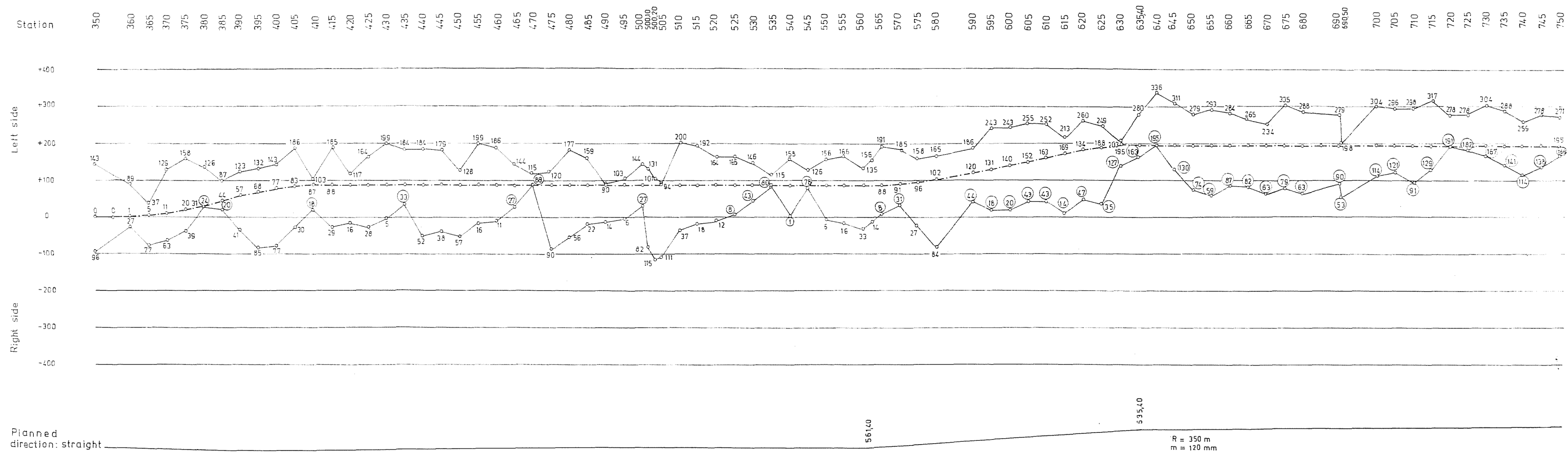


Fig. 10. Diagram of horizontal shifts
 Numbers in circle denote required shifts = 39
 Bare numbers denote permissible shifts = 24

Summary

The keen competition between rail and road transport in the recent decades made implementation of latest cybernetic procedures a necessity. Rail transport, where track, station and other service equipment, hauling and hauled vehicles, upkeep and repair shops are centrally managed, lends itself to computerization. This study presents some of the computer programs developed at the Department of Railway Construction, such as:

1. Computer design of tracing railway lines in the horizontal plane;
2. Computer determination of the railway line profiles and the amount of earthwork;
3. Computer analysis of the trace of an underground railway line.

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