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Metrication in highway design and operations

Taher A. Al-Fadhli
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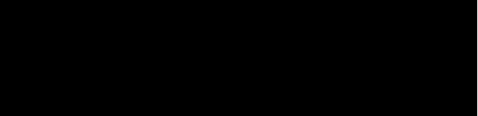
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AN ABSTRACT OF THE THESIS OF Taher A. Al-Fadhli for the Master of Science
in Applied Science presented March 13, 1978.


Title: Metrication in Highway Design and Operations

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:


Kendall B. Wood, Chairman


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The complex problem of metrication of highway design, construction and maintenance has been the subject of a number of studies and pilot projects carried out by the Federal Highway Administration (F.H.W.A.) of the United States and the Roads and Transportation Association of Canada. Through a research grant, the FHWA of the U.S.A. assigned the Ohio Department of Transportation, the Illinois Department of Transportation and the Oregon Highway Division to design, construct, and maintain these metric projects. The author has reviewed the experience and conclusions of these studies and the problems encountered in the pilot projects relative to

the design, survey, contracting, construction, signing, and public reactions to the metrication process. In the conclusions to this review, the author questions some of the recommendations of these studies, specifically in the area of curvature and station definition, notation convention, and the concept of dual signing. In these and other areas recommended guidelines for highway metrication are proposed.

Finally, the author presents a set of equations and computer generated tables for highway design and layout in metric incorporating the flexibility of 10, 20, 40, and 100 metre station and curvature definition.

METRICATION IN HIGHWAY DESIGN AND OPERATIONS

by

TAHER AHMED AL-FADHLI

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
APPLIED SCIENCE

Portland State University

1978

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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CHAPTER I

INTRODUCTION

The metrication concept was introduced in the world as early as the 18th century and in the United States in the beginning of the 19th century (1821) followed by several debates which were concluded in legal issues as stated here in chronological order:

1866 - Congress passed legislation legalizing the metric system.

1893 - The U.S. Bureau of Standards adopted the metric system.

1968 - Congress authorized a study to be conducted by the
Department of Commerce.

1971 - A study done at this time recommended a statute setting up
the Metric Conversion Board and time table.

December 1975 - President Ford signed into law the Metric Conversion Act setting up a 17-man metrication board to be appointed by the president and confirmed by the Senate. No time limit was set. Senate adjourned before confirming President Ford's appointments. President Carter has appointed a new board but it has not yet been confirmed.

The recent studies and research (U.S.A., Britain and Canada) which have been devoted to the investigations and introduction of the metric system of units reveal a need for an early selection of the metric units to be used, the vital importance of early metrication of specifications

and standards, and the absolute necessity of co-ordination of metrication activities on the national level.

The Federal Highway Administration (FHWA) recognizing this fact initiated a study in 1974 to investigate problems that confront the highway industry when, and if, it converts all of its functions to the metric system. After a series of negotiations in March of that year, the FHWA entered into a contract with the Ohio Department of Transportation (ODOT) to perform research in the field of highway metrication. Subsequently the ODOT engaged Ohio State University to assist in the study.

The scope of the Ohio research covers most of the important areas of highway work including administration, standards and specifications, planning, location and design, right-of-way, construction, operations and public reactions. The research is organized into four principle areas of investigation denoted as Tasks 1 through 4. Task 1 contains a historical review of the experiences in highway metrication in foreign countries, notably Great Britain and the United States (U.S.A.). This task also reviews the standard international (SI) units and modifications thereof for use in highway work.

Task 2 of the Ohio study consists of five phases identified as: the design of two projects in metric, the construction of these projects, the conduct of a questionnaire survey to determine motorist reactions to metric signing, the distribution of metric brochures and lastly, a broader based survey of public reactions to highway metrication.

Task 3 identifies problems encountered in the technical areas of planning, location design, construction, quality control, maintenance, inventory and traffic control. Task 4 outlines a program of research and draws up conclusions and recommendations.

An interim report covering Tasks 1 and 2 was published in July, 1974 and a final report which covered all four tasks was completed in April of 1975. Further studies in metrication were initiated by the Illinois Department of Transportation (IDOT) early in 1973. In August of the same year an initial study of the effect of conversion was conducted to find the scope of the problem in the Department, the possible advantages to be derived from the change, and any current activities in the area. This study covered several areas such as photolog, mileage tables, route description, vehicle mile report, standard specifications, design manual highway signs, project control, traffic control, right-of-way, training programs, computer programs, cost/benefits analysis, and leadership in metrication.

The Oregon State Highway Division (OSHD) on July 10, 1973 reviewed the Ohio interim report on metrication of highway work and found it a reasonable approach. Using the Ohio experience as a guide, the OSHD undertook an investigation into metrication. OSHD work included specifications and standards, planning, bridge, roadway design, traffic control, and construction. Studies carried out by several sections of the Division (OSHD) resulted in implementation of a five-phase program which included development of the design of three pilot projects (which

were later merged into two), construction of these pilot projects, placement of dual signs to acquaint highway users, and distribution of metric information to motorists and to the public. One of the two projects is under construction in Coos County at the present time.

Canada conducted a recent study and adopted the metric system based on the experience of other countries such as Australia and South Africa. The Canadian Study started in early 1970 and final "Geometric Design Standards" were issued in 1976. Canadian study consisted of five steps including the review of the existing manual, the examination of the fundamental standards in highway work, a review and modification of the current and past practices, the design of projects in metric, and the planning and scheduling to begin the construction of these projects as of 1978. In July, 1975, the consulting firm M/S De Leuw Cather, Canada Ltd. and M/S Fenco Consultant Ltd. were retained by the Roads and Transportation Association of Canada to prepare the manual of "Geometric Design Standards" in metric.

The recent studies and research prepared by the United States, Federal Highway Administration (FHWA) in 1973-1977 and Canadian, Roads and Transportation Association of Canada (RTAC) in 1973 to 1976, are the subject matter of Chapter II. Problem areas identifications and alternative solutions will be discussed in Chapter III. Chapter IV will be devoted to the computer generated tables and their use. Finally Chapter V will close this study with a summary of conclusions together with recommendations proposed for highway geometric design.

CHAPTER II

RECENT STUDIES, RESEARCH AND PILOT PROJECTS

IN HIGHWAY METRICATION

Chapter II, as indicated previously, contains a detailed review of the research, conclusions and recommendations of studies and pilot metric projects conducted in recent years by four agencies, namely the Ohio Department of Transportation, the Illinois Department of Transportation, the Oregon State Division of Highways, and the Roads and Transportation Association of Canada. In the foregoing, these studies will be sequentially referred to as the Ohio, Illinois, Oregon, and Canadian studies. To avoid misinterpretation, and to identify the problem areas, the author used several extracts and quotations from the original texts.

THE OHIO STUDY

1974 - 1975

Task 1.

The objectives of this task were to research the accomplishments in the United States and other countries, notably Great Britain, and to discuss the problems of standard units in the various functions of highway engineering and management.

This task was subdivided into three sections: Section 1 details the sources of information, Section 2 briefly describes the modes of gathering data and information and Section 3 reviews the gathered materials.

In the first section of this task it was stated that the source of the gathered data and information were from organizations and individuals in the United States and from certain foreign countries which have legally adopted the metric system or still are in the process of metrication, such as Great Britain, Canada, Australia and New Zealand.

Three main modes of search for information were summarized in Section 2 of this task to include the related literature (e.g., standard reference works, computer information banks, libraries, . . . etc.), correspondence and interviews.

The third section of this task reviews the information gathered and grouped them in the following items.

Metric Units. Three basic metric systems were discussed briefly under this heading such as the C.G.S. system (centimetre, gram and second as basic units), the M.K.S.A. system (metre, kilogram, second and ampere as basic units) and the SI - Standard International system (consisting of seven basic units: the metre, kilogram, second, ampere, kelvin, candela and mole and several derived units). The writing of symbols for units and prefixes was discussed and the use of the SI units was emphasized. "For example, in the field of applied technology, which includes all engineering, the International Standards Organization (ISO) recommended that the prefixes (e.g., hecto-, deca-, deci-, and centi-) be avoided

as much as possible." (17, p. 7) Prefixes representing 10 raised to powers which are multiples of three should be used, i.e., 10^{12} , 10^9 , 10^6 , . . . 10^{-9} , . . . This method facilitates computations and enables users to discover errors easily.

The matter of variance in numeric notation was discussed. In most European countries, the comma (,) is used as a decimal indicator, while digits are separated by dots into groups of 3. For example, 3.000,000.0 in Europe means 3,000.0000 in the United States. Most countries investigated are switching to SI units using the dot as a decimal marker, while South Africa and Rhodesia are using the comma as a decimal marker. The differences between the conventional metric units and the SI units were discussed in the areas of design, construction and operations. In the area of design the SI units, used for length, force and stress, faced an objection from some authors claiming that,

"strict adherence to SI units would result in unwieldy numbers in typical engineering calculations, and suggested that the proliferation of named units and values now used in engineering did not all derive from some arbitrary association, but from better results using convenient numbers." (17, p. 9)

Also the length units were reviewed and the argument of whether to use the centimetre (cm) or the millimetre (mm) as a basic unit was raised. The largest objection to the (mm) occurs when raising it to powers. For example, moments of inertia for sections are given in mm^4 which is 10^{12} times as large. Force units also faced several debates. For example, the SI unit for force is the newton, i.e., the unit of mass (kg) multiplied by

one unit of acceleration (m/s^2) which equals $kg \cdot m/s^2$, while imperial and earlier metric systems used gravitational units, which means a unit of force is the product of one unit of mass (lb or kg), and the gravitational acceleration equals lb.f or kg.f (g). These force units have the advantage that "their magnitude is equal to their counterpart mass in the earth's gravitational field." (17, p. 10)

The slight variations of (g) over the earth's surface was mentioned and South Africa went into considerable research of this matter, however Newton's Laws showed that (g) varies by only 0.5% on the earth's surface, which, for engineering purposes is not significant. The remaining SI units were discussed briefly, debated by some countries and supported by others. The matter of velocity units was discussed. Since drivers are not able to visualize speed limits in metres per second (m/s), no country objected to the use of the non-SI unit, kilometres per hour (kph) in speed designation.

Some authors felt, however, that some design elements should be based on a design speed in m/s. In highway construction, as was the case with design, there was disagreement as to whether the basic unit of measure should be the millimetre or centimetre. The supporters of the centimetre argued that the millimetre is too small to be visualized in most site measurements.

Great Britain chose to use SI units mostly except for pile driving which is still in blows per inch. In surveying, the non-SI practices include using degree, minutes and seconds rather than radians for angles and using hectares for areas. The literature indicates that no country is using

or plans on using radians for angular measurements.

The 360° circle versus the 400° circle was discussed and still the 360° is favored by most countries of the world. The use of the hectare (10,000 m² or 0.01 km²) is more acceptable to real estate even though it is a non-SI unit. British suppliers are still selling material by metric tons which is not a true SI unit (SI unit is the megagram).

Since testing procedures and standards are more scientific and achieve more exactness, therefore there is more strict adherence to the use of the SI units.

In the area of maintenance, the British Standards Institute issued a conversion list from the existing system to the metric units, e.g., the liter per square metre (l/m²) instead of square yard per gallon (yd²/gal).

Metrication Methods: The ensuing topics concern the experience and problems of metrication in Great Britain and countries as they are related to specific areas of highway engineering and management. First of all, however, two distinct modes of conversion must be defined as they are referenced in some of the discussions. "Soft" conversion implies that the conversion takes place on paper and the object remains unchanged, e.g., a six inch diameter pipe is converted by the soft method to equal 152.4 millimetres. "Hard" conversion on the other hand involves choosing a rational metric size or dimension instead of converting its imperial size or dimension. In the following discussions of specific areas, the experience is that of Great Britain unless another country is indicated.

Metrication of Design: During the preparation stage to convert to metric Britain, the National Building Agency (NBA) found no real difficulty in their pilot projects using SI-units. The contract work has a different philosophy according to one author:

...once a design office does its first metric job, it should never have to go back to imperial as all new contracts will be metric. There is much discussion in the literature about rationalization. That is, new metric dimensions should not be converted by "soft" method from the old imperial system but they should be changed to metric values which fit logically with other "rationalized" dimensions, i.e., by "hard" conversion. In order to insure that everyone follows the same procedure for rationalization, the British Standards Institute published a recommendation (BS 4318) entitled "Recommendations for Preferred Metric Basic Sizes for Engineering" (B, 2, 11) (17, p. 17).

Metrication of Specification and Standards: Specifications and Standards are the most delicate issues regarding converting to metric. Without standards metric design is impossible, e.g., the British Road and Bridge Standard is based on 180 other British standards (17, p. 17).

The British and New Zealanders first used interim specifications, and rationalized standards were followed by completely revised specifications. A rationalization concept is used in both countries, e.g., 2 1/4" is rationalized to 50 millimetres or 45 mm.

The tolerance of metrication is discussed. The British Building Research Station is an arbitrator in the interpretation of the metric standards while in the U.S.A., the American Society for Testing and Materials has now "soft converted" most of their standards.

Metrication of Drafting and the Office Drawings: Two concepts were discussed in regards to "drafting and Office Drawings." The first

is a dual dimension concept that proved undesirable. The second is direct metric dimension to avoid confusion. Dual dimensions may be used in the transition period but should be dropped as soon as possible.

The metric dimensions, if followed, are to be in metres followed by three decimals. These concepts were accepted and recommended by the British firm of Newall Engineering Company and in the United States by engineers in Buck County, Ohio State.

A few methods of standardization of dual dimensions were presented, e.g., the left corner of the plans should include a comparison table of imperial and metric units. The John Deere Company in the United States adopted this method. Another method suggested is to have the metric units appear in brackets or parenthesis.

There has been good agreement in deciding which metric scale ratio is to be used. Most agreed that scale ratios should be in the following form: $1/a \times 10^n$ where $a = 1, 2$ or 5 and 'n' is any integer. There have been some difficulties in the acceptance of this notation in Britain, however. Designers used 1:20 scale for concrete reinforcements and 1:50 for most of the general arrangement drawings (B, 1, 27) (17, p. 22).

Metriation of Geometric Design: The Geometric Design dependent and independent variables used in Britain were converted and rationalized in metric. The following standard was treated:

DESIGN SPEED

30 mph	=	50 km/h
35 mph	=	60 km/h
40 mph	=	65 km/h
50 mph	=	80 km/h
60 mph	=	100 km/h
70 mph	=	120 km/h

The only significant difference in the table is the difference between 70 mph and 120 km/h (74.5 mph). This caused certain other standards to increase as well, e.g., minimum radius at 120 km/h is 960 m (3150 ft.), while for 70 mph the minimum radius is 2800 ft. (17, p. 23).

The driver's eye height of 3 feet 6 inches (1.07m) was not rationalized by British engineers and only rounded to 1.05 metre. In New Zealand, however, eye height was rationalized to 1.0 metre which is shorter than previously adopted.

Metriation of Bridge Design: It was found from literature review that bridge structural design used SI units which resulted in inconvenient numbers. Authors in the United States who have discussed the inconvenience of the SI units offer the following alternatives:

...an interim inch-pound force-second system using decimalization, or a more loose combination of the SI and the "common" metric (B, 1, 11 and B, 1, 60).*

...The practice to combine revision of a standard or specification with its metriation has created a real hardship to engineers in England especially when the revision introduces new design concepts and procedures, e.g., "Load Factor and Limit Design" (17, pp. 24-25).

Metriation for Construction: To define some of the problems expected in the construction industry, one (British) publication** identifies the following problem:

1) the natural human reaction is to resist change; 2) most construction personnel will require retraining; there will be an initial reduction in output due to working with new

* Burgess, J. W., "The Impact of Metriation on Design Engineering and Construction," Chemical Engineering Progress, Vol. 68, No. 6, June 1972, pp. 69-70.

** Ministry of Public Engineering and Works, "Metric in Practice," in Metriation in the Construction Industry, No. 1.

terminology; 4) new tools and equipment must be obtained;
5) reference data and tables will need revision.

Whereas in the design field, a one time conversion is possible, it is not possible in the construction field.

"According to the trade union officers concerned there will be no difficulties on site provided each operator has the appropriate rule for the job."*

Metrication of Surveying: In the surveying field the task of "Ordnance Survey" is still facing Britain. The existing maps need 30-40 years to be replaced by metric maps. Britain has made an extensive effort for the last 20 years to convert these maps but still needs an estimated 12 years to finish.

...Contours, spot heights, Bench marks and linear distances are metricated, e.g., the six inches to one mile (1:10560) ordnance survey map was changed to 1:10000 and contour intervals of 25 feet to 10 m in flat area and 5 m in mountain area.

Bench marks, spot heights and parcel accuracies are used in Britain as follows:

Bench marks ± 0.01 m
Spot heights ± 0.10 m
Parcel area ± 0.001 hectares (17, pp. 26-27).

The contour line metrication has caused a little trouble in laying out highway. The solution suggested by British engineers is to retain the existing intervals and relabel them with a metric value. The leveling in the field was done to ± 5 mm and measurement for cross-section was made at 20 m intervals. In Britain the Highway Survey is using a scale

* Wally, F., "Metrication," in Institute of Civil Engineers Proceedings, vol. 40, May 1968, pp. 107-115.

of 1500.

Contractors: The Ohio study indicated apparent problems facing the British owners and contractors. One of the problems was the unexpected risk that resulted from judgmental errors in pricing metric projects. The other problem is that dealing with the demand-supply of available and needed metric material. However, the Australian National Public Works Conference and Master Builders Federation have written contract clauses to solve this problem (B, 2, 1).*

Most of the literature indicates that the problem of conversion to metric lies in the area of manufacturing.

In addition, however, contractors face the following two problems: "...re-equipping with new or recalibrated site machinery and equipment; and coordinating sub-contractors and suppliers who may be slower in their change to metric than general contractors" (B, 1, 87) (17, p. 28).

Metrication of Material Suppliers: In Britain the Metrication Board's Annual Report of 1972 stated that:

...with the possible exception of storage problems where dual stocking is necessary, the difficulties involved...will be no longer greater than have been experienced with normal commercial and design changes in the past (B, 1, 49).**

On the other hand, the British Standards Institution in 1968 proposed dual stocks (metric and imperial) in order to smooth the conversion process over a two to three year conversion period.

*Guthrie, J. M., et al., "Engineering Intelligence Division, London, How to Handle Metrication", July, 22, 1974.

**Metrication Board, "Going Metric", London, 1972.

The problem of supply and demand was solved in Great Britain by cooperation of material suppliers and customers by keeping communications open. A time schedule for demand-supply was always made ahead of time to produce items and deliver them in due course in metric units.

No doubt there were some lacks in communication. For example, in the British screw supplies where small sizes were produced but demands were not rewarding. In Australia another approach was used as follows: suppliers could manufacture metric products with imperial labels. "For example, a part measuring 250 mm x 350 mm would carry a label of 9 27/32" x 13 25/32" or 10" x 14" nominally" (17, p. 29). Then, at an appropriate time, the supplier can start producing these products with a metric label. This experience was successful in Australia. The contractors in the United States, however, working on a metric project abroad faced difficulties in early stages of their experience for material supplies.

To help solve this problem and the problem of metrication in general, the government, which is the single largest consumer of many industrial products could use its prestige and influence the suppliers to metricate their products (17, p. 30).

Metrication of Testing: For the testing of material and equipment mostly in metric, existing imperial instruments need replacement and calibration. The test sieves are manufactured in both systems but existing ones can either be kept or replaced by a new set of metric dimensions.

Operations. The traffic modification of operations can be carried out on a national basis by enforcement of traffic laws with a program of training the motorist and the public on metric signs and measures.

Signs. Different countries have taken various courses of action in this area (17, p. 32). The signs experience of some countries are summarized in the following paragraphs.

In Australia the planners proposed two methods:

... a) to replace existing signs by completely metricated signs; and b) in some cases, only numerals were replaced either by painting out the old ones, taking off the old ones and using stickers bearing the new numerals (B, 1, 77). (17, P, 32).

The speed limit sign used in Australia is a rectangular one with a white background. In the foreground are black numerals enclosed by a red circle. No units are to appear on the sign.

In Canada, the new speed limit signs look like the Australian ones except that they are rounded rather than rectangular. Canada planned the conversion transition period to be from three to five years (project began in 1977).

In Great Britain public opinion delayed the sign metrication. Two plans were proposed to replace the speed limit signs. The first was to replace existing imperial signs by metric signs covering the plates. The second was to replace each road sign separately. Both plans were used and were successful (17, p. 34).

In the United States, metric speed limit signs have been erected underneath imperial signs in Huntsville, Alabama. The arrangement has a similar appearance to the Canadian signs. The period of conversion proposed may extend to five years from the beginning of

the transition period (17, p. 35).

Metrication of Traffic Control: The British experience with traffic devices was that there is no need for rationalization of specifications because "radical changes in size would require retooling, which was considered unnecessary. The change will not be noticed by drivers. Also the maintenance is done always by manufacturers" (17, p. 35).

Conversion Time Tables: The conversion timetables discussed here are decisions made by each separate country. The range of recommended schedules runs from five to ten years. These schedules include the re-orientation and training period, control survey, engineering, planning and design, construction, public education, maintenance and operation.

Metrication of Cost/Benefit: The last important item discussed in this task was the "cost/benefits" of highway metrification. It was based on three concepts:

(a) to find out whether overall benefits are higher than overall costs, i.e. to inform the decision-makers whether it is worthwhile to change over to the metric system;

(b) to choose between several alternative timetables for conversion that one which is expected to result in the largest net gain, and

(c) to find the distribution of costs and benefits among organizations and individuals, which would help in planning the conversion for these entities, and also substantiate their possible claims for support, etc. (17, p. 108).

Benefits: In the United States some traffic engineers do not favor metric but international motivation: trade, scientific and technical data are factors to encourage conversion into metric. The

cost/benefit is a direct and indirect concept, e.g., if the period of transition is prolonged, some equipment costs will be reduced, but a timetable is important as well, for any firm planning to meet such schedules.

Benefits in Design: The benefits have a wide range of areas, e.g., in design, calculations will be speeded up using SI units.

Benefits in Costs: In construction simplicity of surveying activities encourages standard methods in construction which cut down cost and increase benefits.

Benefits in Operations: In highway operations the United States may benefit by the uniform international traffic control devices.

COSTS

Cost in Design: The increase in design cost resulted from metrification cost of revising manuals, standards, maps, records, and from purchasing metric tools. The additional cost of efficiency loss is also considered as a factor (17, p. 114).

Cost in Construction: The construction cost is caused by factors such as change of design standards. For example:

- ...a. design speed of 120 kilometers per hour is more than the Imperial design speed of 70 mph (previously used in Great Britain)
- ...b. increased costs in the construction industry as reflected in bids submitted to highway authorities (17, p. 115).

Costs in Operations: Traffic signs and their replacement and maintenance tools are found to be costly in material and time, especially if a dual signing approach is adopted. The British estimated a cost of two million pounds for changing over of road signs to metric, and that figure doubled in 1974 (B, 2, 1) as confirmed below:

...The British have postponed changing the signs because of the magnitude of immediate expenses "although in truth such road signs are being replaced all the time and in need of repair; there must be at least that much (2 to 2½ million pounds) spent anyway on road signs annually as a matter of course" (B, 2, 2) (17, p. 119-120).

In the U. S. A. experiences on traffic cost showed that the state of Kentucky spent one-fourth to one-half million dollars for annual replacement and maintenance of road signs (B, 1, 99). The cost of an individual sign ranges from \$1.14 to \$10.30, depending on size, quality, and location (1972 prices) (17, pp. 119-120).

MISCELLANEOUS

Further investigations were carried out in Ohio's study, among which are included the following:

Legislative Action: Metrication in Britain needed law and regulation changes which were categorized in the three following types:

...(a) changing laws which require use of imperial units to allow metric units as well, (b) supplementing laws, which quote only imperial units, with a set of corresponding metric units so that both can be used, and (c) replacing imperial units in some laws by metric.

The items a) and b) above are solved by changing local laws and amending regulations by using "...so called 'blanket legislation' "

(A, 2, 39)* But item 'c' may only be pursued by amending specific acts, e.g., Britain accepted a bill which provides:

...for the authorization and definition of units of measurement which are to be used for all purposes...; for the removal of certain barriers to metrication in the existing legislation; and for constituting the Metrication Board as a statutory body (B, 1, 53).**

The role of the British government was positive in taking several actions trying to convince the public of the necessity of metric system acceptance. The British effort was slow as reported by the Ohio Study:

...The Government has been encouraging everybody to go metric but they have been very slow themselves in metricating their legislation. A lot of people have complained about it, but...if they had pushed through all their metric legislation at an early stage you could have had a lot of people in trouble because they couldn't get their equipment recalibrated. But it is an essential part for the government to change its legislation into metric terms (B, 2, 7).***

* Sleep, R. P., Assistant Chief Engineer, Engineering Intelligence Division, Ministry of Transport, London.

** Metrication Board, "Going Metric", London, 1970.

*** Federation of Manufacturers of Construction Equipment and Cranes, London, 1974.

TASK 2 (OHIO'S STUDY)

This task of the metrification research project involves the summarization and evaluation of the Ohio Department of Transportation (ODOT) metric work programs. Five phases as mentioned in the introduction are detailed here as follows (17, p. 126):

Phase I: Previously it was mentioned that under this phase two projects were involved. This was true since only two projects were included in the design and construction program. However, ODOT has actually been involved in three projects as briefly detailed here:

Metric Project No. 1 (LIC - 161 - 0.00). This project involved the surfacing (with bituminous concrete) of 8.206 kilometers (km) of State Route 161 in Licking County. This project was originally designed and calculated using the customary American units. After a decision was made to change it to a metric project, it was recalculated in metric. The general summary in the plans was presented in both metric and customary units. The width of two lanes was chosen as 7.32 metres (24.0055 ft.) and the asphalt thickness was 0.025 m (0.984) inch. Stationing was at 100 m intervals with the first several stakes at 50 m spacing (17, p. 128).

Metric Project No. 2 (HOC - 93 - 0.14). This project involves 1.698 kilometres of highway re-location and upgrading and includes a bridge. The project is located in Hocking County, which is part of ODOT District 10, about 17 miles (27 km) south of Logan on State Route 93 (17, p. 128).

Various units of ODOT were involved with the design of this project, such as the Transportation District, the Bureau of Bridges, the Bureau of Roadway Design, Aerial Engineering, and the Bureau of Research and Development Specifications.

ODOT's interim report of July 15, 1974 includes complete details on this project. A summary of activities for this project are listed below:

Metrication of Surveying: The field surveying instruments and tools used were not originally metric, but modified ones such as a 3.6 metre leveling rod and a 30 metre drag chain. These tools were used to minimize cost and to justify the availability of metric tools on the market. The experience of using these tools indicated additional modifications, such as adding marking in pencil at the last part of a drag chain, would be necessary (17, p. 129).

The degree of accuracy of field measurements was recommended as 0.01 metre for elevation readings, and 0.001 metre for horizontal measurements.

In the area of aerial surveying it was found that:

...most of the measuring devices are in metric and one instrument read both the metric and customary American units. This device was considered as an excellent aid during the transition period. For manuscript preparation "The AP/C co-ordinatograph" was fitted with lead screws 1200 mm x 1400 mm (17, p. 130).

The recommended scales for contouring, aerial surveying, and mapping are summarized here:

<u>Scale</u>	<u>Where Applied</u>	<u>Accuracy</u>
1:100	Cross-sections	Read to 0.10 m
1:200	Site Plan	0.50 m Contours
1:500	Design Maps	0.50 m Contours
1:200	Location Maps	2.00 m Contours

(17, p. 130).

The curvature definition of 100 metre station was used to prepare the horizontal curves and spirals tables. The following major problem in control surveying and mapping was noticed and identified as follows:

The major problem in metrication for surveying is the lack of a

metric projection system for metric ground co-ordinates. This problem will continue to exist until the SI co-ordinate system will be available, hopefully by 1980, by satellite observations. The former USCGS survey was always measured in metric, however now the SI definition of $1'' = 25.40 \text{ mm}$ (exact) has rendered all the published data obsolete (17, pp. 130-131).

This survey conversion problem stems from two major problems.

The control survey for most route engineering projects must be based on a geodetically oriented plane coordinate system because distances are usually sufficiently great to require field measurements to be transformed for earth curvature and meridian convergence. Most state highway departments work with the legalized state coordinate systems which are based on a conformal transformation of ellipsoidal coordinates (latitudes and longitudes) to a foot-oriented plane coordinate system for design purposes. The second problem is caused by the fact that the survey foot is not precisely the same as the standard metre-foot conversion accepted today. The U. S. Coast and Geodetic Survey (USCGS) adopted the metric system in the middle of the last century for the establishment of continental control and all published data in plane coordinates is based on the accepted metre-foot relationship of that date.

A standard set of universal transverse-Mercator coordinate zones in a metric plane coordinate system has been nationally proposed but the conversion of continental control is a monumental task which may not be realized until the next century. The author has proposed interim solutions to the survey and mapping problems in the following chapter, Chapter III.

It was observed that when survey parties were involved with non-

metric projects during this period, each time they returned to the metric project a short period of readjustment was required. The computer program for calculating earthwork volumes was easier due to the fact that the typical cross-section in metric was all in one unit (in metres). This eliminated the need to convert inches to feet and slopes to inches/foot.

Metriation of Roadway and Bridge Design: The scale rules in metric were available in limited types and did not cause a major problem for draftsmen and engineers. The paper and linen in metric were a local problem solved by designing the plan sheets on an A1 (594 x 841 mm) metric format.

"Horizontal curve templates based on a (100 m) definition of degree of curvature were not available. This did not pose a great problem as the project had only few horizontal curves" (17, p. 133). But obviously this would become significant in areas with curvature, such as mountainous regions. They would be required when a decision is reached on what horizontal curve definition would be adopted. The use of programmable calculators for conversion purposes was suggested during the transition period.

The ODOT recommended the following design speeds:

<u>M.P.H.</u>	<u>Actual Km/Hr</u>	<u>Rounded Km/Hr</u>
40	64.3720	65
50	80.4650	80
60	96.5588	95
70	112.6510	110

(17, p. 133-134).

Other elements of roadway and bridge standards such as the degree

of curve, 100 metre station and 20 metre substation were used, horizontal, vertical and spiral curve computations were prepared in metric. The hydraulic charts were not converted and the bridge design was calculated in English units, then converted to metric (17, pp. 133-134).

Soft conversion was used for roadway-typical cross-section dimensioning.

For construction purposes, the drawings were prepared on reduced negatives, converted to metric, then enlarged.

The cost estimate was prepared by converted units to English, calculated in English units, totaled in English units, then converted to metric unit price.

Fifty per cent of the ODOT specifications were revised, except for those items which are not commonly in use. The ASTM E380-72* was used as a guide for the specification conversion (17, p. 137).

The metre, centimetre, and millimetre were used as units for linear measurements. The litre was used for the volume unit of liquids (17, pp. 138-139).

The interim report of Ohio's study (1974) used the following scales for plan preparation:

Plan	1:500	
Vertical Profile	1:100	
Horizontal Profile	1:500	
Cross Section	1:100	
Details	1:100	(17, p. 140)

* ASTM = American Society of Testing Materials

This interim report abandoned the conventional definition of station designated by 1 + 00, which means one station of 100 feet or 100 metres, and substituted the following (17, p. 140):

...e.g., 1,234.56 (large numbers for kilometre, hectometre, and the small numbers for decimetres). This designation faced negative comments. The reasons for these objections were that they could not be typed and too many numbers were required to be put on a stake. There were discrepancies between roadway and bridge plans with regard to the call out for standard American sizes and the degree of rounding (16, p. 10).

Metrication Right-of-Way Design and Acquisition: This area of metrication posed no problems and simple conversion scales were used for property lines and deeds description. The unit of hectare replaced the square metre for real estate computations (17, p. 143).

Metric Project No. 3 (PER - 188 - 03.84): This project involved a 0.685 kilometre stretch of highway relocation and upgrading plus a major culvert. It is located in Perry County, which is part of ODOT District 5 (17, p. 144).

Metrication of Surveying: Equipment and tools obtained and used were the same as those used for Project No. 2. All elevations and horizontal measurements were treated with the same level of accuracy in Project No. 2.

During the design stage of this project, the designer converted the degree, minutes, and seconds to angles of units of degrees and their decimals. This later facilitated the surveyor field work.

The stationing adopted by District 10 was not used by District 5

personnel and the 100 metre station with "pluses" was used again (17, p. 147).

Metrication of Roadway Design: The supply of metric grid paper, scales, rules, etc. posed no problem for this part of the project.

The field dimensions were used as a criterion to rationalize nominal metric dimensions. The paper A1 (594 x 841 mm) format was found desirable for standard drawings. The roadway typical lane width of 3.6 metres was used. The side slopes presently used in ratios were retained. No revision for standard was made but designers worked out alignments in metric. The definition of curves and stations was adopted as in Project No. 2 (17, pp. 147-149). The following scales for plan preparation were used:

Plan	1:400	
Vertical Profile	1:100	
Horizontal Profile	1:400	
Cross-Sections	1:100	
Culvert Details	1:100	(17, p. 149)

Metrication of Right-of-Way Design and Acquisition: The approach used in Project No. 2 is adopted in this project except that direct metric units are used in the appraising and negotiating (17, p. 151).

Phase II: Construction of Metric Projects

Project No. 1 is mentioned here for general information since it was not specifically included in the ODOT research (17, p. 156).

Project No. 1: The project in nature and scale is simple as described previously, therefore the ODOT representative invited five

contractors who had expressed an interest in the contract to give their bids. Three bids were received. The ODOT and successful bidder's personnel were trained for a short period and no problem was faced.

Project No. 2 (HOC - 93 - 00.14): After completion of the design stage the following stages were programmed:

<u>Stage</u>	<u>Date</u>	<u>Purpose</u>
1. Pre-contract award	8/26 to 9/10, 1974	Advertisement period; all information given in metric
2. Pre-bid conference	9/4/1974	Conference between ODOT and bidder represen- tatives for brief description and discussion of project
3. Bidding stage	-	Bids submitted in metric unit prices. Lowest bid: \$686,047.38. Highest bid: \$1,072,353.26. ODOT estimate: \$860,000.00
4. Post bid conference	-	Metric project prices discussed with successful contractor
5. Pre-construction stage	-	Contractor-owner coord- ination program in construction and material supplies
6. Construction stage	-	Construction to start with ODOT inspection control

(17, pp. 157-165)

Project No. 3 (PER - 188 - 0.384): The same procedures used on

Metric Project No. 2 were applied to this project.

Phase III: Public Use and Adaptions

This phase was carried on by ODOT in ways such as interviews, meetings, questionnaire surveys, informational publications, etc. The objectives of this phase are summarized as follows:

...(1) to determine the change over time in the public awareness, acceptance, and general understanding of the metric system and to determine the inter-relationships between these factors, and (2) to determine the effect of the extensive dual-unit signing system on the change in the public's awareness, acceptance, and general understanding of the metric system (17, pp. 189-190).

Three major surveys were conducted by ODOT personnel. Five thousand drivers were included in the study and the following responses tabulated:

<u>Percentage</u>	<u>Reaction of Driver</u>
86	Aware of the change to metric
45	In favor of the change to metric
42	Not in favor of change to metric
13	No opinion of change to metric
80	Understood the basic distance relationship (miles/km)
78	Understood the basic relationship between weights (ounce/gram)
77	Agreed that dual signing is helpful during transition period

(17, pp. 313-214)

Based on the above surveys, the following conclusions were drawn:

1. Motorists were approximately evenly divided on the issue of metrication.
2. The motorist understood the U.S. and metric system relationship.
3. The motorist's ability to convert present units to metric was increasing over time.
4. 77% of the highway users indicated that dual-unit destination signing would be helpful in a transition period. (17, p. 214).

Phase IV: Public Information

This part of the program was to inform the general public. ODOT prepared two packages of information:

Original Package: This included the description of ODOT's five-phased scheme, the ODOT pilot projects nos. 1-3, and metric information (17, pp. 215-216).

Current Package: In addition to the original package, newsletters, photographs of projects, and correspondences were included (17, p. 217).

Phase V: Public Reaction:

This phase included "observations and analysis of public reaction to the metric signs and other phases of metrication. This phase differs from the motorist reaction previously explained" (17, p. 223). The reactions came from professionals, high school students, individuals, organizations, and agencies in the United States and in foreign countries. Reactions were also procured from public speeches, news clippings that analyzed various news stories published in newspapers and magazines about the metric system, ODOT clippings, trip to England stories, and metric

surveys at the Ohio State fairs where the public was contacted through a new questionnaire. This questionnaire was designed to include three fundamental groups of questions. The first group deals with the public familiarity of the metric system. The second group is related to the adaptation and use of the dual distance signs. The third group of questions is designed to evaluate the public opinion and effect of metric information.

Public Familiarity: This type of questionnaire is designed to discover the degree of understanding and responses of individuals at all levels of public sectors for the new metric system and their degree of familiarity with it. The factor of individual age is designed to be used as a base to group the population sample in certain categories, to carry out proper survey technique, and to evaluate the reaction and awareness of each individual to the new system. The results of the 1974 survey (compared to the 1973 survey) showed that there is a significant increase in the number of the responses of the age category of 18 years and under for a specific type of questions and a decrease for another type of questions. On the other hand, the age categories of higher than 18 years indicated a greater degree of familiarity and understanding of the metric system of units.

Dual Distance Signs: The idea behind this group of questions is to find the public observations of new signs in both customary American and metric units installed in several locations along the routes.

The result of this survey proved that the degree of observation and number of responses is related to the age category, e.g., a group of 18 years and under responded positively to the question of "usefulness of dual distance signs", 423 persons (57%) compared to 334 persons (43%) responding negatively. The age category of 19-35 years was strongly supporting the above question, while elderly persons of 51 years of age and over strongly disagreed.

Phase VI: Public Opinion and Information

The adoption of the metric system by the United States was raised as a question to several groups of individuals. The group of 19-35 years of age favored the idea and the survey of 1974 showed an increase of public opinion about the metric system compared to 1973's survey. The disagreement about adopting the metric system is supported by the younger people (18 years of age and under), and by the elderly people (51 years of age and over) as well.

Summary of Phase V

This phase included "observations and analysis of public reaction to the metric signs and other phases of metrication. This phase differs from the motorist reaction previously explained" (17, p. 221). The reactions came from professionals, high school students, individuals, organizations, and agencies in the United States and in foreign countries. Reactions were also procured from public speeches, news clippings that analyzed various news stories published in newspapers

and magazines about the metric system, ODOT clippings, trip to England stories, and metric surveys at the Ohio State fairs where the public was contacted through a new questionnaire (17, p. 221-224).

TASK 3: IDENTIFICATION OF PROBLEM AREAS

The objectives of this task were to:

...(a) identify problems in conversion to and use of the metric system in highway planning, location, design, construction, quality control, maintenance, inventory and traffic control, and (b) enumerate alternative solutions to these problems and analyze the feasibility of implementing such solutions (17, p. 253).

The following problem areas were discussed in detail in Tasks 1 and 2, and are briefly stated again in this task. A listing of these areas is introduced here and conclusions and recommendations made by this study team are stated as well.

Problem Areas on the National Level: There is a need for a national organization for the co-ordination of the metrication system. Units of measurements, as well as, product standards and specifications proved to be another area of concern. Metrication methods, whether "soft" or "hard" conversions, and the costs of metrication were other causes for consideration.

Problem Areas on the State Agency Level: A metrication organization within the highway agencies was needed. Agency specifications and policies, highway signs, computer services for metrication, and training programs were all problem areas on this level (17, p. 314).

Problem Areas in Planning, Location, and Design: The impact of metrication on surveying and aerial surveying and mapping were sources of dilemma. The accuracy of measurement in surveying, the "360° concept", design policies and aid revisions needed careful study. The

impact of metrication on design policies, aids, hardware, and specifications, as well as on plan preparations, was great. There was a great need for design personnel and surveyor training (17, p. 276).

Problem Areas of the Right-of-Way: Problems encountered in this area were the impact of metrication on equipment, right-of-way appraisal, and manual revisions, the property owners, the agency, and training personnel (17, pp. 286-290).

Problems of Construction: In this area, problems arose in project layouts, alternative materials, bid estimates and costs, hard and soft conversions, material demands and supplies, the testing of materials, and training personnel (17, pp. 291-300).

Problems in Operations: Problems in this area were due to traffic control (sign changes), road inventories, hard versus soft conversions, and the repair of customary American items (17, pp. 301-312).

Conclusions: A summary of the conclusions of this task is stated below:

On the National Level: Based on the assumption that few states are involved in metric projects and several states will follow, coordination of metrication activities is a must. For example, the SI and non-SI units to be selected should be based on nation-wide agreement. The material specifications, the method of conversion, the choice as to whether "soft" or "hard" are other examples of national needs

(17, pp. 313-314).

On the State Agency Level: Since the state is part of the nation, conversion costs resulting from revision of its standards, specifications, and policies, should be established within its highway agency, e.g. highway sign conversion, if coordinated among state, regional, and national agencies, will cut down costs (17, p. 314).

Public- and driver-training could be a state, regional, and national responsibility.

Planning, Location and Design: The USCGS topomapping conversion could take decades, but it has relatively small side effects on highway activities. The accuracy of measurements in field surveying needs revision. The design aids need revision, particularly the "software", such as computer programs, charts, tables, etc.

Preparing the design and construction drawings in metric requires proper metric scales, paper standard sizes, standard stationing, and standard templates.

The training of technical and non-technical personnel is required based on the responsibility and capability of individuals.

Right-of-Ways: No major problem is noted in this area except for computer program revisions, scales, and manuals. The acquisition representative and property owner argument is a problem which can be solved by cooperation.

Construction: The construction activities included such problem areas as field surveying, supply of material in metric, possibility of American substitutes, bid preparation estimates, and standardized metric price units. The difficulty of heavy construction equipment conversion by replacement is another problem facing contractors (17, pp. 316-317).

Operations: The changing of signs is a problem in the metrification process and considered a costly one, whether a single sign in metric or a dual sign in both systems is used.

The replacement and maintenance of these signs is an additional task to be considered (17, p. 317).

Procedural Recommendations (ODOT): Reviewing the above task and its conclusions, ODOT recommended the following (17, p. 318):

On the National Level: A national metric agency is necessary for coordination and enforcement of metric conversion. The SI and non-SI system of units are to be agreed upon nationally.

The method of "hard" conversion must be adopted for rational metrification. The traffic signs must be adopted based on a national economical cost-benefit relationship.

On the State Agency Level: The state task is to train the public and to survey their awareness of and reactions to the metrification process. The head of metric organization should be assigned to control the metrification process.

Metric equipment and tool availability is necessary to avoid confusion.

The construction of different metric pilot projects is the proper approach to acquaint technical and non-technical highway users.

Design and Plan Preparation: The dual dimension should be discouraged, including during the transition period. The roadway design elements such as 360^o circle system, 100 metre station, the cross slopes, and longitudinal grades should be continued.

The use of metres and millimetres is necessary in dimensioning (17, pp. 320-333).

Right-of-Way (ROW): Long range programs can be used for converting the records. The dual dimensions are discouraged in ROW plans (17, p. 321).

Construction: The metric material substitutes such as American products should be explained in clauses in the contract documents. The field measuring devices should be in metric.

Operations: Non-SI units such as kilometres per hour (kph) can be used instead of more difficult to conceptualize units such as metres per second (m/s). A 10 kph increment in design speed is recommended.

TASK 4: PROGRAM FOR RESEARCH

This task is devoted to the exploration of the additional need for further research into the metric process. The objectives of this task are summarized below:

...(a) to prepared a detailed plan for research aimed at solving conversion problems, and (b) to develop a detailed plan for research needed to support a smooth and effective conversion from the English to the SI measurement system in various phases of highway operations (planning, layout, construction, traffic control, maintenance, and inventory) (17, p. 323).

Timetables: Research is required in this area to determine the effects each major area has on the other major areas and where each fits into the overall timetables.

Metriation of the Transportation Industry: The metriation of the transportation industry may take 5-6 years based on the experience of Britain. However, the conversion of transportation modes (such as the highway and railway modes) are related to construction and manufacturing activities (17, p. 325).

Metriation of the Highway Mode: This mode consists of several interrelated components such as administration, standards, specifications, planning, design, right-of-way, construction, and operations (17, p. 326).

The following is a brief summary for several of these components:

Administration: Public training programs, information, and budgeting are tasks that the Administration personnel should handle.

Standards and Specifications: Two areas of concern are discovered. First, the national need for unified standards and specifications is noted. The second area of concern is that of the method and type of conversion, i.e. whether "soft" or "hard" (17, p. 321).

Planning: This poses no problem other than that of short-term confusion. The metric project should be planned to meet the metrication process.

Design: The following is an ODOT major consideration:

...there still remains many things that must be determined. Since revision of 'policy and design aids' will be the 'major' problem of this area, most of the recommendations for 'further' study pertain to this area. A study should be conducted to determine what national policy and aids are extensively used by state and local agencies as bases for their manuals (17, pp. 333-334).

The degree of accuracy should not be relaxed and should be based on theoretical and practical needs and experiences, e.g. the accuracy limits of 1/10 inch and 1/100 inch are practices in the customary American system, but they are not true for the metric (17, pp. 333-334).

Right-of-Way: The negotiations and present appraising practices need further study (17, p. 334).

Construction: The metrication of heavy construction equipment such as concrete plant, paving machines, asphalt plants, etc. need further study and research.

The effect of metric conversion on the equipment and spare parts should be studied carefully. The manufacturers, suppliers, and project

owners should coordinate and cooperate to lead the metrication process to success. This combined task needs further study.

The last problem area investigated by ODOT's personnel, the cost of the rate of production of construction of metric pilot projects, proved that at the start it is very expensive to build such projects but this cost disappeared gradually when the contractors and their employees familiarized themselves with the metric system. The required period of time and the cost involved need economic and managerial study (17, p. 335).

Operations: Two major components are involved in the area of operations: a. the signs; b. their repair. To design, construct, and maintain metre signs, whether single or dual, needs careful study and research because the large number of signs could turn into a costly problem. Based on this fact, sound and economical studies should be made to reduce costs. ODOT's study emphasized the importance of specific criteria to be adopted for further pure research in optimizing the overlay method for the present signs. These criteria are summarized in their report as indicated below:

- 1) It must be reasonably inexpensive to produce and place on newly manufactured and existing signs.
- 2) It should be durable enough to last through the transition period proposed for highway signs.
- 3) It should be reasonably easy to remove from the sign without damaging the covered message.
- 4) It should be reasonably non-susceptible to vandalism.

The negative comments that faced these criteria were that the short range programs were costly but long-range budgeting programs

would absorb such cost.

The economic life of signs and its effect on the transition period of conversion to metric still needs further analysis and evaluation. Further investigation in the area of sign repair is needed to cut down replacement and maintenance costs, e.g., using adapter devices will save expenses.

Legal Impact of Metrication: The highway functions related to traffic laws should be regulated to meet metrication process requirements such as speed limits, contractual documents, etc. (17, p. 338).

Highway Projects: ODOT's study recommended further metric pilot projects using different approaches (17, p. 338).

Metrication of a Highway Agency: Long range or short range plans should propose and implement metrication. These plans are to include highway planning, design, construction, etc. (17, p. 338).

ILLINOIS STUDY (1973 - 1976)

THE EFFECT OF METRICATION ON (IDOT)

The Study: This study was conducted on the basis of future planning to evaluate the effects of metrication on the Illinois Department of Transportation (IDOT).

The Department employs about 8200 people and has an annual construction program which averages more than \$400 million. The Department has four model divisions which include highways, public transportation, water resources, and aeronautics. These divisions are supported by the Office of Administration, Transportation, Safety, Legislative Affairs, Public Affairs, Planning, Programming and Environmental Science (25, p. 1).

The IDOT was authorized by the Federal Government to carry out the responsibility for state-wide transportation planning, development, construction, operation and maintenance of transportation facilities, and the administration of transportation grants and programs to local agencies of government. In 1973, IDOT began the study of the national status of metric conversion. During this year, IDOT conducted a study to determine the scope of the problem in the department, and the possible advantage to be derived from the change (25, p. 2).

Study Approach: The effect of the metric conversion is approached by the IDOT Metric Committee using the following questionnaire system:

...(1) How will conversion to the metric system of measure affect your operation? (a) In what specific areas? (b) To what extent or degree? (2) What do you estimate would be the cost in each of these areas if you had 5 or 10 years to convert (immediate with no dual dimensions, etc.)? (3) What do you recommend for conversion time? (4) What, if any, would be the continuing cost over and above the

use of our customary American System? (5) What will be the short or long range benefits? (6) What are your comments or remarks on the idea of conversion? (25, pp. 2-3).

Summary of Findings: The areas affected by the Metric Conversion are summarized below:

Photology: The problem of photography is affected by the difference between the intervals of photologging (0.01 mile) and log mile-point. This problem was solved by re-filming the roadway.

Mileage Tables, etc.: The mileage tables, route description, specification book, standard book and design manual were reviewed and it was suggested that they be revised to facilitate metrification process.

Measuring Equipment: The office and field work tools such as tapes, rods, scales, etc. need to be revised either by replacement with metric tools or modified: "...All measuring equipment such as tapes, studio boards, level rods, rules, scales, chains, thermometers, ...etc., need to be replaced or converted." (25, p. 5).

Highway Signs: Single or dual signs, replacement paint, or overlay cost was investigated:

Metrification will cause a high cost in signs, whether painting, replacing, overlaying, ...etc. Also equipment for converting these signs such as silk screens and monoprints will cost as well (25, p. 5).

Uniform Traffic Control Devices (UTC): Extensive changes in the manual of the U. T. C. resulted in a recommendation of the manual's

complete revision.

Project Control: Soil and bituminous mixes proved to be particularly difficult and needed a conversion to metric.

Right-of-Way: The right-of-way elements such as legal description and plans faced the problem of the historical data conversion argument as to whether to convert.

Training Program: Training programs will need revision.

Computer Programs: All programs with customary units require conversion to include formats for records, print layouts, and history files.

Environmental Engineering: Air quality analysis will need conversion, noise analysis needs conversion, ecological studies and reports need conversion and land surveying needs conversion for changes of location that are required (25, p. 6).

Conclusions: The Illinois study on cost/benefit concept basis resulted in the following conclusions:

Timing: Time tables for conversion are to be flexible enough to maintain a successful program.

Training: IDOT is responsible for planning an adequate and sound training program such as signs, information, brochures, etc., for the public to implement successfully the conversion process.

Costs: The cost effect was investigated and proved to be costly within a short term but could be absorbed by long period budgetary procedures.

Benefits: Cost reduction will cause an increase in benefits such as simplification of metric calculations compared to customary American calculations. This will prove valid in long-range prospects.

OREGON'S STUDY AND RESEARCH

(1973 - 1977)

On July 10, 1973 the Oregon State Highway Division (OSHD) officials reviewed the Ohio plan outlined in a related report (Interim Report) and considered this plan as a reasonable approach to the introduction of the metric system by a state agency. The following problem areas were investigated and commented upon by the different section heads of OSHD (29, pp. 1-9).

Specifications: The difficult period for owner and contractor is the initial period. This problem of specification has been solved by AASHO which provides most of the material specifications in both systems.

Construction: It was recommended that the field surveying alignment, stream flow data and bench marks be converted into metric. This would facilitate the work for the office and field personnel.

Planning: Planning poses no problem except for the normal confusion during the transition period.

Bridge Design: There was no major problem noticed except in plate dimensions and design computer programming. The pilot project should be limited to one concrete structure.

Maintenance: The maintenance field involved such problems as:
All historical data would require computer conversion to the new

system. All specifications for buying material would have to be rewritten. This is not critical, but does require time and money. It is in the area of the truck replacement, equipment, and machine-shops that considerable problems would be anticipated (29, pp. 1-9).

Traffic: The investigation in this area indicated a high cost in the area of dual signing, directional signing, etc. "The change-over of the directional signing could run as high as ten million dollars" (29, pp. 1-9).

Materials: The testing of materials poses no problem as most laboratories use the dual system.

Data Processing: Software, such as plans, and hardware, such as equipment, were investigated and need to be revised.

Some additional costs could be anticipated for the replacement of the equipment and for differences and confusion during the introduction period. There would always be a difference between the present system which includes costs of historical data replacment, right-of-way, construction plans...etc., and the metric system (29, p. 2).

It was suggested by OSHD that the following six phases be adopted for conversion:

Phase I: During this phase three pilot projects are to be developed, starting in 1976, using the metric system.

Phase II: The design stage, including plans, reports and specifications, is a continuation of Phase I.

Phase III: The construction stage will include all activities

such as staking, inspection, layout, testing, etc.

Phase IV: This phase introduces the metric system to the public in the format of dual signs, markers, etc.

Phase V: This phase facilitates public awareness and education by a distribution process of metric information containing material explaining the benefits of the metric system and its simplicity.

Phase VI: During this phase attitudes and responses are investigated by exposing the public and highway users to dual signing and other metric information.

The Oregon study arrived at a specific definition of technical parameters covering the areas of horizontal alignment, vertical alignment, map scales, design speeds, etc. The following details their recommendations:

Stationing: Standard station is 100-metre length.

Angles: A 360° circle system and concept of degrees, minutes and seconds are recommended.

Circular Curves: The curve is defined by the arc length of 100 metres subtended by the central angle.

Spiral Curves: No change is required in the existing spiral tables.

Vertical Alignment: The basic unit is the metre.

Gradients: The percentage (%) used for rate of gradients should not be changed.

Vertical Curves: The length of vertical curve may range between 20 to 500 metres with 20 metre intervals.

Leveling: Metres and decimals of a metre are recommended to be used for the measurement of elevations.

Cross-Section and Earthwork:

Cross-Section: It is recommended that the scale of 1:100 [similar to 1" = 10' (1:120)] must be used in both vertical and horizontal measurement.

Earthwork: The cubic metre is recommended.

Profiles:

Rural Profile: Scales 1:1000 horizontal (1" = 83.333) and 1:100 vertical (1" = 8.3333) are recommended.

Urban Profiles: Scales 1:500 horizontal (1" = 41.6666) and 1:50 vertical (1" = 4.16666) are recommended.

Detail Maps (Basic Unit - The Metre): The OSHD recorded the following scales to be used for contour intervals (c.i.):

<u>Present System</u>	<u>Metric System</u>
1" = 50', 2' c.i.	1:500, 1 metre c.i.
1" = 100', 5' c.i.	1:1000, 2 metre c.i.
1" = 200', 10' c.i.	1:2000, 3 metre c.i.
1" = 400', 20' c.i.	1:5000, 5 metre c.i.

Precision of Measurement: Precision of measurement is investigated in several areas and it is concluded that each case has its own particular requirements, e.g., horizontal and vertical control surveys require accuracy up to 0.01 metre, whereas topographical conditions need greater accuracy (up to 0.001 metre).

Design Speed: The OSHD converted the present speeds by soft method and recorded them as follows:

<u>Miles Per Hour</u>	<u>Kilometres Per Hour (Rounded)</u>
40	65
50	80
60	95
70	110

Lane and Shoulder Widths (Basic Unit - The Metre): The OSHD recorded the following rounded widths:

<u>Lanes</u>	<u>Shoulders</u>
12' (3.6 metres)	10' (3.0 metres)
11' (3.4 metres)	8' (2.4 metres)
10' (3.0 metres)	6' (1.8 metres)

Roadway Templates: No change is recommended for pavement, shoulder slopes, etc.

Right-of-Way Maps: The scales of the plans will remain the same using the ratio approach. The dual dimensions will be used.

Units: The basic unit, i.e. the metre, is to be used. Two digits following the decimal is recommended.

Pilot Projects: It was mentioned in the implementation stages (Phase III) that there are three projects to be constructed but in a recent contract (1976) two of them were combined. The following are the final (two) projects.

Project No. 1: The location is in Fat Elk Creek-Pulaski Creek, Coquille-Bandon Highway, Coos County. The type of work consists of grading, paving and structures. The standard specifications used were the 1974 edition of the "Standard Specifications". The plans were prepared using the SI units. This project is under construction at the present time (1978) (16, pp. 1-5).

Project No. 2: The location is in Millican Creek (Lafayette), Yamhill County. The type of work consists of grading, paving, and structures. The standards and specifications used are the same as for Project No. 1. The units of SI system were adopted the same as for Project No. 1. This project is under scheduling for bidding in the middle of 1978.

CANADA'S STUDY

(1975 - 1978)

In July, 1975 M/S De Leuw Cather, Canada Ltd. and Fenco Consultants Ltd. were appointed by the Roads and Transportation Association of Canada to prepare the manual of "Geometric Design Standards" for Canadian Roads and Streets in "Metric Units" (4, p. 1).

The following steps were taken for the preparation of this manual:

Step 1: The manual should remain in its present format but, together with the introduction of metric units, the manual will be updated to reflect current practices and standards based on criteria available to today's road and traffic conditions.

Step 2: Examination of the "most fundamental standards required in highway engineering and a review of current and past practices in the light of present day conditions" (4, p. 1).

Step 3: Modify and develop the basic criteria based on discussions with various highway agencies.

Step 4: Design pilot projects and prepare contract documentation.

Step 5: (1) Plan and schedule for target date construction starting in January, 1978. (2) Parallel to item (1) above, construction industries are expected to be ready to construct projects using the

metric system of units.

In addition to the Ohio study, the Canadian study also recognizes the modes of 'hard' versus 'soft' conversion and includes research and redefinitions of some of the parameters of highway design leading to hard conversion values (4, p. 1).

Manual Present Criteria (1973): There are a number of basic criteria and standards that need to be re-evaluated and assessed.

Review of Literature and Practices of Other Countries:

Australia and South Africa are among the countries who in recent years have dropped the 'Imperial' systems of units in favor of the 'metric' system. Both have gone through the conversion period which Canada is using as a comparison approach for guidelines to convert its present practices to the metric system within the Canadian interests.

Review, Reassessment of Present Design Criteria: The following items were reviewed, reassessed and evaluated by the consulting firms (De Leuw Cather, Canada Ltd. and Fenco Consultants Ltd.). "Hard" conversions were used in most cases. "Soft" conversions were used in some cases.

Range of Design Speed: The Canadians investigated the speed limit increments from lower speed to upper speed. The following argument was introduced in the Geometric Design Manual of 1973:

...range of speed 30 mph (48 Km/h) to 80 mph (129 Km/h), in increments of 10 mph (16 Km/h) from 30 mph to 60 mph and increments of 5 mph (8 Km/h) from 60 mph to 80 mph giving a total of 8 values.

A soft conversion suggests a range from 50 Km/h (31 mph) to 130 Km/h (81 mph) (4, p. 6).

Reviewing the experience of the Canadian authorities, it was noted that the lower recorded speed limit is 40 kph (close to 25 mph), and the higher value is 140 kph (close to 87 mph). This speed range resulted in 11 values compared to 8 values in present use (1973 manual) (4, p. 6).

Definition of Horizontal Curvature: There are two definitions in practice: a) curvature definition; b) radius definition. Most European countries are using radius definition. In the U. S. A. the curvature definition is favored.

The Canadian authorities used and supported both definitions during the conversion period, based on their favorite practices. The recent Canadian Geometric Design Manual (1976) adopted the radius definition.

The relationship between the two definitions can be presented as follows:

$$R = \frac{18000}{\pi} \quad (\text{for } 100 \text{ metre of arc})$$

where the R is the radius of curve in metres and D is the degree of curve in degrees, minutes, and seconds.

Both systems pose no problem to the Office designers and technicians. On the other hand, field personnel using deflection angles method for staking and laying out find it easier and simpler to use the curvature definition (i.e. using degree of curve as even value) (4, p. 9).

The above discussions are summarized as follows:

...(1) Curvature definition: Simple relationship, particularly

useful to a surveyor. Existing tables of properties for circular, spiral, and compound spirals may be used if the 100 m definition is used. (2) Radius definition, however, is used widely in other countries and has been adopted by some provinces. Circular and spiral curve templates are available (4, p. 15).

Side Friction Factors: The AASHTO practices were used in RTAC manual since they have a reasonable margin of safety at higher speeds and are somewhat low for low design speeds.

...This is considered desirable since drivers tend to overdrive low design speed roadway elements. The linear relationships are expressed mathematically as follows:

English System: $f = 0.19 - 0.001V$ (where V is in miles per hour,
f is in ratio)

Metric System: $f = 0.19 - \frac{v}{1609}$ (4, p. 16).

Stopping Sight Distance Criteria (SSD): To stop a vehicle, the driver needs the following minimum safe distances:

...(1) Distance traveled during perception time. (2) Distance traveled during break reaction time, and (3) Distance traveled during breaking (4, p. 23).

The AASHTO practices were used in previous manuals but recent research in Canada shows that values for stopping sight distance need not be based on assumed speed for the lower range of speed, i.e. up to 90 kph. This means that the wet conditions criterion is not materially different from those of dry conditions for this lower range of speeds. The perception time is defined as 1.5 seconds, the braking time 1.0 second. Therefore, the minimum values applied to horizontal crest and sag curves is 2.5 seconds. On the other hand the desirable values of stopping time range between 2.5 and 3.5 seconds. For crest curves the height of an

object (6") and driver eye level average height of 3' 9" are adopted from Canadian (1974) recent research and AASHTO manual (1965) (4, p. 23).

Sag Curve: The vehicle headlight deflection of 1° at a height of 2' 0" recommended by AASHTO is adopted by the Canadians since a costly survey would be needed to investigate such criteria (4, p. 21).

Rider Comfort: The Canadians adopted the AASHTO criteria for the acceleration of 1 ft./second/second (4, p. 25).

Passing Sight Distance (PSD): The AASHTO criteria for PSD is adopted since the procedure for research involves so many factors which are subject to fluctuations and so many assumptions. The PSD ranges from 1100' - 2700' (335 to 825 metres). The 3' 9" height of driver eye and 4' 6" for height of object were adopted and a 'soft' conversion of these values was used (1.14 m and 1.37 m respectively) (4, p. 27).

Lane Width: The soft conversion of present lane width of 12', 11' and 10' is 3.66 m, 3.35 m, and 3.05 m respectively. The most common values suggested on the basis of existing Canadian pavements, construction equipment, capacity and safety are 3.75 m, 3.7 m, 3.6 m for 12' 4", 12' 2", and 11' 9" respectively. After a review of the current Canadian Highway Authorities and other metric countries it was concluded that 3.7 metres is preferable (4, p. 28).

Summary of Recommendations:

The following summary of recommendations for the salient features

of the Canadian study (4, pp. 3-5) is presented in tabulation format:

<u>Design Element</u>	<u>Recommendation</u>
1. Conversion method	Hard conversion
2. Design speed	Range 40-140 kph
3. Curve definition	Radius definition
4. Stationing	Standard station of 100 metre of arc
5. Side friction	Present side friction factors are retained
6. Stop sight distance (SSD)	A. Perception time of 1.5 sec. for minimum values of SSD B. Perception time of 2.5 sec. for desirable values of SSD C. Brake reaction time of 1.0 sec. D. SSD is calculated for wet conditions of 90 to 140 kph
7. SSD for "crest curve"	A. The height of eye is 1.05 m B. The height of object is 380 mm for minimum value of SSD and 150 mm for desirable value of SSD
8. SSD for "sag curve"	Height of headlight of 0.6 m for an upward deflection of 1° headlight
9. PSD	The present practice to be retained
10. PSD measurement	A. The height of eye is 1.05 m B. The height of object is 1.3 m
11. Lane width	A. One-lane roadway widths of 3.6, 3.7, and 3.75 m are recommended B. Two-lane roadway width of 7.5 m is recommended
12. Shoulder widths	Five standard widths recorded, 1.0-3.0 m with .5 m increments

CHAPTER III

PROBLEM AREAS IDENTIFICATION AND PROPOSED SOLUTIONS

In reviewing the previous chapters, one realizes that the matter of metrication is not a simple "soft" conversion from one system of units to another. It is a nation-wide task and a world-wide present and future interaction system. The cost indicators in recent studies for "sign changes" only is estimated in the millions of dollars, e.g. California state must spend 30% of its total cost of metrication for highway signs. This represents approximately U.S. \$3,300,000.* Another example is the Oregon State Highway Division's estimate of \$1,000,000 for a dual signing system. Enlarging this cost base to include all items of the metrication process and hypothetically having it adopted by all the states in this country will probably cost hundreds of millions, if not billions, of dollars. The major part of this cost (if not all) will be charged to the taxpayers.

In this chapter and the following chapters the contribution of this work to the highway metrication activities will be concentrated on combined discussions and evaluations of field surveying, roadway design and alternative approaches to the problem of signing.

In the field of route surveying and roadway design, there are several basic elements. Two of the most important basic elements are the "station"

*Input to AASHTO and HOC Task Force Report, See Reference No. 17.

as a unit of measurement and the "curve", as a geometric feature of a roadway. These two elements are discussed in detail as follows:

Stationing: In field surveying the common practice is to stake on the ground regular intervals along a line before taking the elevation of points at these intervals. These regular intervals are known as stations or substations. The present practice in the United States for a full station is 100 feet, a substation may be 25 or 50 feet. Historically, the justification for the 100-foot station in American Route engineering was not only due to the fact that 100 feet was a useful unit of roadway length for these purposes but also was tied to the fact that survey layouts with a 100 foot tape was simplified. A tape length became a station. Once the instrument man was set up on an even station of a curve, each new station could be set at one tape-length and a full degree of curvature from the back station on the curve or one-half degree of curvature from the tangent. It also has been useful to have the station decimally related to total roadway length.

The station in practice in the metric countries is standardized in several different lengths such as 10, 20, 40, and 100 metres (14, p. 22). The reason for choosing a 100-metre station is justified in some countries by virtue of using existing 100-foot curve and spiral tables. Others claim that shorter stations are useful for sharper curves and irregular topography of the existing terrain along the route location.

It has been noticed that from the standard station lengths mentioned above a station of 30 metres was not legally adopted by any metric

country. This station (30 m) which is close in length to the present 100-foot station (i.e. 100 feet = 30.48 metres) could cause confusion in dual thinking of metric and foot systems at the same time. There has been no specific treatment by the SIO (Standard International Organization) to standardize major areas in highway design (e.g., the station definition) except for the length of the metre and the plane and solid angles (radians and steradians).

From the above review it is obvious that there exists no uniformity in station definition or standardization in metric on route engineering. The North American studies reviewed in the previous chapter have all indicated that a 100-metre station has been given interim acceptance primarily for the reason that existing highway design tables based on the 100-foot station can be employed without change.

In the author's view, this is hardly sufficient reason to make a 'hard' conversion without further analysis and study into the 'function' of the highway standard station.

The primary purpose of stationing in route engineering is to create a unit of roadway length sufficiently short to represent a 'homogeneous' section of route profile upon which to base unit costs, earthwork calculation and other roadway elements.

The station length should be determined on the following criteria:

- (a) The useful definition and a standardization of a practical unit of roadway length for purposes of excavation, unit costs, contracting, etc.;
- (b) The station should be decimally related to the total distance of the

route; and (c) The station should be short enough so that sub-stations will not be needed.

The criteria in items 'a', 'b', and 'c' above can be demonstrated by examples. In item 'a' the length of the station should be tied up with economy and field work practices, e.g., in earthwork calculations if end areas of the cross-sections are at larger intervals, say 50 metres apart, are in use and the resulted volume is fill or cut material, there is a possibility that end areas at intermediate points may cause a change in the resulted volume to more exact calculations whether in cut or fill. To avoid such considerable errors in volumes, shorter stations are required at smaller intervals, such as 10 metres or even 5 metres depending upon the topography of the terrain along the roadway's alignment.

The reason for using shorter stations results in more accurate computations. To put it simply, the shorter the station, the closer the elevations readings to the existing ground elevation. This procedure no doubt will give acceptable, practical and economical earthwork computations and will help the contractor to manage economically the earthwork movement such as the overhaul, free-haul and waste disposal.

Referring again to item 'b' above, the relationship between the total length of a roadway or a project and its unit of measurement should be consistent.

These conditions could be achieved by adopting a standard station which is decimally related to the total roadway or project length. This relationship can simply be represented by the following equation:

$$S_m = L_m \times 10^{-i} \text{ ----- (Equation 1) where:}$$

S_m = Number of stations for a given roadway length in metric.

L_m = Total length of a given roadway in metres.

i = 1, 2, . . . etc., depending on the length of the standard station, e.g., 10, 100 (metres) . . . etc.

As an example of the application of equation (1), a roadway length is assumed to be 12,220 metres. To find the length of this roadway in stations of 10, 20, 40, 50 and 100 metre lengths, the equation is applied in the following way:

$$S_m = 12,220 \times 10^{-1} = 1,222 \text{ stations for 10 metres length}$$

$$S_m = 12,220 \div 2 \times 10^{-1} = 611 \text{ stations for 20 metres length}$$

$$S_m = 12,220 \div 4 \times 10^{-1} = 305.5 \text{ stations for 40 metres length}$$

$$S_m = 12,220 \div 5 \times 10^{-1} = 244.4 \text{ stations for 50 metres length}$$

$$S_m = 12,220 \times 10^{-2} = 122.20 \text{ stations for 100 metres length}$$

From the above results the 10^{-1} is a common multiplier to these calculations and it proves to be the easiest to use. However, the 10^{-2} is another good multiplier but the author is justifying the use of a shorter length for a standard station, i.e., 10 metres instead of 100 for practical and economical reasons as explained in item 'a' above and more detailed in item 'c' as follows:

In item 'c' above, it is noticed that little attention has been given in the recent studies and research to the fact that the station should

represent a visible and practical unit of roadway length upon which the office and field work can be handled economically and efficiently.

In the use of 10, 20, 40, 50, and 100 metre stations, it has been observed that when the curve is fairly flat, this is when the degree of curve D_m does not exceed 6 or 7 degrees, the layout of the curve by 20, 40, 50, or 100 metre stations is usually satisfactory but for sharper curves and particularly in rough areas, it is often desirable to set stakes at closer intervals, say 10 metres apart (14, pgs. 18, 22). Furthermore, curves seldom begin and end on an even number of stations, so it is necessary to use shorter station-lengths to avoid intermediate intervals.

In urban areas where the visibility range is limited by existing trees, buildings, telephone poles, private property, several roadway intersections, crossings, . . . , etc., the use of a 10-metre station is more practical and accessible than longer stations, such as the 100-metre station. Another example of the 10-metre station is in laying out sharper ramps in both urban and rural highways. The 100-metre station is not visual or practical to surveying crews doing a tape or chain measurement, particularly in rough topographical areas or where the weather conditions in the working area are not clear.

Also the shorter station may facilitate the calculations of curve elements, e.g., if one memorizes the value of the radius of one degree of circular curve, which is $572.96/D_m$ for a 10-metre arc (D_m = degree of curve in metric), one can easily calculate the radius of a curve of any other degree. This approach is also applicable to the spiral curve

length and degree, e.g., if $\Delta_s = L_s D / 20$ for a 10 metre arc then for 1° of curve, $L_s = 20\Delta_s$ where Δ_s is the spiral angle.

It is concluded from the discussion and examples stated above that a shorter station length such as 10 metres is favored.

The following demonstrates the simplicity of the 10-metre station (arc definition), how it can easily be related to longer distances, and why it can be used as a basic definition. Using the basic relationship between the radius (R_m) and degree of curve (D_m) formula:

$$R_m = \frac{S(180)}{\pi D_m} \quad \text{----- (Equation 2 for 100-metre arc)}$$

$$R_m = \frac{S(57.296)}{D_m} \quad \text{----- (Equation 3 for 10-metre arc)}$$

If R_m is to remain constant and D_m is assumed to be one degree then $R_m = R_{10} = R_{20} = R_{40} = R_{100}$, where R_{10} means the radius for 10 metre arc, R_{20} means the radius for 20-metre arc and so on. Based on the above assumption:

$$R_{10} = \frac{572.96}{1} \quad \text{and} \quad R_{20} = \frac{1145.92}{D_{20}}$$

where D_{20} is the degree of curve for a 20 metre arc.

Thus, $R_{10} = R_{20}$

$$\frac{1145.92}{D_{20}} = \frac{572.96}{1}$$

$$D_{20} = \frac{1145.92}{572.96} = 2 \text{ degrees}$$

$$D_{40} = \frac{2291.83}{572.96} = 4 \text{ degrees}$$

$$D_{50} = \frac{2864.79}{572.96} = 5 \text{ degrees}$$

$$D_{100} = \frac{5729.60}{572.96} = 10 \text{ degrees}$$

This procedure can be applied to a radius of curve if the degree of curve remains constant and the results are:

$$R_{20} = 2R_{10}$$

$$R_{40} = 4R_{10}$$

$$R_{50} = 5R_{10}$$

$$R_{100} = 10R_{10}$$

The preceding simple relationship can be applied to the simple spiral curves for example: If the basic formula of spiral angle (s) and the radius (R) or degree of curve (D_m) is

$$\Delta_{s10} = \frac{L_s}{2R} = \frac{L_s D_{10}}{20} \quad (\text{Equation 4 for 10-metre arc})$$

$$\Delta_{s20} = \quad = \frac{L_s D_{20}}{40} \quad (\text{Equation 5 for 20-metre arc})$$

$$\Delta_{s40} = \quad = \frac{L_s D_{40}}{80} \quad (\text{Equation 6 for 40-metre arc})$$

$$\Delta_{s50} = \quad = \frac{L_s D_{50}}{100} \quad (\text{Equation 7 for 50-metre arc})$$

$$\Delta_{s100} = \quad = \frac{L_s D_{100}}{200} \quad (\text{Equation 8 for 100-metre arc})$$

assuming $\Delta_{s10} = \Delta_{s20} = \Delta_{s30} = \Delta_{s50} = \Delta_{s100} = 1^\circ$

$$\frac{L_s D_{10}}{20} = \frac{L_s D_{20}}{40} = \frac{L_s D_{40}}{80} = \frac{L_s D_{50}}{100} = \frac{L_s D_{100}}{200}$$

$$L_{s20} = 2L_{s10}; \quad L_{s40} = 4L_{s10}; \quad L_{s50} = 5L_{s10}; \quad L_{s100} = 10L_{s10}$$

The last point to be discussed and demonstrated with examples is the use of stations in marking a roadway length in both the office and the field. The conventional method of stationing in the American highway and route surveying is the regular 100-foot interval as a full station and '+!' for intermediate sub-station, e.g., a roadway length of 1,555.50 metres can be represented by the number of stations as follows:

(15 + 55.50) stations

This station designation has been disputed by Ohio's Interim Report of 1974 for pilot projects in District 10, Ohio State, based on the fact that elimination of plus (+) will prevent confusion between the present foot system and the metric system, and instead propose a new concept of stationing methods. The stationing marking considered the kilometre as the basic unit, e.g., 10,341.63. This point is 10,341.63 metres from origin point (0) and the 10 metres units and smaller are written half as high as the kilometre and hectometre. The comma is used to identify the whole kilometre units from the smaller units. The figures behind the decimal point indicate the distance less than 1 metre. No more than three digits should be used behind the decimal point. The alignment can be staked at stations divisible by 20 metres. This method of stationing faced a negative response from other districts and states based on the complicated digit arrangements and the difficulty of typing and printing them.

The author's view in this matter is compatible with the idea of minimizing the possibility of confusion by not using '+' marks for both the foot and metric systems. On the other hand, it is advisable to use the 100-metre station with + marks for intermediate sub-stations for proper and practical designation of stations, e.g., the + system can easily be written on layout stakes in the field. The American Engineers and Surveyors considered the '+' system for a long period of time and experienced its validity and feasibility. From both methods of stationing discussed above, another alternative of station markings is suggested to combine the two methods by direct reading from the origin (0), e.g., a roadway length of 10,341.63 can be expressed by the number of stations as follows:

S1034.163 (for 10-metre station)

or S103.4163 (for 100-metre station)

where 'S' stands for the point of origin and the abbreviation of the word 'station' and its standard length.

In conclusion to the definition of 'stationing', the author rejects the 100-metre definition and favors the 10-metre definition of a station. The prime purpose of stationing is to create a standard unit of measure for a specific section of roadway upon which office and field work will be feasible, such as design calculations, drawing preparations, unit costs, earthwork management, field surveying, etc., can be evaluated. Stationing should therefore be a length greater than (1) metre and probably not more than 40 metres, taking into consideration the standardization of a full

station length of 10 metres as previously discussed and justified in this chapter. It is also desirable to have this station unit directly employed in the curvature definition in order to avoid confusion. The definition of the standard station is summarized as follow: The standard station is a uniform and homogenous distance, ten (10) metres long around a curve or along a straight line and decimally related to a specific section of a roadway. The unit of measurement of stations are in numbers.

Curve Definition: The most important matter is to provide in metric the horizontal curve, spiral and super-elevation tables for a center line layout based on the metric degree of curvature. To brief the reader on the curve definition (for further details, interested individuals or groups may refer to relevant surveying texts) there are two international practices used to define the arc of a curve. One is called "curvature" definition and the other is "radius" definition. The relationship between the radius and curvature was given previously in this chapter in Equation Number 2 and is re-written here for discussion purposes:

$$D_m = \frac{S(180)}{\pi R_m} \quad \{\text{For both radius and curvature definitions}\}$$

where, R_m is in metres and D_m is in degrees, and S is the length of the defined roadway station. These definitions make no significant difference to the design engineer in the office because he can select (with the aid of a computer or an electronic calculator) even values for any one of them. Since the most common method of staking circular or spiral curves is the

deflection angles' method, the field personnel favor using the curvature definition (4, p. 9).

The curvature definition provides rational deflection angle values with consequent simplification of curve calculations and layout. Furthermore the present practice in North America is to use the 'curvature definition'. Recently, Canada adopted the 'radius' definition, and at the same time in Central Europe, South Africa, Australia and some Middle Eastern countries, the 'radius' definition, is legally practised in their metric systems (4, p. 8).

The major difficulty in employing the 'radius' definition is the inaccessibility (particularly for longer radii or higher intensity of obstruction objects along the line of the radii or the survey line) in both rural and urban areas, and the deflection angles produced by this method are always uneven (if even values of radii are used in Equation No. 13) which is not acceptable to the field personnel. Assuming the 'curvature' definition is favored now there are two elements to be decided upon. The first one is the 'chord' definition which means that the degree of curve is defined as the central angle subtended by a chord, e.g., 100 metres. The second is the 'arc' definition which means that the degree of curve is defined as the central angle subtended by an arc, e.g., 100 metres (14, p. 18).

Also the 100 m arc definition shows a larger degree of curvature than it would with the 100 foot definition so that the curves look sharper, but in reality, they are not. The curve definition, based on 100 metres

was disputed as explained in the previous section. Horizontal curve standard templates in metric should be established based on a policy of standardization.

The present templates used in the United States' highway design can not always be retained simply because the degree of curve in metric is different, not only in units of measurement but also in angle value and length of chord (or arc) of the said stations. Thus, by analogy, from the following foot system equations, the above argument can be clearly understood.

$$\frac{D_c}{360} = \frac{100}{2\pi R} \quad (\text{Equation No. 9})$$

D_c = degree of curve in degrees

R = radius of curve in foot

100 = 100 feet standard station (length of arc)

If 100 metre of arc is used instead of 100 feet and R is kept constant then and D_m is the degree of curve in metric.

$$\frac{D_m}{360} = \frac{100 \text{ m}}{2\pi R} \quad (\text{Equation No. 10})$$

m = metre

ft = feet

Therefore, by using Equation No. 9 and Equation No. 10

$$\frac{D_c}{100 \text{ ft}} = \frac{360}{2\pi R} \quad \text{and} \quad \frac{D_m}{100 \text{ m}} = \frac{360}{2\pi R};$$

$$\frac{D_c}{100 \text{ feet}} = \frac{D_m}{100 \text{ metres}}; \text{ and since } 100 \text{ feet} = 30.48 \text{ metres}$$

$$\frac{D_m}{30.48 \text{ metres}} = \frac{D_m}{100 \text{ metres}}, \text{ i.e. } \frac{D_m}{D_c} = \frac{100}{30.48} = (3.3 \text{ ratio})$$

In this thesis, the standardization of 10 metres as a full station is suggested as a homogenous, economical and practical unit of measure for a given roadway length. Also the curve definition is suggested to be related to the unit of stationing using Equation No. 3 in the form of curvature-arc relationships to maintain even values for degree of curve and odd values for the radius as follows:

$$D_m = \frac{S(57.296)}{R_m} \quad (S \text{ stands for } 10 \text{ metre-station}) \quad (\text{Eq. No. 11})$$

Furthermore, the 'curvature-arc' definition is suggested and used, based on these reasons: (a) It offers a simple relationship, particularly useful to the field personnel of the owners and contractors; (b) There is no need for computing sub-chords and correcting curve lengths; (c) It is practical to the surveyor to use the computed length around an exact curve; (d) It offers accessibility in staking and laying out curves with the use of the deflection angle's method, particularly for urban areas; (e) The values of even degrees simplifies calculations and field surveying; and (f) It allows the use of some one-degree curve tables for 100 feet (arc or chord) replacing the 100 metres (arc or chord) (4, 14, 18, 22); (g) The degree of curve is inversely proportional to the radius for the circular curve and directly proportional to the length of the curve for the

spiral curve. Finally the curve definition is summarized as follows: The curvature of a circular arc is defined by the constant angular change in direction per standard station along the arc. The unit of measurement is the degree, minute and second based on the use of the conventional 360° circle. In this thesis the degree of curve is the central angle subtended by a ten (10) metre standard station around the arc.

Having now established recommendations for the ten metre station and the degree-curvature definition, the following discussion summarizes and recommends metrication procedures in other areas of highway engineering including field survey, engineering design and operations.

Field Surveying:

Surveying Tools and Equipment: The present software, such as surveying manuals and field books must be metricated for future use. This will be resolved by new formats to meet the proposed stationing and curve definition. The surveying tools which were used in Ohio's study and pilot projects should have been the standard metric tools and not local modifications. For example, the 'add-metre' drag chain with incomplete and improper measurement graduation for centimetres and millimetres caused a reduction in the field measurement accuracy. Another example is the leveling rod obtained from the standard thirteen (13) foot Philadelphia staff with a metric face, actually was only 3.7 metres long (standard metric leveling rod is 4.0 metres). The problem with this rod is caused by its assembly, i.e., when the rod is extended it reads 3.6 metres properly, but then jumps

suddenly to the overhang where it reads 1.9 and 2.0 metres. This type of tool caused notable error and confusion to site personnel who are accustomed to the use of conventional standard leveling rods such as the Philadelphia rod of 7.0 feet down and 13 feet when extended. The direction equipment used in the Ohio study and pilot projects posed no problems because the angular definition of the 360° circle was retained and used.

No metrication can be adopted without using proper metric tools and local tools cannot be converted to metric units.

Precision of Measurement: The accuracy of 2 millimetres (mm) on a cloth tape was not necessary for topographical and cross-section measurements. A chain of added decimetres (D_c) marked off is needed for this type of work. Millimetres are too fine to be used for cross-sections, but they are necessary for bench marks. Accuracy in other horizontal measurements for control and layout is required to the (mm) since centimetres (cm) are too large compared to 1/100 of a foot. In summary, the present foot system (customary American) uses the tenth of a foot (1/10') or the hundredth of a foot (1/100') but no nominal limits like these are found in the metric system. Therefore, the author favors the following accuracy standards based on the recent studies in North America.

<u>Type of Work</u>	<u>Accuracy</u>
Control Survey	10 millimetres (0.01 metric)
Topographical Conditions	1 millimetre (0.001 metric)
Roadway Elements	100 millimetres (0.10 metric)

Angular Units: The degree and decimal of minutes and seconds proved to be simpler in curve calculations compared to the use of degrees, minutes and seconds. This type of standardization if used in field work will need the replacement of horizontal and vertical scales (drums) built into the surveying equipment, such as levels and theodolites which will mean very complicated replacement and maintenance processes. This thesis work suggests a combined process which means the use of the degree and its decimals in the curve calculation to avoid conversion of minutes and seconds and to use the degrees, minutes and seconds in field surveying equipment to save any possible replacement of permanent parts of theodolites and leveling equipment.

Control Surveys and Design Mapping: In the Ohio study, it was indicated that metrication of coordinate systems for control and mapping will only be 'hard' converted when the continental control net is re-adjusted and the proposed metric transverse Mercator universal projections are calculated therefrom. This may be several decades off so that an interim 'soft' conversion of the existing state coordinate systems should be contemplated for control survey and design mapping purposes. In states having zones of the Lambert conic projection, such as Oregon, this is relatively simple with the following equivalents:

1). Standard conversion should be based on survey foot relationship to metre.

1 metre = 3.280833333 survey feet.

1 survey foot = 0.3048006096 metres.

2). Constants of projection (for Oregon North Zone), soft converted, would be, for example:

$$C = 609,601.219 \text{ m}$$

$$R_b = 6,517,811.272 \text{ m}$$

$$l = .7091860252 \text{ (no change)}$$

$$K = 11,860391.430 \text{ m}$$

The constants C , R_b and K are simply soft converted using the metre-survey foot relationship. Since projection radii vary directly with K in the equation $R = k(\tan Z/2)^l$ (30, p. 120, Equation No. 99), foot projection tables can be soft converted in the same manner to their metric equivalent. Also, since $x = R \sin\theta + C$ and $y = R_b - R \cos\theta$, published values for Lambert coordinates can be soft converted with the same multiplier.

Design maps and control coordinates, in the usual Oregon highway practice, are enlarged or reduced from the true grid coordinate values by a multiplier which includes the grid scale and the sea level factors so that ground distances on the construction sight agree with control distances. This scale factor is usually shown on all drawings. It would be reasonable to propose that the metric scale factor be shown in a similar manner, so that coordinates in the contract and design documents could be directly related back to their equivalent values in the Oregon coordinate system.

Roadway Design:

Design Aids: The major problem expressed by the District 10 personnel (Ohio's study) in the conversion process was finding what had to be converted, because the design policy and aids came in fragmented form rather than in one easily used manual. Converting back and forth with unrevised design aids was both time consuming and an added source of errors. Some of the design aids, such as metric templates were not used because of a cost of U.S. \$150. This subjected the new metric pilot project to possible error and should have been avoided. The standard site distance charts were used with curve lengths converted to present American foot system. The difficulty faced in drawing up the plans was the lack of horizontal curve templates. The plan and profile and cross-section sheets used were narrower than is needed for reasonable detailing in the metric system.

In designing a profile of a roadway, vertical curve intervals of 5 metres or 10 metres are useful depending upon the sharpness of the curve and the topography of the existing ground. There is no justification in adopting 5 or 10 metre intervals compared to 25 feet, except that 25 feet is too long for a short tangent, yet the longer the tangent, the longer the intervals that can be used.

The hydraulic charts for culvert design were not converted in the Ohio studies and time lost could not be saved because proper efforts were not made to prepare these charts. If all design aids were provided, no difficulty in the metric system would have been faced, and time and efforts

could have been saved. In summary, this indicates that design without proper aids, is time consuming and frustrating.

The procurement of standard metric paper is not a problem when the supplier is aware of the demand, but the replacement or alteration of copying machines and files are to be researched prior to a metrication nation-wide policy being adopted. Finally, the computer programs should be converted and specific programs should be designed for nation-wide use to save efforts and time and to avoid repetitive work.

Design Speed: Recent studies in the United States recommended a 'soft' conversion of the present design speed of four values (40, 50, 60, and 70 mph) to rounded values of (65, 80, 95, and 110 kilometres per hour). There is no change in sight distance tables for horizontal and vertical curves.

The design speed evaluation was not an easy task to perform since it affects the quality of service, safety, cost and environmental impact of the facility. The design speed is a permanent feature for an already established road which cannot be altered without extensive reconstruction. Based on these facts, and on the recent study in Canada, the only solution is to metricate the design speed for a range of 40 to 140 kph, with a uniform increment of 10 kph, taking into consideration the wet and dry conditions which are retained for both upper and lower ranges of design speeds. To maintain a safe stopping and passing sight distance, the distances should be calculated using the 'running speed' and not the

'design speed' as adopted by the Canadians, where the wet conditions were not considered for the lower range of the design speed, i.e., 40 to 90 kph.

Signs: The dual speed limit and distance signs are a problem. The change of these signs is one of the most important and costliest items presented, and has been improperly treated by recent studies and pilot projects in the United States. This task is considered in this work as a new language for the nation and should be treated on this basis. The idea is to teach the public to think metric, to learn metric, and to visualize metric. Therefore dual signs in the two systems will cause more confusion and there is no need to erect any of these signs during the transition period. To justify this, it is the same as teaching a non-native speaker, the basics of a new language, e.g., the alphabet is presented to the student in its language. It is not translated nor does dual-lettering occur. A repetitive method of learning is applied until the student becomes familiar with the new alphabet. This simple example could be applied to the public by several approaches, one of which is to overlay or paint the signs and then mark them with metric readings only and provide the public with a simplified conversion table in a format of a 'sticker' mandatorily enforced to be placed on the window shield or on the dashboard of each vehicle to enable the driver to read the speed limit, the distance and units in both systems. This is their directory for a while until they become accustomed to the metric measurement. This method, hopefully, will help the public

to learn the metric units faster and easier saving time in terms of millions of the taxpayers dollars compared to the dual signing's costly method. To support the proposal suggested above, in regards to distance signing, an expert* on metrication recently reviewing the Canadian signs indicated that their cost in most provinces for distance signing has been minimal. First of all, 'they are doing no dual signing'. They have been able to salvage a large number of signs by simply moving the sign physically to the location for its mileage value in Km and fixing a small square sign to the marker simply with the abbreviation 'Km'.

Computer Generated Tables and AASHO's Manual Revision: In the conclusions derived by the Ohio and Illinois studies, emphasis was projected on the impact of metrication on location and design of highways. "The greatest impact of metrication on location and design will be in the area of the design software. Design policy and design aids (computer programs, charts and graphs, and standard drawings) will have to be revised" (17, p. 333).

The recommendations by the Ohio study for further research stressed policy and design aid revisions. This matter was stated in their study as follows:

"Since revision of policy and design aids will be the major problem for this area, most of the recommendations for further study pertain to this area.

*Earnest Rubin, former chairman of the U.S. Metric Association, OMSI Chpater, Portland, Oregon.

"As with specifications, a study should be conducted to determine what national policy and aids are extensively used by state and local agencies as bases for their manuals. When actual metrication begins, these would necessarily be the first to be revised." (17, p. 333)

A series of formulas and computer-generated tables used by AASHO's manual for the design controls for horizontal, vertical and combined alignment which was published in 1965 has been developed. This manual is A Policy on Geometric Design of Rural Highways. This effort hopefully will serve in facilitating the establishment of a design manual for roadway design with useful computer programs for several options of 10, 20, 40, and 100 metre arcs.

Finally the policy needs the re-assessment of all characteristics of the roadway, vehicle and motorist and other social-economical and environmental impacts.

Standard Notation: To distinguish and visualize the metric system from any other system, the following standard notations are proposed:

Plans: The letter 'M', in capital form and in the size of 2.5 x 5.0 centimetres can be printed in the far right-hand side and halfway between the top and bottom of each sheet of the plans to indicate plans in metric.

Stationing: Station markings can be used as (S1.00) for a standard station of 10 metres long from the origin, instead of the conventional station of '1 + 00' to avoid confusion with foot system and to read directly from the point of origin.

Curve Definition: The length of a curve in metric for a circular arc is to be labeled in (L_m) symbols in metres or as (S) in number standard stations instead of (L) as in the foot system. The degree of circular curve in metric is to be designated as (D_m) or (D_{mc}) instead of the conventional (D_a) for arc definition.

The radius of a curve may be denoted as (R_m) instead of the present radius symbol (R).

The present spiral angle Δ_s , S or θ_s may be replaced by a metric notation as Δ_m or θ_m . Intersection angle or central angle and other curve elements need no change in notations.

Design Speed: The design speed notation (kph) adapted by the Canadian and the Oregon study can replace any other symbols such as Km/h or Kmph or m/s used by others.

Signs: The 'M' in capital form in adequate size depending on the size of the sign can be placed in a format of printing or replaceable sticker in the upper left corner of the sign to indicate the sign in metric and to avoid confusion with the unit of the sign whether speed limit or distance signs.

Systems: To give the metric system proper identity from other systems, a standard notation may be used in this form (M - SYS).

CHAPTER IV

COMPUTER GENERATED TABLES AND THEIR USE

This chapter will introduce and discuss the development of the computer generated tables and how to use them in metric highway design. The tables' output is a result of the development of the required formulas from the present foot system (Customary American) to their equivalent in the metric (SI) system of units, then rationalize them by rounding the constants to the nearest complete set of numbers (without decimals) or to the nearest number of decimals depending on the accuracy of the output of each formula. These developed formulas were programmed by the use of the computer language, Fortran IV. Computations output were controlled by writing a main program with subroutines. This approach facilitates computing several tables' results in one main program.

The number of tables produced are eleven with subtables which are detailed in this chapter. Preceding each table, an explanation is presented to enable the reader to understand the purpose of developing this table, the meaning of notations and formulas used and an example of the application. Computer programs and formulas are presented in this work for 10, 20, 40 and 100 metre-arc. Ten metre tables* are presented here only to coincide with the author's recommendations for the adoption of a 10 metre standard station. Two sets of computer printout for 20, 40 and 100 metre-arc are available on reserve in the Department of Engineering and Applied Science at Portland State University, Portland, Oregon.

*Except Table III-A, where 20 metres is presented on the same sheet

TABLE I
 SUPERELEVATION AND MINIMUM TRANSITION LENGTH
 IN METRIC, A UNIT CURVE OF LENGTH
 10, 20, 40 AND 100 METRE ARC

Purpose

To read directly the length of minimum of transition curves required to keep the vehicle on the roadway and to provide safety and comfort to the motorist and passengers (design speed should not be exceeded).

Notations

10 metre of Arc (or one station) = Length of curve along the arc and not along the chord in metres.

40 kph = Design speed of 40 kilometre per hour (kph).

D = Degree of curve in degrees or the central angle subtended by 10 metre of Arc. = D_m

R = Radins of curve in metres. = R_m

E = Maximum superelevation metre per metre.

L_s = Minimum transition curve length in metres. = L_{sm}

L_{sm} values are considered in this table for E values ranges from 0.006 to 0.12 i.e. superelevation in excess of maximum value (0.12) recommended by AASHO produces unsafe curves for the indicate design speed.

Formulas

$$E = \frac{v^2}{226R} \text{ in metric (Radins definition) or} \quad (\text{Eq. No. 12})$$

$$E_{100} = \frac{v^2 D}{226(5729.578)} \text{ for 100 m of Arc (Arc definition) (Eq. No. 13)}$$

$$E_{10} = 0.00000772 V^2 D \text{ for } 10 \text{ m of Arc (Arc definition)} \quad (\text{Eq. No. 14})$$

$$E_{20} = 0.00000386 V^2 D \text{ for } 20 \text{ m of Arc (Arc definition)} \quad (\text{Eq. No. 15})$$

$$E_{40} = 0.00000193 V^2 D \text{ for } 40 \text{ m of Arc (Arc definition)} \quad (\text{Eq. No. 16})$$

$$E_{100} = 0.000000772 V^2 D \text{ for } 100 \text{ m of Arc (Arc definition)} \quad (\text{Eq. No. 17})$$

$$L_{s100} = \frac{0.0366V^3}{R} \text{ for } 100 \text{ m (Radins definition)} \quad (\text{Eq. No. 18})$$

$$L_{s10} = \frac{0.0366V^3 D}{572.9578} = 0.0000639 V^3 D \text{ (Arc definition)} \quad (\text{Eq. No. 19})$$

$$L_{s20} = \frac{0.0366V^3 D}{1145.916} = 0.0000314 V^3 D \text{ (Arc definition)} \quad (\text{Eq. No. 20})$$

$$L_{s40} = \frac{0.0366V^3 D}{2291.831} = 0.000016 V^3 D \text{ (Arc definition)} \quad (\text{Eq. No. 21})$$

$$L_{s100} = \frac{0.0366V^3 D}{5729.578} = 0.00000639 V^3 D \text{ (Arc definition)} \quad (\text{Eq. No. 22})$$

Example How to Use

Given: $D = 10^\circ$, $V = 100 \text{ kph}$, Station = 10 m of Arc

Required: E and L_s for 10 metres of Arc.

Solution: Direct reading with $D = 10^\circ$

$$\therefore R = 57.30 \text{ m}, E = 0.06, L_s = 40 \text{ m}$$

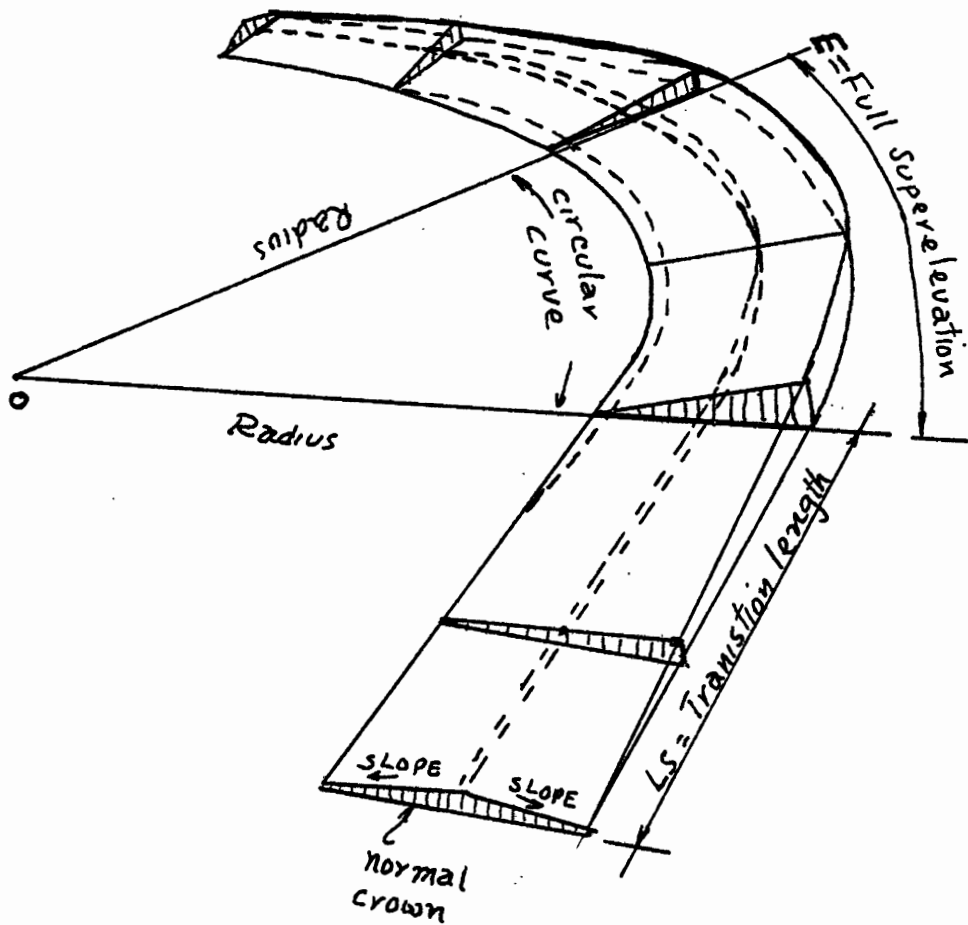


Figure 1.

Superelevation and Minimum Transition Length

TABLE 1
 SUPERELEVATIONS AND MINIMUM TRANSITION
 LENGTHS IN METRIC

10 METERS OF ARC

D	R	40		50		60		70		80		90		100		110		120		130		140	
		KPH	E	LS	KPH	E	LS	KPH	E	LS	KPH	E	LS	KPH	E	LS	KPH	E	LS	KPH	E	LS	KPH
1	572.96	.012	40	.02	40	.03	40	.04	40	.05	40	.06	46	.08	63	.09	85	.11	110	.13	140	.15	175
2	286.48	.02	40	.04	40	.06	40	.08	40	.10	65	.13	93	.15	127	.19	170	.22	220	.26	280	.30	350
3	190.99	.04	40	.08	40	.11	65	.15	98	.19	139	.25	186	.31	255	.37	340	.44	441	.52	561	.61	701
4	143.24	.05	40	.08	40	.11	68	.15	109	.20	130	.25	166	.31	222	.37	290	.44	362	.52	441	.61	541
5	114.59	.06	40	.10	40	.14	68	.19	109	.25	163	.31	232	.39	319	.47	425	.56	551	.65	701	.76	876
6	95.49	.07	40	.12	47	.17	82	.23	131	.30	196	.38	279	.46	383	.56	510	.67	662	.78	842	.91	1011
7	81.85	.09	40	.14	55	.19	96	.26	153	.35	228	.44	325	.54	447	.65	595	.78	772	.91	982	1.11	1211
8	71.62	.10	40	.15	63	.22	110	.30	175	.40	261	.50	372	.62	511	.75	680	.89	883	1.01	1111	1.11	1311
9	63.66	.11	40	.17	71	.25	124	.34	197	.44	294	.56	410	.69	574	.84	765	1.01	993	1.11	1211	1.21	1411
10	57.30	.12	40	.19	79	.28	137	.38	219	.49	327	.63	465	.77	638	.93	850	1.11	1111	1.21	1311	1.31	1511
11	52.09	.14	44	.21	87	.31	151	.42	241	.54	359	.69	512	.85	702	1.01	935	1.11	1111	1.21	1311	1.31	1511
12	47.75	.15	49	.23	95	.33	165	.45	262	.59	392	.75	558	.93	766	1.11	1011	1.21	1311	1.31	1511	1.41	1711
13	44.07	.16	53	.25	103	.36	179	.49	284	.64	425	.81	605	1.01	830	1.11	1011	1.21	1311	1.31	1511	1.41	1711
14	40.93	.17	57	.27	111	.39	193	.53	306	.69	457	.88	651	1.01	898	1.11	1011	1.21	1311	1.31	1511	1.41	1711
15	38.20	.19	61	.29	119	.42	206	.57	328	.74	490	.94	698	1.01	958	1.11	1011	1.21	1311	1.31	1511	1.41	1711
16	35.81	.20	65	.31	127	.44	220	.61	350	.79	523	1.01	745	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911
17	33.70	.21	69	.33	135	.47	234	.64	372	.84	556	1.01	791	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911
18	31.83	.22	73	.35	143	.50	248	.68	394	.89	588	1.01	838	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911
19	30.16	.23	77	.37	151	.53	262	.72	416	.94	621	1.01	888	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911
20	28.65	.25	81	.39	159	.56	275	.76	438	.99	654	1.01	931	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911
21	27.28	.26	85	.41	167	.58	289	.79	460	1.01	686	1.11	977	1.21	1011	1.31	1511	1.41	1711	1.51	1911	1.61	2111
22	26.04	.27	89	.42	175	.61	303	.83	482	1.01	719	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911	1.61	2111
23	24.91	.28	94	.44	183	.64	317	.87	503	1.01	752	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911	1.61	2111
24	23.87	.30	98	.46	191	.67	331	.91	525	1.01	784	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911	1.61	2111
25	22.92	.31	102	.48	199	.69	344	.95	547	1.01	817	1.11	1011	1.21	1311	1.31	1511	1.41	1711	1.51	1911	1.61	2111

TABLE II
 RADII, DEFLECTIONS AND CHORDS
 "ARC DEFINITION"
 FOR 10, 20, 40 AND 100 METRE ARC

Purpose

Given either the degree or the radius of a simple circular curve, thus deflection and chords length for 10, 20, 40 and 100 metre arc can be found. The table is computed by "Arc definition".

Notations

The notations in this table is self explanatory except the following notation.

° = degree,

' = minutes

Formulas

For 10-metre Arc:

$$\text{Degree of curve} = D = \frac{572.9578}{\text{Radius}} = D_m \quad (\text{Eq. No. 23})$$

$$\text{Deflection angle for 1 metre of arc} = \delta = \frac{D}{40} \quad (\text{Eq. No. 24})$$

$$\text{Deflection angle for 20 metre of arc} = \delta = \frac{D}{2} \quad (\text{Eq. No. 25})$$

$$\text{Chord length for 10 m Arc} = 2 \text{ Radius} \left(\sin \frac{D}{2} \right) \quad (\text{Eq. No. 26})$$

$$\text{Chord length for 20 m Arc} = 2 \text{ Radius} (\sin D) \quad (\text{Eq. No. 27})$$

$$\text{Chord length for 40 m Arc} = 2 \text{ Radius} (\sin 2D) \quad (\text{Eq. No. 28})$$

$$\text{Chord length for 100 m Arc} = 2 \text{ Radius} (\sin 5D) \quad (\text{Eq. No. 29})$$

Example How to Use:

Given: $D = 0^{\circ}30' = D_m$, $R = 2291.832 \text{ metres} = R_m = \text{Radius in metric}$

Required: Deflection angles for 1, 20 metre, and chords for 10, 20, 40, 100 for 10 m Arc.

Solution: Read directly under degree of curve for value of 30 minutes. $\therefore \delta_{1m} = 0.03'$ $\delta_{20m} = 15'$

Chords for 10 m Arc = 10.000 metres

Chords for 20 m Arc = 20.000 metres

Chords for 40 m Arc = 39.998 metres

Chords for 100 m Arc = 99.968 metres

To find the value of other subdeflection angles (δ), the relationship

$$\delta = \frac{CD}{20} \text{ for 10 m arc}$$

$$\delta = \frac{CD}{40} \text{ for 20 m arc}$$

$$\delta = \frac{CD}{80} \text{ for 40 m arc}$$

$$\delta = \frac{CD}{200} \text{ for 100 m arc}$$

where C = length of subarc, D = degree of curve, δ = subdeflection

For 20-metre Arc:

$$\text{Degree of curve} = D = \frac{1145.916}{\text{Radius}} \quad (\text{Eq. No. 30})$$

$$\text{Deflection angle for 1 metre of Arc} = \delta = \frac{D}{40} \quad (\text{Eq. No. 31})$$

$$\text{Deflection angle for 20 metre of Arc} = \delta = \frac{D}{2} \quad (\text{Eq. No. 32})$$

$$\text{Chord length for 10 m Arc} = 2 \text{ Radius} \left(\sin \frac{D}{2} \right) \quad (\text{Eq. No. 33})$$

$$\text{Chord length for 20 m Arc} = 2 \text{ Radius} \left(\sin \frac{D}{4} \right) \quad (\text{Eq. No. 34})$$

$$\text{Chord length for 40 m Arc} = 2 \text{ Radius } (\sin D) \quad (\text{Eq. No. 35})$$

$$\text{Chord length for 100 m Arc} = 2 \text{ Radius } \left(\sin \frac{5D}{2}\right) \quad (\text{Eq. No. 36})$$

Example how to use: same procedure used in previous example is applicable.

For 40-metre Arc:

$$\text{Degree of curve} = D = \frac{2291.832}{\text{Radius}} = D_m \quad (\text{Eq. No. 37})$$

$$\text{Deflection angle for 1 metre of Arc} = \partial = \frac{D}{40} \quad (\text{Eq. No. 38})$$

$$\text{Deflection angle for 20 metre of Arc} = \partial = \frac{D}{2} \quad (\text{Eq. No. 39})$$

$$\text{Chord length for 10 m arc} = 2 \text{ Radius } \left(\sin \frac{D}{2}\right) \quad (\text{Eq. No. 40})$$

$$\text{Chord length for 20 m arc} = 2 \text{ Radius } \left(\sin \frac{D}{8}\right) \quad (\text{Eq. No. 41})$$

$$\text{Chord length for 40 m arc} = 2 \text{ Radius } \left(\sin \frac{D}{4}\right) \quad (\text{Eq. No. 42})$$

$$\text{Chord length for 100 m arc} = 2 \text{ Radius } \left(\sin \frac{5D}{2}\right) \quad (\text{Eq. No. 43})$$

Example how to use: Same procedure used in previous example is applicable.

For 100-metre Arc:

$$\text{Degree of curve} = D = \frac{5729.578}{\text{Radius}} = D_m \quad (\text{Eq. No. 44})$$

$$\text{Deflection angle for 1 metre of Arc} = \partial = \frac{D}{40} \quad (\text{Eq. No. 45})$$

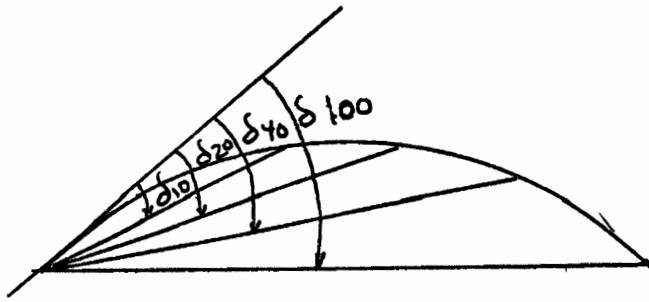
$$\text{Deflection angle for 20 metre of Arc} = \partial = \frac{D}{2} \quad (\text{Eq. No. 46})$$

$$\text{Chord length for 10 m Arc} = 2 \text{ Radius } \left(\sin \frac{D}{2}\right) \quad (\text{Eq. No. 47})$$

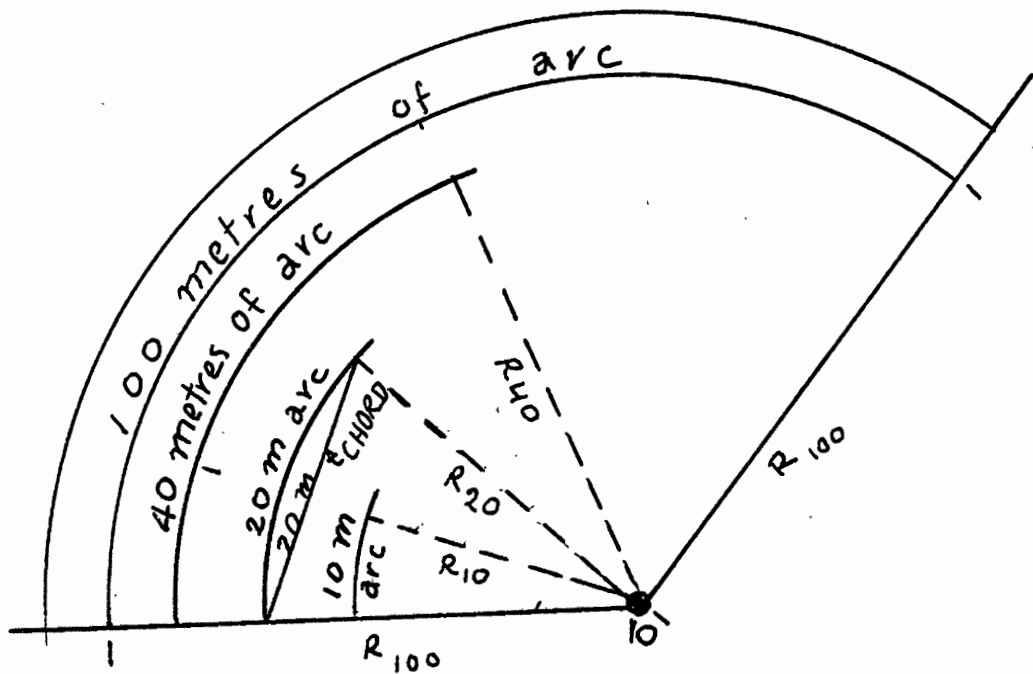
Chord length for 20 m Arc = 2 Radius $(\text{Sin } \frac{D}{20})$ (Eq. No. 48)

Chord length for 40 m Arc = 2 Radius $(\text{Sin } \frac{D}{10})$ (Eq. No. 49)

Chord length for 100 m Arc = 2 Radius $(\text{Sin } \frac{D}{5})$ (Eq. No. 50)



a) Deflection Angle



b) Arc and Chord for
10, 20, 40 and 100 metres
of arc

Figure 2.

Radii, Deflections and "Arc Definition"

TABLE II
 RADII, DEFLECTIONS AND CHORDS "ARC DEFINITION"

DEGREE OF CURVE	RADIUS OF CURVE	DEFLECTIONS FOR					CHORD FOR				
		1 M. OF ARC	20 M. OF ARC	10 M. OF ARC	20 M. OF ARC	40 M. OF ARC	100 M. OF ARC	20 M. OF ARC	40 M. OF ARC	100 M. OF ARC	
0'	METER	0'	0'	0'	METER	METER	METER	METER	METER		
0	0	0	0	0	0	0	0	0	0		
0	10	3437.747	0.01	0	5	10.000	20.000	40.000	99.997		
	20	1718.873	0.02	10	10.000	20.000	39.999	99.986	99.986		
	30	1145.916	0.03	15	10.000	20.000	39.998	99.969	99.969		
	40	859.437	0.03	20	10.000	20.000	39.996	99.944	99.944		
	50	687.549	0.04	25	10.000	19.999	39.994	99.912	99.912		
1	0	572.958	0.05	0	30	10.000	19.999	39.992	99.873		
	10	491.107	0.06	35	10.000	19.999	39.989	99.827	99.827		
	20	429.718	0.07	40	10.000	19.998	39.986	99.775	99.775		
	30	381.972	0.07	45	10.000	19.998	39.982	99.715	99.715		
	40	343.775	0.08	50	10.000	19.997	39.977	99.648	99.648		
	50	312.522	0.09	55	10.000	19.997	39.973	99.574	99.574		
2	0	286.079	0.10	1	0	9.999	19.996	39.968	99.493		
	10	264.442	0.11	5	9.999	19.995	39.962	99.405	99.405		
	20	245.553	0.12	10	9.999	19.994	39.956	99.310	99.310		
	30	229.183	0.12	15	9.999	19.994	39.949	99.209	99.209		
	40	214.859	0.13	20	9.999	19.993	39.942	99.100	99.100		
	50	202.220	0.14	25	9.999	19.992	39.935	99.984	99.984		
3	0	190.986	0.15	1	30	9.999	19.991	39.927	99.862		
	10	180.934	0.16	35	9.999	19.990	39.919	99.732	99.732		
	20	171.887	0.17	40	9.999	19.989	39.910	99.596	99.596		
	30	163.702	0.17	45	9.998	19.988	39.901	99.452	99.452		
	40	156.261	0.18	50	9.998	19.986	39.891	99.302	99.302		
	50	149.467	0.19	55	9.998	19.985	39.881	99.145	99.145		
4	0	143.239	0.20	2	0	9.998	19.984	39.870	97.982		
	10	137.510	0.21	5	9.998	19.982	39.859	97.811	97.811		
	20	132.221	0.22	10	9.998	19.981	39.848	97.634	97.634		
	30	127.324	0.22	15	9.997	19.979	39.836	97.450	97.450		
	40	122.777	0.23	20	9.997	19.978	39.823	97.259	97.259		
	50	118.543	0.24	25	9.997	19.976	39.811	97.061	97.061		
5	0	114.592	0.25	2	30	9.997	19.975	39.797	96.857		
	10	110.895	0.26	35	9.997	19.973	39.784	96.646	96.646		
	20	107.430	0.27	40	9.996	19.971	39.769	96.429	96.429		
	30	104.174	0.28	45	9.996	19.969	39.755	96.205	96.205		
	40	101.110	0.28	50	9.996	19.967	39.740	95.974	95.974		
	50	98.221	0.29	55	9.996	19.965	39.724	95.737	95.737		

TABLE II
 RADIUS, DEFLECTIONS AND CHORDS "ARC DEFINITION"

DEGREE OF CURVE	RADIUS OF CURVE	DEFLECTIONS FOR					CHORD FOR					
		1 M. OF ARC	20 M. OF ARC	10 M. OF ARC	20 M. OF ARC	40 M. OF ARC	100 M. OF ARC	0'	1'	METER	METER	METER
12	0	95.493	0.30	6	0	9.995	19.963	39.708	95.493			
10	10	94.185	0.30	5		9.995	19.962	39.700	95.369			
20	20	92.912	0.31	10		9.995	19.961	39.692	95.243			
30	30	91.673	0.31	15		9.995	19.960	39.683	95.115			
40	40	90.467	0.32	20		9.995	19.959	39.675	94.986			
50	50	89.292	0.32	25		9.995	19.958	39.666	94.855			
13	0	88.147	0.32	6	30	9.995	19.957	39.658	94.723			
10	10	87.032	0.33	35		9.995	19.956	39.649	94.589			
20	20	85.944	0.33	40		9.994	19.955	39.640	94.454			
30	30	84.883	0.34	45		9.994	19.954	39.631	94.317			
40	40	83.848	0.34	50		9.994	19.953	39.622	94.178			
50	50	82.837	0.35	55		9.994	19.951	39.613	94.038			
14	0	81.851	0.35	7	0	9.994	19.950	39.603	93.896			
10	10	80.888	0.35	5		9.994	19.949	39.594	93.752			
20	20	79.948	0.36	10		9.993	19.948	39.584	93.607			
30	30	79.029	0.36	15		9.993	19.947	39.574	93.461			
40	40	78.131	0.37	20		9.993	19.945	39.565	93.313			
50	50	77.253	0.37	25		9.993	19.944	39.555	93.163			
15	0	76.394	0.38	7	30	9.993	19.943	39.545	93.012			
10	10	75.555	0.38	35		9.993	19.942	39.535	92.859			
20	20	74.734	0.38	40		9.993	19.940	39.524	92.705			
30	30	73.930	0.39	45		9.992	19.939	39.514	92.549			
40	40	73.144	0.39	50		9.992	19.938	39.503	92.392			
50	50	72.374	0.40	55		9.992	19.936	39.493	92.233			
16	0	71.620	0.40	8	0	9.992	19.935	39.482	92.073			
10	10	70.881	0.40	5		9.992	19.934	39.471	91.911			
20	20	70.158	0.41	10		9.992	19.932	39.460	91.747			
30	30	69.449	0.41	15		9.991	19.931	39.449	91.582			
40	40	68.755	0.42	20		9.991	19.930	39.438	91.416			
50	50	68.074	0.42	25		9.991	19.928	39.427	91.248			
17	0	67.407	0.42	8	30	9.991	19.927	39.416	91.079			
10	10	66.752	0.43	35		9.991	19.925	39.404	90.908			
20	20	66.111	0.43	40		9.990	19.924	39.393	90.736			
30	30	65.481	0.44	45		9.990	19.922	39.381	90.562			
40	40	64.863	0.44	50		9.990	19.921	39.369	90.387			
50	50	64.257	0.45	55		9.990	19.919	39.357	90.210			

TABLE II
RADI, DEFLECTIONS AND CHORDS "ARC DEFINITION"

DEGREE OF CURVE	RADIUS OF CURVE	DEFLECTIONS FOR			CHORD FOR				
		1 M. OF ARC	20 M. OF ARC	100 M. OF ARC	10 M. OF ARC	20 M. OF ARC	100 M. OF ARC		
0'	METER	0'	0'	0'	METER	METER	METER		
12	0	47.746	0.60	6	0	9.982	19.854	38.841	82.699
	10	47.092	0.61	5	5	9.981	19.850	38.808	82.243
	20	46.456	0.62	10	9.981	19.846	38.776	81.781	
	30	45.837	0.62	15	9.980	19.842	38.743	81.315	
	40	45.234	0.63	20	9.980	19.837	38.709	80.849	
	50	44.646	0.64	25	9.979	19.833	38.676	80.369	
13	0	44.074	0.65	6	30	9.979	19.829	38.641	79.889
	10	43.516	0.66	35	9.978	19.824	38.607	79.404	
	20	42.972	0.67	40	9.977	19.820	38.571	78.915	
	30	42.441	0.67	45	9.977	19.815	38.536	78.421	
	40	41.924	0.68	50	9.976	19.811	38.500	77.923	
	50	41.419	0.69	55	9.976	19.806	38.464	77.421	
14	0	40.926	0.70	7	0	9.975	19.802	38.427	76.915
	10	40.444	0.71	5	5	9.975	19.797	38.390	76.404
	20	39.974	0.72	10	9.974	19.792	38.352	75.890	
	30	39.514	0.72	15	9.973	19.787	38.314	75.371	
	40	39.065	0.73	20	9.973	19.782	38.275	74.848	
	50	38.626	0.74	25	9.972	19.777	38.237	74.322	
15	0	38.197	0.75	7	30	9.971	19.772	38.197	73.791
	10	37.777	0.76	35	9.971	19.767	38.157	73.257	
	20	37.367	0.77	40	9.970	19.762	38.117	72.719	
	30	36.965	0.77	45	9.970	19.757	38.077	72.178	
	40	36.572	0.78	50	9.969	19.752	38.036	71.632	
	50	36.187	0.79	55	9.968	19.746	37.994	71.080	
16	0	35.810	0.80	8	0	9.968	19.741	37.953	70.532
	10	35.441	0.81	5	5	9.967	19.736	37.910	69.976
	20	35.079	0.82	10	9.966	19.730	37.868	69.417	
	30	34.725	0.82	15	9.965	19.725	37.825	68.855	
	40	34.377	0.83	20	9.965	19.719	37.781	68.290	
	50	34.037	0.84	25	9.964	19.714	37.738	67.722	
17	0	33.703	0.85	8	30	9.963	19.708	37.693	67.150
	10	33.376	0.86	35	9.963	19.702	37.649	66.576	
	20	33.055	0.87	40	9.962	19.696	37.604	65.999	
	30	32.740	0.87	45	9.961	19.690	37.558	65.419	
	40	32.432	0.88	50	9.960	19.685	37.512	64.836	
	50	32.128	0.89	55	9.960	19.679	37.466	64.250	

TABLE III-A AND B

FUNCTIONS OF SIMPLE CIRCULAR CURVE,
A UNIT CURVE OF LENGTH
10, 20, 40 AND 100 METRES OF ARC

Purpose

To compute simple circular curve elements in arc definition for 10, 20, 40 and 100 for 1° curve.

Notations

Delta = Central angle subtended by a 10, 20, 40 or 100 metre arc

= Δ

R = Radius of curvature in metres = R_m

T = Initial tangent distance between point of tangency (T.C.) and point of tangents intersection (P.I.)

L = Length of curve in metres = L_m

M = Middle ordinate in metres

E = External distance in metres

C = Chord length in metres

D = Degree of curve which is one (1°) degree for this table = D_m

Formulas10-metre arc:

$$R = \frac{572.9578}{\Delta} \quad (\text{Eq. No. 51})$$

$$T = R \tan \frac{\Delta}{2} \quad (\text{Eq. No. 52})$$

$$L = \frac{10\Delta}{D} \quad (\text{Eq. No. 53})$$

$$M = R(1 - \cos \frac{\Delta}{2}) \quad (\text{Eq. No. 54})$$

$$E = T \tan \frac{\Delta}{4} \quad (\text{Eq. No. 55})$$

$$C = 2R \sin \frac{\Delta}{2} \quad (\text{Eq. No. 56})$$

$$\Delta = \frac{LD}{10} \quad (\text{Eq. No. 57})$$

20-metre arc:

$$R = \frac{1145.916}{\Delta}$$

$$T = R \tan \frac{\Delta}{2}$$

$$L = 20 \frac{\Delta}{D}$$

$$M = R(1 - \cos \frac{\Delta}{2})$$

$$E = T \tan \frac{\Delta}{4}$$

$$C = 2R \sin \frac{\Delta}{2}$$

$$\Delta = \frac{LD}{20}$$

40-metre arc:

$$R = \frac{2291.832}{\Delta}$$

$$T = R \tan \frac{\Delta}{2}$$

$$L = 40 \frac{\Delta}{D}$$

$$M = R(1 - \cos \frac{\Delta}{2})$$

$$E = T \tan \frac{\Delta}{4}$$

$$C = 2R \sin \frac{\Delta}{2}$$

$$\Delta = \frac{LD}{40}$$

100-metre arc:

$$R = \frac{5729.578}{\Delta}$$

$$T = R \tan \frac{\Delta}{2}$$

$$L = 100 \frac{\Delta}{D}$$

$$M = R(1 - \cos \frac{\Delta}{2})$$

$$E = T \tan \frac{\Delta}{4}$$

$$C = 2R \sin \frac{\Delta}{2}$$

$$\Delta = \frac{LD}{100}$$

Example How to Use

Given: $\Delta = 4^\circ$, $D = 1^\circ$

Required: Values of R, T, L, M, E and C

Solution: Direct reading under delta equals 4°

R = 143.24 metre

T = 5.0 metre

L = 40.0 metre

M = 0.09 metre

C = 0.09 metre

E = 9.998 metre

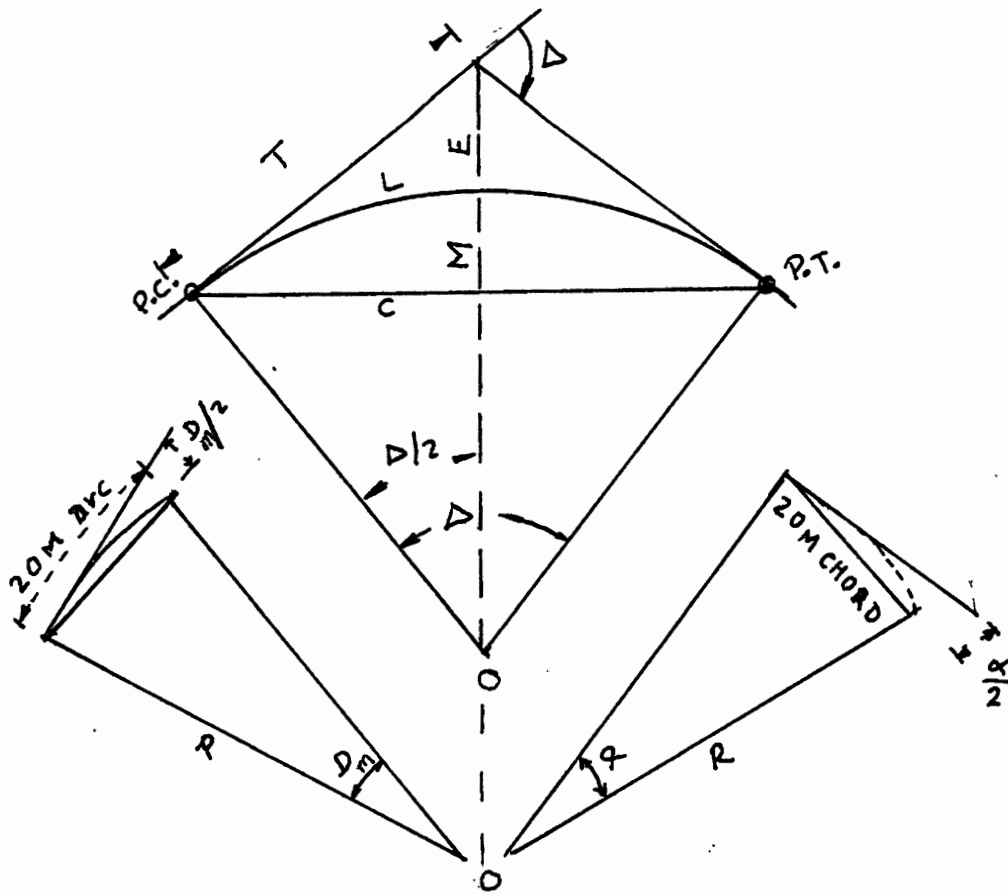


Figure 3.

Functions of Simple Circular Curve.

TABLE III - A

A UNIT CURVE OF LENGTH 10 METERS OF ARC		FUNCTIONS OF SIMPLE CIRCULAR CURVE		A UNIT CURVE OF LENGTH 20 METERS OF ARC		A UNIT CURVE OF LENGTH 30 METERS OF ARC		A UNIT CURVE OF LENGTH 40 METERS OF ARC		A UNIT CURVE OF LENGTH 50 METERS OF ARC					
DELTA	R	T	L	M	F	C	DELTA	R	T	L	M	E	C		
0	1	0	572.96	5.00	10.00	0.02	0.02	10.000	10	1145.92	10.00	20.00	0.04	0.04	20.000
10	491.11	5.00	11.67	0.03	0.03	10.000	10	982.21	10.00	23.33	0.05	0.05	0.05	20.000	
20	429.72	5.00	13.33	0.03	0.03	10.000	20	859.44	10.00	26.67	0.06	0.06	0.06	20.000	
30	381.77	5.00	15.00	0.03	0.03	10.000	30	763.94	10.00	30.00	0.07	0.07	0.07	19.999	
40	343.77	5.00	16.67	0.04	0.04	10.000	40	687.55	10.00	33.33	0.07	0.07	0.07	19.999	
50	312.52	5.00	18.33	0.04	0.04	10.000	50	625.05	10.00	36.67	0.08	0.08	0.08	19.999	
2	0	286.40	5.00	20.00	0.04	0.04	9.999	2	0	572.96	10.00	40.00	0.09	0.09	19.999
10	264.44	5.00	21.67	0.05	0.05	9.999	10	528.88	10.00	43.33	0.09	0.09	0.09	19.999	
20	245.55	5.00	23.33	0.05	0.05	9.999	20	491.11	10.00	46.67	0.10	0.10	0.10	19.999	
30	229.18	5.00	25.00	0.05	0.05	9.999	30	458.37	10.00	50.00	0.11	0.11	0.11	19.998	
40	214.86	5.00	26.67	0.06	0.06	9.999	40	429.72	10.00	53.33	0.12	0.12	0.12	19.998	
50	202.22	5.00	28.33	0.06	0.06	9.999	50	404.44	10.00	56.67	0.12	0.12	0.12	19.998	
3	0	190.99	5.00	30.00	0.07	0.07	9.999	3	0	381.97	10.00	60.00	0.13	0.13	19.998
10	180.93	5.00	31.67	0.07	0.07	9.999	10	361.67	10.00	63.33	0.14	0.14	0.14	19.997	
20	171.89	5.00	33.33	0.07	0.07	9.999	20	343.77	10.00	66.67	0.15	0.15	0.15	19.997	
30	163.70	5.00	35.00	0.08	0.08	9.998	30	327.40	10.00	70.00	0.15	0.15	0.15	19.997	
40	156.26	5.00	36.67	0.08	0.08	9.998	40	312.52	10.00	73.33	0.16	0.16	0.16	19.997	
50	149.47	5.00	38.33	0.08	0.08	9.998	50	298.93	10.00	76.67	0.17	0.17	0.17	19.996	
4	0	143.24	5.00	40.00	0.09	0.09	9.998	4	0	246.48	10.00	80.00	0.17	0.17	19.996
10	137.51	5.00	41.67	0.09	0.09	9.998	10	275.02	10.00	83.33	0.18	0.18	0.18	19.996	
20	132.22	5.00	43.33	0.09	0.09	9.998	20	264.44	10.00	86.67	0.19	0.19	0.19	19.995	
30	127.32	5.00	45.00	0.10	0.10	9.997	30	254.65	10.01	90.00	0.20	0.20	0.20	19.995	
40	122.78	5.00	46.67	0.10	0.10	9.997	40	245.55	10.01	93.33	0.20	0.20	0.20	19.994	
50	118.54	5.00	48.33	0.11	0.11	9.997	50	237.09	10.01	96.67	0.21	0.21	0.21	19.994	

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE.
A UNIT CURVE OF LENGTH 10 METERS OF ARC.

DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C		
0	1						0								
5	0	114.59	5.00	50.00	0.11	0.11	9.997	5	0	229.18	10.01	100.00	0.22	0.22	19.994
10	110.90	5.00	51.67	0.11	0.11	9.997	10	221.79	10.01	103.33	0.23	0.23	19.993		
20	107.43	5.00	53.33	0.12	0.12	9.996	20	214.86	10.01	106.67	0.23	0.23	19.993		
30	104.17	5.00	55.00	0.12	0.12	9.996	30	208.35	10.01	110.00	0.24	0.24	19.992		
40	101.11	5.00	56.67	0.12	0.12	9.996	40	202.22	10.01	113.33	0.25	0.25	19.992		
50	98.22	5.00	58.33	0.13	0.13	9.996	50	196.44	10.01	116.67	0.25	0.25	19.991		
6	0	95.49	5.00	60.00	0.13	0.13	9.995	6	0	190.99	10.01	120.00	0.26	0.26	19.991
10	92.91	5.00	61.67	0.13	0.13	9.995	10	185.82	10.01	123.33	0.27	0.27	19.990		
20	90.47	5.01	63.33	0.14	0.14	9.995	20	180.93	10.01	126.67	0.28	0.28	19.990		
30	88.15	5.01	65.00	0.14	0.14	9.995	30	176.29	10.01	130.00	0.28	0.28	19.989		
40	85.94	5.01	66.67	0.15	0.15	9.994	40	171.89	10.01	133.33	0.29	0.29	19.989		
50	83.85	5.01	68.33	0.15	0.15	9.994	50	167.70	10.01	136.67	0.30	0.30	19.988		
7	0	81.85	5.01	70.00	0.15	0.15	9.994	7	0	163.70	10.01	140.00	0.31	0.31	19.988
10	79.95	5.01	71.67	0.16	0.16	9.993	10	159.90	10.01	143.33	0.31	0.31	19.987		
20	78.13	5.01	73.33	0.16	0.16	9.993	20	156.26	10.01	146.67	0.32	0.32	19.986		
30	76.39	5.01	75.00	0.16	0.16	9.993	30	152.79	10.01	150.00	0.33	0.33	19.986		
40	74.73	5.01	76.67	0.17	0.17	9.993	40	149.47	10.01	153.33	0.33	0.34	19.985		
50	73.14	5.01	78.33	0.17	0.17	9.992	50	146.29	10.02	156.67	0.34	0.34	19.984		
8	0	71.62	5.01	80.00	0.17	0.17	9.992	8	0	143.24	10.02	160.00	0.35	0.35	19.984
10	70.16	5.01	81.67	0.18	0.18	9.992	10	140.32	10.02	163.33	0.36	0.36	19.983		
20	68.75	5.01	83.33	0.18	0.18	9.991	20	137.51	10.02	166.67	0.36	0.36	19.982		
30	67.41	5.01	85.00	0.19	0.19	9.991	30	134.81	10.02	170.00	0.37	0.37	19.982		
40	66.11	5.01	86.67	0.19	0.19	9.990	40	132.22	10.02	173.33	0.38	0.38	19.981		
50	64.86	5.01	88.33	0.19	0.19	9.990	50	129.73	10.02	176.67	0.39	0.39	19.980		

TABLE III - A

A UNIT CURVE OF LENGTH 10 METERS OF ARC		FUNCTIONS OF SIMPLE CIRCULAR CURVE		A UNIT CURVE OF LENGTH 20 METERS OF ARC									
DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C
0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	63.66	5.01	90.00	0.20	0.20	9.990	9	127.32	10.07	180.00	0.39	0.39	19.979
10	62.50	5.01	91.67	0.20	0.20	9.989	10	125.01	10.02	183.33	0.40	0.40	19.979
20	61.39	5.01	93.33	0.20	0.20	9.989	20	122.78	10.02	186.67	0.41	0.41	19.978
30	60.31	5.01	95.00	0.21	0.21	9.989	30	120.62	10.02	190.00	0.41	0.42	19.977
40	59.27	5.01	96.67	0.21	0.21	9.988	40	118.54	10.02	193.33	0.42	0.42	19.976
50	58.27	5.01	98.33	0.21	0.22	9.988	50	116.53	10.02	196.67	0.43	0.43	19.975
10	57.30	5.01	100.00	0.22	0.22	9.987	10	114.59	10.03	200.00	0.44	0.44	19.975
10	56.36	5.01	101.67	0.22	0.22	9.987	10	112.71	10.03	203.33	0.44	0.45	19.974
20	55.45	5.01	103.33	0.23	0.23	9.986	20	110.90	10.03	206.67	0.45	0.45	19.973
30	54.57	5.01	105.00	0.23	0.23	9.986	30	109.13	10.03	210.00	0.46	0.46	19.972
40	53.71	5.01	106.67	0.23	0.23	9.986	40	107.43	10.03	213.33	0.47	0.47	19.971
50	52.89	5.01	108.33	0.24	0.24	9.985	50	105.78	10.03	216.67	0.47	0.47	19.970
11	52.09	5.02	110.00	0.24	0.24	9.985	11	104.17	10.03	220.00	0.48	0.48	19.969
10	51.31	5.02	111.67	0.24	0.24	9.984	10	102.62	10.03	223.33	0.49	0.49	19.968
20	50.56	5.02	113.33	0.25	0.25	9.984	20	101.11	10.03	226.67	0.49	0.50	19.967
30	49.82	5.02	115.00	0.25	0.25	9.983	30	99.64	10.03	230.00	0.50	0.50	19.966
40	49.11	5.02	116.67	0.25	0.26	9.983	40	98.22	10.03	233.33	0.51	0.51	19.965
50	48.42	5.02	118.33	0.26	0.26	9.982	50	96.84	10.04	236.67	0.52	0.52	19.964
12	47.75	5.02	120.00	0.26	0.26	9.982	12	95.49	10.04	240.00	0.52	0.53	19.963
10	47.09	5.02	121.67	0.27	0.27	9.981	10	94.18	10.04	243.33	0.53	0.53	19.962
20	46.46	5.02	123.33	0.27	0.27	9.981	20	92.91	10.04	246.67	0.54	0.54	19.961
30	45.84	5.02	125.00	0.27	0.27	9.980	30	91.67	10.04	250.00	0.54	0.55	19.960
40	45.23	5.02	126.67	0.28	0.28	9.980	40	90.47	10.04	253.33	0.55	0.56	19.959
50	44.65	5.02	128.33	0.28	0.28	9.979	50	89.29	10.04	256.67	0.56	0.56	19.958

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C		
0							0								
13	0	44.07	5.02	130.00	0.28	0.29	9.979	13	0	88.15	10.04	260.00	0.57	0.57	19.957
	10	43.52	5.02	131.67	0.29	0.29	9.978	10	87.03	10.04	263.33	0.57	0.58	19.956	
	20	42.97	5.02	133.33	0.29	0.29	9.977	20	85.94	10.05	266.67	0.58	0.59	19.955	
	30	42.44	5.02	135.00	0.29	0.30	9.977	30	84.88	10.05	270.00	0.59	0.59	19.954	
	40	41.92	5.02	136.67	0.30	0.30	9.976	40	83.85	10.05	273.33	0.60	0.60	19.953	
	50	41.42	5.02	138.33	0.30	0.30	9.976	50	82.84	10.05	276.67	0.60	0.61	19.951	
14	0	40.93	5.03	140.00	0.31	0.31	9.975	14	0	81.85	10.05	280.00	0.61	0.61	19.950
	10	40.44	5.03	141.67	0.31	0.31	9.975	10	80.89	10.05	283.33	0.62	0.62	19.949	
	20	39.97	5.03	143.33	0.31	0.31	9.974	20	79.95	10.05	286.67	0.62	0.63	19.948	
	30	39.51	5.03	145.00	0.32	0.32	9.973	30	79.03	10.05	290.00	0.63	0.64	19.947	
	40	39.07	5.03	146.67	0.32	0.32	9.973	40	78.13	10.05	293.33	0.64	0.64	19.945	
	50	38.63	5.03	148.33	0.32	0.33	9.972	50	77.25	10.06	296.67	0.65	0.65	19.944	
15	0	38.20	5.03	150.00	0.33	0.33	9.971	15	0	76.39	10.06	300.00	0.65	0.66	19.943
	10	37.78	5.03	151.67	0.33	0.33	9.971	10	75.55	10.06	303.33	0.66	0.67	19.942	
	20	37.37	5.03	153.33	0.33	0.34	9.970	20	74.73	10.06	306.67	0.67	0.67	19.940	
	30	36.97	5.03	155.00	0.34	0.34	9.970	30	73.93	10.06	310.00	0.68	0.68	19.939	
	40	36.57	5.03	156.67	0.34	0.34	9.969	40	73.14	10.06	313.33	0.68	0.69	19.938	
	50	36.19	5.03	158.33	0.34	0.35	9.968	50	72.37	10.06	316.67	0.69	0.70	19.936	
16	0	35.81	5.03	160.00	0.35	0.35	9.968	16	0	71.62	10.07	320.00	0.70	0.70	19.935
	10	35.44	5.03	161.67	0.35	0.36	9.967	10	70.88	10.07	323.33	0.70	0.71	19.934	
	20	35.08	5.03	163.33	0.36	0.36	9.966	20	70.16	10.07	326.67	0.71	0.72	19.932	
	30	34.72	5.03	165.00	0.36	0.36	9.965	30	69.45	10.07	330.00	0.72	0.73	19.931	
	40	34.38	5.04	166.67	0.36	0.37	9.965	40	68.75	10.07	333.33	0.73	0.73	19.930	
	50	34.04	5.04	168.33	0.37	0.37	9.964	50	68.07	10.07	336.67	0.73	0.74	19.928	

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA 0' 17 0	R	T	L	M	E	C	DELTA 0' 17 0	R	T	L	M	E	C
10	33.70	5.04	170.00	0.37	0.37	9.963	17 0	67.41	10.07	340.00	0.74	0.75	19.927
20	33.38	5.04	171.67	0.37	0.38	9.963	10	66.75	10.08	343.33	0.75	0.76	19.925
30	33.06	5.04	173.33	0.38	0.38	9.962	20	66.11	10.08	346.67	0.75	0.76	19.924
40	32.74	5.04	175.00	0.38	0.39	9.961	30	65.48	10.08	350.00	0.76	0.77	19.922
50	32.43	5.04	176.67	0.38	0.39	9.960	40	64.86	10.08	353.33	0.77	0.78	19.921
18 0	32.13	5.04	178.33	0.39	0.39	9.960	50	64.26	10.08	356.67	0.78	0.79	19.919
19 0	31.83	5.04	180.00	0.39	0.40	9.959	18 0	63.66	10.08	360.00	0.78	0.79	19.918
10	31.54	5.04	181.67	0.40	0.40	9.958	10	63.08	10.08	363.33	0.79	0.80	19.916
20	31.25	5.04	183.33	0.40	0.40	9.957	20	62.50	10.09	366.67	0.80	0.81	19.915
30	30.97	5.04	185.00	0.40	0.41	9.957	30	61.94	10.09	370.00	0.81	0.82	19.913
40	30.69	5.04	186.67	0.41	0.41	9.956	40	61.39	10.09	373.33	0.81	0.82	19.912
50	30.42	5.05	188.33	0.41	0.42	9.955	50	60.85	10.09	376.67	0.82	0.83	19.910
19 0	30.16	5.05	190.00	0.41	0.42	9.954	19 0	60.31	10.09	380.00	0.83	0.84	19.909
10	29.89	5.05	191.67	0.42	0.42	9.953	10	59.79	10.09	383.33	0.83	0.85	19.907
20	29.64	5.05	193.33	0.42	0.43	9.953	20	59.27	10.10	386.67	0.84	0.85	19.905
30	29.38	5.05	195.00	0.42	0.43	9.952	30	58.76	10.10	390.00	0.85	0.86	19.904
40	29.13	5.05	196.67	0.43	0.43	9.951	40	58.27	10.10	393.33	0.86	0.87	19.902
50	28.89	5.05	198.33	0.43	0.44	9.950	50	57.78	10.10	396.67	0.86	0.88	19.900
20 0	28.65	5.05	200.00	0.44	0.44	9.949	20 0	57.30	10.10	400.00	0.87	0.88	19.899
10	28.41	5.05	201.67	0.44	0.45	9.948	10	56.82	10.10	403.33	0.88	0.89	19.897
20	28.18	5.05	203.33	0.44	0.45	9.948	20	56.36	10.11	406.67	0.88	0.90	19.895
30	27.95	5.05	205.00	0.45	0.45	9.947	30	55.90	10.11	410.00	0.89	0.91	19.894
40	27.72	5.05	206.67	0.45	0.46	9.946	40	55.45	10.11	413.33	0.90	0.91	19.892
50	27.50	5.06	208.33	0.45	0.46	9.945	50	55.00	10.11	416.67	0.91	0.92	19.890

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 20 METERS OF ARC

A UNIT CURVE OF LENGTH 10 METERS OF ARC		A UNIT CURVE OF LENGTH 20 METERS OF ARC										
DELTA	T	L	M	E	C	DELTA	R	T	L	M	E	C
0						0						
21	0	210.00	0.46	0.46	9.944	21	0	54.57	420.00	0.91	0.93	19.888
10	27.07	211.67	0.46	0.47	9.943	10	54.14	10.12	423.33	0.92	0.94	19.886
20	26.86	213.33	0.46	0.47	9.942	20	53.71	10.12	426.67	0.93	0.94	19.885
30	26.65	215.00	0.47	0.48	9.941	30	53.30	10.12	430.00	0.94	0.95	19.883
40	26.44	216.67	0.47	0.48	9.941	40	52.89	10.12	433.33	0.94	0.96	19.881
50	26.24	218.33	0.47	0.48	9.940	50	52.48	10.12	436.67	0.95	0.97	19.879
22	0	220.00	0.48	0.49	9.939	22	52.09	10.12	440.00	0.96	0.97	19.877
10	25.85	221.67	0.48	0.49	9.938	10	51.70	10.13	443.33	0.96	0.98	19.876
20	25.65	223.33	0.49	0.50	9.937	20	51.31	10.13	446.67	0.97	0.99	19.874
30	25.46	225.00	0.49	0.50	9.936	30	50.93	10.13	450.00	0.98	1.00	19.872
40	25.28	226.67	0.49	0.50	9.935	40	50.56	10.13	453.33	0.99	1.01	19.870
50	25.09	228.33	0.50	0.51	9.934	50	50.19	10.13	456.67	0.99	1.01	19.868
23	0	230.00	0.50	0.51	9.933	23	49.82	10.14	460.00	1.00	1.02	19.866
10	24.73	231.67	0.50	0.51	9.932	10	49.46	10.14	463.33	1.01	1.03	19.864
20	24.56	233.33	0.51	0.52	9.931	20	49.11	10.14	466.67	1.01	1.04	19.862
30	24.38	235.00	0.51	0.52	9.930	30	48.76	10.14	470.00	1.02	1.04	19.860
40	24.21	236.67	0.51	0.53	9.929	40	48.42	10.14	473.33	1.03	1.05	19.858
50	24.04	238.33	0.52	0.53	9.928	50	48.08	10.15	476.67	1.04	1.06	19.856
24	0	240.00	0.52	0.53	9.927	24	47.75	10.15	480.00	1.04	1.07	19.854
10	23.71	241.67	0.53	0.54	9.926	10	47.42	10.15	483.33	1.05	1.07	19.852
20	23.55	243.33	0.53	0.54	9.925	20	47.09	10.15	486.67	1.06	1.08	19.850
30	23.39	245.00	0.53	0.54	9.924	30	46.77	10.16	490.00	1.06	1.09	19.848
40	23.23	246.67	0.54	0.55	9.923	40	46.46	10.16	493.33	1.07	1.10	19.846
50	23.07	248.33	0.54	0.55	9.922	50	46.14	10.16	496.67	1.08	1.11	19.844

TABLE III - A
 FUNCTIONS OF SIMPLE CIRCULAR CURVE
 A UNIT CURVE OF LENGTH 10 METERS OF ARC
 A UNIT CURVE OF LENGTH 20 METERS OF ARC

DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C		
0							0								
25	0	22.92	5.08	250.00	0.54	0.56	9.921	25	0	45.84	10.16	500.00	1.09	1.11	19.842
10	22.77	5.08	251.67	0.55	0.56	9.920	10	45.53	10.16	503.33	1.09	1.12	19.840		
20	22.62	5.08	253.33	0.55	0.56	9.919	20	45.23	10.17	506.67	1.10	1.13	19.837		
30	22.47	5.08	255.00	0.55	0.57	9.918	30	44.94	10.17	510.00	1.11	1.14	19.835		
40	22.32	5.09	256.67	0.56	0.57	9.917	40	44.65	10.17	513.33	1.12	1.14	19.833		
50	22.18	5.09	258.33	0.56	0.58	9.916	50	44.36	10.17	516.67	1.12	1.15	19.831		
26	0	22.04	5.09	260.00	0.56	0.58	9.914	26	0	44.07	10.18	520.00	1.13	1.16	19.829
10	21.90	5.09	261.67	0.57	0.58	9.913	10	43.79	10.18	523.33	1.14	1.17	19.827		
20	21.76	5.09	263.33	0.57	0.59	9.912	20	43.52	10.18	526.67	1.14	1.17	19.824		
30	21.62	5.09	265.00	0.58	0.59	9.911	30	43.24	10.18	530.00	1.15	1.18	19.822		
40	21.49	5.09	266.67	0.58	0.60	9.910	40	42.97	10.18	533.33	1.16	1.19	19.820		
50	21.35	5.09	268.33	0.58	0.60	9.909	50	42.70	10.19	536.67	1.17	1.20	19.818		
27	0	21.22	5.09	270.00	0.59	0.60	9.908	27	0	42.44	10.19	540.00	1.17	1.21	19.815
10	21.09	5.10	271.67	0.59	0.61	9.907	10	42.18	10.19	543.33	1.18	1.21	19.813		
20	20.96	5.10	273.33	0.59	0.61	9.905	20	41.92	10.19	546.67	1.19	1.22	19.811		
30	20.83	5.10	275.00	0.60	0.61	9.904	30	41.67	10.20	550.00	1.19	1.23	19.809		
40	20.71	5.10	276.67	0.60	0.62	9.903	40	41.42	10.20	553.33	1.20	1.24	19.806		
50	20.59	5.10	278.33	0.60	0.62	9.902	50	41.17	10.20	556.67	1.21	1.25	19.804		
28	0	20.46	5.10	280.00	0.61	0.63	9.901	28	0	40.93	10.20	560.00	1.22	1.25	19.802
10	20.34	5.10	281.67	0.61	0.63	9.900	10	40.68	10.21	563.33	1.22	1.26	19.799		
20	20.22	5.10	283.33	0.61	0.63	9.898	20	40.44	10.21	566.67	1.23	1.27	19.797		
30	20.10	5.11	285.00	0.62	0.64	9.897	30	40.21	10.21	570.00	1.24	1.28	19.794		
40	19.99	5.11	286.67	0.62	0.64	9.896	40	39.97	10.21	573.33	1.24	1.28	19.792		
50	19.87	5.11	288.33	0.63	0.65	9.895	50	39.74	10.22	576.67	1.25	1.29	19.790		

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA 0°	R	T	L	N	E	C	DELTA 0'	R	T	L	M	E	C
29 0	19.76	5.11	290.00	0.63	0.65	9.894	29 0	39.51	10.22	580.00	1.26	1.30	19.787
10	19.64	5.11	291.67	0.63	0.65	9.892	10	39.29	10.22	583.33	1.27	1.31	19.785
20	19.53	5.11	293.33	0.64	0.66	9.891	20	39.07	10.22	586.67	1.27	1.32	19.782
30	19.42	5.11	295.00	0.64	0.66	9.890	30	38.84	10.23	590.00	1.28	1.32	19.780
40	19.31	5.11	296.67	0.64	0.67	9.889	40	38.63	10.23	593.33	1.29	1.33	19.777
50	19.21	5.12	298.33	0.65	0.67	9.887	50	38.41	10.23	596.67	1.29	1.34	19.775
30 0	19.10	5.12	300.00	0.65	0.67	9.886	30 0	38.20	10.23	600.00	1.30	1.35	19.772
10	18.99	5.12	301.67	0.65	0.68	9.885	10	37.99	10.24	603.33	1.31	1.36	19.770
20	18.89	5.12	303.33	0.66	0.68	9.884	20	37.78	10.24	606.67	1.32	1.36	19.767
30	18.79	5.12	305.00	0.66	0.69	9.882	30	37.57	10.24	610.00	1.32	1.37	19.765
40	18.68	5.12	306.67	0.67	0.69	9.881	40	37.37	10.25	613.33	1.33	1.38	19.762
50	18.58	5.12	308.33	0.67	0.69	9.880	50	37.16	10.25	616.67	1.34	1.39	19.760
31 0	18.48	5.13	310.00	0.67	0.70	9.878	31 0	36.97	10.25	620.00	1.34	1.40	19.757
10	18.38	5.13	311.67	0.68	0.70	9.877	10	36.77	10.25	623.33	1.35	1.40	19.754
20	18.29	5.13	313.33	0.68	0.71	9.876	20	36.57	10.26	626.67	1.36	1.41	19.752
30	18.19	5.13	315.00	0.68	0.71	9.875	30	36.38	10.26	630.00	1.37	1.42	19.749
40	18.09	5.13	316.67	0.69	0.71	9.873	40	36.19	10.26	633.33	1.37	1.43	19.746
50	18.00	5.13	318.33	0.69	0.72	9.872	50	36.00	10.27	636.67	1.38	1.44	19.744
32 0	17.90	5.13	320.00	0.69	0.72	9.871	32 0	35.81	10.27	640.00	1.39	1.44	19.741
10	17.81	5.14	321.67	0.70	0.73	9.869	10	35.62	10.27	643.33	1.39	1.45	19.738
20	17.72	5.14	323.33	0.70	0.73	9.868	20	35.44	10.27	646.67	1.40	1.46	19.736
30	17.63	5.14	325.00	0.70	0.73	9.866	30	35.26	10.28	650.00	1.41	1.47	19.733
40	17.54	5.14	326.67	0.71	0.74	9.865	40	35.08	10.28	653.33	1.42	1.48	19.730
50	17.45	5.14	328.33	0.71	0.74	9.864	50	34.90	10.28	656.67	1.42	1.48	19.727

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C
0 1							0 1						
33 0	17.36	5.14	330.00	0.71	0.75	9.862	33 0	34.72	10.29	660.00	1.43	1.49	19.725
10	17.26	5.14	331.67	0.72	0.75	9.861	10	34.55	10.29	663.33	1.44	1.50	19.722
20	17.19	5.15	333.33	0.72	0.75	9.860	20	34.38	10.29	666.67	1.44	1.51	19.719
30	17.10	5.15	335.00	0.73	0.76	9.858	30	34.21	10.29	670.00	1.45	1.52	19.716
40	17.02	5.15	336.67	0.73	0.76	9.857	40	34.04	10.30	673.33	1.46	1.52	19.714
50	16.93	5.15	338.33	0.73	0.77	9.855	50	33.87	10.30	676.67	1.47	1.53	19.711
34 0	16.85	5.15	340.00	0.74	0.77	9.854	34 0	33.70	10.30	680.00	1.47	1.54	19.708
10	16.77	5.15	341.67	0.74	0.77	9.852	10	33.54	10.31	683.33	1.48	1.55	19.705
20	16.69	5.16	343.33	0.74	0.78	9.851	20	33.38	10.31	686.67	1.49	1.56	19.702
30	16.61	5.16	345.00	0.75	0.78	9.850	30	33.21	10.31	690.00	1.49	1.56	19.699
40	16.53	5.16	346.67	0.75	0.79	9.848	40	33.06	10.32	693.33	1.50	1.57	19.696
50	16.45	5.16	348.33	0.75	0.79	9.847	50	32.90	10.32	696.67	1.51	1.58	19.693
35 0	16.37	5.16	350.00	0.76	0.79	9.845	35 0	32.74	10.32	700.00	1.52	1.59	19.690
10	16.29	5.16	351.67	0.76	0.80	9.844	10	32.59	10.33	703.33	1.52	1.60	19.688
20	16.22	5.16	353.33	0.76	0.80	9.842	20	32.43	10.33	706.67	1.53	1.61	19.685
30	16.14	5.17	355.00	0.77	0.81	9.841	30	32.28	10.33	710.00	1.54	1.61	19.682
40	16.06	5.17	356.67	0.77	0.81	9.839	40	32.13	10.34	713.33	1.54	1.62	19.679
50	15.99	5.17	358.33	0.78	0.81	9.838	50	31.98	10.34	716.67	1.55	1.63	19.676
36 0	15.92	5.17	360.00	0.78	0.82	9.836	36 0	31.83	10.34	720.00	1.56	1.64	19.673
10	15.84	5.17	361.67	0.78	0.82	9.835	10	31.68	10.35	723.33	1.57	1.65	19.670
20	15.77	5.17	363.33	0.79	0.83	9.833	20	31.54	10.35	726.67	1.57	1.65	19.667
30	15.70	5.18	365.00	0.79	0.83	9.832	30	31.39	10.35	730.00	1.58	1.66	19.664
40	15.63	5.18	366.67	0.79	0.84	9.830	40	31.25	10.36	733.33	1.59	1.67	19.660
50	15.56	5.18	368.33	0.80	0.84	9.829	50	31.11	10.36	736.67	1.59	1.68	19.657

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C	
0							0							
37	0	15.49	370.00	0.80	0.84	9.827	37	0	30.97	10.36	740.00	1.60	1.69	
10	15.42	5.18	371.67	0.80	0.85	9.826	10	30.83	10.37	743.33	1.61	1.70	19.651	
20	15.35	5.18	373.33	0.81	0.85	9.824	20	30.69	10.37	746.67	1.61	1.70	19.648	
30	15.28	5.19	375.00	0.81	0.86	9.822	30	30.56	10.37	750.00	1.62	1.71	19.645	
40	15.21	5.19	376.67	0.81	0.86	9.821	40	30.42	10.38	753.33	1.63	1.72	19.642	
50	15.14	5.19	378.33	0.82	0.86	9.819	50	30.29	10.38	756.67	1.64	1.73	19.639	
38	0	15.08	380.00	0.82	0.87	9.818	38	0	30.16	10.38	760.00	1.64	1.74	19.635
10	15.01	5.19	381.67	0.82	0.87	9.816	10	30.02	10.39	763.33	1.65	1.75	19.632	
20	14.95	5.20	383.33	0.83	0.88	9.815	20	29.89	10.39	766.67	1.66	1.75	19.629	
30	14.88	5.20	385.00	0.83	0.88	9.813	30	29.76	10.39	770.00	1.66	1.76	19.626	
40	14.82	5.20	386.67	0.84	0.89	9.811	40	29.64	10.40	773.33	1.67	1.77	19.623	
50	14.75	5.20	388.33	0.84	0.89	9.810	50	29.51	10.40	776.67	1.68	1.78	19.619	
39	0	14.69	390.00	0.84	0.89	9.808	39	0	29.38	10.40	780.00	1.69	1.79	19.616
10	14.63	5.20	391.67	0.85	0.90	9.806	10	29.26	10.41	783.33	1.69	1.80	19.613	
20	14.57	5.21	393.33	0.85	0.90	9.805	20	29.13	10.41	786.67	1.70	1.80	19.610	
30	14.51	5.21	395.00	0.85	0.91	9.803	30	29.01	10.42	790.00	1.71	1.81	19.606	
40	14.44	5.21	396.67	0.86	0.91	9.801	40	28.89	10.42	793.33	1.71	1.82	19.603	
50	14.38	5.21	398.33	0.86	0.92	9.800	50	28.77	10.42	796.67	1.72	1.83	19.600	
40	0	14.32	400.00	0.86	0.92	9.798	40	0	28.65	10.43	800.00	1.73	1.84	19.596
10	14.26	5.22	401.67	0.87	0.92	9.796	10	28.53	10.43	803.33	1.73	1.85	19.593	
20	14.21	5.22	403.33	0.87	0.93	9.795	20	28.41	10.43	806.67	1.74	1.86	19.590	
30	14.15	5.22	405.00	0.87	0.93	9.793	30	28.29	10.44	810.00	1.75	1.86	19.586	
40	14.09	5.22	406.67	0.88	0.94	9.791	40	28.18	10.44	813.33	1.76	1.87	19.583	
50	14.03	5.22	408.33	0.88	0.94	9.790	50	28.06	10.45	816.67	1.76	1.88	19.579	

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
A UNIT CURVE OF LENGTH 10 METERS OF ARC

DELTA 0°	R	T	L	M	E	C	DELTA 0°	R	T	L	M	E	C
41 0	13.97	5.22	410.00	0.88	0.94	9.788	41 0	27.95	10.45	820.00	1.77	1.89	19.576
10	13.92	5.23	411.67	0.89	0.95	9.786	10	27.84	10.45	823.33	1.78	1.90	19.573
20	13.86	5.23	413.33	0.89	0.95	9.785	20	27.72	10.46	826.67	1.78	1.91	19.569
30	13.81	5.23	415.00	0.90	0.96	9.783	30	27.61	10.46	830.00	1.79	1.92	19.566
40	13.75	5.23	416.67	0.90	0.96	9.781	40	27.50	10.47	833.33	1.80	1.92	19.562
50	13.70	5.23	418.33	0.90	0.97	9.779	50	27.39	10.47	836.67	1.81	1.93	19.559
42 0	13.64	5.24	420.00	0.91	0.97	9.778	42 0	27.28	10.47	840.00	1.81	1.94	19.555
10	13.59	5.24	421.67	0.91	0.97	9.776	10	27.18	10.48	843.33	1.82	1.95	19.552
20	13.53	5.24	423.33	0.91	0.98	9.774	20	27.07	10.48	846.67	1.83	1.96	19.548
30	13.48	5.24	425.00	0.92	0.98	9.772	30	26.96	10.49	850.00	1.83	1.97	19.545
40	13.43	5.24	426.67	0.92	0.99	9.771	40	26.86	10.49	853.33	1.84	1.98	19.541
50	13.38	5.25	428.33	0.92	0.99	9.769	50	26.75	10.49	856.67	1.85	1.98	19.538
43 0	13.32	5.25	430.00	0.93	1.00	9.767	43 0	26.65	10.50	860.00	1.85	1.99	19.534
10	13.27	5.25	431.67	0.93	1.00	9.765	10	26.55	10.50	863.33	1.86	2.00	19.530
20	13.22	5.25	433.33	0.93	1.01	9.763	20	26.44	10.51	866.67	1.87	2.01	19.527
30	13.17	5.25	435.00	0.94	1.01	9.762	30	26.34	10.51	870.00	1.88	2.02	19.523
40	13.12	5.26	436.67	0.94	1.01	9.760	40	26.24	10.51	873.33	1.88	2.03	19.519
50	13.07	5.26	438.33	0.94	1.02	9.758	50	26.14	10.52	876.67	1.89	2.04	19.516
44 0	13.02	5.26	440.00	0.95	1.02	9.756	44 0	26.04	10.52	880.00	1.90	2.05	19.512
10	12.97	5.26	441.67	0.95	1.03	9.754	10	25.95	10.53	883.33	1.90	2.05	19.509
20	12.92	5.27	443.33	0.96	1.03	9.752	20	25.85	10.53	886.67	1.91	2.06	19.505
30	12.88	5.27	445.00	0.96	1.04	9.751	30	25.75	10.53	890.00	1.92	2.07	19.501
40	12.83	5.27	446.67	0.96	1.04	9.749	40	25.65	10.54	893.33	1.92	2.08	19.497
50	12.78	5.27	448.33	0.97	1.04	9.747	50	25.56	10.54	896.67	1.93	2.09	19.494

TABLE III - A

FUNCTIONS OF SIMPLE CIRCULAR CURVE
 A UNIT CURVE OF LENGTH 10 METERS OF ARC
 A UNIT CURVE OF LENGTH 20 METERS OF ARC

DELTA U	T	R	L	M	E	C	DELTA 0	R	T	L	M	E	C
45 0	5.27	12.73	450.00	0.97	1.05	9.745	45 0	25.46	10.55	900.00	1.94	2.10	19.490
10	5.28	12.69	451.67	0.97	1.05	9.743	10	25.37	10.55	903.33	1.95	2.11	19.486
20	5.28	12.64	453.33	0.98	1.06	9.741	20	25.28	10.56	906.67	1.95	2.12	19.482
30	5.28	12.59	455.00	0.98	1.06	9.739	30	25.18	10.56	910.00	1.96	2.12	19.479
40	5.28	12.55	456.67	0.98	1.07	9.737	40	25.09	10.57	913.33	1.97	2.13	19.475
50	5.28	12.50	458.33	0.99	1.07	9.736	50	25.00	10.57	916.67	1.97	2.14	19.471
46 0	5.29	12.46	460.00	0.99	1.08	9.734	46 0	24.91	10.57	920.00	1.98	2.15	19.467
10	5.29	12.41	461.67	0.99	1.08	9.732	10	24.82	10.58	923.33	1.99	2.16	19.463
20	5.29	12.37	463.33	1.00	1.08	9.730	20	24.73	10.58	926.67	1.99	2.17	19.459
30	5.29	12.32	465.00	1.00	1.09	9.728	30	24.64	10.59	930.00	2.00	2.18	19.456
40	5.30	12.28	466.67	1.00	1.09	9.726	40	24.56	10.59	933.33	2.01	2.19	19.452
50	5.30	12.23	468.33	1.01	1.10	9.724	50	24.47	10.60	936.67	2.02	2.20	19.448
47 0	5.30	12.19	470.00	1.01	1.10	9.722	47 0	24.38	10.60	940.00	2.02	2.21	19.444
10	5.30	12.15	471.67	1.01	1.11	9.720	10	24.30	10.61	943.33	2.03	2.21	19.440
20	5.31	12.10	473.33	1.02	1.11	9.718	20	24.21	10.61	946.67	2.04	2.22	19.436
30	5.31	12.06	475.00	1.02	1.12	9.716	30	24.12	10.62	950.00	2.04	2.23	19.432
40	5.31	12.02	476.67	1.03	1.12	9.714	40	24.04	10.62	953.33	2.05	2.24	19.428
50	5.31	11.98	478.33	1.03	1.13	9.712	50	23.96	10.62	956.67	2.06	2.25	19.424
48 0	5.31	11.94	480.00	1.03	1.13	9.710	48 0	23.87	10.63	960.00	2.06	2.26	19.420
10	5.32	11.90	481.67	1.04	1.13	9.708	10	23.79	10.64	963.33	2.07	2.27	19.416
20	5.32	11.85	483.33	1.04	1.14	9.706	20	23.71	10.64	966.67	2.08	2.28	19.412
30	5.32	11.81	485.00	1.04	1.14	9.704	30	23.63	10.64	970.00	2.08	2.29	19.408
40	5.32	11.77	486.67	1.05	1.15	9.702	40	23.55	10.65	973.33	2.09	2.30	19.404
50	5.33	11.73	488.33	1.05	1.15	9.700	50	23.47	10.65	976.67	2.10	2.30	19.400

TABLE III - A

A UNIT CURVE OF LENGTH 10 METERS OF ARC		FUNCTIONS OF SIMPLE CIRCULAR CURVE		A UNIT CURVE OF LENGTH 20 METERS OF ARC		A UNIT CURVE OF LENGTH 30 METERS OF ARC		A UNIT CURVE OF LENGTH 40 METERS OF ARC		A UNIT CURVE OF LENGTH 50 METERS OF ARC					
DELTA	R	T	L	M	E	C	DELTA	R	T	L	M	E	C		
0							0								
49	0	11.69	5.33	490.00	1.05	1.16	9.698	49	0	23.39	10.66	980.00	2.11	2.31	19.396
10	11.65	5.33	491.67	1.06	1.16	9.696	10	23.31	10.66	983.33	2.11	2.32	19.392		
20	11.61	5.33	493.33	1.06	1.17	9.694	20	23.23	10.67	986.67	2.12	2.33	19.388		
30	11.57	5.34	495.00	1.06	1.17	9.692	30	23.15	10.67	990.00	2.13	2.34	19.384		
40	11.54	5.34	496.67	1.07	1.18	9.690	40	23.07	10.68	993.33	2.13	2.35	19.380		
50	11.50	5.34	498.33	1.07	1.18	9.688	50	22.99	10.68	996.67	2.14	2.36	19.376		
50	0	11.46	5.34	500.00	1.07	1.18	9.686	50	0	22.92	10.69	1000.00	2.15	2.37	19.371
10	11.42	5.35	501.67	1.08	1.19	9.684	10	22.84	10.69	1003.33	2.15	2.38	19.367		
20	11.38	5.35	503.33	1.08	1.19	9.682	20	22.77	10.70	1006.67	2.16	2.39	19.363		
30	11.35	5.35	505.00	1.08	1.20	9.679	30	22.69	10.70	1010.00	2.17	2.40	19.359		
40	11.31	5.35	506.67	1.09	1.20	9.677	40	22.62	10.71	1013.33	2.17	2.41	19.355		
50	11.27	5.36	508.33	1.09	1.21	9.675	50	22.54	10.71	1016.67	2.18	2.42	19.350		

TABLE IV
SIDE FRICTION VS DESIGN SPEED

Purpose

To compute the side friction which provides counterbalance force to vehicle side skidding.

Notation

K.P.H. = Kilometre per hour

Formulas

$F = 0.19 - 0.0006 (V)$ where (Eq. No. 58)

F = Side friction

V = Design speed in Kph

Example How to Use

Given: V = 100 Kph

Required: F

Solution: $F = 0.19 - 0.0006 (100) = 0.13$ or direct by table

F = 0.13

TABLE-IV
SIDE FRICTION VS. DESIGN SPEED

DESIGN SPEED IN K.P.H.	SIDE FRICTION
40	0.17
50	0.16
60	0.15
70	0.15
80	0.14
90	0.13
100	0.13
110	0.12
120	0.12
130	0.11
140	0.10

TABLE V

MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS
DETERMINED FOR LIMITING VALUES
OF SUPERELEVATION AND SIDE FRICTION

Purpose

To compute the maximum value of degree of curve and minimum radius for four values of rate of superelevation (0.06, 0.08, 0.10 and 0.12) which are nationwide practice as adopted by AASHTO "A policy on geometric design manual 1965" and the maximum side friction values range from 0.10 to 0.17.

Notation

E = maximum superelevation metric per metric

F = maximum friction factor

Minimum Radius = minimum radius in metres

Maximum degree of curve = maximum degree of curve (Arc definition)

= D = D_m in metric

Formulas

$$D = \frac{72765.64 (E+F)}{v^2} \text{ for 10 m of Arc} \quad (\text{Eq. No. 59})$$

$$D = \frac{145551.24 (E+F)}{v^2} \text{ for 20 m of Arc} \quad (\text{Eq. No. 60})$$

$$D = \frac{291062.56}{v^2} \text{ for 40 m of Arc} \quad (\text{Eq. No. 61})$$

$$D = \frac{727656.41 (E+F)}{v^2} \text{ for 100 m of Arc} \quad (\text{Eq. No. 62})$$

$$R = \frac{0.00787 v^2}{E+F} \text{ for all Arcs.} \quad (\text{Eq. No. 63})$$

where D = degree of curve in degrees, R = Radius of curve in metres

V = Design speed in Kph

In this table the radius value used as a constant for all arcs but the degree of curve changed according to the length of arc. If radius value is required for each arc length, then a separate set of table need to be developed. The degree of curve value took priority in this thesis on the radius definition.

Example How to Use

Given: $V = 80$ Kph, $E = 0.06$, $F = 0.14$

Required: R, D for 10, 20, 40 and 100 m of Arc.

Solution: Direct reading

$R = 251$ m for 10 metre of arc

$R = 229$ m for 20 metre of arc

$R = 209$ m for 40 metre of arc

$R = 193$ m for 100 metre of arc

$D = 2, 5, 9, 23^\circ$ degrees rounded for 10 m of arc

$D = 3, 5, 10, 25^\circ$ degrees rounded for 20 m of arc

$D = 3, 5, 11, 27^\circ$ degrees rounded for 40 m of arc

$D = 3, 6, 12, 30^\circ$ degrees rounded for 100 m of arc

f = coefficient of friction
 N = Normal force to the surface

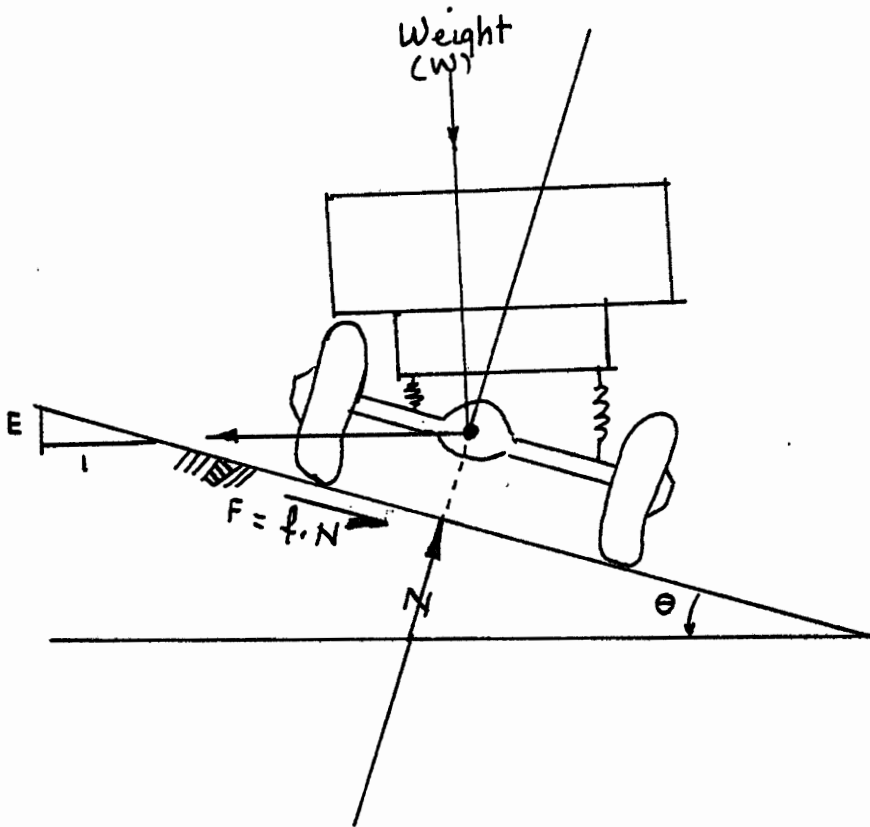


Figure 4.

Limited Values of Superelevation (E)
and Coefficient of Friction (F).

TABLE V
 MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS
 DETERMINED FOR LIMITING VALUES OF E AND F

DESIGN SPEED K.P.H.	MAXIMUM UM E	MAXIMUM UM F	TOTAL E+F	* MINIMUM RADIUS IN METER	MAX DEGREE OF CURVE FOR				MAX. D.C. ROUNDED			
					10M ARC	20M ARC	40M ARC	100M ARC	10	20	40	100
40	.06	0.17	0.23	54	10.46	20.92	41.84	104.60	10	21	42	105
50	.06	0.16	0.22	89	6.40	12.81	25.61	64.03	6	13	26	64
60	.06	0.15	0.21	134	4.24	8.49	16.98	42.45	4	8	17	42
70	.06	0.15	0.21	183	3.12	6.24	12.47	31.19	3	6	12	31
80	.06	0.14	0.20	251	2.27	4.55	9.10	22.74	2	5	9	23
90	.06	0.13	0.19	335	1.71	3.41	6.83	17.07	2	3	7	17
100	.06	0.13	0.19	414	1.38	2.77	5.53	13.83	1	3	6	14
110	.06	0.12	0.18	529	1.08	2.16	4.33	10.82	1	2	4	11
120	.06	0.12	0.18	629	0.91	1.82	3.64	9.10	1	2	4	9
130	.06	0.11	0.17	782	0.73	1.46	2.93	7.32	1	1	3	7
140	.06	0.10	0.16	964	0.59	1.19	2.38	5.94	1	1	2	6

*RADIUS ASSUMED SAME FOR ALL ARCS, I.E.
 DEGREE OF CURVES ARE CHANGED.

TABLE V
 MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS
 DETERMINED FOR LIMITING VALUES OF E AND F

DESIGN SPEED K.P.H.	MAXIM- UM E	MAXIM- UM F	TOTAL E+F	* MINIMUM RADIUS IN METER	MAX DEGREE OF CURVE FOR				MAX. D.C. ROUNDED			
					10M ARC	20M ARC	40M ARC	100M ARC	10	20	40	100
40	.08	0.17	0.25	50	11.37	22.74	45.48	113.70	11	23	45	114
50	.08	0.16	0.24	82	6.99	13.97	27.94	69.86	7	14	28	70
60	.08	0.15	0.23	123	4.65	9.30	18.60	46.49	5	9	19	46
70	.08	0.15	0.23	167	3.42	6.83	13.66	34.16	3	7	14	34
80	.08	0.14	0.22	229	2.50	5.00	10.01	25.01	3	5	10	25
90	.08	0.13	0.21	303	1.89	3.77	7.55	18.87	2	4	8	19
100	.08	0.13	0.21	374	1.53	3.06	6.11	15.28	2	3	6	15
110	.08	0.12	0.20	476	1.20	2.41	4.81	12.03	1	2	5	12
120	.08	0.12	0.20	566	1.01	2.02	4.04	10.11	1	2	4	10
130	.08	0.11	0.19	700	0.82	1.64	3.27	8.18	1	2	3	8
140	.08	0.10	0.18	857	0.67	1.34	2.67	6.68	1	1	3	7

*RADIUS ASSUMED SAME FOR ALL ARCS, I.E.
 DEGREE OF CURVES ARE CHANGED.

TABLE V
 MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS
 DETERMINED FOR LIMITING VALUES OF E AND F

DESIGN SPEED K.P.H.	MAXIMUM UM	E	MAXIMUM UM	F	TOTAL E+F	★ MINIMUM RADIUS IN METER	MAX DEGREE OF CURVE FOR				MAX. D.C. ROUNDED			
							10M ARC	20M ARC	40M ARC	100M ARC	10	20	40	100
40	.10		0.17		0.27	46	12.28	24.56	49.12	122.79	12	25	49	123
50	.10		0.16		0.26	75	7.57	15.14	30.27	75.68	8	15	30	76
60	.10		0.15		0.25	113	5.05	10.11	20.21	50.53	5	10	20	51
70	.10		0.15		0.25	154	3.71	7.43	14.85	37.13	4	7	15	37
80	.10		0.14		0.24	209	2.73	5.46	10.91	27.29	3	5	11	27
90	.10		0.13		0.23	277	2.07	4.13	8.26	20.66	2	4	8	21
100	.10		0.13		0.23	342	1.67	3.35	6.69	16.74	2	3	7	17
110	.10		0.12		0.22	433	1.32	2.65	5.29	13.23	1	3	5	13
120	.10		0.12		0.22	515	1.11	2.22	4.45	11.12	1	2	4	11
130	.10		0.11		0.21	633	0.90	1.81	3.62	9.04	1	2	4	9
140	.10		0.10		0.20	771	0.74	1.49	2.97	7.43	1	1	3	7

★RADIUS ASSUMED SAME FOR ALL ARCS, I.E.
 DEGREE OF CURVES ARE CHANGED.

TABLE V
 MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS
 DETERMINED FOR LIMITING VALUES OF E AND F

DESIGN SPEED K.P.H.	MAXIMUM- UM E	MAXIMUM- UM F	TOTAL E+F	* MINIMUM RADIUS IN, METER	MAX DEGREE OF CURVE FOR						MAX. D.C. ROUNDED	
					10M ARC	20M ARC	40M ARC	100M ARC	10	20	40	100
40	.12	0.17	0.29	43	13.19	26.38	52.76	131.89	13	26	53	132
50	.12	0.16	0.28	70	8.15	16.30	32.60	81.50	8	16	33	81
60	.12	0.15	0.27	104	5.46	10.91	21.83	54.57	5	11	22	55
70	.12	0.15	0.27	142	4.01	8.02	16.04	40.10	4	8	16	40
80	.12	0.14	0.26	193	2.96	5.91	11.82	29.56	3	6	12	30
90	.12	0.13	0.25	255	2.25	4.49	8.98	22.46	2	4	9	22
100	.12	0.13	0.25	314	1.82	3.64	7.28	18.19	2	4	7	18
110	.12	0.12	0.24	396	1.44	2.89	5.77	14.43	1	3	6	14
120	.12	0.12	0.24	472	1.21	2.43	4.85	12.13	1	2	5	12
130	.12	0.11	0.23	578	0.99	1.98	3.96	9.90	1	2	4	10
140	.12	0.10	0.22	701	0.82	1.63	3.27	8.17	1	2	3	8

*RADIUS ASSUMED SAME FOR ALL ARCS, I.E.
 DEGREE OF CURVES ARE CHANGED.

TABLE VI
 SELECTED SPIRALS, FOR
 10, 20, 40 AND 100 METRES OF ARCS

Purpose

To compute the spiral elements with a given even values of length of spiral, selected degree of curvature and corresponding radius. These elements are; Delta, DA, O, CS, DA, XO, CS, X, Y, LT, ST, LC, TS and ES.

Notations

L_{s_m} = Spiral length in metres (selected)

Delta (Δ) = Central angle of each spiral in degrees

DA = O = The "Throw" of the curve in metres (arc definition) =
 offset ordinate

CS = Corrections to be subtracted from DA if chord definition is used.

X_o = Offset abscissa in metres i.e. the throw abscissa

X = Spiral to curve (S.C.) point abscissa in metres

Y = S.C. point ordinate in metres

LT = Long tangent of spiral in metres

ST = Short tangent of spiral in metres

LC = Long chord of spiral in metres

TS = Total tangent (TS to P.I.) in metres

ES = External distance in metres

A = a_i = Deflection angle of spiral between LT and ST or between Δt_i and $s t_i$ of any other point (i) on the spiral in degrees.

$R_{10, 20, 40 \text{ \& } 100}$ = Radius of curvature of 10, 20, 40 & 100 metres
of arc. = R_m

$D_{10, 20, 40 \text{ \& } 100}$ = Degree of curvature of 10, 20, 40 & 100 metres
of arc, in degrees. = D_m

RC = Radius of curvature (chord definition)

RA = Radius of curvature (arc definition)

I = Total intersection angle

AC = Central angle of circular curve portion in the total spiral
curve (spiral - circular - spiral)

b = $57.29578^\circ = 1$ Radian

Formulas

Exact Method $D > 5^\circ$

10-meter of Arc:

$$R = \frac{572.9578}{D}, \text{ metres}$$

$$\Delta = \frac{L_s D}{20}, \text{ degrees}$$

$$\text{or } = \frac{L_s}{2R}, \text{ radians}$$

$$X = L_s \left[1 - \frac{(\Delta)^2}{10b^2} + \frac{(\Delta)^4}{216b^4} - \frac{(\Delta)^6}{9360b^6} + \dots \right]$$

$$Y = L_s \left[\frac{\Delta}{3b} - \frac{(\Delta)^3}{42b^3} + \frac{(\Delta)^5}{1320b^5} - \frac{(\Delta)^7}{75600b^7} + \dots \right]$$

$$O = Y - R(1 - \cos \Delta)$$

$$X_o = X - R \sin \Delta = DA$$

$$DA = O \text{ (arc definition)}$$

$$DA = O - CS \text{ (chord definition)}$$

Approximate Method $D \leq 5^\circ$

$$R = \frac{573}{D} \quad (\text{Eq. No. 64})$$

- same -

- same -

$$X_{\text{app.}} = L_s - \frac{Y^2}{2L_s}$$

$$Y_{\text{app.}} = L_s \sin \frac{\Delta}{3}$$

- same -

- same -

- same -

- same -

Exact MethodApproximate Method

$$RC = \frac{5}{\sin \frac{D}{2}} \quad (\text{chord definition})$$

- same - (Eq. No. 65)

$$RA = 572.9578/D$$

$$RA = \frac{573}{D} \quad (\text{Eq. No. 66})$$

$$CS = (RC - RA)(1 - \cos \Delta) \text{ for } 0$$

no need for CS (Eq. No. 67)

$$CS = (RC - RA)(\sin \Delta) \text{ for } X_0$$

no need for CS (Eq. No. 68)

$$LT = X - Y \cot \Delta$$

- same - (Eq. No. 69)

$$ST = Y/\sin \Delta$$

- same - (Eq. No. 70)

$$I = 2\Delta + \Delta C = \frac{L_s D}{10}$$

- same - (Eq. No. 71)

$$\Delta C = I - 2\Delta$$

- same - (Eq. No. 72)

$$TS = (R + 0) \tan \frac{I}{2} + X_0$$

- same - (Eq. No. 73)

$$E = R(\sec \frac{I}{2} - 1)$$

- same - (Eq. No. 74)

$$ES = E + 0 \sec \frac{I}{2} \quad \text{or}$$

- same - (Eq. No. 75)

$$ES = \sec \frac{I}{2} (R + 0) - R$$

- same - (Eq. No. 76)

For 20, 40 and 100 metres of arc all above equations are applicable except the following:

20-metre arc:

$$R = \frac{1145.916}{D} \quad \text{in metres} = RA = R_m, \quad \Delta = \frac{L_s D}{40}$$

$$I = \frac{L_s D}{20}, \quad \text{in degrees}$$

$$RC = \frac{10}{\sin \frac{D}{2}} \quad \text{in metres}$$

40-metre arc:

$$R = \frac{2291.831}{D} \text{ in metres} = RA$$

$$\Delta = \frac{L_s D}{80}$$

$$I = \frac{L_s D}{40} \text{ in degrees}$$

$$RC = \frac{20}{\sin \frac{D}{2}} \text{ in metres}$$

100-metre arc:

$$R = \frac{5729.578}{D} \text{ in metres} = RA$$

$$\Delta = \frac{L_s D}{200}$$

$$I = \frac{L_s D}{100} \text{ in degrees}$$

$$RC = \frac{50}{\sin \frac{D}{2}} \text{ in metres}$$

Table VI functions are calculated using the exact method as indicated in the following example.

Example How to Use

Given: $L_s = 200$ metres, $D = 6^\circ$, $b = 57.29578^\circ = 1$ Rad.

Length of station = 10 metres of Arc.

Required: Spiral elements, Δ , O , DA , CS , X_0 , X , Y , LT , ST , LC ,
 TS , ES

Solution: Direct reading from the table for the 100 metres of Arc:

$$R = 95.493 \text{ metres} = RA$$

$$\Delta = 6^\circ$$

$$X = 179.15 \text{ metres}$$

$$Y = 64.53 \text{ metres}$$

$$O = 16.76 \text{ metres}$$

$$RC = 95.537 \text{ metres}$$

$$CS = 0.02 \text{ for } O$$

$$CS = 0.04 \text{ for } X_0$$

$$X_o = 96.45 \text{ metres} = DA$$

$$LT = 141.90 \text{ metres}$$

$$ST = 74.52 \text{ metres}$$

$$A = 1.95 \text{ degrees}$$

$$LC = 190.61 \text{ metres}$$

$$I = \frac{200 \times 6}{20} = 60$$

$$TS = 290.93 \text{ metres}$$

$$ES = 129.06 \text{ metres}$$

This table is improved to previous works by adding the elements TS and ES to it.

Negative (-) values (e.g., $L_s = 550$, $\Delta = 110^\circ$ and $D = 8^\circ$ for 20 m arc)* are a result of having the tangent of Δ in the second quadrant.

Elements values with (*) are a result of exceeding the assigned spacing in the program of this table.

* Refer to pg. 85 for location of 20, 40, and 100 metre tables.

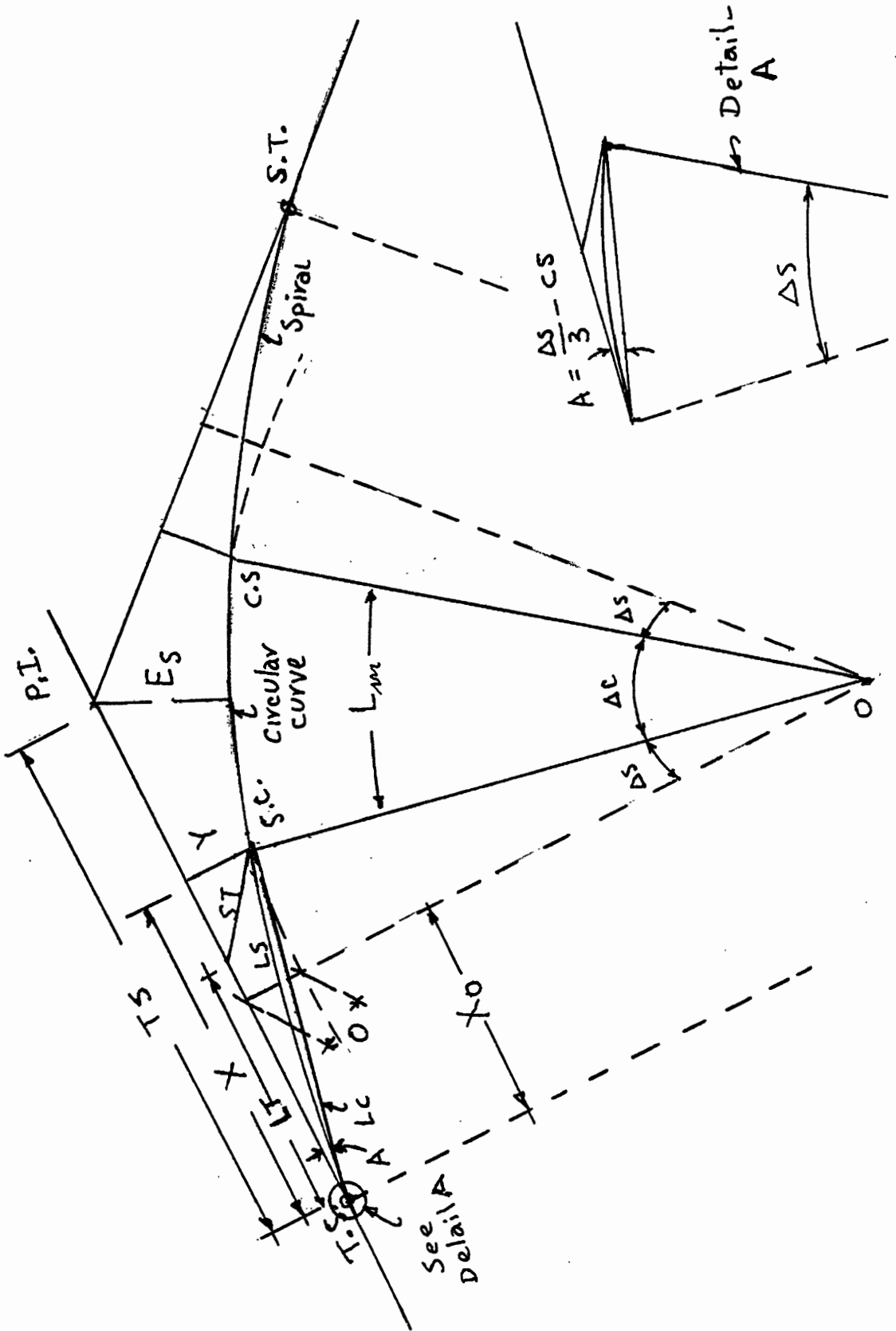


Figure 5.

Spiral Curve Elements.

TABLE VI SELECTED SPIRALS

LS	DELTA	U										E S				
		D A	C S	D A	C S	X	Y	L T	S T	L C	T S					
10-METER-ARC																
		R = 1145.92 METERS														
100	2	30.0	0.36	0.00	0.00	50.00	0.00	0.00	0.00	99.98	1.45	66.67	33.34	99.99	100.04	1.46
125	3	7.5	0.57	0.00	0.00	62.49	0.00	0.00	0.00	124.96	2.27	83.35	41.68	124.98	125.09	2.28
150	3	45.0	0.82	0.00	0.00	74.99	0.00	0.00	0.00	149.94	3.27	100.02	50.02	149.97	150.15	3.28
200	5	0.0	1.45	0.00	0.00	99.97	0.00	0.00	0.00	199.85	5.81	133.39	66.72	199.93	200.36	5.84
250	6	15.0	2.27	0.00	0.00	124.95	0.00	0.00	0.00	249.70	9.08	166.77	83.43	249.87	250.70	9.14
300	7	30.0	3.27	0.00	0.00	149.91	0.00	0.00	0.00	299.49	13.07	200.18	100.16	299.77	301.21	13.19
350	8	45.0	4.45	0.00	0.00	174.86	0.00	0.00	0.00	349.18	17.79	233.62	116.93	349.64	351.92	18.00
400	10	0.0	5.81	0.00	0.00	199.80	0.00	0.00	0.00	398.78	23.22	267.09	133.72	399.46	402.88	23.58
450	11	15.0	7.35	0.00	0.00	224.71	0.00	0.00	0.00	448.27	29.37	300.61	150.55	449.23	454.11	29.95
500	12	30.0	9.07	0.00	0.00	249.60	0.00	0.00	0.00	497.63	36.24	336.17	167.43	498.94	505.66	37.12
550	13	45.0	10.98	0.00	0.00	274.47	0.00	0.00	0.00	546.84	43.82	367.78	184.34	548.59	557.56	45.11
600	15	0.0	13.06	0.00	0.00	299.32	0.00	0.00	0.00	595.90	52.10	401.45	201.31	598.18	609.86	53.94
700	17	30.0	17.76	0.00	0.00	348.91	0.00	0.00	0.00	693.50	70.79	466.97	235.43	697.11	715.82	74.23
800	20	0.0	23.17	0.00	0.00	396.38	0.00	0.00	0.00	790.31	92.28	536.78	269.80	795.69	823.89	98.20
900	22	30.0	29.24	0.00	0.00	447.70	0.00	0.00	0.00	886.22	116.52	604.92	304.48	893.86	934.48	126.12
1000	25	0.0	36.11	0.00	0.00	496.84	0.00	0.00	0.00	981.13	143.48	673.44	339.50	991.59	1048.03	158.31
10-METER-ARC																
		R = 859.44 METERS														
100	3	20.0	0.48	0.00	0.00	49.99	0.00	0.00	0.00	99.97	1.94	66.68	33.34	99.98	100.08	1.94
125	4	10.0	0.76	0.00	0.00	62.49	0.00	0.00	0.00	124.93	3.03	83.36	41.69	124.97	125.15	3.04
150	4	60.0	1.09	0.00	0.00	74.98	0.00	0.00	0.00	149.89	4.36	100.04	50.04	149.95	150.27	4.38
200	6	40.0	1.94	0.00	0.00	99.95	0.00	0.00	0.00	199.73	7.75	133.43	66.75	199.88	200.64	7.80
250	8	20.0	3.03	0.00	0.00	124.91	0.00	0.00	0.00	249.47	12.10	166.85	83.50	249.76	251.24	12.23
300	9	60.0	4.36	0.00	0.00	149.85	0.00	0.00	0.00	299.09	17.42	200.32	100.29	299.59	302.16	17.68
350	11	40.0	5.93	0.00	0.00	174.76	0.00	0.00	0.00	348.55	23.69	233.84	117.13	349.36	353.44	24.19
400	13	20.0	7.74	0.00	0.00	199.64	0.00	0.00	0.00	397.84	30.91	267.43	134.02	399.04	405.16	31.76
450	14	60.0	9.79	0.00	0.00	224.49	0.00	0.00	0.00	446.93	39.00	301.08	150.99	448.63	457.40	40.46
500	16	40.0	12.08	0.00	0.00	249.30	0.00	0.00	0.00	495.79	48.19	334.82	168.02	498.12	510.21	50.30
550	18	20.0	14.61	0.00	0.00	274.06	0.00	0.00	0.00	544.40	58.23	368.65	185.14	547.51	563.69	61.35
600	19	60.0	17.38	0.00	0.00	298.79	0.00	0.00	0.00	592.73	69.21	402.58	202.35	596.76	617.92	73.65
700	23	20.0	23.62	0.00	0.00	348.07	0.00	0.00	0.00	688.48	93.90	470.79	237.08	694.87	728.99	102.27
800	26	40.0	30.79	0.00	0.00	397.13	0.00	0.00	0.00	782.84	122.21	539.51	272.29	792.36	844.22	136.75
900	29	60.0	38.89	0.00	0.00	445.92	0.00	0.00	0.00	875.64	154.03	608.85	308.06	889.14	964.57	177.86
1000	33	20.0	47.90	0.00	0.00	494.41	0.00	0.00	0.00	966.68	189.29	678.88	344.47	985.14	1091.18	226.56
10-METER-ARC																
		R = 687.55 METERS														
100	4	10.0	0.61	0.00	0.00	49.99	0.00	0.00	0.00	99.95	2.42	66.69	33.35	99.98	100.12	2.43
125	5	12.5	0.95	0.00	0.00	62.48	0.00	0.00	0.00	124.90	3.79	83.37	41.70	124.95	125.24	3.48
150	6	15.0	1.36	0.00	0.00	74.97	0.00	0.00	0.00	149.82	5.45	100.06	50.06	149.92	150.42	5.48
200	8	20.0	2.42	0.00	0.00	99.93	0.00	0.00	0.00	199.58	9.68	133.48	66.80	199.81	201.00	9.78
250	10	25.0	3.78	0.00	0.00	124.86	0.00	0.00	0.00	249.17	15.11	166.96	83.60	249.63	251.95	15.37
300	12	30.0	5.04	0.00	0.00	149.76	0.00	0.00	0.00	298.58	21.74	200.50	100.46	299.37	303.40	22.27
350	14	35.0	7.41	0.00	0.00	174.62	0.00	0.00	0.00	347.74	29.56	234.13	117.39	348.99	355.43	30.54
400	16	40.0	9.67	0.00	0.00	199.44	0.00	0.00	0.00	396.63	38.55	267.86	134.42	398.50	408.17	40.24
450	18	45.0	12.22	0.00	0.00	224.20	0.00	0.00	0.00	445.20	48.71	301.70	151.55	447.86	461.74	51.44
500	20	50.0	15.04	0.00	0.00	248.90	0.00	0.00	0.00	493.43	60.03	335.67	168.79	497.07	516.27	64.23
550	22	55.0	18.25	0.00	0.00	273.54	0.00	0.00	0.00	541.27	72.49	369.79	186.10	546.11	571.91	78.71
600	24	60.0	21.67	0.00	0.00	298.11	0.00	0.00	0.00	588.64	86.09	404.06	203.70	594.95	628.82	94.99
700	29	10.0	29.42	0.00	0.00	347.00	0.00	0.00	0.00	682.08	116.60	473.16	239.25	692.01	747.15	133.53
800	33	20.0	38.32	0.00	0.00	395.53	0.00	0.00	0.00	773.54	151.43	543.11	275.40	788.11	872.94	181.25
900	37	30.0	48.34	0.00	0.00	443.65	0.00	0.00	0.00	862.20	170.42	614.04	312.40	883.13	1008.32	240.02
1000	41	40.0	59.47	0.00	0.00	491.31	0.00	0.00	0.00	948.39	213.40	686.12	351.09	976.91	1156.10	312.44

TABLE VI SELECTED SPIRALS

I.S	DELTA	D A	C S	D A	C S	X	Y	L T	S T	L C	T S	E S
R = 572.96 METERS												
100	5	0.0	0.73	0.00	0.00	99.92	2.91	66.69	33.36	99.97	100.18	2.92
125	6	15.0	1.14	0.00	0.00	124.85	4.54	83.39	41.71	124.93	125.35	4.57
150	7	30.0	1.64	0.00	0.00	149.74	6.54	100.09	50.08	149.89	150.60	6.59
200	10	0.0	2.91	0.00	0.00	199.39	11.61	133.55	66.86	199.73	201.84	11.79
250	12	30.0	4.54	0.00	0.00	248.81	16.12	167.08	83.71	249.47	252.83	16.56
300	15	0.0	6.53	0.00	0.00	297.95	28.05	200.72	100.66	299.09	304.93	28.97
350	17	30.0	8.88	0.00	0.00	346.75	35.40	234.48	117.71	348.55	357.91	37.11
400	20	0.0	11.58	0.00	0.00	395.15	44.14	268.39	134.90	397.84	411.95	49.10
450	22	30.0	14.64	0.00	0.00	443.11	58.26	302.46	152.24	446.93	467.24	63.06
500	25	0.0	18.06	0.00	0.00	490.56	71.74	336.72	169.75	495.80	524.02	79.16
550	27	30.0	21.82	0.00	0.00	537.46	86.56	371.19	181.45	544.41	582.52	97.58
600	30	0.0	25.92	0.00	0.00	583.76	102.69	405.90	205.37	592.76	643.04	118.57
700	35	0.0	35.16	0.00	0.00	674.33	138.78	476.13	241.96	688.54	771.50	169.42
800	40	0.0	45.74	0.00	0.00	761.88	179.79	547.62	279.70	782.97	912.74	234.70
900	45	0.0	57.62	0.00	0.01	846.05	225.44	620.61	318.82	875.87	1071.49	318.82
1000	50	0.0	70.77	0.00	0.01	926.48	275.84	695.36	359.57	967.08	1254.74	428.51
R = 458.37 METERS												
100	6	15.0	0.91	0.00	0.00	99.88	3.63	66.71	33.37	99.95	100.28	3.65
125	7	48.8	1.42	0.00	0.00	124.77	5.67	83.41	41.74	124.90	125.55	5.73
150	9	22.5	2.04	0.00	0.00	149.60	8.17	100.14	50.13	149.82	150.95	8.28
200	12	30.0	3.63	0.00	0.00	199.05	14.50	133.67	66.97	199.58	202.26	14.85
250	15	37.5	5.67	0.00	0.00	248.15	22.61	167.32	83.93	249.17	254.47	23.47
300	18	45.0	8.15	0.00	0.00	296.80	32.68	201.13	101.03	298.58	307.83	34.30
350	21	52.5	11.08	0.00	0.00	344.93	44.08	235.14	118.31	347.74	362.63	47.50
400	25	0.0	14.45	0.00	0.00	392.45	57.39	269.38	135.80	396.64	419.21	63.32
450	28	7.5	18.25	0.00	0.00	439.28	72.37	303.88	153.53	445.22	477.96	82.06
500	31	15.0	22.48	0.00	0.00	485.33	88.99	338.68	171.54	493.45	539.33	104.09
550	34	22.5	27.15	0.00	0.01	530.53	107.20	373.83	189.66	541.31	603.86	129.88
600	37	30.0	32.23	0.00	0.00	574.80	126.95	409.36	208.54	588.75	672.21	160.02
700	43	45.0	43.62	0.00	0.00	660.27	170.89	481.76	287.12	682.23	823.86	236.56
800	50	0.0	56.62	0.00	0.00	741.19	220.35	556.29	330.57	773.66	1003.60	342.81
900	56	15.0	71.14	0.00	0.00	817.04	274.86	633.39	330.57	862.79	1228.40	494.73
1000	62	30.0	87.13	0.00	0.01	887.39	333.85	713.59	376.38	949.41	1528.71	723.02
R = 381.97 METERS												
100	7	30.0	1.09	0.00	0.00	99.83	4.36	66.73	33.39	99.92	100.40	4.40
125	9	22.5	1.70	0.00	0.00	124.67	6.90	83.45	41.77	124.85	125.79	6.90
150	11	15.0	2.45	0.00	0.00	149.42	9.79	100.20	50.18	149.74	151.37	9.98
200	15	0.0	4.35	0.00	0.00	198.63	17.37	133.82	67.10	199.39	203.29	17.98
250	18	45.0	6.79	0.00	0.00	247.34	27.06	167.61	84.19	248.81	256.52	28.38
300	22	30.0	9.76	0.00	0.00	295.41	38.84	201.64	101.49	297.95	311.49	42.04
350	26	15.0	13.26	0.00	0.00	342.72	52.65	235.95	119.05	346.76	368.69	58.71
400	30	0.0	17.28	0.00	0.01	389.17	68.86	270.60	136.92	395.17	428.70	79.05
450	33	45.0	21.82	0.00	0.00	434.63	86.19	305.64	155.14	442.14	492.23	103.66
500	37	30.0	26.86	0.00	0.00	479.00	105.79	341.13	173.78	490.62	560.18	133.55
550	41	15.0	32.39	0.00	0.00	522.17	127.89	377.14	192.89	537.56	633.71	169.16
600	45	0.0	38.41	0.00	0.01	564.03	150.29	413.74	212.55	583.91	714.32	212.55
650	48	45.0	44.91	0.00	0.00	604.49	175.03	450.99	232.81	629.62	804.08	265.97
700	52	30.0	51.87	0.00	0.01	643.47	201.32	488.99	253.76	674.66	905.83	330.70
800	60	0.0	67.14	0.00	0.01	716.61	258.13	547.58	298.06	762.56	1163.70	516.25
900	67	30.0	84.10	0.00	0.01	782.86	319.90	650.35	346.26	847.30	1555.17	835.94

TABLE VI SELECTED SPIRALS

10-METER-ARC

LS	DELTA	D A	C S	D A	C S	X	Y	L T	S T	L C	T S	F S
R = 327.40 METERS												
100	45.0	1.27	0.00	49.96	0.00	99.77	5.08	66.75	33.41	99.90	100.55	5.14
125	10	56.3	0.00	62.42	0.00	124.55	7.93	83.99	41.81	124.80	126.08	6.08
150	13	7.5	2.86	74.87	0.00	149.21	11.41	100.28	50.25	149.65	151.88	11.72
200	17	30.0	5.07	99.69	0.00	198.14	20.23	133.99	67.26	199.17	204.52	21.21
250	21	52.5	7.91	124.40	0.00	246.38	31.49	167.96	84.51	248.39	259.02	33.93
300	26	15.0	11.37	148.96	0.01	293.76	45.13	202.24	102.04	297.22	316.02	50.32
350	30	37.5	15.43	173.35	0.01	340.13	61.10	236.92	119.94	345.60	376.30	71.00
400	35	0.0	20.09	197.54	0.01	385.33	79.30	272.07	138.26	393.45	440.86	96.81
450	39	22.5	25.34	221.50	0.01	429.21	99.66	307.77	157.09	440.71	510.99	128.92
500	43	45.0	31.16	245.22	0.01	471.62	122.06	344.12	176.51	487.30	588.47	168.97
550	48	7.5	37.54	268.66	0.01	512.44	146.40	381.20	196.62	533.18	675.73	219.32
600	52	30.0	44.46	291.80	0.01	551.54	172.56	419.14	217.51	578.28	776.43	283.46
650	56	52.5	51.91	314.61	0.01	588.81	200.40	458.04	239.29	622.54	895.93	366.73
700	61	15.0	59.87	337.08	0.01	624.13	229.60	498.05	262.11	665.91	1043.00	477.77
800	70	0.0	77.23	360.90	0.01	688.56	292.67	582.04	311.45	749.82	1492.66	855.70
900	78	45.0	96.39	423.11	0.01	744.22	359.93	672.62	366.98	829.70	2553.72	1444.95

LS	DELTA	D A	C S	D A	C S	X	Y	L T	S T	L C	T S	F S
R = 286.48 METERS												
100	10	0.0	1.45	49.95	0.00	99.70	5.81	66.77	33.43	99.86	100.72	5.99
125	12	30.0	2.27	62.40	0.00	124.41	9.06	83.54	41.86	124.74	126.41	9.28
150	15	0.0	3.26	74.83	0.00	148.94	13.03	100.36	50.33	149.54	152.47	13.49
200	20	0.0	5.79	99.60	0.00	197.58	23.07	134.19	67.45	198.92	205.97	24.55
250	25	0.0	9.03	124.21	0.01	245.28	35.87	168.36	84.87	247.90	262.01	39.58
300	30	0.0	12.96	148.64	0.01	291.88	51.34	202.95	102.69	296.38	321.52	59.29
350	35	0.0	17.58	172.85	0.01	337.16	69.39	238.06	120.98	344.27	385.75	84.71
400	40	0.0	22.87	196.79	0.01	380.94	89.89	273.81	139.85	391.48	456.37	117.35
450	45	0.0	28.81	220.45	0.01	423.02	112.72	310.30	159.41	437.92	535.74	159.41
500	50	0.0	35.38	243.79	0.01	463.24	137.72	347.68	179.78	483.53	627.37	214.26
550	55	0.0	42.57	266.77	0.01	501.44	164.74	386.08	201.11	528.21	736.71	287.21
600	60	0.0	50.35	289.36	0.01	537.46	193.60	425.69	223.55	571.91	872.78	387.19
700	70	0.0	67.58	333.29	0.01	602.49	256.08	509.29	272.52	656.09	1306.08	748.74
800	80	0.0	86.85	375.37	0.01	657.50	323.60	600.44	328.59	735.66	2492.70	1863.52

LS	DELTA	D A	C S	D A	C S	X	Y	L T	S T	L C	T S	F S
R = 259.65 METERS												
100	11	15.0	1.63	49.94	0.00	99.62	6.53	66.80	33.46	99.83	100.91	6.65
125	14	3.8	2.55	62.37	0.00	124.25	10.18	83.60	41.91	124.67	126.80	10.50
150	16	52.5	3.67	74.78	0.00	148.70	14.64	100.46	50.42	149.42	153.14	15.29
200	22	30.0	6.51	99.49	0.01	196.94	25.89	134.83	67.66	198.63	207.66	28.03
250	28	7.5	10.14	124.00	0.01	244.04	40.21	168.82	85.29	247.34	265.53	45.59
300	33	45.0	14.54	148.28	0.01	289.76	57.46	203.76	103.43	295.42	328.15	69.11
350	39	22.5	19.71	172.28	0.01	333.03	77.51	239.38	122.18	342.77	397.44	100.27
400	45	0.0	25.61	195.96	0.01	376.02	100.20	275.83	141.70	389.26	476.22	141.70
450	50	37.5	32.22	219.27	0.01	416.12	125.33	313.26	162.13	434.81	568.83	197.55
500	56	15.0	39.52	242.18	0.01	453.91	152.70	351.88	183.65	479.31	682.44	274.85
550	61	52.5	47.48	264.65	0.01	489.23	182.09	391.90	206.47	522.68	829.90	386.28
600	67	30.0	56.06	286.64	0.02	521.91	213.27	433.57	230.84	564.85	1036.78	557.30
700	78	45.0	74.97	329.08	0.02	578.84	279.95	523.15	285.43	645.31	1948.22	1434.96
800	90	0.0	95.94	369.27	0.02	623.92	350.61	623.92	350.61	720.32	*****	*****

TABLE VI SELECTED SPIRALS

10-METER-ARC

LS	DELTA	D A	C S	D A	C S	D A	C S	X	Y	L T	S T	L C	Y S	F S
R = 229.18 METERS														
100	12	30.0	1.81	0.00	0.00	49.92	0.00	99.53	7.25	66.83	33.49	99.79	101.13	7.42
125	15	37.5	2.63	0.00	0.00	62.35	0.00	124.07	11.30	83.66	41.96	124.59	127.23	11.74
150	18	45.0	4.07	0.00	0.00	74.73	0.01	148.40	16.24	100.57	50.52	149.29	153.91	17.15
200	25	0.0	7.22	0.00	0.00	99.37	0.01	196.23	28.70	134.69	61.90	198.32	209.61	31.66
250	31	15.0	11.24	0.00	0.00	123.77	0.01	242.66	41.49	169.34	85.77	246.72	269.66	52.05
300	37	30.0	16.11	0.00	0.00	147.88	0.01	287.40	63.47	204.68	104.27	294.37	336.11	80.01
350	43	45.0	21.81	0.01	0.01	171.65	0.01	330.14	85.44	240.88	123.56	341.11	411.93	118.28
400	50	0.0	28.30	0.01	0.01	195.03	0.01	370.59	110.18	278.14	145.82	386.82	501.90	171.41
450	56	15.0	35.57	0.01	0.02	217.96	0.01	408.52	137.43	316.69	165.29	431.38	614.20	247.37
500	62	30.0	43.56	0.01	0.02	240.41	0.02	443.69	166.93	356.80	189.19	474.68	764.35	361.51
550	68	45.0	52.24	0.01	0.02	262.32	0.02	475.92	198.37	398.78	218.84	516.64	886.03	547.32
600	75	0.0	61.57	0.01	0.02	283.66	0.02	505.03	231.45	443.01	239.62	557.16	1368.43	894.27
700	87	30.0	82.00	0.02	0.02	324.49	0.02	553.45	301.21	540.30	301.49	633.70	7452.19	6905.31
800	100	0.0	94.93	0.02	0.02	362.66	0.02	588.36	373.46	654.21	379.22	704.06	*****	*****
R = 208.35 METERS														
100	13	45.0	2.00	0.00	0.00	49.90	0.00	99.43	7.97	66.87	33.52	99.74	101.38	8.20
125	17	11.3	3.11	0.00	0.00	62.31	0.01	123.88	12.42	83.73	42.03	124.50	127.72	13.00
150	20	37.5	4.48	0.00	0.00	74.68	0.01	148.07	17.83	100.69	50.63	149.14	154.78	19.05
200	27	30.0	7.93	0.00	0.00	99.24	0.01	195.44	31.48	134.98	68.16	197.96	211.83	35.98
250	34	22.5	12.34	0.00	0.00	123.52	0.01	241.15	48.73	169.92	86.30	246.04	274.48	59.04
300	41	15.0	17.66	0.01	0.01	147.45	0.01	284.82	69.37	205.71	103.21	293.21	345.66	92.27
350	48	7.5	23.88	0.01	0.01	170.96	0.01	326.10	93.16	242.58	125.12	339.29	430.03	139.57
400	55	0.0	30.96	0.01	0.02	194.01	0.02	364.64	119.81	280.79	146.26	384.14	535.79	208.68
450	61	52.5	38.84	0.01	0.02	216.53	0.02	400.28	148.99	320.64	168.93	427.64	679.01	316.05
500	68	45.0	47.49	0.01	0.02	238.47	0.02	432.65	180.34	362.52	193.49	469.66	896.39	497.57
550	75	37.5	56.45	0.02	0.02	259.78	0.02	461.61	213.49	406.89	220.39	510.11	1294.60	859.92
600	82	30.0	66.87	0.02	0.02	280.42	0.02	486.99	248.05	454.33	250.19	548.92	2371.08	1900.35
700	96	15.0	88.66	0.02	0.02	319.54	0.02	526.65	319.72	561.67	321.63	621.45	*****	*****
R = 190.99 METERS														
100	15	0.0	2.18	0.00	0.00	49.89	0.01	99.32	8.68	66.91	33.55	99.70	101.64	8.99
125	18	45.0	3.39	0.00	0.00	62.28	0.01	123.67	13.53	83.81	42.10	124.41	128.26	14.29
150	22	30.0	4.88	0.00	0.00	74.62	0.01	147.70	19.42	100.82	50.75	148.97	155.75	21.02
200	30	0.0	8.64	0.00	0.00	99.09	0.01	194.59	34.23	135.30	68.46	197.58	214.35	39.52
250	37	30.0	13.42	0.00	0.00	123.24	0.01	239.50	52.90	170.57	86.49	245.30	280.09	66.67
300	45	0.0	19.20	0.01	0.01	146.97	0.02	282.02	75.15	206.87	106.27	291.94	357.16	106.27
350	52	30.0	25.93	0.01	0.02	170.21	0.02	321.73	100.66	244.50	126.88	337.32	452.92	165.35
400	60	0.0	33.56	0.01	0.02	192.91	0.02	358.31	129.06	283.79	149.03	381.26	581.65	258.13
450	67	30.0	42.04	0.01	0.02	214.98	0.02	391.43	159.95	325.18	173.13	423.62	777.59	417.97
500	75	0.0	51.31	0.02	0.02	236.38	0.02	420.66	192.88	369.18	199.68	464.29	1140.69	745.22
550	82	30.0	61.30	0.02	0.02	257.05	0.02	446.40	227.38	416.47	229.34	503.17	2173.49	1741.98
600	90	0.0	71.95	0.02	0.02	276.95	0.02	467.94	262.96	467.94	262.96	540.21	*****	*****
700	105	0.0	94.93	0.03	0.03	314.24	0.02	498.76	335.37	588.62	347.20	608.72	-752.86	*****

TABLE VI SELECTED SPIRALS

10-METER-ARC

LS	DELTA	D A	C S	O A	X O	D E	X	Y	L T	S T	L C	T S	E S
R = 163.70 METERS													
100	17	30.0	0.00	49.84	0.01	3	99.07	10.11	67.00	33.63	99.59	102.26	10.60
125	21	52.5	0.00	62.20	0.01	3	123.19	15.74	83.98	42.25	124.19	129.51	16.96
150	26	15.0	0.00	74.48	0.01	3	146.88	22.57	101.12	51.02	148.61	150.01	25.16
200	35	0.0	0.00	98.77	0.01	3	192.66	39.65	136.04	69.13	196.72	220.43	48.41
250	43	45.0	0.01	122.61	0.02	3	235.81	61.03	172.06	88.26	243.64	294.24	84.49
300	52	30.0	0.01	145.90	0.02	3	275.77	86.28	209.57	108.75	289.12	380.21	141.73
350	61	15.0	0.01	168.54	0.02	3	312.06	114.90	249.03	131.06	332.93	521.50	230.08
400	70	0.0	0.02	190.45	0.02	3	348.28	146.33	291.02	155.72	374.88	746.33	427.85
450	78	45.0	0.02	211.55	0.02	3	372.11	179.97	336.31	183.49	414.81	1276.86	922.47
500	87	30.0	0.02	231.78	0.03	3	395.32	215.15	385.93	215.35	452.61	5322.99	1932.36
550	96	15.0	0.03	251.07	0.03	3	413.80	251.21	441.31	252.71	488.25	*****	*****
600	105	0.0	0.03	269.38	0.02	3	427.51	287.46	504.53	297.60	521.74	-645.31	*****
700	122	30.0	0.04	302.97	0.02	3	441.04	357.88	669.03	424.33	582.72	-120.72	-666.07
R = 143.24 METERS													
100	20	0.0	0.00	49.80	0.01	4	98.79	11.53	67.10	33.73	99.46	102.99	12.27
125	25	0.0	0.00	62.11	0.01	4	122.64	17.93	84.18	42.44	123.95	131.00	19.79
150	30	0.0	0.00	74.32	0.01	4	145.94	25.67	101.47	51.34	148.18	160.76	29.64
200	40	0.0	0.01	98.40	0.02	4	190.47	44.95	136.90	69.92	195.73	228.18	58.67
250	50	0.0	0.01	121.89	0.02	4	231.62	68.86	173.84	89.89	241.75	313.69	107.13
300	60	0.0	0.01	144.68	0.02	4	268.73	96.80	212.84	111.77	285.93	436.39	193.60
350	70	0.0	0.02	166.65	0.03	4	301.25	128.04	254.64	136.26	328.01	653.04	374.37
400	80	0.0	0.02	187.68	0.03	4	328.75	161.80	300.22	164.29	367.79	1246.35	931.76
450	90	0.0	0.03	207.71	0.03	4	350.95	197.22	350.95	197.22	405.13	*****	*****
500	100	0.0	0.03	226.66	0.03	4	367.72	233.41	408.88	237.02	439.99	-956.04	*****
550	110	0.0	0.04	244.47	0.03	4	379.08	269.50	477.17	286.80	472.42	-361.38	-787.98
600	120	0.0	0.04	261.12	0.03	4	385.17	304.62	561.04	351.74	502.62	-142.44	-609.24
650	130	0.0	0.05	276.59	0.02	4	386.32	337.93	669.88	441.14	530.92	-16.41	-525.73
R = 127.32 METERS													
100	22	30.0	0.00	49.74	0.01	4	98.47	12.95	67.21	33.83	99.32	103.83	14.01
125	28	7.5	0.00	62.00	0.02	4	122.02	20.10	84.41	42.65	123.67	132.77	22.80
150	33	45.0	0.01	74.14	0.02	4	144.88	28.73	101.88	51.71	147.71	164.08	34.55
200	45	0.0	0.01	97.98	0.02	4	188.01	50.10	137.91	70.85	194.62	238.11	70.05
250	56	15.0	0.01	121.09	0.03	4	226.96	76.35	175.94	91.83	239.64	341.22	137.43
300	67	30.0	0.02	143.32	0.03	4	260.95	106.63	216.78	115.42	282.39	518.39	278.65
350	78	45.0	0.03	164.54	0.03	4	289.42	139.97	261.58	142.72	322.61	993.11	717.48
400	90	0.0	0.03	184.63	0.03	4	311.96	175.30	311.96	175.30	360.10	*****	*****
450	101	15.0	0.04	203.51	0.03	4	328.39	211.51	370.46	215.65	394.00	-734.95	*****
500	112	30.0	0.05	221.11	0.03	4	338.74	247.47	441.25	267.86	426.80	-258.71	-646.68
550	123	45.0	0.05	237.39	0.03	4	343.26	282.10	531.75	339.28	456.36	-78.94	-507.77
600	135	0.0	0.06	252.35	0.02	4	342.38	314.37	656.75	444.59	484.00	28.00	-444.59
650	146	15.0	0.06	266.01	0.02	4	336.74	343.39	850.66	618.08	510.54	107.30	-412.99

TABLE VI SELECTED SPIRALS

LS	DELTA	10-METER-ARC													
		D A	C S	D A	C S	X ⁰	D A	C S	X	Y	L T	S T	L C	T S	E S
R = 114.59 METERS															
100	25	0.0	3.61	0.00	0.00	0.00	49.68	0.02	98.11	14.35	67.34	33.95	99.16	104.80	15.83
125	31	15.0	5.62	0.01	0.01	0.02	61.89	0.02	121.33	22.25	84.67	42.88	123.36	134.83	26.02
150	37	30.0	8.05	0.01	0.01	0.02	73.94	0.02	143.70	31.74	102.34	52.13	147.18	168.05	40.00
200	50	0.0	14.14	0.01	0.01	0.03	97.51	0.03	165.30	55.09	139.07	71.91	193.39	250.95	85.70
250	62	30.0	21.76	0.02	0.02	0.03	120.20	0.03	221.85	83.46	178.40	94.09	237.32	382.18	140.75
300	75	0.0	30.77	0.03	0.03	0.04	141.83	0.04	252.52	115.73	221.51	119.81	278.54	684.41	447.13
350	87	30.0	40.98	0.03	0.03	0.04	162.24	0.04	276.73	150.60	270.15	150.75	316.80	3726.09	3452.65
400	100	0.0	52.20	0.04	0.04	0.04	181.33	0.04	294.18	186.73	327.10	189.61	351.96	-764.83	*****
450	112	30.0	64.23	0.05	0.05	0.03	199.00	0.03	304.87	222.73	397.12	241.04	384.10	-232.84	-582.01
500	125	0.0	76.86	0.06	0.06	0.06	215.20	0.03	309.87	257.24	489.19	314.03	413.55	-58.30	-448.44
550	137	30.0	89.88	0.06	0.06	0.06	229.94	0.02	307.36	289.02	622.77	427.80	440.94	42.52	-392.01
600	150	0.0	*****	0.07	0.07	0.02	243.25	0.02	300.55	316.98	849.57	633.96	467.39	117.54	-366.01
D = 5 - 0															
R = 104.17 METERS															
100	27	30.0	3.96	0.00	0.00	0.02	49.62	0.02	97.72	15.74	67.09	34.08	98.98	105.91	17.74
125	34	22.5	6.16	0.01	0.01	0.02	61.76	0.02	120.58	24.36	84.96	43.15	123.02	137.24	29.52
150	41	15.0	8.82	0.01	0.01	0.03	73.72	0.03	142.41	34.69	102.66	52.61	146.59	172.83	46.14
200	55	0.0	15.47	0.02	0.02	0.03	97.01	0.03	182.34	59.90	140.39	73.13	192.05	267.89	104.44
250	68	45.0	23.73	0.03	0.03	0.04	119.24	0.04	216.33	90.17	181.26	96.75	234.00	400.19	248.78
300	82	30.0	33.41	0.03	0.03	0.04	140.21	0.04	243.49	124.02	227.17	125.09	274.41	1185.54	950.17
350	96	15.0	44.30	0.04	0.04	0.04	159.77	0.04	263.53	159.86	280.83	160.81	310.66	*****	*****
400	110	0.0	56.15	0.05	0.05	0.04	177.80	0.04	275.69	196.00	347.03	208.58	343.53	-262.82	-573.08
450	123	45.0	68.70	0.06	0.06	0.06	194.23	0.03	280.85	230.81	435.07	277.59	373.35	-64.59	-415.45
500	137	30.0	81.70	0.07	0.07	0.07	209.04	0.03	279.42	262.75	566.15	388.91	400.84	38.66	-356.37
550	151	15.0	94.90	0.08	0.08	0.02	222.28	0.02	272.39	290.48	801.86	603.92	427.30	113.02	-331.32
600	165	0.0	*****	0.08	0.08	0.01	234.07	0.01	261.03	312.96	*****	*****	454.98	177.18	-324.00
D = 6 - 0															
R = 95.09 METERS															
100	30	0.0	4.32	0.01	0.01	0.02	49.55	0.02	97.29	17.11	67.65	34.23	98.79	107.17	19.76
125	37	30.0	6.71	0.01	0.01	0.03	61.62	0.03	119.75	26.45	85.28	43.44	122.65	140.04	33.34
150	45	0.0	9.59	0.01	0.01	0.03	73.48	0.03	141.01	37.57	103.43	53.14	145.96	178.58	53.14
200	60	0.0	16.76	0.02	0.02	0.04	96.45	0.04	179.15	64.53	141.90	74.52	190.61	290.93	129.06
250	75	0.0	25.63	0.03	0.03	0.04	118.19	0.04	210.43	96.44	184.59	99.84	232.10	570.34	372.61
300	90	0.0	35.94	0.04	0.04	0.04	138.88	0.04	233.97	131.48	233.97	131.48	270.04	*****	*****
350	105	0.0	47.42	0.05	0.05	0.04	157.14	0.04	249.38	167.69	294.31	173.60	304.28	-376.43	-647.89
400	120	0.0	58.77	0.07	0.07	0.04	174.08	0.04	256.78	203.08	374.03	234.49	335.02	-94.96	-406.16
450	135	0.0	72.69	0.07	0.07	0.07	189.26	0.03	256.78	235.78	492.56	333.44	362.95	21.00	-333.44
500	150	0.0	85.87	0.08	0.08	0.02	202.71	0.02	250.46	264.15	707.97	528.30	389.46	97.95	-305.01
550	165	0.0	99.06	0.09	0.09	0.01	214.56	0.01	239.28	286.88	*****	*****	417.06	162.41	-297.00

TABLE VI SELECTED SPIRALS

LS	DELTA	D A	C S	D A	C S	D A	C S	10-METER-ARC		X	Y	L T	S T	L C	T S	E S
								X0	Y0							
R = 80.15 METERS																
100	32	30.0	4.67	0.01	49.47	0.03	D= 6 -30	96.83	18.48	67.83	34.39	98.58	108.60	21.91		
125	40	37.5	7.24	0.01	61.47	0.03		118.66	28.50	85.64	43.77	122.24	143.31	37.55		
150	48	45.0	10.35	0.02	73.23	0.04		139.50	40.39	104.08	53.72	145.28	165.56	61.26		
200	65	0.0	18.03	0.03	95.86	0.04		175.75	68.96	143.59	76.09	189.05	323.63	163.17		
250	81	15.0	27.47	0.04	117.07	0.05		204.00	102.25	188.46	103.45	229.25	672.14			
300	97	30.0	38.35	0.05	136.63	0.05		224.03	138.06	242.20	139.25	265.49	824.61			
350	113	45.0	50.34	0.07	154.37	0.04		235.06	174.05	311.64	190.15	297.78	160.51	432.16		
400	130	0.0	63.07	0.08	170.21	0.04		237.74	207.96	412.23	271.47	326.65	10.20	323.52		
450	146	15.0	76.20	0.09	184.16	0.03		233.13	237.73	508.92	427.90	353.39	74.28	285.92		
500	162	30.0	89.41	0.09	196.33	0.01		222.84	261.71	*****	870.33	380.51	140.32	274.41		
550	178	45.0	*****	0.09	207.00	0.00		208.92	278.77	*****	*****	412.64	202.84	278.84		
R = 81.85 METERS																
100	35	0.0	5.01	0.01	49.30	0.03	D= 7	96.33	19.03	68.02	34.57	98.35	110.21	24.20		
125	43	45.0	7.78	0.01	61.30	0.04		117.91	30.52	86.03	44.13	121.81	147.12	42.24		
150	52	30.0	11.10	0.02	72.95	0.04		137.89	43.14	104.78	54.38	144.55	194.11	70.86		
200	70	0.0	19.28	0.03	95.23	0.05		172.14	73.17	145.51	77.86	187.41	373.16	213.93		
250	87	30.0	29.24	0.05	115.89	0.05		197.66	107.57	192.96	107.68	226.25	2661.50	2466.18		
300	105	0.0	40.63	0.06	134.69	0.05		213.75	143.73	252.27	148.80	260.79	322.66	553.33		
350	122	30.0	53.03	0.08	151.49	0.04		220.52	178.94	334.52	212.17	291.27	-60.36	333.04		
400	140	0.0	66.04	0.09	166.23	0.03		218.84	210.68	469.92	327.76	318.70	42.06	275.02		
450	157	30.0	79.24	0.10	178.99	0.02		210.32	236.81	782.03	618.82	345.33	112.22	256.33		
500	175	0.0	92.32	0.10	190.03	0.00		197.16	255.81	*****	*****	375.52	174.78	256.79		
550	192	30.0	*****	0.10	199.83	-0.01		182.12	266.89	*****	*****	418.10	241.29	273.37		
R = 71.62 METERS																
100	40	0.0	5.70	0.01	49.20	0.04	D= 8	95.23	22.47	68.45	34.96	97.86	114.09	29.34		
125	50	0.0	8.83	0.02	60.95	0.04		115.81	34.43	86.92	44.95	120.86	136.84	53.56		
150	60	0.0	12.56	0.03	72.34	0.05		134.36	48.40	106.42	55.99	142.94	218.19	96.80		
200	80	0.0	21.67	0.05	93.84	0.06		164.37	80.90	150.11	82.15	183.85	623.18	465.88		
250	100	0.0	32.50	0.07	113.33	0.06		183.86	116.71	204.44	118.51	219.92	-478.02	672.09		
300	120	0.0	44.79	0.09	130.56	0.05		192.59	152.31	280.52	175.87	251.22	-71.22	304.62		
350	140	0.0	57.76	0.10	145.45	0.04		191.48	184.34	411.18	286.79	278.84	36.80	240.64		
400	160	0.0	70.96	0.11	158.08	0.02		182.58	209.99	759.53	613.98	305.60	106.15	223.47		
450	180	0.0	83.97	0.12	168.81	0.00		168.81	227.32	*****	*****	337.62	168.81	227.32		
500	200	0.0	96.52	0.11	178.38	-0.02		153.88	235.56	*****	*****	388.82	239.62	250.67		
550	220	0.0	*****	0.10	188.23	-0.04		142.20	235.33	*****	*****	496.88	339.66	307.20		

TABLE VI SELECTED SPIRALS

LS	DELTA	0	DA	CS	0	CS	DA	CS	XN	X	Y	L	T	ST	LC	TS	ES
10-METER-ARC																	
R= 63.66 METERS																	
100	45	0.0	6.38	0.02	0.05	48.99	0.05	0.05	D=9	94.01	25.05	68.96		35.42	97.30	119.05	55.42
125	56	15.0	9.85	0.03	0.05	60.54	0.06	0.06		113.48	38.17	87.97		45.91	119.80	170.61	68.71
150	67	30.0	13.98	0.04	0.06	71.66	0.06	0.06		130.48	53.32	108.39		57.71	141.17	259.20	139.32
200	90	0.0	23.92	0.07	0.07	92.32	0.07	0.07		155.98	87.65	155.98		87.65	179.99	*****	*****
250	112	30.0	35.62	0.09	0.06	110.55	0.06	0.06		169.37	123.74	220.62		133.93	213.31	-129.36	-323.34
300	135	0.0	48.40	0.11	0.05	126.17	0.05	0.05		171.19	157.19	328.38		222.30	241.90	14.00	-222.30
350	157	30.0	61.58	0.13	0.04	139.22	0.04	0.04		163.58	184.19	608.25		481.31	268.55	87.29	-199.36
400	180	0.0	74.61	0.13	0.06	150.06	0.06	0.06		150.06	202.06	*****		*****	300.11	150.06	-202.06
450	202	30.0	87.14	0.13	0.06	159.60	-0.03	0.03		135.24	209.74	*****		*****	353.77	222.12	-227.03
500	225	0.0	99.37	0.11	0.08	169.80	-0.05	0.05		124.78	208.16	-83.38		*****	483.58	352.94	-294.38
550	247	30.0	*****	0.09	0.06	184.62	-0.06	0.06		125.81	200.70	42.67		*****	971.63	610.33	-524.45
D=10																	
100	50	0.0	7.05	0.03	0.06	48.76	0.06	0.06		92.65	27.54	69.54		35.96	96.68	125.47	42.95
125	62	30.0	10.85	0.04	0.06	60.10	0.06	0.06		110.92	41.73	89.20		47.05	118.63	191.09	90.38
150	75	0.0	15.34	0.05	0.07	70.91	0.07	0.07		126.26	57.86	110.75		59.90	139.23	342.21	223.57
200	100	0.0	26.04	0.09	0.06	90.66	0.07	0.06		147.09	93.37	163.55		94.81	175.91	-382.42	-537.67
250	125	0.0	38.35	0.11	0.06	107.60	0.06	0.06		154.54	128.62	244.60		157.02	206.68	-29.15	-224.24
300	150	0.0	51.44	0.14	0.04	121.63	0.04	0.04		150.27	158.49	424.78		316.98	233.61	50.77	-183.01
350	175	0.0	64.55	0.15	0.02	133.02	0.01	0.01		138.02	179.07	*****		*****	262.85	122.35	-179.75
400	200	0.0	77.17	0.14	0.02	142.70	-0.02	0.02		123.11	188.45	*****		*****	311.12	191.69	-200.54
450	225	0.0	89.41	0.12	0.02	152.82	-0.05	0.05		112.30	187.35	-75.04		*****	435.37	299.65	-268.95
500	250	0.0	*****	0.10	0.06	168.16	-0.07	0.07		114.32	179.78	48.68		*****	994.88	608.26	-525.64
550	275	0.0	*****	0.07	0.07	198.97	-0.07	0.07		141.89	174.27	157.13		*****	*****	*****	1999.50
D=11																	
100	55	0.0	7.71	0.03	0.07	48.50	0.07	0.07		91.17	29.95	70.20		36.57	96.01	133.95	52.22
125	68	45.0	11.82	0.05	0.07	59.62	0.07	0.07		108.16	45.08	90.83		48.37	117.37	224.10	124.39
150	82	30.0	16.65	0.07	0.08	70.11	0.08	0.08		121.75	62.01	113.58		62.55	137.16	592.77	475.09
200	110	0.0	27.99	0.11	0.08	88.90	0.08	0.08		137.85	98.00	173.52		104.29	171.68	-131.41	-286.54
250	137	30.0	40.74	0.14	0.04	104.52	0.05	0.05		139.71	131.37	283.08		194.46	200.32	19.33	-178.19
300	165	0.0	53.92	0.16	0.04	117.04	0.02	0.02		130.52	156.48	714.50		604.58	227.43	88.59	-162.00
350	192	30.0	66.74	0.16	0.02	127.17	-0.02	0.02		115.89	169.84	*****		*****	266.13	153.55	-173.96
400	220	0.0	79.02	0.14	0.00	136.90	-0.05	0.05		103.41	171.15	*****		*****	361.66	247.03	-223.42
450	247	30.0	92.08	0.11	0.05	151.05	-0.07	0.07		102.93	164.21	34.91		*****	794.40	499.36	-429.09
500	275	0.0	*****	0.07	0.08	180.88	-0.08	0.08		128.99	158.42	142.85		*****	*****	*****	1617.72
550	302	30.0	*****	0.04	0.04	251.04	-0.07	0.07		207.11	172.37	316.92		*****	*****	*****	320.80

TABLE VI SELECTED SPIRALS

LS	DELTA	D A	C S	D A	C S	X	Y	L T	S T	L C	T S	E S
10-METER-ARC												
R= 47.75 METERS												
100	60	0.0	8.35	0.04	0.04	89.50	32.27	70.95	37.26	95.28	145.46	64.53
125	75	0.0	12.77	0.06	0.06	105.22	48.22	92.29	49.92	116.01	205.17	106.31
150	90	0.0	17.91	0.09	0.09	116.98	65.74	116.98	65.74	134.96	*****	*****
200	120	0.0	29.79	0.13	0.13	128.39	101.54	187.01	117.25	167.42	-47.48	-203.08
250	150	0.0	42.81	0.16	0.16	125.23	132.07	353.99	264.15	194.64	48.98	-152.51
300	180	0.0	55.88	0.17	0.17	112.54	151.55	*****	*****	225.08	112.54	-151.55
350	210	0.0	68.34	0.16	0.16	98.22	157.60	*****	*****	287.77	189.21	-181.98
400	240	0.0	80.88	0.13	0.13	92.74	152.63	4.62	*****	538.11	357.11	-305.26
450	270	0.0	97.66	0.09	0.09	111.23	145.49	111.23	*****	*****	*****	*****
500	300	0.0	*****	0.04	0.04	180.41	155.39	270.13	*****	*****	-88.74	310.79
550	330	0.0	*****	0.01	0.01	354.10	221.55	737.91	*****	*****	226.26	255.83
R= 44.07 METERS												
100	65	0.0	8.98	0.05	0.05	87.67	34.48	71.80	38.04	94.50	161.81	81.58
125	81	15.0	13.67	0.08	0.08	102.10	51.12	94.23	51.73	114.58	434.25	336.07
150	97	30.0	19.09	0.11	0.11	112.01	69.03	121.10	69.62	132.67	-412.31	-526.84
200	130	0.0	31.42	0.16	0.16	118.87	103.98	206.12	135.73	163.23	-5.05	-161.76
250	162	30.0	44.56	0.18	0.18	111.42	130.86	526.84	435.16	190.19	70.16	-137.21
300	195	0.0	57.38	0.19	0.19	96.92	144.21	*****	*****	229.54	135.56	-149.30
350	227	30.0	69.67	0.16	0.16	85.97	143.68	-45.69	*****	352.97	242.77	-212.67
400	260	0.0	84.05	0.11	0.11	93.34	135.89	69.36	*****	1651.47	863.99	-782.53
450	292	30.0	*****	0.06	0.06	144.09	138.15	201.31	*****	*****	-189.43	361.00
500	325	0.0	*****	0.02	0.02	290.08	188.26	558.94	*****	-919.60	158.26	229.82
550	357	30.0	*****	0.00	0.00	644.14	368.22	*****	*****	*****	628.06	368.57
R= 40.93 METERS												
100	70	0.0	9.59	0.07	0.07	86.07	36.58	72.76	38.93	93.67	186.58	106.96
125	87	30.0	14.55	0.10	0.10	98.83	53.79	96.88	53.84	113.07	1330.75	1233.09
150	105	0.0	20.22	0.13	0.13	106.88	71.87	126.13	74.40	130.32	-161.33	-277.67
200	140	0.0	32.88	0.18	0.18	109.42	105.34	234.96	163.88	159.25	21.03	-137.51
250	175	0.0	46.01	0.20	0.20	98.58	127.90	*****	*****	187.74	87.39	-128.39
300	210	0.0	58.53	0.19	0.19	84.19	135.09	*****	*****	246.75	162.18	-155.98
350	245	0.0	71.26	0.15	0.15	80.26	129.63	19.81	*****	559.95	358.25	-306.73
400	280	0.0	90.82	0.08	0.08	108.66	124.72	130.65	*****	*****	-598.69	718.26
450	315	0.0	*****	0.03	0.03	213.53	152.35	365.88	*****	-821.14	61.17	215.46
500	350	0.0	*****	0.00	0.00	496.21	286.10	*****	*****	*****	445.76	290.51
550	385	0.0	*****	0.01	0.01	*****	694.68	*****	*****	*****	1507.74	766.50

TABLE VI SELECTED SPIRALS

LB	DELTA	D	A	C	S	D	A	C	S	X	Y	L	T	S	T	L	C	T	S	E	S
10-METER-ARC																					
R= 38.20 METERS																					
100	75	0.0	10.18	0.08	0.11	47.28	0.11	0.15	0.11	84.17	30.58	73.84	39.94	92.79	226.14	149.04					
125	93	45.0	15.39	0.12	0.11	57.32	0.11	0.15	0.11	95.43	56.20	99.12	56.32	111.50	-762.00	-859.28					
150	112	30.0	21.28	0.15	0.10	66.33	0.10	0.20	0.10	101.62	78.24	132.37	80.36	127.92	-77.61	-198.00					
200	150	0.0	34.18	0.20	0.10	81.08	0.05	0.20	0.10	100.18	105.66	283.19	211.32	155.68	39.18	-122.00					
250	187	30.0	47.17	0.22	0.11	91.99	-0.01	0.22	0.11	87.00	123.45	455.00	*****	188.51	103.26	-124.52					
300	225	0.0	59.50	0.19	0.11	101.88	-0.08	0.19	0.11	74.87	124.90	-50.03	*****	290.74	199.77	-176.63					
350	262	30.0	74.03	0.12	0.11	120.44	-0.11	0.12	0.11	82.57	117.33	67.12	*****	1978.59	973.80	-898.92					
400	300	0.0	88.00	0.05	0.11	177.41	-0.09	0.05	0.11	144.33	124.32	216.10	*****	-823.45	-70.99	248.63					
450	337	30.0	99.00	0.01	0.11	354.65	-0.04	0.01	0.11	340.03	203.92	832.35	*****	-886.98	255.56	220.73					
500	375	0.0	110.00	0.00	0.11	853.18	0.03	0.00	0.11	863.06	498.00	*****	*****	*****	996.50	515.56					
550	412	30.0	120.00	0.04	0.11	*****	0.09	0.04	0.11	*****	*****	*****	*****	*****	3900.70	2207.81					
R= 35.81 METERS																					
100	80	0.0	10.76	0.10	0.11	46.92	0.11	0.16	0.11	82.19	40.45	75.05	41.07	91.88	311.59	232.94					
125	100	0.0	16.19	0.14	0.11	56.67	0.11	0.16	0.11	91.93	58.35	102.22	59.25	109.89	-239.01	-336.05					
150	120	0.0	22.26	0.17	0.10	65.28	0.10	0.17	0.10	96.29	76.15	140.26	87.94	125.52	-35.61	-152.31					
200	160	0.0	35.31	0.23	0.10	79.04	0.04	0.23	0.10	91.29	105.00	379.76	306.99	152.73	53.07	-111.73					
250	200	0.0	48.09	0.23	0.11	89.19	-0.04	0.23	0.11	76.94	117.78	*****	*****	194.57	119.81	-125.34					
300	240	0.0	60.58	0.17	0.11	100.57	-0.10	0.17	0.11	69.56	114.47	3.46	*****	404.60	267.83	-228.95					
350	280	0.0	79.45	0.10	0.11	130.34	-0.11	0.10	0.11	95.08	109.13	114.32	*****	*****	-523.65	626.48					
400	320	0.0	93.00	0.03	0.11	232.59	-0.07	0.03	0.11	209.57	142.11	378.93	*****	-727.53	90.32	185.51					
450	360	0.0	106.00	0.00	0.11	557.03	0.07	0.00	0.11	557.03	318.14	*****	*****	*****	557.03	318.14					
500	400	0.0	120.00	0.03	0.11	*****	0.07	0.03	0.11	*****	905.71	413.98	*****	*****	2257.35	1182.32					
550	440	0.0	135.00	0.10	0.11	*****	0.11	0.10	0.11	*****	*****	*****	*****	*****	*****	*****					
R= 33.70 METERS																					
100	85	0.0	11.32	0.11	0.12	46.55	0.12	0.16	0.12	80.12	42.20	76.43	42.36	90.92	562.48	404.20					
125	106	15.0	16.95	0.16	0.12	55.98	0.12	0.16	0.12	88.34	60.24	105.90	62.75	108.24	-118.35	-215.29					
150	127	30.0	23.18	0.20	0.10	64.20	0.10	0.20	0.10	90.94	77.60	150.48	97.82	123.15	-10.20	-127.48					
200	170	0.0	36.28	0.25	0.10	77.01	0.02	0.25	0.10	82.87	103.42	669.41	595.59	150.71	64.63	-105.02					
250	212	30.0	48.04	0.23	0.11	86.76	-0.07	0.23	0.11	68.65	111.20	*****	*****	209.80	139.49	-131.85					
300	255	0.0	62.20	0.16	0.12	101.54	-0.12	0.16	0.12	68.98	104.79	40.90	*****	810.83	460.05	-404.86					
350	297	30.0	89.90	0.07	0.11	151.07	-0.11	0.07	0.11	121.18	108.11	177.05	*****	-751.71	-86.50	234.13					
400	340	0.0	106.00	0.01	0.12	330.55	-0.01	0.01	0.12	319.03	199.28	839.06	*****	-808.08	250.13	201.43					
450	382	30.0	120.00	0.01	0.12	903.80	0.05	0.01	0.12	916.70	535.40	*****	*****	*****	1138.47	579.51					
500	425	0.0	135.00	0.07	0.12	*****	0.11	0.07	0.12	*****	*****	*****	*****	*****	*****	6065.37	3895.20				
550	467	30.0	150.00	0.16	0.12	*****	0.16	0.16	0.12	*****	*****	*****	*****	*****	*****	*****	*****				

TABLE VI SELECTED SPIRALS

LS	DELTA	DA	CS	DA	CS	XO	X	Y	LT	ST	LC	TS	ES
10-METER-ARC													
R = 31.83 METERS													
100	90	0.0	0.13	46.16	0.13	D=18	77.99	43.83	77.99	43.83	89.94	*****	*****
125	112	30.0	0.18	55.28	0.12		84.69	61.87	110.31	66.97	106.57	-64.68	-161.67
150	135	0.0	0.22	63.09	0.09		85.59	78.59	164.19	111.15	120.85	7.00	-111.15
200	180	0.0	0.26	75.03	0.00		75.03	101.03	*****	*****	150.06	75.03	-101.03
250	225	0.0	0.22	84.90	-0.09		62.39	104.08	-41.69	*****	242.53	166.47	-147.19
300	270	0.0	0.13	105.99	-0.13		74.16	96.99	74.16	-96.99	*****	*****	*****
350	315	0.0	0.04	108.58	-0.09		166.08	118.50	284.57	*****	-637.81	47.58	167.58
400	360	0.0	.00	495.14	-0.00		495.14	282.80	*****	*****	-990.28	495.14	282.80
450	405	0.0	0.04	*****	0.09		*****	919.15	578.18	*****	*****	2416.47	1299.87
500	450	0.0	0.13	*****	0.13		*****	*****	*****	*****	*****	*****	*****
550	495	0.0	0.22	*****	0.09		*****	*****	*****	*****	*****	2652.16	*****
R = 30.16 METERS													
100	95	0.0	0.15	45.75	0.14	D=19	75.79	45.32	79.76	45.49	88.92	-442.23	-520.00
125	118	45.0	0.21	58.55	0.12		80.99	63.22	115.67	72.11	104.90	-34.25	-131.44
150	142	30.0	0.25	61.96	0.08		80.31	79.14	183.85	130.00	118.69	19.59	-99.75
200	190	0.0	0.28	73.12	-0.02		67.89	97.93	*****	*****	151.39	85.15	-99.44
250	237	30.0	0.21	83.88	-0.12		58.45	96.82	-3.24	*****	314.31	210.43	-180.20
300	285	0.0	0.10	115.66	-0.13		86.54	92.53	111.33	-95.79	-967.07	-258.78	357.50
350	332	30.0	0.02	251.55	-0.06		237.63	146.32	518.71	*****	-666.20	161.46	164.96
400	380	0.0	0.01	760.82	0.05		771.13	448.00	*****	*****	*****	934.34	477.18
450	427	30.0	0.09	*****	0.13		*****	*****	*****	*****	*****	6195.03	4094.20
500	475	0.0	0.20	*****	0.13		*****	*****	*****	*****	*****	*****	*****
R = 28.65 METERS													
100	100	0.0	0.17	45.33	0.14	D=20	73.54	46.68	81.78	47.40	87.68	-191.21	-268.84
125	125	0.0	0.23	53.80	0.12		77.27	64.31	122.30	78.51	103.24	-14.58	-112.12
150	150	0.0	0.27	60.81	0.07		75.14	79.24	212.39	150.49	116.72	29.39	-91.50
200	200	0.0	0.28	71.35	-0.05		61.55	94.22	*****	*****	155.72	95.85	-100.27
250	250	0.0	0.20	84.08	-0.14		57.16	89.89	24.44	-95.66	502.65	304.13	-262.82
300	300	0.0	0.07	133.06	-0.13		108.25	93.24	162.08	*****	-615.67	-53.24	186.47
350	350	0.0	0.00	352.32	-0.03		347.35	200.27	*****	*****	-773.26	312.03	203.36
400	400	0.0	0.03	*****	0.09		*****	724.57	331.18	*****	*****	1802.68	945.86
450	450	0.0	0.15	*****	0.15		*****	*****	*****	*****	*****	*****	*****
500	500	0.0	0.26	*****	0.09		*****	*****	*****	*****	*****	3919.78	*****

TABLE VII
LENGTH OF CROWN RUNOUT

Purpose

To compute the length of the superelevation runoff or crown runout using the slope ratio method.

Notations

N = Number of lanes.

D_m = Transverse distance for axis of rotation to outer edge of pavement in metres.

E = Crown slope or superelevation rate, metre per metre.

R = Slope ratio of outer edge of pavement in relation to axis of rotation.

L = Length of crown runout or superelevation runoff in metres.

Formulas

Using the slope ratio method

$$L = \frac{DS}{R}$$

Example How to Use

Given: N = 2 lane-roadway, E = 0.08, D = 6.7 metres, R = 1/175

Required: L in metres

Solution: $L = \frac{DS}{R} = \frac{6.7(0.08)}{1/175} = 93.80$ metres

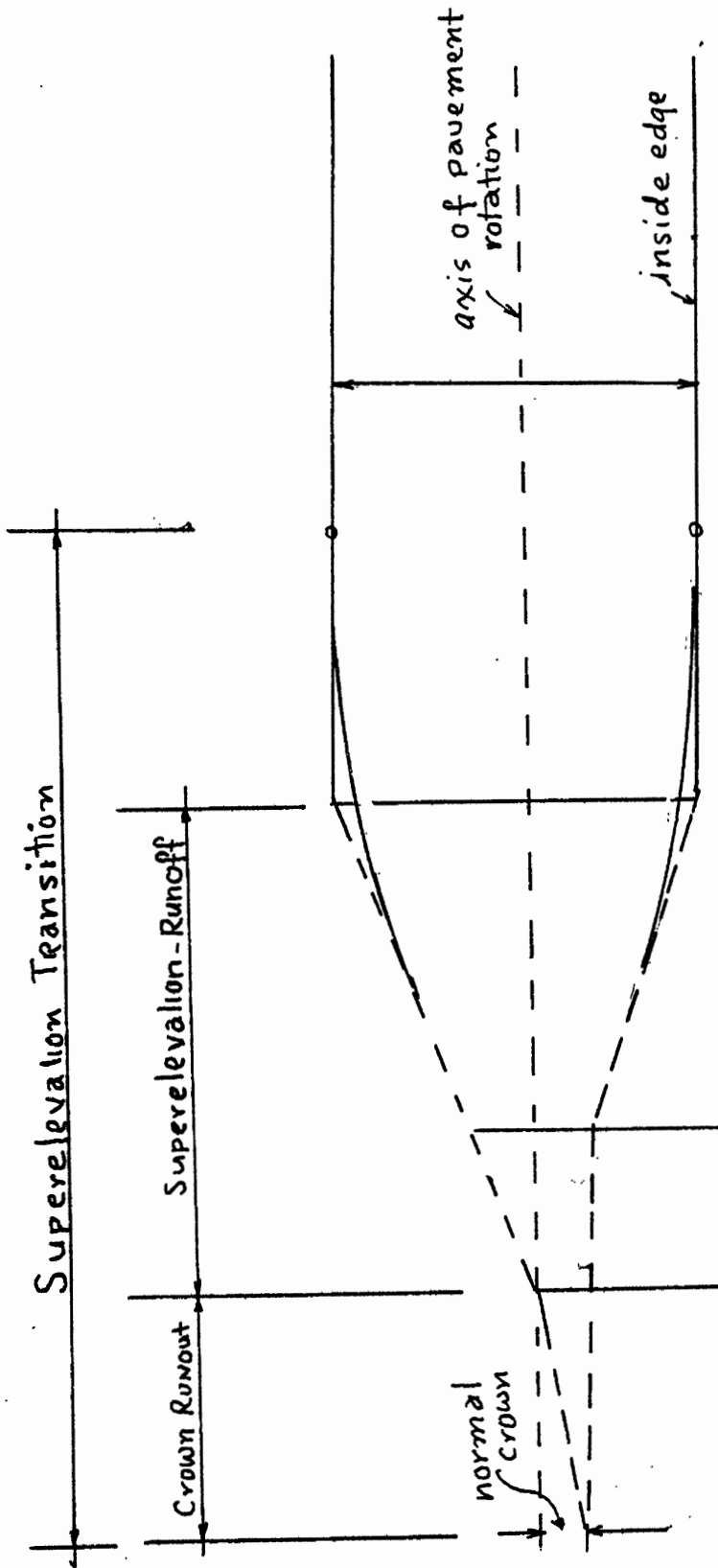


Figure 6.

Crown Runout and Superelevation Runoff.

TABLE VII
LENGTH OF CROWN RUNOUT

N	D	E	R	L
IN METER IN M/M RATIO IN-METERS				
1	3.0-3.6	0.01		6.00 - 7.20
		0.02		12.00 - 14.40
		0.06	1:200	36.00 - 43.20
		0.08		48.00 - 57.60
		0.10		60.00 - 72.00
		0.12		72.00 - 86.40
2	6.7-8.8	0.01		11.73 - 15.40
		0.02		23.46 - 30.80
		0.06	1:175	70.38 - 92.40
		0.08		93.84 - 123.20
		0.10		117.25 - 154.00
		0.12		140.70 - 184.80
3	9.2-12.5	0.01		13.80 - 18.75
		0.02		27.60 - 37.50
		0.06	1:150	82.80 - 112.50
		0.08		110.40 - 150.00
		0.10		136.00 - 187.50
		0.12		165.60 - 225.00
4	13.4-15.9	0.01		16.75 - 19.88
		0.02		33.50 - 39.75
		0.06	1:125	100.50 - 238.50
		0.08		134.00 - 318.00
		0.10		167.50 - 397.50
		0.12		201.00 - 477.00

TABLE VIII-A, B, C, D

PAVEMENT WIDENING ON OPEN HIGHWAY CURVES,
2 LANE PAVEMENTS ONE WAY OR TWO WAYS FOR
10, 20, 40 AND 100 METRE OF ARCPurpose

To compute the extra pavement necessary in order to avoid extra costs on the width of the designed roadway width.

Notations

W = Widening for 2-lane pavement on curve, metre (m)

Wc = Width of 2-lane pavement on curve, m

Wn = Width of 2-lane pavement on tangent, m

U = Track width of vehicle (out-to-out), m

C = Lateral clearance per vehicle, assumed 0.92 m, 0.76 m, 0.61 metre for Wn of 7.40, 6.80, and 6.20 metres.

FA = Width of Front overhang, m

Z = Extra width allowance for difficulty of driving on curves, m

u = Track width on tangent (out-to-out), 2.6 metres for standard unit truck (SU)

R = Radius on centerline of 2-lane pavement, metre = R_m

L = Wheel-base, 6.10 metres

A = Front overhang for SU = 1.22 metres

V = Design speed in Kph , $D = D_m =$ degree of metres

N = $(2AL + A^2)/3.2808 = 5.0$, $D = D_m =$ Degree of curve

Formulas

AASHO practices are adopted in this research.

$$W = Wc - Wn$$

(Eq. No. 77)

$$U = [2.6 + R - (R^2 - L^2)^{1/2}] \quad (\text{Eq. No. 78})$$

$$FA = [(R^2 + N)^{1/2} - R] \quad (\text{Eq. No. 79})$$

$$Z = \frac{V}{3.70 R^{1/2}} \quad (\text{Eq. No. 80})$$

$$R = 572.9578 / D \text{ for 10 metres of arc}$$

$$R = 1145.916 / D \text{ for 20 metres of arc}$$

$$R = 2291.831 / D \text{ for 40 metres of arc}$$

$$R = 5729.578 / D \text{ for 100 metres of arc}$$

Example How to Use

Given: $R = 572.96 \text{ m}$ for 10 metre of arc.

$D = 4^\circ$, $V = 80 \text{ Kph}$.

Required: W in metres

$$\text{Solution: } U = 2.60 + \frac{572.96}{4} - [(572.96/4)^2 - 37.21]^{1/2}$$

$$FA = [((572.96/4)^2 + 5.0)^{1/2} - \frac{572.96}{4}]$$

$$= 0.02 \text{ m}$$

$$Z = \frac{80}{3.7(572.96/4)^{1/2}} = 1.8 \text{ metres}$$

$$W_c = 2(2.73 + 0.92) + 0.04 + 1.81 = 9.15 \text{ metres}$$

$$W = 9.15 - 7.40 = 1.75 \text{ metres}$$

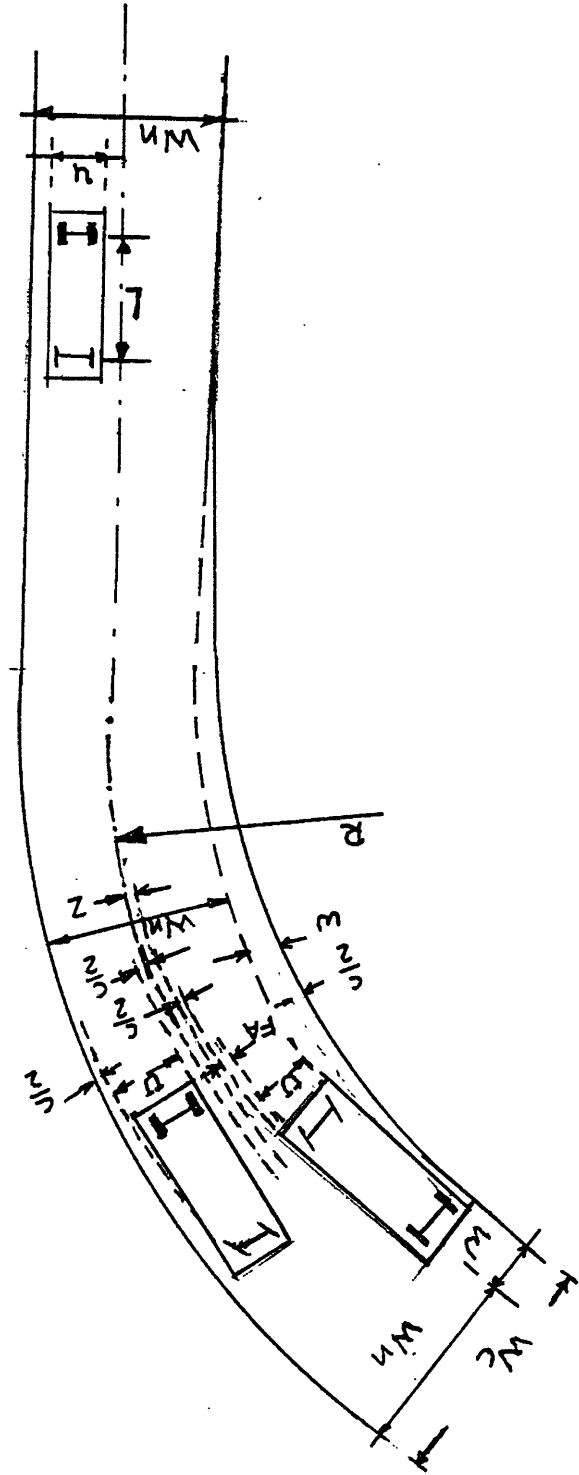


Figure 7.

Pavement Widening.

TABLE VIII - A

10 METER OF ARC

PAVEMENT WIDENING ON OPEN HIGHWAY CURVES

2-LANE PAVEMENTS ONE-WAY OR TWO-WAY

W = WIDENING IN METERS FOR 2-LANE PAVEMENTS ON

CURVES FOR WIDTH OF PAVEMENT ON TANGENT OF 1

DEGREE

CURVE	WN = 7.40 METERS					WN = 6.60 METERS					WN = 6.20 METERS												
	50	60	70	80	90	100	110	120	130	140	50	60	70	80	90	100	110	120	130	140			
1	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.3	0.8	1.0	1.1	1.2	1.3	1.4
2	0.6	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.8	0.8	1.0	1.2	1.3	1.5	1.6	1.8	2.0	1.1	1.3	1.5	1.6	1.8	1.9
3	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	1.4	1.6	1.8	2.0	2.2	2.4
4	1.0	1.3	1.5	1.7	1.9	2.2	2.4	2.6	2.8	1.3	1.5	1.8	2.0	2.2	2.4	2.7	2.9	1.6	1.8	2.1	2.3	2.5	2.7
5	1.2	1.5	1.7	2.0	2.2	2.5	2.7	3.0	3.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	1.8	2.1	2.3	2.6	2.8	3.1
6	1.4	1.7	2.0	2.3	2.5	2.8	3.1	3.4	3.6	1.7	2.0	2.3	2.5	2.8	3.1	3.4	3.6	2.0	2.3	2.6	2.8	3.1	3.4
7	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	2.2	2.5	2.8	3.1	3.4	3.7
8	1.8	2.1	2.4	2.7	3.1	3.4	3.7	4.0	4.3	2.1	2.4	2.7	3.0	3.3	3.7	4.0	4.3	2.4	2.7	3.0	3.3	3.6	4.0
9	1.9	2.3	2.6	3.0	3.3	3.6	4.0	4.3	4.7	2.2	2.6	2.9	3.2	3.6	3.9	4.3	4.6	2.5	2.9	3.2	3.5	3.9	4.2
10	2.1	2.5	2.8	3.2	3.5	3.9	4.2	4.6	5.0	2.4	2.7	3.1	3.5	3.8	4.2	4.5	4.9	2.7	3.0	3.4	3.8	4.1	4.5
11	2.3	2.6	3.0	3.4	3.8	4.1	4.5	4.9	5.3	2.5	2.9	3.3	3.7	4.0	4.4	4.8	5.2	2.8	3.2	3.6	4.0	4.3	4.7
12	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.5	2.7	3.1	3.5	3.9	4.3	4.6	5.0	5.4	3.0	3.4	3.8	4.2	4.6	4.9
13	2.6	3.0	3.4	3.8	4.2	4.6	5.0	5.4	5.8	2.8	3.3	3.7	4.1	4.5	4.9	5.3	5.7	3.1	3.6	4.0	4.4	4.8	5.2
14	2.7	3.1	3.6	4.0	4.4	4.8	5.2	5.7	6.1	3.0	3.4	3.8	4.3	4.7	5.1	5.5	5.9	3.3	3.7	4.1	4.6	5.0	5.4
15	2.9	3.3	3.7	4.2	4.6	5.0	5.5	5.9	6.4	3.1	3.6	4.0	4.4	4.9	5.3	5.8	6.2	3.4	3.9	4.3	4.7	5.2	5.6

TABLE VIII - A

10 METER OF ARC

PAVEMENT WIDENING ON OPEN HIGHWAY CURVES

2-LANE PAVEMENTS ONE-WAY OR TWO-WAY

W = WIDENING IN METERS FOR 2-LANE PAVEMENTS ON
CURVES FOR WIDTH OF PAVEMENT ON TANGENT OF 1

DEGREE

OF

WN = 7.40 METERS

WN = 6.00 METERS

WN = 6.20 METERS

CURVE	DESIGN SPEED IN KPH										DESIGN SPEED IN MPH										DESIGN SPEED IN KPH																									
	50	60	70	80	90	100	110	120	130	140	50	60	70	80	90	100	110	120	130	140	50	60	70	80	90	100	110	120	130	140																
16	3.0	3.4	3.9	4.4	4.8	5.3	5.7	6.2	6.6	3.3	3.7	4.2	4.6	5.1	5.5	6.0	6.4	3.6	4.0	4.5	4.9	5.4	5.8	3.0	3.4	3.9	4.4	4.8	5.3	5.7	6.2	6.6	3.3	3.7	4.2	4.6	5.1	5.5	6.0	6.4	3.6	4.0	4.5	4.9	5.4	5.8
17	3.1	3.6	4.1	4.5	5.0	5.5	5.9	6.4	6.9	3.4	3.9	4.3	4.8	5.3	5.7	6.2	6.7	3.7	4.2	4.6	5.1	5.6	6.0	3.1	3.6	4.1	4.5	5.0	5.5	5.9	6.4	6.9	3.4	3.9	4.3	4.8	5.3	5.7	6.2	6.7	3.7	4.2	4.6	5.1	5.6	6.0
18	3.3	3.8	4.2	4.7	5.2	5.7	6.2	6.6	7.1	3.6	4.0	4.5	5.0	5.5	6.0	6.4	6.9	3.9	4.3	4.8	5.3	5.8	6.3	3.3	3.8	4.2	4.7	5.2	5.7	6.2	6.6	7.1	3.6	4.0	4.5	5.0	5.5	6.0	6.4	6.9	3.9	4.3	4.8	5.3	5.8	6.3
19	3.4	3.9	4.4	4.9	5.4	5.9	6.4	6.9	7.4	3.7	4.2	4.7	5.2	5.7	6.2	6.6	7.1	4.0	4.5	5.0	5.5	6.0	6.5	3.4	3.9	4.4	4.9	5.4	5.9	6.4	6.9	7.4	3.7	4.2	4.7	5.2	5.7	6.2	6.6	7.1	4.0	4.5	5.0	5.5	6.0	6.5
20	3.5	4.1	4.6	5.1	5.6	6.1	6.6	7.1	7.6	3.8	4.3	4.8	5.3	5.8	6.4	6.9	7.4	4.1	4.6	5.1	5.6	6.1	6.7	3.5	4.1	4.6	5.1	5.6	6.1	6.6	7.1	7.6	3.8	4.3	4.8	5.3	5.8	6.4	6.9	7.4	4.1	4.6	5.1	5.6	6.1	6.7
21	3.7	4.2	4.7	5.2	5.7	6.3	6.8	7.3	7.8	4.0	4.5	5.0	5.5	6.0	6.5	7.1	7.6	4.3	4.8	5.3	5.8	6.3	6.8	3.7	4.2	4.7	5.2	5.7	6.3	6.8	7.3	7.8	4.0	4.5	5.0	5.5	6.0	6.5	7.1	7.6	4.3	4.8	5.3	5.8	6.3	6.8
22	3.8	4.3	4.9	5.4	5.9	6.5	7.0	7.5	8.1	4.1	4.6	5.2	5.7	6.2	6.7	7.3	7.8	4.4	4.9	5.5	6.0	6.5	7.0	3.8	4.3	4.9	5.4	5.9	6.5	7.0	7.5	8.1	4.1	4.6	5.2	5.7	6.2	6.7	7.3	7.8	4.4	4.9	5.5	6.0	6.5	7.0
23	3.9	4.5	5.0	5.6	6.1	6.7	7.2	7.7	8.3	4.2	4.8	5.3	5.9	6.4	6.9	7.5	8.0	4.5	5.1	5.6	6.2	6.7	7.2	3.9	4.5	5.0	5.6	6.1	6.7	7.2	7.7	8.3	4.2	4.8	5.3	5.9	6.4	6.9	7.5	8.0	4.5	5.1	5.6	6.2	6.7	7.2
24	4.1	4.6	5.2	5.7	6.3	6.8	7.4	7.9	8.5	4.4	4.9	5.5	6.0	6.6	7.1	7.7	8.2	4.7	5.2	5.8	6.3	6.9	7.4	4.1	4.6	5.2	5.7	6.3	6.8	7.4	7.9	8.5	4.4	4.9	5.5	6.0	6.6	7.1	7.7	8.2	4.7	5.2	5.8	6.3	6.9	7.4
25	4.2	4.8	5.3	5.9	6.5	7.0	7.6	8.2	8.7	4.5	5.1	5.6	6.2	6.7	7.3	7.9	8.4	4.8	5.4	5.9	6.5	7.0	7.6	4.2	4.8	5.3	5.9	6.5	7.0	7.6	8.2	8.7	4.5	5.1	5.6	6.2	6.7	7.3	7.9	8.4	4.8	5.4	5.9	6.5	7.0	7.6
26	4.3	4.9	5.5	6.1	6.6	7.2	7.8	8.4	8.9	4.6	5.2	5.8	6.3	6.9	7.5	8.1	8.6	4.9	5.5	6.1	6.6	7.2	7.8	4.3	4.9	5.5	6.1	6.6	7.2	7.8	8.4	8.9	4.6	5.2	5.8	6.3	6.9	7.5	8.1	8.6	4.9	5.5	6.1	6.6	7.2	7.8
27	4.5	5.1	5.6	6.2	6.8	7.4	8.0	8.6	9.2	4.7	5.3	5.9	6.5	7.1	7.7	8.3	8.9	5.0	5.6	6.2	6.8	7.4	8.0	4.5	5.1	5.6	6.2	6.8	7.4	8.0	8.6	9.2	4.7	5.3	5.9	6.5	7.1	7.7	8.3	8.9	5.0	5.6	6.2	6.8	7.4	8.0
28	4.6	5.2	5.8	6.4	7.0	7.6	8.2	8.8	9.4	4.9	5.5	6.1	6.7	7.3	7.9	8.5	9.1	5.2	5.8	6.4	7.0	7.6	8.2	4.6	5.2	5.8	6.4	7.0	7.6	8.2	8.8	9.4	4.9	5.5	6.1	6.7	7.3	7.9	8.5	9.1	5.2	5.8	6.4	7.0	7.6	8.2
29	4.7	5.3	5.9	6.5	7.2	7.8	8.4	9.0	9.6	5.0	5.6	6.2	6.8	7.4	8.0	8.6	9.3	5.3	5.9	6.5	7.1	7.7	8.3	4.7	5.3	5.9	6.5	7.2	7.8	8.4	9.0	9.6	5.0	5.6	6.2	6.8	7.4	8.0	8.6	9.3	5.3	5.9	6.5	7.1	7.7	8.3
30	4.8	5.5	6.1	6.7	7.3	7.9	8.6	9.2	9.8	5.1	5.7	6.4	7.0	7.6	8.2	8.8	9.5	5.4	6.0	6.7	7.3	7.9	8.5	4.8	5.5	6.1	6.7	7.3	7.9	8.6	9.2	9.8	5.1	5.7	6.4	7.0	7.6	8.2	8.8	9.5	5.4	6.0	6.7	7.3	7.9	8.5

TABLE IX-A
MINIMUM STOPPING SIGHT DISTANCES (SSD)

Purpose

To compute very important elements in highway geometric design which are safe stopping sight distance, safe passing sight distance and effect of grade on the (SSD). For consideration of safety and continuity of traffic these criteria should carefully be designed. SSD is to be corrected by values in Table IX-B and C. In this table the wet and dry conditions are introduced for proper design procedure to fit the prevailing conditions.

Notations

S1 = Reaction distance in metres

F = Coefficient of friction, (F_w = wet conditions)

S2 = Braking distance in metres

SSD = Stopping sight distance in metres

Formulas

$$SSD = 0.279 VT + \frac{v^2}{255F} \quad (\text{Eq. No. 81})$$

where:

V = design speed or assumed speed as dry or wet condition, (V_D, V_w)

T = 2.5 second perception and brake reaction time

F = Friction factor for wet or dry condition as the case may be.

Example How to Use

Given: $V_w = 37$ Kph, $V_D = 40$, $F_w = 0.38$, $F_D = 0.64$

Required: SSD

Solution: Wet condition - $SSD = 0.279(2.5)(37) + \frac{(37)^2}{255(0.38)} = 39.94$ m

$$\text{Dry condition - SSD} = 0.279(2.5)(40) + \frac{(40)^2}{255(0.64)} = 37.70 \text{ m}$$

TABLE IX - A

MINIMUM STOPPING SIGHT DISTANCE (S.S.D)

DESIGN RUNNING SPEED	PERCEPTION AND REACTION TIME	COEFFICIENT OF FRICTION	BRAKING DISTANCE	STOPPING DISTANCE	SIGHT DISTANCE
KPH	SECOND	F	METERS	COMPUTED	ROUNDED

DESIGN CRITERIA-WET PAVEMENTS

40	37	2.5	25.81	0.38	14.13	39.94	40
50	47	2.5	32.78	0.36	24.06	56.85	57
60	54	2.5	37.66	0.34	33.63	71.30	71
70	63	2.5	43.94	0.32	48.64	92.58	93
80	70	2.5	48.83	0.31	61.99	110.81	111
90	78	2.5	54.40	0.30	79.53	133.93	134
100	87	2.5	60.68	0.30	98.94	159.62	160
110	91	2.5	63.47	0.29	111.98	175.45	175
120	97	2.5	67.66	0.28	131.78	199.44	199
130	104	2.5	72.54	0.27	157.10	229.64	230
140	111	2.5	77.42	0.27	178.95	256.38	256

COMPARATIVE VALUES-DRY PAVEMENTS

40	40	2.5	27.90	0.64	9.80	37.70	38
50	50	2.5	34.88	0.62	15.81	50.69	51
60	60	2.5	41.85	0.60	23.53	65.38	65
70	70	2.5	48.83	0.58	33.13	81.96	82
80	80	2.5	55.80	0.57	44.03	99.83	100
90	90	2.5	62.78	0.56	56.72	119.50	119
100	100	2.5	69.75	0.56	70.03	139.78	140
110	110	2.5	76.72	0.55	86.27	163.00	163
120	120	2.5	83.70	0.54	104.58	188.28	188
130	130	2.5	90.68	0.53	125.05	215.72	216
140	140	2.5	97.65	0.53	145.02	242.67	243

TABLE IX-B
EFFECT OF GRADE ON (SSD)

Purpose

To compute very important elements in highway geometric design which are safe stopping sight distance, safe passing sight distance and effect of grade on the (SSD). For consideration of safety and continuity of traffic these criteria should carefully be designed. In this table the wet and dry conditions are introduced for proper design procedure to fit the prevailing conditions.

Notations

Self explanatory.

- Notes: 1) Assumed speed are used to calculate corrections for stopping sight distance for "wet" and "dry" conditions with change of friction factor only.
- 2) These corrections in this table are to be used with Table IX-A.

Formulas

Decreasing for upgrade:
$$CSSD = \frac{V^2}{255 F} - \frac{V^2}{255 (F+G)} \quad (\text{Eq. No. 82})$$

Increasing for downgrade:
$$CSSD = \frac{V^2}{255 (F-G)} - \frac{V^2}{255 F} \quad (\text{Eq. No. 83})$$

Example How to Use

- Given: $V = 70$ Kph for wet conditions, CSSD = corrections for SSD
 $V = 80$ Kph for dry conditions
 $F_w = 0.31$ for wet conditions
 $F_D = 0.57$ for dry conditions
 $G = 10\%$ = grade percentage

Required: Corrections for stopping sight distance for both wet and dry conditions.

Solution:

Wet condition:

$$\text{Decreasing for upgrade* CSSD} = \frac{(70)^2}{255(0.31)} - \frac{(70)^2}{255(0.31+0.10)}$$

$$= 15.10 \text{ m. (Table IX-B Value} = 15.10 \text{ m)}$$

$$\text{Increasing for downgrade* CSSD} = \frac{(70)^2}{255(0.31-0.10)} - \frac{(70)^2}{255(0.31)}$$

$$= 29.52 \text{ m. (Table IX-B Value} = 29.50)$$

Dry conditions:

$$\text{Decreasing for upgrade* CSSD} = \frac{(70)^2}{255(0.57)} - \frac{(70)^2}{255(0.57+0.10)}$$

$$= 5.03 \text{ m. (Table IX-B Value} = 5.0 \text{ m)}$$

$$\text{Increasing for downgrade* CSSD} = \frac{(70)^2}{255(0.57-0.10)} - \frac{(70)^2}{255(0.57)}$$

$$= 7.2 \text{ m. (Table IX-B Value} = 7.2 \text{ m)}$$

* To compare Table IX-B output a complete calculation by formulas are presented here.

TABLE IX-B
EFFECT OF GRADE ON STOPPING SIGHT DISTANCE

WET CONDITIONS

DESIGN SPEED ASSUMED	CORRECTION IN STOPPING SIGHT DISTANCE IN METERS											CORRECTION CHANGES
	40	50	60	70	80	90	100	110	120	130	140	
SPEED	37	47	54	63	70	78	87	91	97	104	111	
K.P.M.												
FRICITION FACTOR	0.30	0.36	0.34	0.32	0.31	0.30	0.30	0.29	0.28	0.27	0.27	
GRADE %												
1	0.4	0.7	1.0	1.5	1.9	2.6	3.2	3.7	4.5	5.6	6.4	
2	0.7	1.3	1.9	2.9	3.8	5.0	6.2	7.2	8.8	10.8	12.3	DECREASING
3	1.0	1.9	2.7	4.2	5.5	7.2	9.0	10.5	12.8	15.7	17.9	FOR
4	1.3	2.4	3.5	5.4	7.1	9.4	11.6	13.6	16.5	20.3	23.1	UPGRADE
5	1.6	2.9	4.3	6.6	8.6	11.4	14.1	16.5	20.0	24.5	28.0	
6	1.9	3.4	5.0	7.7	10.1	13.3	16.5	19.2	23.3	28.6	32.5	
7	2.2	3.9	5.7	8.7	11.4	15.0	18.7	21.8	26.4	32.3	36.8	
8	2.5	4.4	6.4	9.7	12.7	16.7	20.8	24.2	29.3	35.9	40.9	
9	2.7	4.8	7.0	10.7	13.9	18.4	22.8	26.5	32.1	39.3	44.7	
10	2.9	5.2	7.6	11.6	15.1	19.9	24.7	28.7	34.7	42.5	48.4	
11	3.2	5.6	8.2	12.4	16.2	21.3	26.5	30.8	37.2	45.5	51.8	
12	3.4	6.0	8.8	13.3	17.3	22.7	28.3	32.8	39.5	48.3	55.1	
13	3.6	6.4	9.3	14.1	18.3	24.0	29.9	34.7	41.8	51.1	58.2	
14	3.8	6.7	9.8	14.8	19.3	25.3	31.5	36.5	43.9	53.6	61.1	
15	4.0	7.1	10.3	15.5	20.2	26.5	33.0	38.2	46.0	56.1	63.9	

16	4.2	7.4	10.6	16.2	21.1	27.7	34.4	39.8	47.9	58.5	66.6
17	4.4	7.7	11.2	16.9	22.0	28.8	35.8	41.4	49.8	60.7	69.1
18	4.5	8.0	11.6	17.5	22.8	29.8	37.1	42.9	51.6	62.8	71.6
19	4.7	8.3	12.1	18.1	23.6	30.6	38.4	44.3	53.3	64.9	73.9
20	4.9	8.6	12.5	18.7	24.3	31.8	39.6	45.7	54.9	66.8	76.2
21	5.0	8.9	12.8	19.3	25.0	32.7	40.7	47.0	56.5	68.7	78.3
22	5.2	9.1	13.2	19.8	25.7	33.6	41.9	48.3	58.0	70.5	80.3
23	5.3	9.4	13.6	20.3	26.4	34.5	42.9	49.5	59.4	72.3	82.3
24	5.5	9.6	13.9	20.8	27.0	35.3	44.0	50.7	60.8	73.9	84.2
25	5.6	9.9	14.3	21.3	27.7	36.1	45.0	51.8	62.2	75.5	86.0
1	0.4	0.7	1.0	1.6	2.1	2.7	3.4	4.0	4.9	6.0	6.9
2	0.6	1.4	2.1	3.2	4.3	5.7	7.1	8.3	10.1	12.6	14.3
3	1.2	2.2	3.3	5.0	6.6	8.8	11.0	12.9	15.8	19.6	22.4
4	1.7	3.0	4.5	6.9	9.2	12.2	15.2	17.9	22.0	27.3	31.1
5	2.1	3.9	5.8	9.0	11.9	15.9	19.8	23.3	28.6	35.7	40.7
6	2.6	4.8	7.2	11.2	14.9	19.9	24.7	29.2	35.9	44.9	51.1
7	3.2	5.8	8.7	13.6	18.1	24.2	30.1	35.6	43.9	55.0	62.6
8	3.8	6.9	10.3	16.2	21.6	28.9	36.0	42.7	52.7	66.1	75.3
9	4.4	8.0	12.1	19.0	25.4	34.1	42.4	50.4	62.4	78.5	89.5
10	5.0	9.3	14.0	22.1	29.5	39.8	49.5	58.9	73.2	92.4	105.3
11	5.8	10.6	16.1	25.5	34.1	46.0	57.3	68.4	85.3	108.0	123.0
12	6.5	12.0	18.3	29.2	39.1	53.0	66.0	79.0	98.8	125.7	143.2
13	7.3	13.6	20.8	33.3	44.8	60.8	75.7	91.0	114.2	145.9	166.2
14	8.2	15.3	23.5	37.8	51.0	69.6	86.6	104.5	131.8	169.2	192.7
15	9.2	17.2	26.6	42.9	58.1	79.5	98.9	120.0	152.1	196.4	223.7
16	10.3	19.3	29.9	48.6	66.1	90.9	113.1	137.8	175.7	228.5	260.3
17	11.4	21.5	33.6	55.1	75.3	104.0	129.4	158.6	203.7	267.1	304.2

INCREASING

FOR

DOWNGRADE

18	12.7	24.1	37.8	62.5	85.8	119.3	148.4	183.2	237.2	314.2	357.9
19	14.1	26.9	42.6	71.1	98.1	137.4	170.9	212.8	278.2	373.1	425.0
20	15.7	30.1	48.0	81.1	112.7	159.1	197.9	248.8	329.4	448.8	511.3
21	17.5	33.7	54.3	92.9	130.2	185.6	230.9	294.0	395.3	549.8	626.3
22	19.4	37.8	61.7	107.0	151.5	218.7	272.1	351.9	483.2	691.2	787.4
23	21.7	42.6	70.3	124.3	178.2	261.3	325.1	429.3	606.2	903.3	1029.0
24	24.2	48.1	80.7	145.9	212.5	318.1	395.8	537.5	790.7	1256.8	1431.6
25	27.2	54.7	93.4	173.7	258.3	397.6	494.7	699.9	1098.2	1963.7	2236.9

DRY CONDITIONS

GRADE %	0.64	0.62	0.60	0.58	0.57	0.56	0.56	0.56	0.55	0.54	0.53	0.53
1	0.1	0.2	0.3	0.5	0.6	0.7	0.9	1.1	1.2	1.5	1.7	
2	0.3	0.4	0.6	0.9	1.1	1.5	1.8	2.1	2.4	2.9	3.3	DECREASING
3	0.4	0.6	0.9	1.3	1.7	2.2	2.7	3.1	3.6	4.3	4.9	FOR
4	0.5	0.8	1.2	1.7	2.2	2.8	3.5	4.0	4.7	5.6	6.4	UPGRADE
5	0.6	1.0	1.5	2.1	2.7	3.5	4.3	4.9	5.8	6.9	7.9	
6	0.7	1.2	1.7	2.5	3.2	4.1	5.1	5.8	6.8	8.1	9.3	
7	0.8	1.4	2.0	2.9	3.7	4.7	5.9	6.7	7.8	9.3	10.6	
8	0.9	1.6	2.2	3.3	4.1	5.3	6.6	7.5	8.8	10.5	12.0	
9	1.0	1.8	2.5	3.6	4.6	5.9	7.3	8.3	9.8	11.6	13.2	
10	1.1	1.9	2.7	3.9	5.0	6.5	8.0	9.1	10.7	12.7	14.5	
11	1.2	2.1	3.0	4.3	5.5	7.0	8.7	9.8	11.6	13.8	15.7	
12	1.3	2.3	3.2	4.6	5.9	7.5	9.4	10.6	12.4	14.8	16.8	
13	1.4	2.4	3.4	4.9	6.3	8.0	10.0	11.3	13.3	15.8	18.0	

14	1.5	2.6	3.6	5.2	6.6	8.5	10.6	12.0	14.1	16.7	19.0
15	1.6	2.7	3.8	5.5	7.0	9.0	11.2	12.7	14.9	17.7	20.1
16	1.7	2.9	4.0	5.8	7.4	9.5	11.8	13.3	15.6	18.6	21.1
17	1.8	3.0	4.2	6.1	7.7	9.9	12.3	13.9	16.4	19.4	22.1
18	1.8	3.1	4.4	6.4	8.1	10.4	12.9	14.6	17.1	20.3	23.1
19	1.9	3.3	4.6	6.6	8.4	10.8	13.4	15.2	17.8	21.1	24.1
20	2.0	3.4	4.8	6.9	8.8	11.2	13.9	15.7	18.5	21.9	25.0
21	2.1	3.5	4.9	7.1	9.1	11.6	14.5	16.3	19.1	22.7	25.9
22	2.1	3.7	5.1	7.4	9.4	12.0	14.9	16.9	19.8	23.5	26.7
23	2.2	3.8	5.3	7.6	9.7	12.4	15.4	17.4	20.4	24.2	27.6
24	2.3	3.9	5.4	7.9	10.0	12.8	15.9	17.9	21.0	24.9	28.4
25	2.4	4.0	5.6	8.1	10.3	13.1	16.4	18.5	21.6	25.7	29.2
1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.5	1.8
2	0.3	0.5	0.7	1.0	1.2	1.6	2.0	2.2	2.6	3.1	3.6
3	0.4	0.7	1.0	1.5	1.9	2.4	3.0	3.4	4.0	4.8	5.5
4	0.6	1.0	1.4	2.0	2.5	3.3	4.1	4.6	5.5	6.5	7.4
5	0.7	1.2	1.7	2.5	3.2	4.2	5.2	5.9	7.0	8.3	9.5
6	0.9	1.5	2.1	3.1	4.0	5.1	6.4	7.2	8.5	10.2	11.6
7	1.0	1.8	2.5	3.7	4.7	6.1	7.6	8.6	10.2	12.2	13.9
8	1.2	2.1	2.9	4.3	5.5	7.1	8.8	10.1	11.9	14.2	16.2
9	1.4	2.4	3.4	4.9	6.3	8.2	10.1	11.6	13.7	16.4	18.6
10	1.6	2.7	3.8	5.6	7.2	9.3	11.5	13.1	15.5	18.6	21.2
11	1.7	3.0	4.3	6.3	8.1	10.4	13.0	14.8	17.5	21.0	23.9
12	1.9	3.4	4.8	7.0	9.0	11.6	14.5	16.5	19.5	23.4	26.7
13	2.1	3.7	5.3	7.8	10.0	12.9	16.0	18.3	21.7	26.0	29.6
14	2.3	4.1	5.8	8.5	11.0	14.2	17.7	20.2	23.9	28.7	32.7
15	2.6	4.5	6.4	9.4	12.0	15.6	19.4	22.1	26.3	31.6	36.0

INCREASING

FOR

DOWNGRADE

16	2.8	4.9	6.9	10.2	13.2	17.0	21.2	24.2	28.8	34.6	39.4
17	3.0	5.3	7.5	11.1	14.3	18.6	23.1	26.4	31.4	37.8	43.1
18	3.3	5.7	8.2	12.1	15.6	20.2	25.1	28.7	34.2	41.2	46.9
19	3.5	6.2	8.8	13.1	16.9	21.9	27.2	31.2	37.1	44.7	50.9
20	3.8	6.7	9.5	14.1	18.2	23.7	29.4	33.7	40.2	48.5	55.3
21	4.1	7.2	10.3	15.2	19.7	25.6	31.8	36.5	43.5	52.5	59.8
22	4.4	7.7	11.0	16.4	21.2	27.6	34.3	39.4	47.0	56.8	64.7
23	4.7	8.2	11.8	17.6	22.8	29.7	36.9	42.4	50.7	61.4	69.9
24	5.0	8.8	12.7	18.9	24.5	32.0	39.8	45.7	54.7	66.2	75.4
25	5.4	9.4	13.6	20.3	26.3	34.4	42.7	49.2	58.9	71.5	81.4

TABLE IX-C
MINIMUM PASSING SIGHT DISTANCE (PSD)

Purpose

To compute very important elements in highway geometric design which are safe stopping sight distance, safe passing sight distance and effect of grade on the (SSD). For consideration of safety and continuity of traffic these criteria should carefully be designed.

Notation

Self explanatory.

Note: This table values to be used for correction purposes, with SSD in Table IX-A.

Formulas

$$\text{PSD} = d_1 + d_2 + d_3 + d_4 \quad (\text{Eq. No. 84})$$

$$d_1 = 0.279t_1V - 0.279t_1m + 0.47 at_1^2 \quad (\text{Eq. No. 85})$$

$$d_2 = 0.279t_2V \quad (\text{Eq. No. 86})$$

$$d_3 = 40 \text{ to } 90 \text{ metres (emperical)} \quad (\text{Eq. No. 87})$$

$$d_4 = 2/3d_2 = 0.186t_2V \quad (\text{Eq. No. 88})$$

where:

d_1 = initial distance for maneuvering, metre

t_1 = initial time for maneuvering, second

V = average speed of passing vehicle, kilometre per hour (kph)

m = difference in speed of passed vehicle and passing vehicle, kph

d_2 = distance travelled while passing vehicle occupies the left lane in metres.

t_2 = time passing vehicle in left lane in second

d_3 = distance between the passing vehicle at end of its maneuver and opposite vehicle in metres.

d_4 = distance travelled by an opposite vehicle for 2/3 of the time.

Example How to Use

Given: $V = 80$ Kph, $a = 1.47/1.609$, $T = 4.3$ sec.

Required: d

Solution: $d_1 = (0.279)(4.3)(80) - 0.279 \times 4 \times 1.609 + 0.457 \times 1.47 \times 1.609(4)^2$
 $= 85$ m

$d_2 = (0.279)(10.7)(80) = 239$ m

$d_3 = 76$ m (for 80-100 kph)

$d_4 = 2/3d_2 = 159$ m

∴ PSD = 559 metres, (Table IX-C Value = 560 metre)

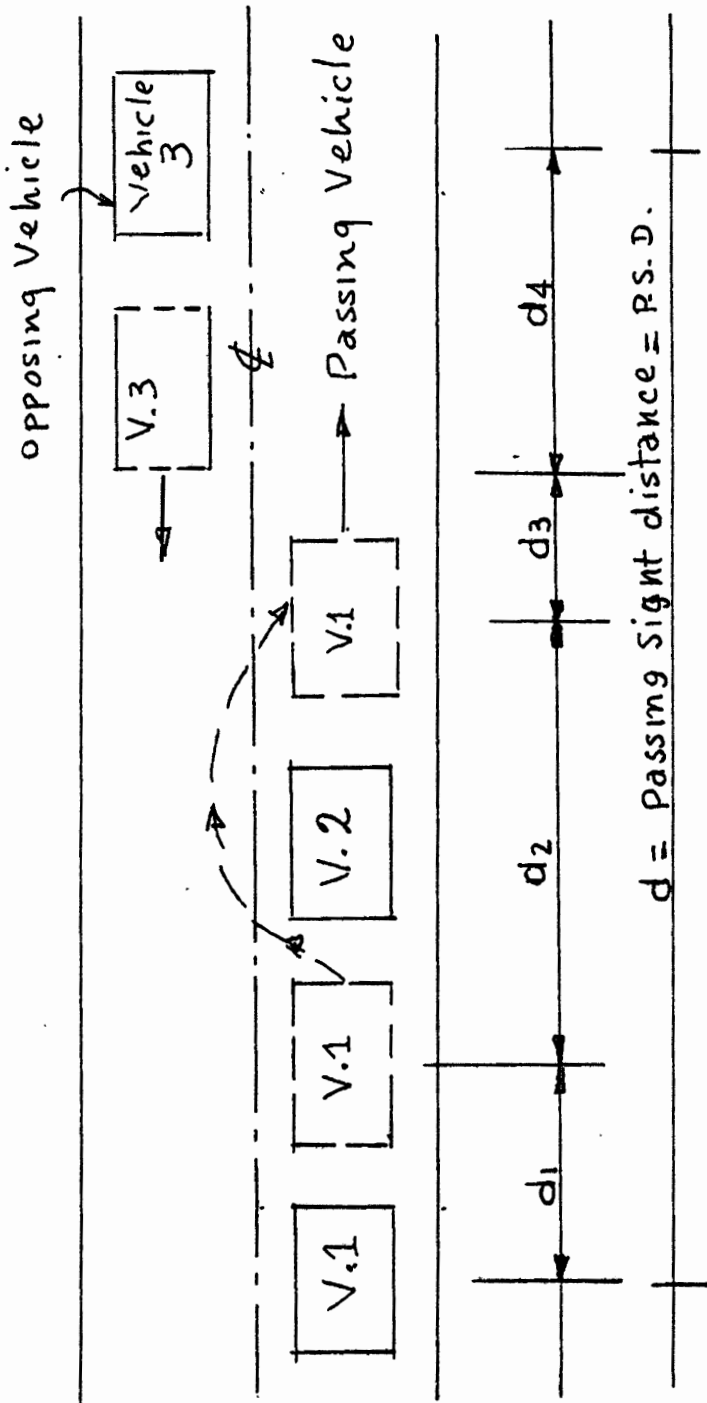


Figure 8.

Minimum Passing Sight Distance

TABLE-IX-C
 MINIMUM PASSING SIGHT DISTANCE FOR
 DESIGN OF 2-LANE HIGHWAY

DESIGN SPEED K.P.H.	ASSUMED SPEED IN K.P.H.		MINIMUM PASSING SIGHT DISTANCE IN METERS	
	PASSED VEHICLE	PASSING VEHICLE	COMPUTED	ROUNDED
40	37	47	170.50	170
50	47	57	345.38	350
60	54	64	419.10	420
70	63	73	489.60	490
80	70	80	557.70	560
90	78	88	626.70	630
100	87	97	675.20	680
110	91	101	741.60	740
120	97	107	790.00	790
130	104	114	842.20	850
140	111	121	890.90	900

TABLE X-A, B, C, D

SIGHT DISTANCE ALONG HORIZONTAL CURVES
FOR 10, 20, 40 AND 100 METRE OF ARCPurpose

To avoid obstruction and to maintain clear visibility around a curve the purpose of this table is to compute safe clearance sight distance along horizontal curves.

Notations

M = Center line inside lane to sight obstruction in metres

S = Sight distance in metres

L = Length of curve in metres, $D = D_m$ = degree of curve, degrees

V = Design speed in Kph, R = Radius of curve in metres = R_m

Formulas

Case 1: $S \leq L$, station = 10 m of arc. Case 2: $S > L$

$$M = R \left(1 - \cos \frac{SD}{20} \right) \quad (\text{Eq. No. 90})$$

$$M = \frac{L(2S-L)}{8R} \quad \text{Eq. No. 91}$$

$$S = \frac{R}{28.65} \cos^{-1} \frac{R-M}{R} \quad (\text{Eq. No. 92})$$

Example How to Use

Case 1: Given: $D = 4^\circ$, $V = 80$ kph, $S = 111$ m

Required: M

$$\text{Solution: } R = \frac{572.958}{4} = 143.24$$

$$M = 143.24 \left(1 - \cos \frac{111 \times 4}{20} \right) = \frac{10.62}{n}$$

$$S = \frac{143.24}{28.65} \cos^{-1} \frac{143.24 - 10.62}{143.42} = 111 \text{ m,}$$

(Table X-A Value = 111 m)

Case 2: Given: $D = 4^\circ$, $S = 111$ m, $L = 40$

Required: M and S

Solution: $R = 143.24$ m

$$M = \frac{40(2 \times 111 - 40)}{8 \times 143.24} = 6.35 \text{ m}$$

$$S = \frac{4 \times 143.24 \times 6.35}{40} + \frac{40}{2} = 111 \text{ metre, (Table X-A)}$$

Value = 111 m)

Note

Same procedure used above, can be applied to 20, 40 and 100 metre arc calculations.

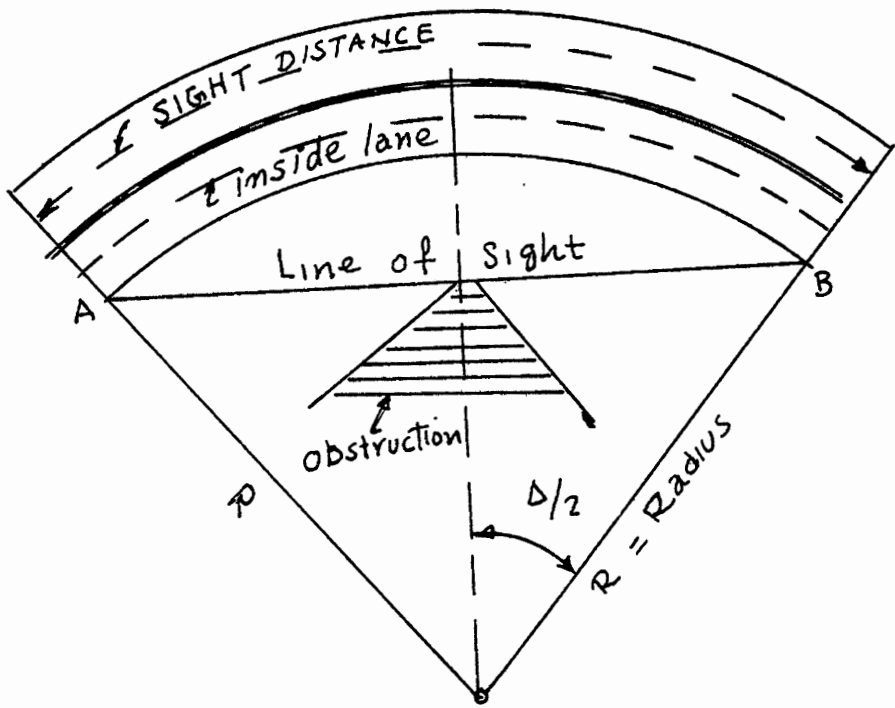


Figure 9.

Sight Distance Along Horizontal Curves

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V 40	S 40	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L													
				50	60	70	80	90	100	110	120	130	140	156	256		
0	100	572.96	0.3	0.7	1.1	1.9	2.7	3.9	5.6	6.7	8.6	11.5	14.2				
10	491.11	0.4	0.8	1.3	2.2	3.1	4.6	6.5	7.8	10.0	13.4	16.6					
20	429.72	0.5	0.9	1.5	2.5	3.6	5.2	7.4	8.9	11.5	15.3	18.9					
30	381.97	0.5	1.1	1.6	2.8	4.0	5.9	8.3	10.0	12.9	17.2	21.2					
40	343.77	0.6	1.2	1.8	3.1	4.5	6.5	9.3	11.1	14.3	19.1	23.6					
50	312.52	0.6	1.3	2.0	3.5	4.9	7.2	10.2	12.2	15.7	20.9	25.8					

TABLE-X-A

10-METER OF ARC
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V 40	S 40	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L												
					50	60	70	80	90	100	110	120	130	140	156	256	
0	100	572.96	10.00	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	1.0	1.1			
10	491.11	11.67	0.2	0.3	0.4	0.5	0.6	0.6	0.9	1.0	1.1	1.3	1.5				
20	429.72	13.33	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.3	1.5	1.7	1.9				
30	381.97	15.00	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.6	1.9	2.2	2.4				
40	343.77	16.67	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.0	2.3	2.7	3.0				
50	312.52	18.33	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.4	2.8	3.2	3.6				

TABLE-X-A

10-METER OF ARC
 SIGHT DISTANCE ALONG HORIZONTAL CURVE
 CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE	RADIUS	OF	V	40	50	60	70	80	90	100	110	120	130	140
0	200	286.48	0.7	1.4	2.2	3.8	5.4	7.8	11.1	13.3	17.1	22.8	28.1	
10	264.44	0.8	1.5	2.4	4.1	5.8	8.4	12.0	14.3	18.5	24.6	30.4		
20	245.55	0.8	1.7	2.6	4.4	6.2	9.1	12.9	15.4	19.9	26.4	32.6		
30	229.18	0.9	1.8	2.7	4.7	6.7	9.7	13.8	16.5	21.3	28.3	34.8		
40	214.86	0.9	1.9	2.9	5.0	7.1	10.4	14.7	17.6	22.6	30.0	37.0		
50	202.22	1.0	2.0	3.1	5.3	7.6	11.0	15.6	18.6	24.0	31.8	39.2		

TABLE-X-A

10-METER OF ARC
 CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE	RADIUS	LENGTH	OF	V	40	50	60	70	80	90	100	110	120	130	140
0	200	286.48	20.00	0.5	0.8	1.1	1.4	1.8	2.2	2.6	2.9	3.3	3.8	4.3	
10	264.44	21.67	0.6	0.9	1.2	1.7	2.1	2.5	3.1	3.4	3.9	4.5	5.0		
20	245.55	23.33	0.7	1.1	1.4	1.9	2.4	2.9	3.5	3.9	4.5	5.2	5.8		
30	229.18	25.00	0.7	1.2	1.6	2.2	2.7	3.3	4.0	4.4	5.1	5.9	6.6		
40	214.86	26.67	0.8	1.4	1.8	2.5	3.0	3.7	4.6	5.0	5.8	6.7	7.5		
50	202.22	28.33	0.9	1.5	2.0	2.8	3.4	4.2	5.1	5.6	6.5	7.6	8.5		

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V 40	S 40	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L														
				50	60	70	80	90	100	110	120	130	140	156				
0	190.99	1.0	2.1	3.3	5.6	8.0	11.6	16.5	19.7	25.3	33.6	41.3						
10	180.93	1.1	2.2	3.5	5.9	8.4	12.3	17.4	20.7	26.7	35.3	43.4						
20	171.89	1.2	2.4	3.7	6.3	8.9	12.9	18.3	21.6	28.0	37.1	45.5						
30	163.70	1.2	2.5	3.8	6.6	9.3	13.5	19.2	22.8	29.3	38.8	47.5						
40	156.26	1.3	2.6	4.0	6.9	9.8	14.1	20.0	23.9	30.6	40.4	49.6						
50	149.47	1.3	2.7	4.2	7.2	10.2	14.8	20.9	24.9	31.9	42.1	51.5						

TABLE-X-A

10-METER OF ARC
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V 40	S 40	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L													
					50	60	70	80	90	100	110	120	130	140	156			
0	190.99	30.00	1.0	1.6	2.2	3.1	3.8	4.7	5.7	6.3	7.2	8.4	9.5					
10	180.93	31.67	1.1	1.8	2.4	3.4	4.2	5.2	6.3	7.0	8.0	9.4	10.5					
20	171.89	33.33	1.1	2.0	2.6	3.7	4.6	5.7	6.9	7.7	8.8	10.3	11.6					
30	163.70	35.00	1.2	2.1	2.9	4.0	5.0	6.2	7.6	8.4	9.7	11.4	12.7					
40	156.26	36.67	1.3	2.3	3.1	4.4	5.4	6.8	8.3	9.2	10.6	12.4	13.9					
50	149.47	38.33	1.3	2.4	3.3	4.7	5.9	7.4	9.0	10.0	11.5	13.5	15.2					

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE	RADIUS	OF	V	40	50	60	70	80	90	100	110	120	130	140	M	
															CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L	←
0																
4 00	143.24		1.4	2.8	4.4	7.5	10.6	15.4	21.8	25.9	33.2	43.7	53.5			
10	137.51		1.5	2.9	4.6	7.8	11.0	16.0	22.6	26.9	34.5	45.3	55.4			
20	132.22		1.5	3.1	4.7	8.1	11.5	16.6	23.5	27.9	35.7	46.9	57.3			
30	127.32		1.6	3.2	4.9	8.4	11.9	17.2	24.3	28.9	36.9	48.5	59.1			
40	122.78		1.6	3.3	5.1	8.7	12.3	17.8	25.2	29.9	38.2	50.0	60.9			
50	118.54		1.7	3.4	5.3	9.0	12.8	18.4	26.0	30.9	39.4	51.5	62.6			

TABLE-X-A

10-METER OF ARC

DEGREE	RADIUS	LENGTH	OF	V	40	50	60	70	80	90	100	110	120	130	140	M	
																CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L	→
0																	
4 00	143.24	40.00		1.4	2.6	3.6	5.1	6.4	8.0	9.8	10.8	12.5	14.7	16.5			
10	137.51	41.67		1.5	2.7	3.8	5.5	6.8	8.6	10.5	11.7	13.5	15.8	17.8			
20	132.22	43.33		1.5	2.9	4.0	5.8	7.3	9.2	11.3	12.6	14.5	17.1	19.2			
30	127.32	45.00		1.5	3.0	4.3	6.2	7.8	9.9	12.1	13.5	15.6	18.3	20.6			
40	122.78	46.67		1.6	3.2	4.5	6.6	8.3	10.5	13.0	14.4	16.7	19.6	22.1			
50	118.54	48.33		1.6	3.3	4.8	7.0	8.9	11.2	13.8	15.4	17.8	21.0	23.6			

TABLE-X-A

10-METER OF ARC		SIGHT DISTANCE ALONG HORIZONTAL CURVE												
DEGREE	RADIUS	OF	V	40	50	60	70	80	90	100	110	120	130	140
CURVE	CURVE	S	40	57	71	93	111	134	160	175	199	230	256	
0	1													
6	00	95.49	2.1	4.2	6.5	11.1	15.7	22.6	31.6	37.4	47.3	61.3	73.7	
10		92.91	2.1	4.3	6.7	11.4	16.1	23.1	32.4	38.2	48.4	62.5	75.1	
20		90.47	2.2	4.5	6.9	11.7	16.5	23.7	33.1	39.1	49.4	63.8	76.4	
30		88.15	2.3	4.6	7.1	12.0	16.9	24.3	33.9	40.0	50.4	65.0	77.7	
40		85.94	2.3	4.7	7.2	12.3	17.3	24.8	34.6	40.8	51.4	66.1	79.0	
50		83.85	2.4	4.8	7.4	12.6	17.7	25.4	35.4	41.7	52.4	67.3	80.1	

TABLE-X-A

10-METER OF ARC		CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L													
DEGREE	RADIUS	LENGTH	OF	V	40	50	60	70	80	90	100	110	120	130	140
CURVE	CURVE	CURVE	S	40	57	71	93	111	134	160	175	199	230	256	
0	1														
6	00	95.49	60.00	1.6	4.2	6.4	9.9	12.7	16.3	20.4	22.8	26.5	31.4	35.5	
10		92.91	61.67	1.5	4.3	6.7	10.3	13.3	17.1	21.4	23.9	27.9	33.0	37.4	
20		90.47	63.33	1.5	4.4	6.9	10.7	13.9	17.9	22.5	25.1	29.3	34.7	39.3	
30		88.15	65.00	1.4	4.5	7.1	11.2	14.5	18.7	23.5	26.3	30.7	36.4	41.2	
40		85.94	66.67	1.3	4.6	7.3	11.6	15.1	19.5	24.6	27.5	32.1	38.1	43.2	
50		83.85	68.33	1.2	4.7	7.5	12.0	15.7	20.3	25.6	28.7	33.6	39.9	45.2	

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V	S	M										
				50	60	70	80	90	100	110	120	130	140	
0	7 00	2.4	4.9	7.6	12.9	18.1	25.9	36.1	42.5	53.4	68.3	81.3		
10	79.95	2.5	5.0	7.6	13.1	18.5	26.5	36.6	43.3	54.3	69.4	82.4		
20	78.13	2.5	5.1	7.9	13.4	18.9	27.0	37.5	44.1	55.2	70.4	83.4		
30	76.39	2.6	5.3	8.1	13.7	19.3	27.5	38.2	44.9	56.1	71.4	84.4		
40	74.73	2.7	5.4	8.3	14.0	19.7	28.1	38.9	45.6	57.0	72.3	85.3		
50	73.14	2.7	5.5	8.4	14.3	20.1	28.6	39.6	46.4	57.9	73.2	86.2		

TABLE-X-A

10-METER OF ARC

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V	S	M									
					50	60	70	80	90	100	110	120	130	140
0	7 00	70.00	1.1	4.7	7.7	12.4	16.2	21.2	26.7	29.9	35.1	41.7	47.3	
10	79.95	71.67	0.9	4.7	7.9	12.6	16.8	22.0	27.8	31.2	36.6	43.5	47.3	
20	78.13	73.33	0.8	4.8	8.1	13.2	17.4	22.8	28.9	32.5	38.1	45.4	51.5	
30	76.39	75.00	0.6	4.8	8.2	13.6	18.0	23.7	30.1	33.7	39.6	47.2	53.6	
40	74.73	76.67	0.4	4.8	8.4	14.0	18.6	24.5	31.2	35.1	41.2	49.2	55.8	
50	73.14	78.33	0.2	4.8	8.5	14.4	19.2	25.4	32.4	36.4	42.8	51.1	58.1	

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	M											
		V	40	50	60	70	80	90	100	110	120	130	140
0	9 00	63.66	3.1	6.3	9.6	16.2	22.7	32.1	44.0	51.2	63.2	78.5	90.8
10	62.50	3.2	6.4	9.8	16.5	23.1	32.6	44.6	51.9	63.8	79.1	91.2	
20	61.39	3.2	6.5	10.0	16.8	23.4	33.1	45.2	52.5	64.5	79.7	91.6	
30	60.31	3.3	6.6	10.1	17.1	23.8	33.5	45.7	53.1	65.1	80.2	91.9	
40	59.27	3.3	6.7	10.3	17.3	24.1	34.0	46.3	53.7	65.7	80.7	92.2	
50	58.27	3.4	6.8	10.5	17.6	24.5	34.5	46.8	54.2	66.2	81.1	92.4	

TABLE-X-A

10-METER OF ARC

M

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V	CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L									
				40	50	60	70	80	90	100	110	120	130
0	9 00	90.00	-1.8	4.2	9.2	17.0	23.3	31.5	40.6	45.9	54.4	65.4	74.6
10	62.50	91.67	-2.1	4.1	9.2	17.3	23.9	32.3	41.9	47.4	56.2	67.5	77.1
20	61.39	93.33	-2.5	3.9	9.2	17.6	24.5	33.2	43.1	48.8	57.9	69.7	79.6
30	60.31	95.00	-3.0	3.7	9.3	17.9	25.0	34.1	44.3	50.2	59.7	71.9	82.1
40	59.27	96.67	-3.4	3.5	9.2	18.2	25.6	34.9	45.5	51.6	61.4	74.1	84.7
50	58.27	98.33	-3.9	3.3	9.2	18.5	26.1	35.8	46.8	53.1	63.2	76.3	87.3

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE
M
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DGREE OF CURVE	RADIUS OF CURVE	V S	M																	
			40	50	60	70	80	90	100	110	120	130	140	150	160	175	199	230	256	
0																				
10	57.30	3.5	6.9	10.7	17.9	24.8	34.9	47.3	54.8	66.8	81.5	92.6								
20	56.36	3.5	7.1	10.8	18.1	25.2	35.4	47.9	55.3	67.3	81.9	92.7								
30	55.45	3.6	7.2	11.0	18.4	25.5	35.8	48.4	55.9	67.7	82.2	92.7								
40	54.57	3.6	7.3	11.1	18.6	25.9	36.2	48.9	56.4	68.2	82.5	92.7								
50	53.71	3.7	7.4	11.3	18.9	26.2	36.6	49.3	56.8	68.6	82.7	92.7								
	52.89	3.7	7.5	11.5	19.2	26.5	37.1	49.8	57.3	69.0	82.9	92.6								

TABLE-X-A

10-METER OF ARC
M
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V S	M																
				40	50	60	70	80	90	100	110	120	130	140	150	160	175	199	230	256
0																				
10	57.30	100.00	-4.4	3.1	9.2	18.8	26.6	36.7	48.0	54.5	65.0	78.5	89.9							
20	56.36	101.67	-4.9	2.8	9.1	19.0	27.1	37.5	49.7	56.0	66.8	80.8	92.5							
30	55.45	103.33	-5.4	2.5	9.0	19.3	27.6	38.4	50.5	57.5	68.6	83.1	95.2							
40	54.57	105.00	-6.0	2.2	8.9	19.5	28.1	39.2	51.7	58.9	70.5	85.4	97.9							
50	53.71	106.67	-6.6	1.8	8.8	19.7	28.6	40.0	53.0	60.4	72.3	87.7	100.6							
	52.89	108.33	-7.3	1.5	8.6	19.9	29.1	40.9	54.2	61.9	74.2	90.0	103.4							

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V S	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L																	
			40	50	60	70	80	90	100	110	120	130	140	150	160	175	199	230	256	
0																				
11.00	52.09	3.6	7.6	11.6	19.4	26.9	37.5	50.3	57.6	69.4	83.1	92.5								
10	51.31	3.6	7.7	11.8	19.7	27.2	37.9	50.7	58.2	69.8	83.2	92.3								
20	50.56	3.9	7.8	12.0	19.9	27.5	38.3	51.1	58.6	70.1	83.3	92.0								
30	49.82	4.0	7.9	12.1	20.2	27.8	38.7	51.6	59.0	70.4	83.3	91.7								
40	49.11	4.0	8.0	12.3	20.4	28.2	39.0	52.0	59.4	70.7	83.3	91.4								
50	48.42	4.1	8.1	12.4	20.7	28.5	39.4	52.4	59.8	71.0	83.3	91.0								

TABLE-X-A

10-METER OF ARC
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V S	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L																
				40	50	60	70	80	90	100	110	120	130	140	150	160	175	199	230	256
0																				
11.00	52.09	110.00	-7.9	1.1	8.4	20.1	29.6	41.7	55.4	63.4	76.0	92.4	106.1							
10	51.31	111.67	-8.6	0.6	8.3	20.2	30.0	42.5	56.7	64.8	77.9	94.8	108.9							
20	50.56	113.33	-9.3	0.2	8.0	20.4	30.5	43.3	57.9	66.3	79.8	97.1	111.7							
30	49.82	115.00	-10.1	-0.3	7.8	20.5	30.9	44.1	59.1	67.8	81.7	99.5	114.5							
40	49.11	116.67	-10.9	-0.8	7.5	20.6	31.3	44.9	60.4	69.3	83.5	102.0	117.4							
50	48.42	118.33	-11.7	-1.3	7.2	20.7	31.7	45.7	61.6	70.8	85.4	104.4	120.3							

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V	CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L															
			0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
0	12.00	47.75	4.1	8.3	12.6	20.9	28.8	39.8	52.7	60.1	71.2	83.2	90.5					
10	47.09	4.2	8.4	12.8	21.2	29.1	40.1	53.1	60.4	71.4	83.1	90.0						
20	46.46	4.2	8.5	12.9	21.4	29.4	40.5	53.5	60.7	71.6	83.0	89.5						
30	45.84	4.3	8.6	13.1	21.6	29.7	40.8	53.8	61.0	71.7	82.8	88.9						
40	45.23	4.3	8.7	13.2	21.9	30.0	41.2	54.1	61.3	71.8	82.6	88.3						
50	44.65	4.4	8.8	13.4	22.1	30.3	41.5	54.4	61.6	71.9	82.3	87.6						

TABLE-X-A

10-METER OF ARC

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V	CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L														
				0	10	20	30	40	50	60	70	80	90	100	110	120	130	140
0	12.00	47.75	120.00	-12.6	-1.9	6.9	20.7	32.0	46.5	62.8	72.3	87.3	106.8	123.2				
10	47.09	121.67	-13.5	-2.5	6.6	20.8	32.4	47.3	64.1	73.7	89.2	109.3	126.1					
20	46.46	123.33	-14.4	-3.1	6.2	20.8	32.7	48.0	65.3	75.2	91.1	111.7	129.0					
30	45.84	125.00	-15.3	-3.7	5.8	20.8	33.1	48.7	66.5	76.7	93.1	114.2	131.9					
40	45.23	126.67	-16.3	-4.4	5.4	20.8	33.4	49.5	67.7	78.2	95.0	116.7	134.9					
50	44.65	128.33	-17.4	-5.2	4.9	20.7	33.7	50.2	68.9	79.6	96.9	119.2	137.9					

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE
M
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS OF CURVE	V 40	S 40	50	60	70	80	90	100	110	120	130	140	150
13.00	44.07	4.5	8.9	13.5	22.3	30.6	41.8	54.7	61.8	72.0	82.0	86.9		
10	43.52	4.5	9.0	13.7	22.6	30.8	42.2	55.0	62.0	72.1	81.7	86.2		
20	42.97	4.6	9.1	13.8	22.8	31.1	42.5	55.3	62.3	72.1	81.4	85.4		
30	42.44	4.6	9.2	14.0	23.0	31.4	42.8	55.6	62.4	72.1	81.0	84.5		
40	41.92	4.7	9.3	14.2	23.3	31.7	43.1	55.8	62.6	72.1	80.6	83.7		
50	41.42	4.7	9.4	14.3	23.5	31.9	43.4	56.0	62.8	72.0	80.1	82.8		

TABLE-X-A

10-METER OF ARC
M
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V 40	S 40	50	60	70	80	90	100	110	120	130	140	150
13.00	44.07	130.00	-18.4	-5.9	4.4	20.6	33.9	50.9	70.1	81.1	98.8	121.7	140.8		
10	43.52	131.67	-19.5	-6.7	3.9	20.5	34.2	51.6	71.2	82.6	100.7	124.2	143.8		
20	42.97	133.33	-20.7	-7.5	3.4	20.4	34.4	52.2	72.4	84.0	102.7	126.7	146.9		
30	42.44	135.00	-21.9	-8.3	2.8	20.3	34.6	52.9	73.6	85.5	104.6	129.2	149.9		
40	41.92	136.67	-23.1	-9.2	2.2	20.1	34.8	53.5	74.7	86.9	106.5	131.8	152.9		
50	41.42	138.33	-24.4	-10.2	1.5	19.9	34.9	54.1	75.8	88.4	108.4	134.3	156.0		

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS	V	40	50	60	70	80	90	100	110	120	130	140	M		
														CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S	L	
0																
14 00	40.93	4.8	9.5	14.5	23.7	32.2	43.6	56.3	62.9	72.0	79.6	81.8				
10	40.44	4.8	9.6	14.6	23.9	32.5	43.9	56.5	63.0	71.9	79.1	80.9				
20	39.97	4.9	9.7	14.8	24.1	32.7	44.2	56.7	63.1	71.7	78.6	79.9				
30	39.51	5.0	9.8	14.9	24.3	33.0	44.4	56.8	63.2	71.6	78.0	78.8				
40	39.07	5.0	9.9	15.1	24.6	33.2	44.7	57.0	63.3	71.4	77.4	77.8				
50	38.63	5.1	10.0	15.2	24.8	33.5	44.9	57.2	63.3	71.2	76.7	76.7				

TABLE-X-A

10-METER OF ARC

CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE OF CURVE	RADIUS	LENGTH OF CURVE	V	40	50	60	70	80	90	100	110	120	130	140	M	
															CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S	L
0																
14 00	40.93	140.00	-25.7	-11.1	0.9	19.7	35.1	54.7	77.0	89.8	110.3	136.8	159.1			
10	40.44	141.67	-27.0	-12.1	0.1	19.4	35.2	55.3	78.1	91.2	112.2	139.4	162.1			
20	39.97	143.33	-28.4	-13.1	-0.6	19.1	35.3	55.9	79.2	92.6	114.1	141.9	165.2			
30	39.51	145.00	-29.8	-14.2	-1.4	18.8	35.3	56.4	80.3	94.0	116.0	144.5	168.3			
40	39.07	146.67	-31.3	-15.3	-2.2	18.5	35.4	56.9	81.3	95.4	118.0	147.0	171.5			
50	38.63	148.33	-32.8	-16.5	-3.0	18.1	35.4	57.4	82.4	96.8	119.8	149.6	174.6			

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	V 40	S 40	M									
				CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L									
		50	60	70	80	90	100	110	120	130	140	150	
0													
15	30.20	5.1	10.1	15.3	25.0	33.7	45.2	57.3	63.4	71.0	76.1	75.6	
10	37.70	5.2	10.3	15.5	25.2	33.9	45.4	57.4	63.4	70.8	75.4	74.4	
20	37.37	5.2	10.4	15.6	25.4	34.2	45.6	57.5	63.4	70.5	74.7	73.2	
30	36.97	5.3	10.5	15.8	25.6	34.4	45.8	57.6	63.4	70.3	73.9	72.0	
40	36.57	5.3	10.6	15.9	25.8	34.6	46.0	57.7	63.4	70.0	73.1	70.8	
50	36.19	5.4	10.7	16.1	26.0	34.8	46.2	57.8	63.3	69.6	72.3	69.6	

TABLE-X-A

10-METER OF ARC

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V 40	S 40	M									
					CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L									
			50	60	70	80	90	100	110	120	130	140		
0														
15	30.20	150.00	-34.4	-17.7	-3.9	17.7	35.3	57.9	83.4	98.2	121.7	152.2	177.7	
10	37.70	151.67	-36.0	-18.9	-4.9	17.2	35.3	58.4	84.5	99.5	123.6	154.7	180.8	
20	37.37	153.33	-37.6	-20.2	-5.8	16.8	35.2	58.8	85.5	100.9	125.5	157.3	184.0	
30	36.97	155.00	-39.3	-21.5	-6.8	16.2	35.1	59.2	86.5	102.2	127.4	159.9	187.1	
40	36.57	156.67	-41.1	-22.8	-7.9	15.7	35.0	59.6	87.5	103.5	129.2	162.4	190.3	
50	36.19	158.33	-42.8	-24.2	-8.9	15.1	34.8	60.0	88.4	104.8	131.1	165.0	193.4	

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE	RADIUS	CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L											
		V	40	50	60	70	80	90	100	110	120	130	140
OF	16.00	5.4	10.0	16.2	26.2	35.1	46.4	57.9	63.2	69.3	71.5	68.3	
CURVE		8	40	57	71	93	111	130	160	175	199	230	256
	10	5.5	10.9	16.3	26.4	35.3	46.6	57.9	63.2	68.9	70.7	67.0	
	20	5.5	11.0	16.5	26.6	35.5	46.8	57.9	63.1	68.5	69.8	65.7	
	30	5.6	11.1	16.6	26.8	35.7	46.9	58.0	63.0	68.1	68.9	64.4	
	40	5.7	11.2	16.8	26.9	35.9	47.1	58.0	62.8	67.7	68.0	63.1	
	50	5.7	11.3	16.9	27.1	36.1	47.2	58.0	62.7	67.3	67.1	61.8	

TABLE-X-A

10-METER OF ARC
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DEGREE	RADIUS	LENGTH	V	CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L										
				40	50	60	70	80	90	100	110	120	130	140
OF	16.00	160.00	8	40	57	71	93	111	134	160	175	199	230	256
CURVE				40	57	71	93	111	134	160	175	199	230	256
	10	161.67	-44.7	-25.7	-10.1	14.5	34.6	60.3	89.4	106.1	132.9	167.6	194.6	
	20	163.33	-46.6	-27.2	-11.2	13.9	34.4	60.6	90.3	107.4	134.8	170.1	199.8	
	30	165.00	-48.5	-28.7	-12.4	13.2	34.1	60.9	91.2	108.6	136.6	172.7	202.9	
	40	166.67	-50.5	-30.3	-13.7	12.5	33.9	61.2	92.1	109.9	138.4	175.2	206.1	
	50	168.33	-52.5	-31.9	-14.9	11.7	33.5	61.4	92.9	111.1	140.2	177.8	209.3	
			-54.6	-33.6	-16.3	10.9	33.2	61.6	93.8	112.3	142.0	180.3	212.5	

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE	RADIUS	M											
		V	40	50	60	70	80	90	100	110	120	130	140
OF	OF	40	50	60	70	80	90	100	110	120	130	140	
CURVE	CURVE	S	40	57	71	93	111	134	160	175	199	230	256
0 °													
17 00	33.70	5.8	11.3	17.0	27.3	36.3	47.4	57.9	62.5	66.8	66.2	60.4	
10	33.38	5.8	11.4	17.2	27.5	36.4	47.5	57.9	62.3	66.3	65.2	59.0	
20	33.06	5.9	11.5	17.3	27.7	36.6	47.6	57.9	62.2	65.8	64.2	57.7	
30	32.74	5.9	11.6	17.4	27.8	36.8	47.7	57.8	61.9	65.3	63.3	56.3	
40	32.43	6.0	11.7	17.6	28.0	37.0	47.8	57.8	61.7	64.8	62.2	54.9	
50	32.13	6.0	11.8	17.7	28.2	37.1	47.9	57.7	61.5	64.2	61.2	53.5	

TABLE-X-A

10-METER OF ARC

DEGREE	RADIUS	LENGTH	M											
			V	40	50	60	70	80	90	100	110	120	130	140
OF	OF	OF	40	50	60	70	80	90	100	110	120	130	140	
CURVE	CURVE	CURVE	S	40	57	71	93	111	134	160	175	199	230	256
0 °														
17 00	33.70	170.00	-56.7	-35.3	-17.7	10.1	32.8	61.8	94.6	113.5	103.8	182.8	215.6	
10	33.38	171.67	-58.9	-37.1	-19.1	9.2	32.4	61.9	95.4	114.7	105.5	185.4	218.8	
20	33.06	173.33	-61.2	-38.9	-20.5	8.3	31.9	62.1	96.1	115.8	107.3	187.9	222.0	
30	32.74	175.00	-63.5	-40.8	-22.0	7.3	31.4	62.1	96.9	116.9	109.0	190.4	225.2	
40	32.43	176.67	-65.8	-42.7	-23.6	6.4	30.9	62.2	97.6	118.0	110.7	192.9	228.3	
50	32.13	178.33	-68.2	-44.6	-25.2	5.3	30.3	62.2	98.3	119.1	112.4	195.4	231.5	

TABLE-X-A

10-METER OF ARC

SIGHT DISTANCE ALONG HORIZONTAL CURVE

DEGREE OF CURVE	RADIUS OF CURVE	M										
		V 40	S 40	70	80	90	100	110	120	130	140	
19 00	30.16	6.4	12.5	18.6	29.3	38.2	48.4	56.8	59.4	59.9	53.8	43.8
10	29.89	6.4	12.6	18.7	29.4	38.3	48.5	56.6	59.1	59.3	52.7	42.4
20	29.64	6.5	12.7	18.8	29.6	38.4	48.5	56.4	58.7	58.6	51.5	41.0
30	29.38	6.5	12.8	19.0	29.7	38.6	48.5	56.2	58.4	57.9	50.4	39.6
40	29.13	6.6	12.9	19.1	29.9	38.7	48.5	56.0	58.0	57.2	49.3	38.3
50	28.89	6.7	13.0	19.2	30.0	38.8	48.5	55.8	57.6	56.5	48.2	36.9

TABLE-X-A

10-METER OF ARC

DEGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V	M									
				S 40	50	60	70	80	90	100	110	120	130
19 00	30.16	190.00	-86.6	-59.9	-37.8	-3.2	25.2	61.4	102.4	126.0	163.8	212.6	253.6
10	29.89	191.67	-89.5	-62.2	-39.8	-4.5	24.3	61.2	102.9	126.9	165.4	215.1	256.7
20	29.64	193.33	-92.4	-64.7	-41.9	-6.0	23.4	60.9	103.3	127.8	166.9	217.5	259.9
30	29.38	195.00	-95.4	-67.2	-44.0	-7.5	22.4	60.6	103.7	128.6	168.4	219.8	263.0
40	29.13	196.67	-98.4	-69.8	-46.1	-9.0	21.4	60.2	104.1	129.4	169.9	222.2	266.1
50	28.89	198.33	-101.6	-72.4	-48.3	-10.6	20.3	59.8	104.4	130.2	171.4	224.6	269.2

TABLE-X-A

10-METER OF ARC
SIGHT DISTANCE ALONG HORIZONTAL CURVE

DGREE OF CURVE	RADIUS OF CURVE	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L															
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
0																	
20	20.00	6.7	13.0	19.3	30.1	38.9	48.5	55.6	57.2	55.7	47.1	35.6					
10	28.41	6.8	13.1	19.4	30.3	39.0	48.5	55.3	56.8	55.0	45.9	34.3					
20	28.18	6.8	13.2	19.6	30.4	39.1	48.5	55.1	56.3	54.2	44.8	32.9					
30	27.95	6.9	13.3	19.7	30.5	39.2	48.5	54.8	55.9	53.5	43.7	31.6					
40	27.72	6.9	13.4	19.8	30.7	39.3	48.5	54.5	55.4	52.7	42.6	30.4					
50	27.50	7.0	13.5	19.9	30.8	39.4	48.4	54.3	55.0	51.9	41.4	29.1					

TABLE-X-A

10-METER OF ARC
CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L

DGREE OF CURVE	RADIUS OF CURVE	LENGTH OF CURVE	V	M CENTERLINE INSIDE LANE TO SIGHT OBSTRUCTION-METERS, S = L													
				0	10	20	30	40	50	60	70	80	90	100	110	120	130
0																	
20	20.00	200.00	-104.7	-75.0	-50.6	-12.2	19.2	59.3	104.7	130.9	172.8	226.9	272.3				
10	28.41	201.67	-108.0	-77.8	-52.9	-13.9	18.0	58.9	105.0	131.6	174.2	229.2	275.3				
20	28.18	203.33	-111.2	-80.6	-55.3	-15.6	16.8	58.3	105.2	132.3	175.6	231.5	278.4				
30	27.95	205.00	-114.6	-83.4	-57.8	-17.4	15.6	57.8	105.4	132.9	177.0	233.8	281.5				
40	27.72	206.67	-118.0	-86.3	-60.3	-19.3	14.3	57.2	105.6	133.6	178.3	236.1	284.5				
50	27.50	208.33	-121.5	-89.3	-62.8	-21.1	12.9	56.5	105.7	134.1	179.6	238.3	287.5				

TABLE XI-A

DESIGN CONTROLS FOR "CREST" VERTICAL CURVE-
STOPPING SIGHT DISTANCE (SSD)

Purpose

To compute the fundamental design criteria for vertical curves. These criteria are computed on basis of AASHTO practice recommended in the AASHTO manual "A Policy on Geometric Design of Rural Highways, 1965."

Notations

DS - KPH = Design speed kilometre per hour (KPH)

V - KPH = Assumed speed (Kph)

SSD = S = Stopping sight distance in metres

A % = Algebraic difference between grades in percentage

Formulas

Case 1: $S \leq L$, $L = \frac{AS^2}{426}$ (Eq. 93) Case 2: $S > L$, $L = 2S - \frac{426}{A}$ (Eq. 94)

Example How to Use

Case 1: Given: $A = 6\%$, $S = 111$ m (Table VIII-A)

Required: $L =$ length of vertical curve in metres

Solution: $L = \frac{6(111)^2}{426} = 173.5$ m $> S$ (Table XI-A Value = 173)

Case 2: Given: $A = 3\%$, $S = 111$ m

Required: L

Solution: $L = 2 \times 111 - \frac{426}{3} = -62$ m

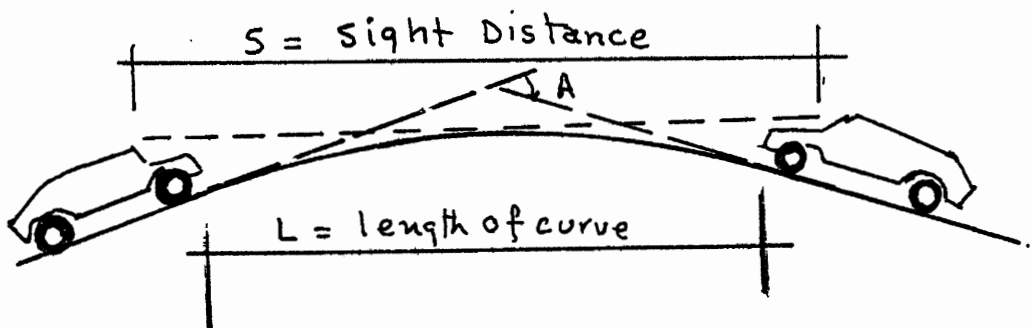
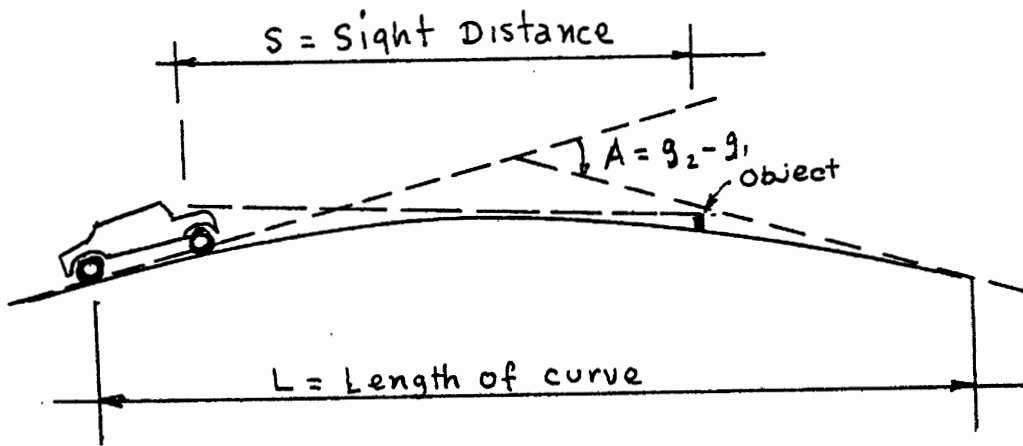


Figure 10.

Stopping Sight Distance Versus Length of Curve.

TABLE XI-4-METRIC

DESIGN CONTROLS FOR CREST VERTICAL CURVES-STOPPING SIGHT DISTANCE

A IN %	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS													
	40	50	60	70	80	90	100	110	120	130	140	150	160	
0.25	1624	1590	1562	1518	1482	1436	1384	1354	1306	1244	1192			
0.50	772	738	710	666	630	584	532	502	454	392	340			
0.75	488	454	426	382	346	300	248	218	170	108	56			
1.00	346	312	284	240	204	158	106	76	28	124	153			
1.25	260	226	198	154	118	72	20	89	116	155	192			
1.50	204	170	142	98	62	16	90	107	139	166	230			
1.75	163	129	101	57	21	73	105	125	162	217	269			
2.00	133	99	71	27	57	84	120	143	185	248	307			
2.25	109	75	47	3	65	94	135	161	209	279	346			
2.50	90	56	28	50	72	105	150	179	232	310	384			
2.75	74	40	12	55	79	115	165	197	255	341	422			
3.00	62	28	0	60	86	126	180	215	278	372	461			
3.25	51	17	38	65	93	136	195	233	302	403	499			
3.50	41	7	41	71	101	147	210	251	325	434	538			
3.75	33	28	44	76	108	158	225	269	348	465	576			
4.00	26	30	47	81	115	168	240	287	371	496	615			
4.25	20	32	50	86	122	179	255	305	394	527	653			
4.50	14	34	53	91	130	189	270	323	418	558	692			
4.75	9	36	56	96	137	200	285	341	441	589	730			
5.00	5	38	59	101	144	210	300	359	464	620	768			
5.25	1	40	62	106	151	221	315	377	487	651	807			
5.50	20	41	65	111	159	231	330	395	511	682	845			
5.75	21	43	68	116	166	242	345	413	534	713	884			
6.00	22	45	70	121	173	252	360	431	557	744	922			
6.25	23	47	73	126	180	263	375	449	580	775	961			
6.50	24	49	76	131	187	273	390	467	604	806	999			
6.75	25	51	79	137	195	284	405	485	627	837	1038			
7.00	26	53	82	142	202	294	420	503	650	869	1076			
7.25	27	55	85	147	209	305	435	521	673	900	1115			
7.50	28	57	88	152	216	316	450	539	697	931	1153			
7.75	29	59	91	157	224	326	465	556	720	962	1191			
8.00	30	60	94	162	231	337	480	574	743	993	1230			
8.25	30	62	97	167	230	347	495	592	766	1024	1268			
8.50	31	64	100	172	245	358	510	610	789	1055	1307			
8.75	32	66	103	177	253	368	525	628	813	1086	1345			
9.00	33	68	106	182	260	379	540	646	836	1117	1384			
9.25	34	70	109	187	267	389	555	664	859	1148	1422			
9.50	35	72	112	192	274	400	570	682	882	1179	1461			
9.75	36	74	115	197	281	410	585	700	906	1210	1499			
10.00	37	76	118	202	289	421	600	718	929	1241	1537			
10.25	38	78	121	208	296	431	615	736	952	1272	1576			
10.50	39	80	124	213	303	442	630	754	975	1303	1614			
10.75	40	81	127	219	310	452	645	772	999	1334	1653			
11.00	41	83	130	223	318	463	660	790	1022	1365	1691			

TABLE XI-A-METRIC
DESIGN CONTROLS FOR CHEST VERTICAL CURVES-STOPPING SIGHT DISTANCE

OS-KPH	40	50	60	70	80	90	100	110	120	130	140
V-KPH	37	47	54	63	70	78	87	91	97	104	111
SSD	40	57	71	93	111	134	160	175	199	230	256
A IN X	LEMINIMUM LENGTH OF VERTICAL CURVE IN METERS										
11.25	42	65	133	220	325	474	675	808	1045	1396	1730
11.50	43	87	136	233	332	484	690	826	1068	1427	1768
11.75	44	89	139	238	339	495	705	844	1091	1458	1807
12.00	45	91	141	243	346	505	720	862	1115	1489	1845
12.25	45	93	144	248	354	516	735	880	1138	1520	1884
12.50	46	95	147	253	361	526	750	898	1161	1551	1922
12.75	47	97	150	258	368	537	765	916	1184	1582	1960
13.00	48	99	153	263	375	547	781	934	1208	1613	1999
13.25	49	101	156	268	383	558	796	952	1231	1644	2037
13.50	50	102	159	274	390	568	811	970	1254	1675	2076
13.75	51	104	162	279	397	579	826	988	1277	1706	2114
14.00	52	106	165	284	404	589	841	1006	1301	1738	2153
14.25	53	108	168	289	412	600	856	1024	1324	1769	2191
14.50	54	110	171	294	419	611	871	1042	1347	1800	2230
14.75	55	112	174	299	426	621	886	1060	1370	1831	2268
15.00	56	114	177	304	433	632	901	1078	1394	1862	2306
15.25	57	116	180	309	440	642	916	1096	1417	1893	2345
15.50	58	118	183	314	448	653	931	1113	1440	1924	2383
15.75	59	120	186	319	455	663	946	1131	1463	1955	2422
16.00	60	121	189	324	462	674	961	1149	1486	1986	2460
16.25	61	123	192	329	469	684	976	1167	1510	2017	2499
16.50	61	125	195	334	477	695	991	1185	1533	2048	2537
16.75	62	127	198	339	484	705	1006	1203	1556	2079	2576
17.00	63	129	201	345	491	716	1021	1221	1579	2110	2614
17.25	64	131	204	350	498	726	1036	1239	1603	2141	2653
17.50	65	133	207	355	506	737	1051	1257	1626	2172	2691
17.75	66	135	209	360	513	747	1066	1275	1649	2203	2729
18.00	67	137	212	365	520	758	1081	1293	1672	2234	2768
18.25	68	139	215	370	527	769	1096	1311	1696	2265	2806
18.50	69	141	218	375	534	779	1111	1329	1719	2296	2845
18.75	70	142	221	380	542	790	1126	1347	1742	2327	2883
19.00	71	144	224	385	549	800	1141	1365	1765	2358	2922
19.25	72	146	227	390	556	811	1156	1383	1788	2389	2960
19.50	73	148	230	395	563	821	1171	1401	1812	2420	2999
19.75	74	150	233	400	571	832	1186	1419	1835	2451	3037
20.00	75	152	236	405	578	842	1201	1437	1858	2482	3075

TABLE XI-B
 DESIGN CONTROL FOR "CREST" VERTICAL CURVE-
 PASSING SIGHT DISTANCE

Purpose

To compute the fundamental design criteria for vertical curves. These criterias are computed on basis of AAHTO practice recommended in the AASHO manual "A Policy on Geometric Design of Rural Highways, 1965."

Notations

Same as in Table XI-A except PSD = Passing sight distance in metres.

Formulas

Case 1: $S \leq L, L = \frac{AS^2}{1004}$

Case 2: $S > L, L = 2S - \frac{1004}{A}$

Example How to Use

Case 1: Given: $A = 3\%, S = 560 \text{ m}$

Required: L

Solution: $L = \frac{3(560)^2}{1004} = 937 \text{ m}$ (Table XI-B, Value = 937)

Case 2: Given: $A = 0.50\%, S = 560 \text{ metre}$

Required: L

Solution: $L = 2 \times 560 - \frac{1004}{0.5} = -888 \text{ m}$ (Table XI-B=888)

for -ve value see note in the table's
 computer output.

TABLE XI-8-METRIC
DESIGN CONTROLS FOR CREST VERTICAL CURVES-PASSING SIGHT DISTANCE

A IN %	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS															
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
DS-KPH	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
V-KPH	37	47	54	63	70	78	87	91	97	104	111	118	125	132	140	148
P80	170	350	420	490	560	630	680	740	790	850	900	950	1000	1050	1100	1150
3676	3316	3176	3036	2896	2756	2656	2536	2436	2316	2216	2116	2016	1916	1816	1716	1616
1668	1308	1168	1028	888	748	648	528	428	308	208	108	8	8	8	8	8
998	638	498	358	218	78	345	409	466	539	605	671	737	803	869	935	1001
664	304	164	24	312	395	460	545	621	719	806	893	980	1067	1154	1241	1328
329	183	263	358	468	592	690	818	932	1079	1210	1341	1472	1603	1734	1865	1996
233	213	307	418	546	691	805	954	1087	1259	1411	1563	1715	1867	2019	2171	2323
162	244	351	478	624	790	921	1090	1243	1439	1613	1787	1961	2135	2309	2483	2657
106	274	395	538	702	889	1036	1227	1398	1619	1815	2016	2218	2420	2622	2823	3025
61	305	439	597	780	988	1151	1363	1554	1799	2016	2218	2420	2622	2823	3025	3227
29	335	483	657	850	1087	1266	1499	1709	1978	2218	2420	2622	2823	3025	3227	3428
86	366	527	717	937	1185	1381	1636	1864	2158	2420	2622	2823	3025	3227	3428	3630
93	396	571	777	1015	1284	1496	1772	2020	2338	2622	2823	3025	3227	3428	3630	3832
100	427	614	837	1093	1383	1611	1908	2175	2518	2823	3025	3227	3428	3630	3832	4033
107	457	658	896	1171	1482	1727	2045	2331	2698	3025	3227	3428	3630	3832	4033	4235
115	488	702	956	1249	1581	1842	2181	2486	2870	3227	3428	3630	3832	4033	4235	4437
122	518	746	1016	1327	1680	1957	2318	2641	3058	3428	3630	3832	4033	4235	4437	4638
129	549	790	1076	1405	1778	2072	2454	2797	3238	3630	3832	4033	4235	4437	4638	4839
136	579	834	1135	1483	1877	2187	2590	2952	3418	3832	4033	4235	4437	4638	4839	5040
143	610	878	1195	1561	1976	2302	2727	3108	3598	4033	4235	4437	4638	4839	5040	5241
151	640	922	1255	1639	2075	2417	2863	3263	3778	4235	4437	4638	4839	5040	5241	5442
158	671	966	1315	1717	2174	2533	2999	3418	3957	4437	4638	4839	5040	5241	5442	5643
165	701	1010	1375	1796	2273	2648	3136	3574	4137	4638	4839	5040	5241	5442	5643	5844
172	732	1054	1434	1874	2371	2763	3272	3729	4317	4840	4839	5040	5241	5442	5643	5844
179	762	1098	1494	1952	2470	2878	3408	3885	4497	5042	4839	5040	5241	5442	5643	5844
187	793	1142	1554	2030	2569	2993	3545	4040	4677	5244	4839	5040	5241	5442	5643	5844
194	823	1185	1614	2108	2668	3108	3681	4195	4837	5445	4839	5040	5241	5442	5643	5844
201	854	1229	1674	2186	2767	3223	3817	4351	5037	5647	4839	5040	5241	5442	5643	5844
208	884	1273	1733	2264	2866	3339	3954	4506	5217	5849	4839	5040	5241	5442	5643	5844
215	915	1317	1793	2342	2964	3454	4090	4642	5397	6050	4839	5040	5241	5442	5643	5844
223	945	1361	1853	2420	3063	3569	4226	4817	5577	6252	4839	5040	5241	5442	5643	5844
230	976	1405	1913	2498	3162	3684	4363	4972	5756	6454	4839	5040	5241	5442	5643	5844
237	1006	1449	1972	2576	3261	3799	4499	5128	5936	6655	4839	5040	5241	5442	5643	5844
244	1037	1493	2032	2654	3360	3914	4636	5283	6116	6857	4839	5040	5241	5442	5643	5844
251	1067	1537	2092	2733	3459	4029	4772	5439	6296	7059	4839	5040	5241	5442	5643	5844
259	1098	1581	2152	2811	3557	4145	4908	5594	6476	7260	4839	5040	5241	5442	5643	5844
266	1128	1625	2212	2889	3656	4260	5045	5749	6656	7462	4839	5040	5241	5442	5643	5844
273	1159	1669	2271	2967	3755	4375	5181	5905	6836	7664	4839	5040	5241	5442	5643	5844
280	1189	1713	2331	3045	3854	4490	5317	6060	7016	7866	4839	5040	5241	5442	5643	5844
287	1220	1756	2391	3123	3953	4605	5454	6216	7196	8067	4839	5040	5241	5442	5643	5844
295	1250	1800	2451	3201	4052	4720	5590	6371	7376	8269	4839	5040	5241	5442	5643	5844
302	1281	1844	2511	3279	4150	4835	5726	6526	7536	8471	4839	5040	5241	5442	5643	5844
309	1311	1888	2570	3357	4249	4950	5863	6682	7745	8672	4839	5040	5241	5442	5643	5844
316	1342	1932	2630	3435	4348	5066	5999	6837	7915	8874	4839	5040	5241	5442	5643	5844

TABLE XI-B-METRIC
DESIGN CONTROLS FOR CREST VERTICAL CURVES-PASSING SIGHT DISTANCE

A IN X	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS																
	PSD	170	350	47	54	60	70	80	90	100	110	120	130	140	170	350	
11.25	323	1372	1976	2690	3513	4447	5181	6135	6993	8095	9076						
11.50	331	1403	2020	2750	3592	4546	5296	6272	7148	8275	9277						
11.75	338	1433	2064	2809	3670	4644	5411	6408	7303	8455	9479						
12.00	345	1464	2108	2869	3748	4743	5526	6545	7459	8635	9681						
12.25	352	1494	2152	2929	3826	4826	5619	6651	7584	8815	9882						
12.50	359	1525	2196	2989	3904	4911	5716	6769	7720	8995	10084						
12.75	367	1555	2240	3049	3982	5040	5872	6954	7925	9175	10286						
13.00	374	1586	2284	3108	4060	5139	5987	7090	8080	9335	10488						
13.25	381	1616	2327	3168	4130	5237	6102	7226	8236	9534	10689						
13.50	388	1647	2371	3228	4216	5336	6217	7363	8391	9714	10891						
13.75	395	1677	2415	3288	4294	5435	6332	7499	8547	9894	11093						
14.00	402	1708	2459	3348	4372	5534	6447	7635	8702	10074	11294						
14.25	410	1738	2503	3407	4450	5633	6562	7772	8857	10254	11496						
14.50	417	1769	2547	3467	4529	5732	6678	7908	9013	10434	11698						
14.75	424	1799	2591	3527	4607	5830	6793	8044	9168	10614	11899						
15.00	431	1830	2635	3587	4685	5929	6908	8181	9324	10794	12101						
15.25	438	1860	2679	3646	4763	6028	7023	8317	9479	10974	12303						
15.50	446	1891	2723	3706	4841	6127	7138	8453	9635	11154	12504						
15.75	453	1921	2767	3766	4919	6226	7253	8590	9790	11334	12706						
16.00	460	1952	2811	3826	4997	6325	7368	8726	9945	11513	12908						
16.25	467	1982	2855	3886	5075	6423	7484	8863	10101	11693	13110						
16.50	474	2013	2899	3945	5153	6522	7599	8999	10256	11873	13311						
16.75	482	2043	2942	4005	5231	6621	7714	9135	10412	12053	13513						
17.00	489	2074	2986	4065	5309	6720	7829	9272	10567	12233	13715						
17.25	496	2104	3030	4125	5388	6819	7944	9408	10722	12413	13916						
17.50	503	2135	3074	4185	5466	6918	8059	9544	10878	12593	14118						
17.75	510	2165	3118	4244	5544	7016	8174	9681	11033	12773	14320						
18.00	518	2196	3162	4304	5622	7115	8290	9817	11189	12953	14521						
18.25	525	2226	3206	4364	5700	7214	8405	9953	11344	13133	14723						
18.50	532	2257	3250	4424	5778	7313	8520	10090	11499	13312	14925						
18.75	539	2287	3294	4483	5856	7412	8635	10226	11655	13492	15126						
19.00	546	2318	3338	4543	5934	7511	8750	10362	11810	13672	15328						
19.25	554	2348	3382	4603	6012	7609	8865	10499	11966	13852	15530						
19.50	561	2379	3426	4663	6090	7708	8980	10635	12121	14032	15732						
19.75	568	2409	3470	4723	6168	7807	9096	10772	12276	14212	15933						
20.00	575	2440	3513	4782	6247	7906	9211	10908	12432	14392	16135						

TABLE XI-C

DESIGN CONTROLS FOR "SAG" VERTICAL
CURVE-STOPPING SIGHT DISTANCE

Purpose

To compute the fundamental design criteria for vertical curves. These criterias are computed on basis of AAHTO practice recommended in the AASHO manual "A Policy on Geometric Design of Rural Highways, 1965."

Notations

DS = Design speed in Kph

V = Assumed speed

A% = Algebraic difference between grades

Formulas

$$\text{Case 1: } S \leq L, \quad L = \frac{AS^2}{122+3.5S} \quad \text{Case 2: } S > L, \quad L = 2S - \frac{122+3.5S}{A}$$

(Eq. No. 95) (Eq. No. 96)

Example How to Use

Case 1: Given: A = 6%, S = 111 m.

Required: L

Solution: $L = \frac{6(111)^2}{122+3.5 \times 111} = 144.8 \text{ m}$ (Table XI-C Value = 144 m)

Case 2: Given: A = 2%, S = 111 m

Required: L

Solution: $L = 2 \times 111 - \frac{122+3.5 \times 111}{2} = -33.3 \text{ m}$

(Table XI-C Value = 33 m) for negative values see note in this table computer output.

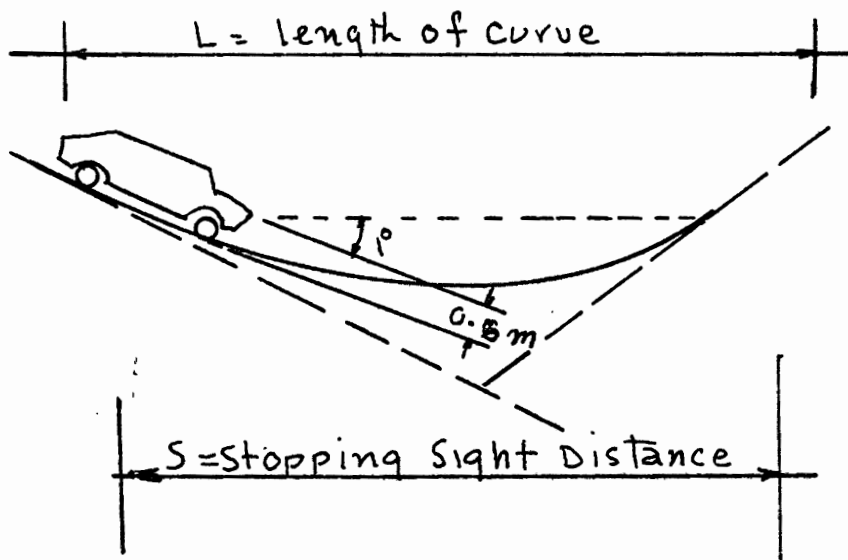


Figure 11.

Sag Curve - Stopping Sight Distance

TABLE XI-C-METRIC

DESIGN CONTROLS FOR SAG VERTICAL CURVES-STOPPING SIGHT DISTANCE-

	40	50	60	70	80	90	100	110	120	130	140
DS-KPH	40	50	60	70	80	90	100	110	120	130	140
V-KPH	37	47	54	63	70	78	87	91	97	104	111
SSD	40	57	71	93	111	134	160	175	199	230	256
A IN %	MINIMUM LENGTH OF VERTICAL CURVE IN METERS										
0.25	967	1171	1339	1603	1819	2095	2407	2587	2875	3207	3559
0.50	443	528	598	708	798	913	1043	1118	1238	1393	1523
0.75	269	314	351	410	458	519	589	659	693	775	845
1.00	181	207	228	261	288	322	361	384	420	466	505
1.25	129	143	154	171	186	204	225	237	256	281	302
1.50	94	100	104	112	118	125	134	139	147	157	166
1.75	69	69	69	69	69	69	69	69	69	69	69
2.00	50	46	43	37	33	27	20	17	11	3	128
2.25	36	28	22	12	4	68	84	93	108	128	144
2.50	24	14	6	48	60	75	93	104	120	142	160
2.75	15	2	37	53	66	83	103	114	133	156	177
3.00	7	30	40	57	72	91	112	125	145	171	193
3.25	0	32	44	62	78	98	122	135	157	185	209
3.50	21	35	47	67	84	106	131	145	169	199	225
3.75	22	37	51	72	90	113	140	156	181	214	241
4.00	24	40	54	77	96	121	150	166	193	228	257
4.25	25	42	57	82	102	129	159	177	205	242	273
4.50	27	45	61	86	108	136	168	187	217	256	289
4.75	29	48	64	91	114	144	178	198	229	271	305
5.00	30	50	68	96	120	151	187	208	241	285	321
5.25	32	53	71	101	126	159	197	218	254	299	338
5.50	33	55	74	106	132	167	206	229	266	313	354
5.75	35	58	78	111	138	174	215	239	278	328	370
6.00	36	60	81	115	144	182	225	250	290	342	386
6.25	38	63	85	120	150	189	234	260	302	356	402
6.50	39	65	88	125	156	197	244	271	314	370	418
6.75	41	68	91	130	162	205	253	281	326	385	434
7.00	42	70	95	135	168	212	262	291	338	399	450
7.25	44	73	98	140	175	220	272	302	350	413	466
7.50	45	75	102	144	181	227	281	312	362	428	482
7.75	47	78	105	149	187	235	290	323	374	442	498
8.00	48	80	108	154	193	243	300	333	387	456	515
8.25	50	83	112	159	199	250	309	344	399	470	531
8.50	51	85	115	164	205	258	319	354	411	485	547
8.75	53	88	119	169	211	265	328	364	423	499	563
9.00	54	90	122	173	217	273	337	375	435	513	579
9.25	56	93	125	178	223	281	347	385	447	527	595
9.50	58	96	129	183	229	288	356	396	459	542	611
9.75	59	98	132	188	235	296	366	406	471	556	627
10.00	61	101	136	193	241	303	375	416	483	570	643
10.25	62	103	139	198	247	311	384	427	495	584	659
10.50	64	106	142	202	253	319	394	437	508	599	676
10.75	65	108	146	207	259	326	403	448	520	613	692
11.00	67	111	149	212	265	334	412	458	532	627	708

TABLE XI-C-METRIC
 DESIGN CONTROLS FOR SAG VERTICAL CURVES--STOPPING SIGHT DISTANCE

DR--KPH	40	50	60	70	80	90	100	110	120	130	140	
V--KPH	37	47	54	63	70	78	87	91	97	104	111	
SSD	40	57	71	93	111	134	160	175	199	230	256	
A IN X	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS											
11.25	68	113	153	217	271	341	422	469	544	642	724	
11.50	70	116	156	222	277	349	431	479	556	656	740	
11.75	71	118	159	227	283	357	441	489	568	670	756	
12.00	73	121	163	231	289	364	450	500	580	684	772	
12.25	74	123	166	236	295	372	459	510	592	699	788	
12.50	76	126	170	241	301	379	469	521	604	713	804	
12.75	77	128	173	246	307	387	478	531	616	727	820	
13.00	79	131	176	251	313	395	488	542	629	741	836	
13.25	80	133	180	256	319	402	497	552	643	756	853	
13.50	82	136	183	260	325	410	506	562	653	770	869	
13.75	83	138	187	265	331	417	516	573	665	784	885	
14.00	85	141	190	270	337	425	525	583	677	798	901	
14.25	87	144	193	275	343	433	534	594	689	813	917	
14.50	88	146	197	280	350	440	544	604	701	827	933	
14.75	90	149	200	285	356	448	553	615	713	841	949	
15.00	91	151	204	289	362	455	563	625	725	856	965	
15.25	93	154	207	294	368	463	572	635	737	870	981	
15.50	94	156	210	299	374	470	581	646	749	884	997	
15.75	96	159	214	304	380	478	591	656	762	896	1014	
16.00	97	161	217	309	386	486	600	667	774	913	1030	
16.25	99	164	221	314	392	493	610	677	786	927	1046	
16.50	100	166	224	318	398	501	619	688	798	941	1062	
16.75	102	169	227	323	404	508	628	698	810	955	1078	
17.00	103	171	231	328	410	516	638	708	822	970	1094	
17.25	105	174	234	333	416	524	647	719	834	984	1110	
17.50	106	176	238	338	422	531	656	729	846	998	1126	
17.75	108	179	241	343	428	539	666	740	858	1013	1142	
18.00	109	181	244	347	434	546	675	750	870	1027	1158	
18.25	111	184	248	352	440	554	685	761	883	1041	1174	
18.50	113	187	251	357	446	562	694	771	895	1055	1191	
18.75	114	189	255	362	452	569	703	781	907	1070	1207	
19.00	116	192	258	367	458	577	713	792	919	1084	1223	
19.25	117	194	261	372	464	584	722	802	931	1098	1239	
19.50	119	197	265	376	470	592	732	813	943	1112	1255	
19.75	120	199	268	381	476	600	741	823	955	1127	1271	
20.00	122	202	272	386	482	607	750	833	967	1141	1287	

TABLE XI-D
 DESIGN CONTROLS FOR "SAG" VERTICAL
 CURVES FOR COMFORT

Purpose

To compute the fundamental design criteria for vertical curves. These criterias are computed on basis of AASHO practice recommended in the AASHTO* manual "A Policy on Geometric Design of Rural Highways, 1965."

Notations

Same as Table XI-A.

Formulas

$$L = \frac{AV^2}{395} \quad A = 6\% \quad V = 80 \text{ Kph} \quad (\text{Eq. No. 104})$$

Example How to Use

$$\therefore L = \frac{6(80)^2}{395} = 97 \text{ m} \quad (\text{Table XI-D, Value} = 97)$$

* AASHTO = American Association of State Highway Transportation Officials.

TABLE XI-D-METRIC

DESIGN CONTROL FOR SAG VERTICAL CURVES--FOR COMFORT		L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS												
DS-KPH	40	50	60	70	80	90	100	110	120	130	140			
V-KPH	37	47	54	63	70	78	87	91	97	104	111			
SSD	40	57	71	93	111	134	160	175	199	230	256			
A IN X														
	1	2	3	4	5	6	7	9	10	12	14	16	18	
0.25	1	1	1	1	1	1	1	1	1	1	1	1	1	
0.50	2	3	4	6	8	10	12	15	18	21	24	27	31	
0.75	3	4	6	9	12	15	18	22	27	32	37	42	49	
1.00	4	6	9	12	16	20	25	30	36	42	49	53	62	
1.25	5	7	11	15	20	25	31	38	45	53	62	64	74	
1.50	6	9	13	18	24	30	37	45	54	64	74	86	86	
1.75	7	11	15	21	28	35	44	53	63	74	86	99	99	
2.00	8	12	18	24	32	41	50	61	72	85	99	111	111	
2.25	9	14	20	27	36	46	56	68	82	96	111	124	124	
2.50	10	15	22	31	40	51	63	76	91	106	124	140	140	
2.75	11	17	25	34	44	56	69	84	100	117	136	154	154	
3.00	12	18	27	37	48	61	75	91	109	128	148	168	168	
3.25	13	20	29	40	52	66	82	99	118	139	161	183	183	
3.50	14	22	31	43	56	71	88	107	127	149	173	198	198	
3.75	15	23	34	46	60	76	94	114	136	160	186	210	210	
4.00	16	25	36	49	64	82	101	122	145	171	198	223	223	
4.25	17	26	38	52	68	87	107	130	154	181	210	235	235	
4.50	18	28	41	55	72	92	113	137	164	192	223	248	248	
4.75	19	30	43	58	76	97	120	145	173	203	235	260	260	
5.00	20	31	45	62	81	102	126	153	182	213	248	272	272	
5.25	21	33	47	65	85	107	132	160	191	224	260	285	285	
5.50	22	34	50	68	89	112	139	168	200	235	272	297	297	
5.75	23	36	52	71	93	117	145	176	209	246	285	310	310	
6.00	24	37	54	74	97	123	151	183	218	256	297	322	322	
6.25	25	39	56	77	101	128	158	191	227	267	310	334	334	
6.50	26	41	59	80	105	133	164	199	236	278	322	347	347	
6.75	27	42	61	83	109	138	170	206	246	288	334	359	359	
7.00	28	44	63	86	113	143	177	214	255	299	347	372	372	
7.25	29	45	66	89	117	148	183	222	264	310	359	384	384	
7.50	30	47	68	93	121	153	189	229	273	320	372	397	397	
7.75	31	49	70	96	125	158	196	237	282	331	384	409	409	
8.00	32	50	72	99	129	164	202	245	291	342	397	421	421	
8.25	33	52	75	102	133	169	208	252	300	353	409	434	434	
8.50	34	53	77	105	137	174	215	260	309	363	421	446	446	
8.75	35	55	79	108	141	179	221	268	319	374	434	459	459	
9.00	36	56	82	111	145	184	227	275	328	385	446	471	471	
9.25	37	58	84	114	149	189	234	283	337	395	459	483	483	
9.50	38	60	86	117	153	194	240	291	346	406	471	496	496	
9.75	39	61	88	120	157	199	246	298	355	417	483	508	508	
10.00	40	63	91	124	162	205	253	306	364	427	496	521	521	
10.25	41	64	93	127	166	210	259	314	373	438	508	533	533	
10.50	42	66	95	130	170	215	265	321	382	449	521	545	545	
10.75	43	68	97	133	174	220	272	329	391	459	533	557	557	
11.00	44	69	100	136	178	225	278	337	401	470	545	569	569	

TABLE XI-D-METRIC

DESIGN CONTROL FOR SAG VERTICAL CURVES--FOR COMFORT

DS-KPH	40	50	60	70	80	90	100	110	120	130	140
V-KPH	37	47	54	63	70	78	87	91	97	104	111
SSD	40	57	71	93	111	134	160	175	199	230	256
A IN X	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS										
11.25	45	71	102	139	182	230	284	344	410	481	558
11.50	46	72	104	142	186	235	291	352	419	492	570
11.75	47	74	107	145	190	240	297	359	428	502	583
12.00	48	75	109	148	194	246	303	367	437	513	595
12.25	49	77	111	151	198	251	310	375	446	524	607
12.50	50	79	113	155	202	256	316	382	455	534	620
12.75	51	80	116	158	206	261	322	390	464	545	632
13.00	52	82	118	161	210	266	329	398	473	556	645
13.25	53	83	120	164	214	271	335	405	483	566	657
13.50	54	85	123	167	218	276	341	413	492	577	669
13.75	55	87	125	170	222	281	348	421	501	588	682
14.00	56	88	127	173	226	287	354	428	510	599	694
14.25	57	90	129	176	230	292	360	436	519	609	707
14.50	58	91	132	179	234	297	367	444	528	620	719
14.75	59	93	134	182	239	302	373	451	537	631	731
15.00	60	94	136	186	243	307	379	459	546	641	744
15.25	61	96	139	189	247	312	386	467	556	652	756
15.50	62	98	141	192	251	317	392	474	565	663	769
15.75	63	99	143	195	255	323	398	482	574	673	781
16.00	64	101	145	198	259	328	405	490	583	684	794
16.25	65	102	148	201	263	333	411	497	592	695	806
16.50	66	104	150	204	267	338	417	505	601	706	818
16.75	67	106	152	207	271	343	424	513	610	716	831
17.00	68	107	154	210	275	348	430	520	619	727	843
17.25	69	109	157	214	279	353	436	528	628	738	856
17.50	70	110	159	217	283	358	443	536	638	748	868
17.75	71	112	161	220	287	364	449	543	647	759	880
18.00	72	113	164	223	291	369	455	551	656	770	893
18.25	73	115	166	226	295	374	462	559	665	780	905
18.50	74	117	168	229	299	379	468	566	674	791	918
18.75	75	118	170	232	303	384	474	574	683	802	930
19.00	76	120	173	235	307	389	481	582	692	813	942
19.25	77	121	175	238	311	394	487	589	701	823	955
19.50	78	123	177	241	315	399	493	597	710	834	967
19.75	80	125	180	245	320	405	500	605	720	845	980
20.00	81	126	182	248	324	410	506	612	729	855	992

TABLE XI-E
DESIGN CONTROLS FOR "SAG" VERTICAL
CURVES FOR UNDERPASS

Purpose

To compute the fundamental design criteria for vertical curves. These criterias are computed on basis of AAHTO practice recommended in the AASHO manual "A Policy on Geometric Design of Rural Highway, 1965."

Notations

Same as Table XI-A

Formuals

$$\text{Case 1: } S > L, \quad L = \frac{AS^2}{2500}$$

(Eq. No. 97)

$$\text{Case 2: } S < L, \quad L = 2S - \frac{2500}{A}$$

(Eq. No. 98)

Example How to Use

$$\text{Case 1: } A = 12.5\%, \quad S = 111 \text{ m}$$

$$\text{Case 2: } A = 12.5\%, \quad S = 111 \text{ m}$$

$$L = \frac{12.5(111)^2}{2500} = 61 \text{ m}$$

$$L = 2 \times 111 - \frac{2500}{12.5}$$

(Table XI-D, Value = 61 m)

= 244 m

Notes

Value above $S = L = 0$ are not considered value lower $S = L = 0$ are considered.

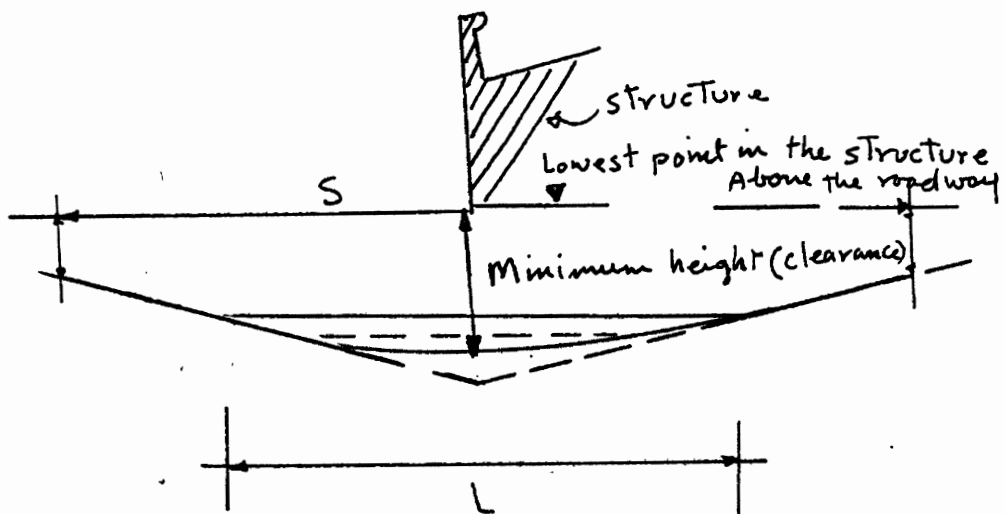


Figure 12.

Sag Curve - Stopping Sight Distance for Underpass.

TABLE XI-F-METRIC

DESIGN CONTROL FOR SAG VERTICAL CURVES-FOR UNDERPAS

DS-KPH	40	50	60	70	80	90	100	110	120	130	140	
V-KPH	37	47	54	63	70	78	87	91	97	104	111	
SSD	40	57	71	93	111	134	160	175	199	230	256	
A IN X	L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS											
0.25	9917	9883	9855	9811	9775	9729	9677	9647	9599	9537	9485	
0.50	4918	4884	4856	4812	4776	4730	4678	4648	4600	4538	4486	
0.75	3252	3218	3190	3146	3110	3064	3012	2982	2934	2872	2820	
1.00	2419	2385	2357	2313	2277	2231	2179	2149	2101	2039	1987	
1.25	1919	1885	1857	1813	1777	1731	1679	1649	1601	1539	1487	
1.50	1586	1552	1524	1480	1444	1398	1346	1316	1268	1206	1154	
1.75	1348	1314	1286	1242	1206	1160	1108	1078	1030	968	916	
2.00	1169	1135	1107	1063	1027	981	929	899	851	789	737	
2.25	1030	996	968	924	888	842	790	760	712	650	598	
2.50	919	885	857	813	777	731	679	649	601	539	487	
2.75	828	794	766	722	686	640	588	558	510	448	396	
3.00	753	719	691	647	611	565	513	483	435	373	321	
3.25	689	655	627	583	547	501	449	419	371	309	257	
3.50	634	600	572	528	492	446	394	364	316	254	202	
3.75	586	552	524	480	444	398	346	316	268	206	154	
4.00	544	510	482	438	402	356	304	274	226	164	112	
4.25	508	474	446	402	366	320	268	238	190	128	76	
4.50	475	441	413	369	333	287	235	205	157	95	43	
4.75	446	412	384	340	304	258	206	176	128	66	14	
5.00	419	385	357	313	277	231	179	149	101	39	131	
5.25	396	362	334	290	254	208	156	126	78	16	137	
5.50	374	340	312	268	232	186	134	104	56	116	144	
5.75	354	320	292	248	212	166	114	84	36	121	150	
6.00	336	302	274	230	194	148	96	66	18	126	157	
6.25	319	285	257	213	177	131	79	49	1	132	163	
6.50	304	270	242	198	162	116	64	34	102	137	170	
6.75	290	256	228	184	148	102	50	20	106	142	176	
7.00	277	243	215	171	135	89	37	7	110	148	183	
7.25	264	230	202	158	122	76	24	88	114	153	190	
7.50	253	219	191	147	111	65	13	91	118	158	196	
7.75	242	208	180	136	100	54	2	94	122	164	203	
8.00	232	198	170	126	90	44	81	98	126	169	209	
8.25	222	188	160	116	80	34	84	101	130	174	216	
8.50	214	180	152	108	72	26	87	104	134	179	222	
8.75	205	171	143	99	63	17	89	107	138	185	229	
9.00	197	163	135	91	55	9	92	110	142	190	235	
9.25	190	156	128	84	48	2	94	113	146	195	242	
9.50	183	149	121	77	41	66	97	116	150	201	249	
9.75	176	142	114	70	34	70	99	119	154	206	255	
10.00	169	135	107	63	27	71	102	122	158	211	262	
10.25	163	129	101	57	21	73	104	125	162	216	268	
10.50	158	124	96	52	16	75	107	128	166	222	275	
10.75	152	118	90	46	10	77	110	131	170	227	281	
11.00	147	113	85	41	5	79	112	134	174	232	288	

TABLE XI-D-METRIC

DESIGN CONTROL FOR SAG VERTICAL CURVES-FOR COMFORT

OS-KPH	40	50	60	70	80	90	100	110	120	130	140
V-KPH	37	47	54	63	70	78	87	91	97	104	111
SSD	40	57	71	93	111	134	160	175	199	230	256

L=MINIMUM LENGTH OF VERTICAL CURVE IN METERS

A IN X	11.25	11.50	11.75	12.00	12.25	12.50	12.75	13.00	13.25	13.50	13.75	14.00	14.25	14.50	14.75	15.00	15.25	15.50	15.75	16.00	16.25	16.50	16.75	17.00	17.25	17.50	17.75	18.00	18.25	18.50	18.75	19.00	19.25	19.50	19.75	20.00	
	45	46	47	48	49	50	51	52	53	54	55	56	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	80	81		
	71	72	74	75	77	79	80	82	83	85	87	88	91	93	94	96	98	99	101	102	104	107	109	110	112	113	115	117	118	120	121	123	125	126	126	126	
	102	104	107	109	111	113	116	118	120	123	125	127	132	134	136	139	141	143	145	148	150	154	157	161	164	166	168	173	175	177	180	182	182	182	182	182	
	139	142	145	148	151	155	158	161	164	167	170	173	179	182	186	189	192	195	198	201	204	210	217	220	223	226	229	235	238	241	245	248	248	248	248	248	
	182	186	190	194	198	202	206	210	214	218	222	226	234	239	243	247	251	255	259	263	267	275	283	287	291	295	299	303	307	311	315	320	324	324	324	324	324
	230	235	240	246	251	256	261	266	271	276	281	287	292	302	307	312	317	323	328	333	338	348	353	358	364	369	374	379	384	389	394	405	410	410	410	410	
	284	291	297	303	310	316	322	329	335	341	348	354	367	373	379	386	392	398	405	411	417	430	436	443	455	462	468	474	481	489	501	506	510	510	510	510	
	344	352	359	367	375	382	390	398	405	413	421	428	444	451	459	467	474	482	490	497	505	520	528	536	551	559	566	574	582	591	605	612	612	612	612	612	
	410	419	428	437	446	455	464	473	483	492	501	510	528	537	546	556	565	574	583	592	601	619	628	638	656	665	674	683	692	701	710	720	729	729	729	729	
	481	492	502	513	524	534	545	556	566	577	588	609	620	631	641	652	663	673	684	695	706	727	738	748	770	780	791	802	813	823	834	845	855	855	855	855	
	558	570	583	595	607	620	632	645	657	669	682	694	707	719	731	744	756	769	781	794	806	818	831	843	856	868	880	893	905	918	930	942	955	967	980	992	

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Horizontal Alignment Design.

Given: Horizontal curve data as shown on plan Fig. These data are fixed based on feasible economical-technical basis. The maximum allowable degree of curvature for the curve at P.I. 1 is used here.

Required: Maximum degree of curve to be calculated. The stationing of all central points (i.e., B.C., E.C., and P.I.) to be calculated and indicated, and all curve data (i.e., Δ , D_c , R , L , T , E , M , C , and super elevation) are to be calculated. data are to be calculated and indicated as necessary.

Vertical Alignment Design.

Given: Vertical curve data as shown on profile in Fig. . These data are based maintaining minimum elevation of 53.50 at station 140 + 00 and meet the horizontal requirement.

Required: The elevations at every 10 metres station for both curves. The elevation at station 140 + 00 to be maintained at 53.50. "Bumps" and "flat sections" of pavement in the transition are to be avoided. Super elevation transition diagram to show location and stations.

Solutions:

Horizontal Alignment Design. The station length is considered here as ten metre (10) in "Arc definition."

$$V = 80 \text{ kph}, R = \frac{v^2}{127 (e + f)} = \frac{(80)^2}{127 (0.08 + 0.12)} \quad (\text{Eq. No. 99})$$

$$R = 229.06 \text{ metres}$$

$$D = \frac{572.958}{229.06} = 2.501 = 2^\circ 30' 5''$$

$$L_1 = \frac{\Delta l}{D} \times 10 = \frac{50}{2.501} \times 10 = 199.93 = 200 \text{ m} = 20 \text{ stations}$$

$$T_1 = R \tan \frac{\Delta l}{2} = 229.06 \times \tan \frac{50}{2} = 106.81 \text{ m} = 11.0 \text{ stations}$$

$$TR = \text{Tangent run out} = \frac{d \times e}{r} \quad (\text{Eq. No. 100})$$

where

d = transverse distance from axis of rotation of pavement to outer edge in metres

e = crown slope or super elevation

r = ratio of slope of profile of pavement to center line

Horizontal.

For 2-lane (lane width = 3.65 m)

$$TR = \frac{3.60 \times 0.08}{\frac{1}{250}} = 14.40 \text{ m}$$

$$SR = \text{super elevation runoff} = \frac{d \times e_s}{r} = \frac{3.65 \times 0.08}{\frac{1}{200}} = 57.60 \text{ m}$$

$$TRS = TR + SR = 72.00 \text{ m}$$

$$\text{Total Tangent} = T_1 + TRS = 106.81 + 72.00$$

$$TT = 178.81 \text{ m}$$

Assume TRS will be the same for curve No. 2

$$\therefore T_2 = 350 - (178.81 + 72.00) = 99.19 \text{ metre} = 10 \text{ stations}$$

$$T_2 = R_2 \tan \frac{\Delta_2}{2}, \quad R_2 = \frac{99.19}{\tan \frac{40}{2}}$$

$$R_2 = 272.52 \text{ m}$$

$$L_2 = \frac{2\Delta\pi R}{360} = \frac{2 \times 40 \times \pi \times 272.52}{360} = 190.25 \text{ say } 200 \text{ m} = 20 \text{ stations}$$

$$D_m = \frac{572.958}{272.52} = 2.102 = 2^\circ 6' 9'', \quad R = R_m$$

Horizontal stopping distance.

Curve No. 1

$$V = 80 \text{ kph}, \quad \text{SSD} = 111 \text{ metres}$$

$$D = 2.501^\circ, \text{ middle ordinate } (M) = 5.0 \text{ metre}$$

clearance provided by the designed curves.

$$m = R(1 - \cos \frac{S \times D}{2 \times 10}) = 229.06(1 - \cos \frac{111 \times 2.501}{20})$$

$$= 6.70 > 5.0 \text{ metres}$$

$$S = \frac{R}{28.65} \cos^{-1} \frac{R - m}{R} \text{ in metric same as english}$$

$$= \frac{229.06}{28.65} \cos^{-1} \frac{229.06 - 6.70}{229.06} = 111.07 > 111 \text{ metres}$$

Curve No. 2

$$D = 2.102^\circ, \quad M = 5.0 \text{ m}, \quad S = 111 \text{ m}$$

$$R_2 = 272.52 \text{ m}$$

clearance provided by the designed curve.

$$M = R(1 - \cos \frac{SD}{2L}) = 272.52(1 - \cos \frac{111 \times 2.102}{20})$$

$$M = 5.63 > 5.0$$

$$S = \frac{272.52}{28.65} \cos^{-1} \frac{272.52 - 5.63}{272.52} = 111$$

Control Points.Curve No. 1:

$$\text{BCI STA.} = \text{PI1} - T_1 = (140 + 00) - (10 + 68) = 129 + 32$$

$$\text{PI1} = 140 + 00$$

$$\text{ECI} = \text{BCI} + L_1 = (128 + 32) + (20 + 00) = 149 + 32$$

Curve No. 2

$$\text{BC2 STA.} = \text{PI2} - T_2 = (180 + 00) - (10 + 00) = 170 + 00$$

$$\text{PI2} = 180 + 00$$

$$\text{EC2} = \text{BC2} + L_2 = (170 + 00) + (18 + 00) = 188 + 00$$

HORIZONTAL ALIGNMENT (CIRCULAR CURVE DESIGN)

Summary of Comparison

Element	Curve 1			Curve 2		
	Computed	By Table Value	Table No.	Computed	By Table Value	Table No.
R	229.06	229.18	III-A	302.39	302.27	III-A
L	199.89	199.90	III-A	211.11	211.08	III-A
T	106.81	106.80	III-A	110.69	110.61	III-A
TR	14.60	14.40	VII	14.60	14.40	VII
SR	58.60	58.40	VII	58.60	58.40	VII

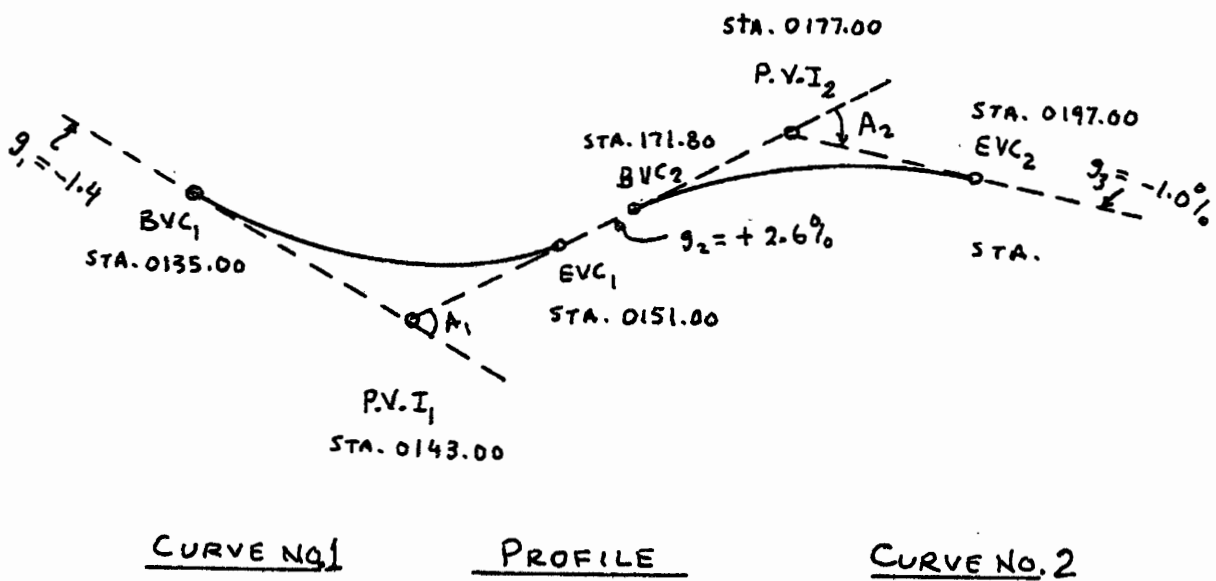
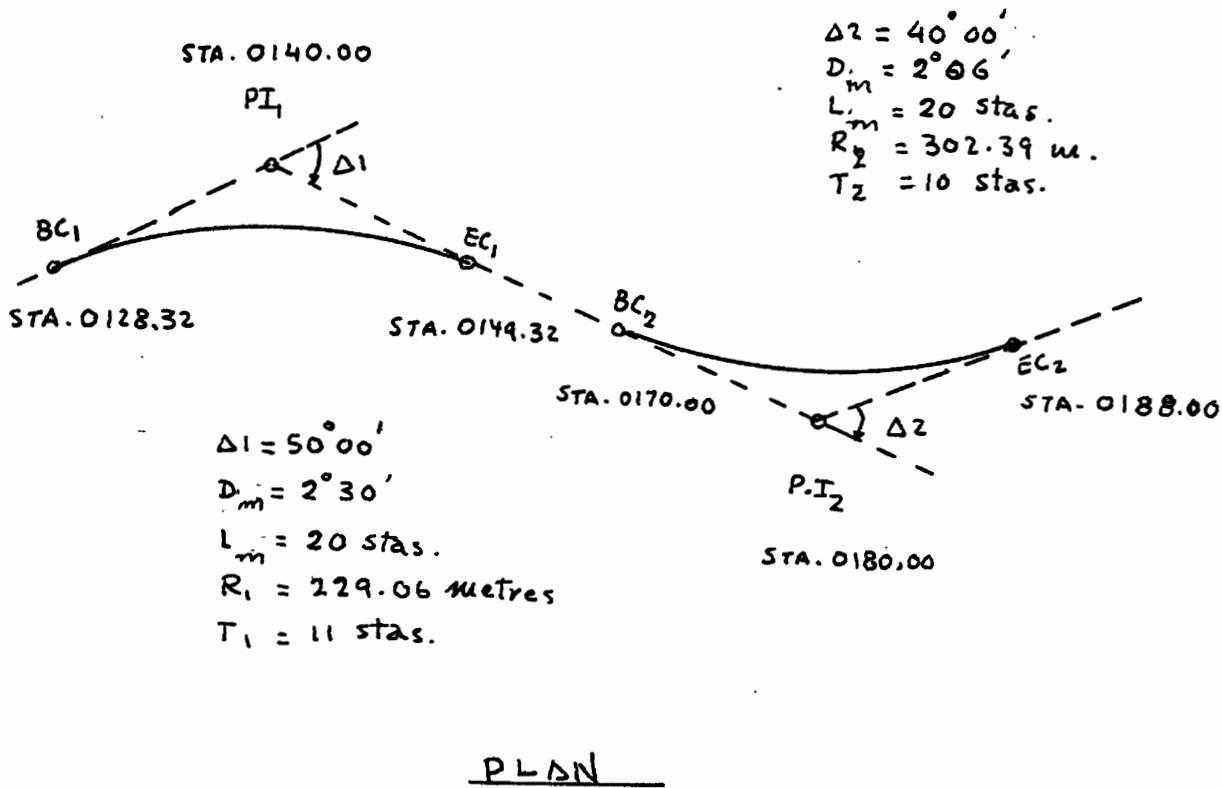


Figure 13.

Project Example, Plan, Profile and Design Criteria for Problem No. 1.

VERTICAL ALIGNMENT DESIGN

(Refer to Fig. 13)

Solution.

$$r = \frac{g_2 - g_1}{L} = \frac{2.6 + 1.4}{L} = \frac{4}{L} \quad (\text{Eq. No. 101})$$

$$E_a = \text{BVC. ELE.} = \text{PVI. ELE.} + g_1 \left(\frac{L}{2}\right)$$

$$E_a = 15 + (-1.4)\frac{L}{2} = 15 - 0.7L$$

x = distance in station from BVC to station 140 + 00

$$x = \frac{L}{2} - (143 - 140) = \frac{L}{2} - 3 \quad (\text{Eq. No. 102})$$

$$g_1 x = (-1.4) \left(\frac{L}{2} - 3\right) = 4.2 - 0.7L, \quad (g = \text{grade in \%}) \quad (\text{Eq. No. 103})$$

$$\left(\frac{1}{2}r\right) (x^2) = \frac{1}{2} \left(\frac{4}{L}\right) \left(\frac{L}{2} - 3\right)^2 = \frac{2}{L} \left(\frac{L^2}{4} - 3L + 9\right) = \frac{L}{2} - 6 + \frac{18}{L} \quad (\text{Eq. 104})$$

$$E_x = E_a + g_1 x + \left(\frac{1}{2}r\right) (x^2) = 15 - 0.7L + 4.2 - 0.7L + \frac{L}{2} - 6 + \frac{18}{L}$$

$$16.0 - 15.0 = 13.2 - 1.4L + \frac{L}{2} + \frac{18}{L}$$

$$1.4L - 0.5L - \frac{18}{L} - 12.2 = 0$$

$$0.9L - \frac{18}{L} - 12.2 = 0$$

Multiply by $\frac{L}{0.9}$

$$L^2 - 20 - 13.56L$$

$$L^2 - 13.56L - 20 = 0$$

$$L_1 = \frac{-(-13.56) + \sqrt{(-13.56)^2 - 4(-20)}}{2} = \frac{+13.56 + 16.24}{2}$$

$$L_1 = \frac{29.80}{2} = 14.90 \text{ station}$$

$$= 14.90 \times 10 \text{ (m/station)}$$

$$= 149 \text{ metres, use } 160 \text{ m} = 16 \text{ stations}$$

CURVE CONTROL POINTS (SAG) (CV)

$$BVC_1 = PVI_1 - L/2 = (143 + 00) - \frac{16}{2} = 135 + 00$$

$$BVC_1 \text{ ELE} = 15.00 + 1.4 (16/2) = 26.20 \text{ metres}$$

$$EVC_1 = BVC_1 + L_1 = (135 + 00) + (16 + 00) = 151 + 00$$

$$EVC_1 \text{ ELE} = 15.00 + 2.6\left(\frac{15}{2}\right) = 35.8 \text{ metres}$$

$$\text{Common tangent} = (177 + 00) - (143 + 00) - \frac{L_2}{2}, \text{ remaining for}$$

crest curve (CI)

$$CT \text{ for } CV_2 = 34 - \frac{16}{2} = 26$$

$$L_2 (\text{CREST}) + 126 \times 10 = 260 \text{ metres} = 26 \text{ stations}$$

CHECKING LOW POINT AT SAG CURVE (CV)

$$E_x = E_a + g_1 x + \frac{1}{2} r x^2$$

$$r = \frac{g_1 - g_2}{L} = \frac{-1.4 - 2.6}{16} = -0.25$$

$$\text{at } \frac{dE_x}{dx} = 0, \quad g_1 + r x = 0$$

$$x_t = -\frac{g_1}{r} = \frac{g_1 L}{g_1 - g_2} = \frac{-1.4(16)}{-1.4 - 2.6} = -5.6 \text{ stations from } BVC_1$$

$$\text{low point station} = (135 + 00) + (5 + 60) = 140 + 60$$

$$\begin{aligned} \text{ELEV. of low point} &= \text{BVC}_1\text{ELV} - 1.4(5.60) + 1/2(0.25)(5.6)^2 \\ &= 26.20 - 7.84 + 3.92 = 22.28 \text{ metres} \end{aligned}$$

CHECKING STOPPING SIGHT-DIST (SSD) (For SAG)

From Table IX-A for $V = 80$ kph, $\text{SSD} = 111$ m

To check the (SSD) provided by the design curve

$$\text{Try } S < L, L = \frac{AS^2}{122 + 3.5S}$$

$$L = \frac{4(111)^2}{122 + 3.5 \times 111} = 96.5 \text{ m is not adequate}$$

Try another formula, $S > L$

$$L = 2 \times S - \frac{122 + 3.5S}{A} = 2 \times 111 - \frac{122 + 3.5 \times 111}{4}$$

$$= 94.4 < S < 111 \text{ metres}$$

∴ Length to curve to provide minimum SSD should not exceed 95 metres.

Checking for comfort:

$$L = \frac{AV^2}{395} = \frac{4(90)^2}{395} = 64.8 < 149 \text{ m}$$

The length of the curve is less than minimum SSD therefore it provides safe sight distance.

Checking for appearance:

$$L = 30.5A = 30.5 \times 4 = 122 < 149 \text{ m}$$

The length of curve is acceptable for appearance.

CREST CURVE

- a) checking SSD, provided by the designed curve compared to the minimum SSD.

$$S > L, \quad L = 2S - \frac{426}{A} = 2 \times 111 - \frac{426}{3.6} = 104 < S$$

$$L/2 = 104/2 = 52 = 5.2 \text{ stations}$$

Control Points

$$BVC_2 = (177 + 00) - (5 + 20) = 171 + 80$$

$$PVI_2 = \text{given, see Fig. 13.} = 177 + 00$$

$$PVI.ELE. = 15.00 + 2.6(177 - 143) = 103.40$$

$$BVC_2.ELE. = 103.40 - 2.6(177 - 171.8) = 89.88$$

$$EVC_2.Sta. = (171 + 80) + (26 + 00) = 197 + 80$$

$$EVC_2.ELE. = 103.40 - 1.0(197.8 - 177) = 82.6$$

$$\text{Distance between } BVC_2 \text{ \& } EVC_1 = (171 + 80) - (151 + 00)$$

$$= 20.80 \text{ stations}$$

$$= 208 \text{ metres}$$

Checking Passing Sight Distance (PSD)

For $V = 80$ kph, minimum PSD = 560 m.

$$S < L, \quad L = \frac{AS^2}{1004} = \frac{4(560)^2}{1004}$$

$$L = 1249 \text{ metres} > s$$

The length of the curve provide SSD more than the required minimum.

Summary

- 1) Elevation at each 10 metre stations

$$\gamma_{\text{sag}} = \frac{2.6 + 1.4}{16} = 0.25, \quad \frac{1}{2}\gamma = 0.125$$

$$\gamma_{\text{crest}} = \frac{-1.0 - 2.6}{26} = -0.139, \quad \frac{1}{2} \gamma = -0.0692$$

$$Ex_{\text{sag}} = 26.20 - 1.4x + 0.125x^2$$

$$Ex_{\text{sag}} = 89.88 + 2.6x - 0.0692x^2$$

Table No. is prepared using equation 1 and 2 above.

Problem No. 2

Using the same criteria in problem No. 1 and design the horizontal for spiral curve with assumed data, (for notation, See Table VI).

Given: For curve 1 and 2, $L_{S1} = 250$ m, $D_{m1} = 4^\circ$, $\Delta 1 = 50^\circ$

$L_{S2} = 200$ m, $D_{m2} = 4^\circ$, $\Delta 2 = 40^\circ$

10 stations used with exact method

Required: Spiral elements and control points

Solution: Using 10 metres station

$$R_m = \frac{572.958}{4} = 143.24 \text{ metres for both curves No.1 and 2.}$$

$$\Delta 1 = \frac{LS_1}{2R} = \frac{250}{2 \times 143.24} = 0.8727 \text{ Radians} = 50^\circ$$

$$\Delta 2 = \frac{LS_2}{20} = \frac{200 \times 4}{20} = 40^\circ$$

$$b = 57.29578^\circ = 1 \text{ Radian}$$

$$x_1 = 250 \left[1 - \frac{(50)^2}{10c^2} + \frac{(50)^4}{216c^4} - \frac{(50)^6}{9360c^6} + \frac{(50)^8}{685440c^8} \dots \right]$$

$$= 231.60 \text{ m (Table VI Value} = 231.62)$$

$$x_2 = 190.45 \text{ m (Table VI Value} = 190.47)$$

$$y_1 = 250 \left(\frac{50}{3c} - \frac{(50)^3}{42c^3} + \frac{(50)^5}{1320c^5} - \frac{(50)^7}{75,600c^7} \dots \right)$$

$$= 68.86 \text{ (Table VI Value} = 68.86)$$

$$y_2 = 44.95$$

$$O_1 = Y - R(1 - \cos \Delta 1)$$

$$= 68.86 - 143.24 (1 - \cos 50)$$

$$= 17.67 \text{ m, (Table VI Value} = 17.69 \text{ m)}$$

$$O_2 = 11.42 \text{ m, (Table VI Value} = 11.44 \text{ m)}$$

$$X_{o_1} = X_1 - R \sin \Delta 1$$

$$= 231.60 - 143.24 \sin 50 = 121.87 \text{ m}$$

(Table VI Value = 121.89 m)

$$X_{o_2} = 98.38$$

(Table VI Value = 98.40 m)

$$\text{CS for } X_{o_1} = (RC - Ra) \sin \Delta 1, \text{ CS for } X_{o_2} = (RC - Ra) \sin \Delta 2$$

$$\text{CS for } O_1 = (RC - Ra)(1 - \cos \Delta 1), \text{ CS for } O_2 = (RC - Ra)(1 - \cos \Delta 2)$$

RA = 143.24 metres.

$$RC = \frac{5}{\sin \frac{4}{2}} = 143.26 \text{ m}$$

$$Rc - Ra = 0.02$$

$$\text{CS}x_{o_1} = (0.02) \sin 50 = 0.02 \text{ (Table Value = 0.02)}$$

$$\text{CS}x_{o_2} = 0.02 \text{ (Table Value = 0.01)}$$

$$\text{CS}_{o_1} = (0.02)(1 - \cos 50) = 0.007 \text{ (Table Value = 0.01)}$$

$$\text{CS}_{o_2} = 0.02 \text{ (Table Value = 0.01)}$$

$$A_1 = \frac{\Delta 1}{3} - \text{CS}x_{o_1} = \frac{50}{3} - 0.02 =$$

$$A_2 = \frac{\Delta 2}{3} - \text{CS}x_{o_2} = \frac{40}{3} -$$

$$\text{LC}_1 = (x)(\sec A) = 268.74 \text{ (Sec 19.974)}$$

$$= 241.74 \text{ m (Table VI Value = 241.75)}$$

$$\text{LC}_2 = 195.71 \text{ m (Table VI Value = 195.73)}$$

$$\text{ST}_1 = \frac{Y}{\sin \Delta 1} = \frac{68.86}{\sin 50} = 111.78 \text{ m (Table VI Value = 89.89)}$$

$$\text{ST}_2 = 69.90 \text{ (Table VI Value = 69.92)}$$

$$\text{LT}_1 = x - Y \cot \Delta 1 = 231.60 - 68.86 \cot 50$$

$$= 173.82 \text{ m (Table VI Value = 173.84)}$$

$$\text{LT}_2 = 136.90$$

$$TS_1 = (R + 0) \tan \frac{\Delta_1}{2} + X_0, \quad (I = \Delta \text{ for single spiral})$$

$$\begin{aligned} TS_1 &= (143.24 + 17.69) \tan \frac{50}{2} + 121.87 \\ &= 196.92 \text{ m (Table VI Value = 196.94)} \end{aligned}$$

$$TS_2 = 154.67 \text{ m (Table VI Value = 154.69)}$$

$$\begin{aligned} ES_1 &= \sec \frac{I}{2} (R + 0) - R \\ &= \sec \frac{50}{2} (143.24 + 17.69) - 143.24 \end{aligned}$$

$$= 34.30 \text{ m (Table VI Value = 34.33)}$$

$$ES_2 = 21.33 \text{ m (Table VI Value = 21.36)}$$

Total length of horizontal alignment between PT1 and PT2 is given 400 metres.

∴ Common tangent between curve 1 and 2

$$= 400 - \frac{1}{2}(LS_1 + LS_2)$$

$$CT = 200 \text{ metre}$$

Stations of Control Points:

$$P.I.1 = 140 + 00 \qquad \qquad \qquad = 140 + 00$$

$$T.S1 = P.I. - T_{S1} = (140 + 00) - (19 + 69) = 159 + 69$$

$$S.CT = T.S1 + L_{S1} = (159 + 69) + (25 + 00) = 184 + 69$$

$$CT.S2 = (S.CT + CT) = (184 + 69) + (20 + 00) = 204 + 69$$

$$S_2T_2 = (CT.S2 + LS_2) = (204 + 69) + (20 + 00) = 224 + 69$$

Deflection angle for 10 metres (see fig. no. 14)

$$\theta_1 = \frac{1}{3} \left(\frac{L_1}{LS_1} \right)^2 \Delta - 0.02 \text{ (for any point)}$$

$$= \frac{1}{3} \left(\frac{10}{250} \right)^2 \times 50 - 0.02 = 0.006 = 0' 24''$$

$$\theta_2 = \frac{1}{3} \left(\frac{L_1}{LS_2} \right)^2 \times 40 - 0.02 = \frac{1}{3} \left(\frac{10}{200} \right)^2 \times 40 - 0.02 = 0.01 = 0' 48''$$

COMPUTATION BY USING TABLES NO.I - XI

Horizontal Alignment (Spiral Curve), Comparison of Results

Element	Computed	Table Value	Table No.
R_m	143.24	143.24 m	VI
Δ	60.00°	60.00°m	VI
Y	96.80	96.80 m	VI
X	268.74	268.73 m	VI
O	25.18	25.16 m	VI
X_o	144.69	144.68 m	VI
LC	285.94	285.93 m	VI
ST	111.78	111.77 m	VI
LT	212.85	212.84 m	VI
CSx_o	.03	.03 m	VI
CSO	.01	.01 m	VI
TS	436.40	436.39 m	VI
ES	193.60	193.60 m	VI

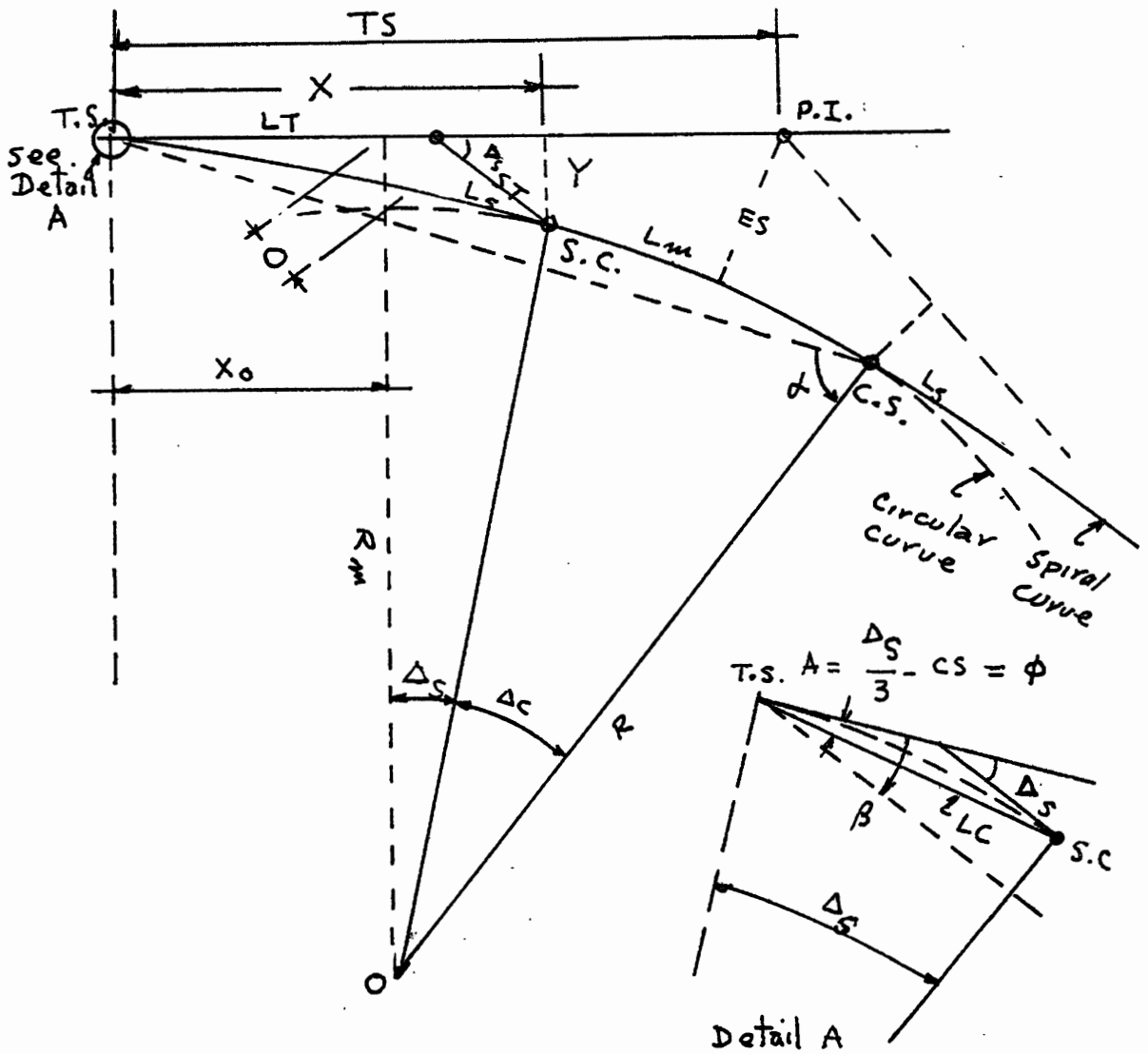


Figure 14.

Project Example, Plan and Design Criteria for Problem No. 2.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The problems of metrication through the entire scope of highway design, survey, traffic control and administration has been explored through a review of the experience of several North American agencies. It has been the combined experience of the various agencies that a 'hard' conversion of all aspects of the process is not immediately possible due to the lack of research into such matters as the flexibility of converting pavement machinery, the standardization and supply of proper metric tools, the lack of complete agreement on rationalized metric units and increments and other matters.

It has been the general experience that no great problem exists in the re-orientation of technical personnel when training facilities are provided and if proper metric tools are available. The matter of availability of metric tools in survey equipment, in design tools, such as curve templates, in proper curve tables, etc. appears to be one of the major difficulties in technical conversion. Indeed the lack of metric curve tables (such as provided by the author in Chapter IV of this study) has caused most agencies to adopt an impractically long station definition (100 m) simply for the reason that standard American 100-foot station tables could be used without revision. The author argues that the metric definition of 'station' should be chosen and rationalized on the basis of

the function of the station as a unit of roadway measurement rather than for the convenience of using existing foot tables. On this point the author proposes the use of the ten metre station definition rather than 100 metres employed in other studies.

In the matter of conversion of highway mileage and speed limit signs, the author rejects the proposals of Ohio and Oregon for dual signs for the reason that it is costly and confusing. Drivers in Canada and elsewhere have adjusted rapidly to direct metric signing.

There has not yet been agreement in the matter of creating a standard and uniquely different convention for denoting stationing in metric. The author rejects the rather cumbersome system used on the first Ohio project and also does not agree with the retention of the 'plus' sign denoting substation points because of its similarity to traditional American convention. Instead, the use of a decimal point for direct reading of roadway length from origin is proposed rather than the plus.

In concluding this study, the above mentioned matters, together with other problems areas identified in the source material are summarized along with the author's recommendations:

Metric Units: The Standard International (SI) units of measurement both the basic (e.g., metre, kilogram) and the derived (e.g., velocity in metre per second, acceleration in metre per second square) are recommended to be used in the highway metrication. Also the useful and practical non-SI units such as the hour, kilometre per hour and hectare are to be used for specific purposes. The use of the metre, millimetre or centimetre should

be related to the degree of accuracy of measurement.

Stationing: The 100-metre station in use is to be replaced by a standard 10-metre station. The present station markings, i.e., the length of a full station and the pluses for intermediate ones are to be replaced by a direct reading from the original point of the surveying using the following designation: S120.50. This means that the point at 120 standard stations and intermediate stations of 5 metres length.

The unit of measurement for a standard station of 10 metres is to be in numbers and decimally related to the length of the total roadway length.

Curve Definition: The curvature of a circular arc is to be defined as the change in direction per length of a standard station of 10 metres along the arc (not the chord). The unit of measurement is to be the degree, minute and second based on the 360° circle system. The degree of curve is to be defined as the central angle subtended by the standard station recommended in this work.

Field Surveying: The present surveying manuals and field books must be metricated in terms of the new definition of the standard station and the curve definition.

The surveying tools intended to be used in design, construction and operation of metric projects must be standard metric tools and not local modifications.

The precision of measurement must be related to the type of work and the degree of accuracy required, e.g., the use of millimetres are too

fine for cross-sections field measurement but they are a necessity for the elevation readings of bench marks. Therefore the author favors the following standards based on recent studies in North America.

<u>Type of Work</u>	<u>Accuracy</u>
1. Bench Marks	± 10 millimetres (0.01 metre)
2. Control Surveying	± 10 millimetres (0.01 metre)
3. Topographical Conditions	± 1 millimetres (0.001 metre)
4. Roadway Elements	± 100 millimetres (0.10 metre)
5. Drainage Elements	± 10 millimetres (0.01 metre), ± 1 millimetre for critical cases
6. Parcel Area	± 0.001 hectare

The angular units must be used based on the 360° circle and the unit of measurement to be used is the degree, minute and second for field surveying to avoid equipment replacement. On the other hand, the degree and its decimals are to be used in the curve calculations to avoid conversion of minutes and seconds to a decimal of a degree.

Control Surveying : The design maps and control co-ordinates in the present system should be converted to metric system by the process detailed in Chapter III of this work based on a scale factor which includes the grid scale and the sea level factor. It is also proposed that the design and contract documents must include such scale factors for direct

relationships between the customary American and the metric system in this respect.

Roadway Design: The design aids (e.g., scales, paper sizes, templates, computer programs, curve tables, . . . etc.) must be converted to facilitate the metrication process as part of these aids are achieved by this work in Chapters III and IV.

The profiles of specific roadway sections must be based on a standard station defined by this work. The earth work calculations, estimates and movements must be based on the same standard station definition.

A typical roadway metric cross-section should be standardized by replacing the present 'soft' converted one. To do this rationalization of a typical cross-section is recommended taking into consideration the design, construction and operation of roadway work such as slope, rate of grades, traffic and roadway conditions and pavement machines design. This typical section could be in the range of 3.10 to 3.70 metre width for one-lane width and 6.20 to 7.40 for 2-lane widths.

The rate of grades, cross-sections, shoulders, ditches, cut and fill slopes are to be standardized in percentages (%) to replace the present practice of percentages and ratios for uniformity purposes.

The design speed values of 40 to 140 kilometres per hour (kph) with a 10 kph increment, adopted by the Canadians, are a reasonable range, but the wet and dry conditions should be applied for both lower and upper design speed ranges to maintain a safe stopping and passing sight distance.

Operation: The signing method proposed in Chapter III of this work must be adopted to avoid the use of a costly dual speed limit zones and distance signs and to maintain a direct understanding and thinking in metric for the motorist and the public as well.

Computer Outputs: The developed series of formulas, computer programs, and computer generated tables in the metric version for design control of horizontal, vertical and combined alignment, should be used for future revision and reassessment of a geometric design manual in a standard format.

Notations: The notations proposed in Chapter III of this work, which were not unified in recent studies can be used as standard notation for the metrication process.

The recent studies have provided valuable information as well as methods and experiences in metrication activities which facilitated the development of this thesis.

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APPENDIX A

COMPUTER PROGRAMS

AND

PRINTOUT

(FORTRAN DIALECT IV)

APPENDIX A

SUMMARY

The computer programs included in this Appendix are written using the "dialect" Fortran IV for both the main and subroutines.

The 1130-Scientific Subroutine Package (SSP)^{*} is used to facilitate branching out for several formulas to be solved. The "CALL" statement was used to transfer control to the subroutine and dummy variables were replaced in the subroutine with values of the actual arguments. The program consists of main steps a) the type of operation, b) input-output statements, c) control statement execution, d) procedure information. The computer programs in this work were executed at HARRIS Computer Center owned by Portland State University.

* SSP = I.B.M.-1130 Scientific Subroutine Package Programmer's Manual, Program Number 1130-CM-02X, International Business Machines Corporation 1967/68, Fifth edition.

```

DIMENSION TABLE1(25,24),TABLE1(25,12),METERS(4),RADII(4)
DATA METERS/10,20,40,100/
DATA RADII/572.9570,1145.916,2291.813,5729.578/
DO 400 K=1,4
WRITE (6,10)
10 FORMAT ('1')
DO 400 M=1,4
WRITE (6,20)
20 WRITE ('2')
DO 400 N=1,4
WRITE (6,30)
30 WRITE ('3')
DO 400 O=1,4
WRITE (6,40)
40 WRITE ('4')
DO 400 P=1,4
WRITE (6,50)
50 WRITE ('5')
DO 100 L1=1,25
V=40.
DO 100 L2=1,11
TABLE1(L1,1)=L1
TABLE1(L1,2)=RADII (K4)/L1
DO 100 L2=1,11
TABLE1(L1,2+L2+1)=0.0000039*D+V**2
TABLE1(L1,2+L2+2)=0.000030540*V**3
IF (TABLE1(L1,2+L2+2)-40.)85.95.95
85 TABLE1(L1,2+L2+2)=40.
95 V=V+10.
100 CONTINUE
DO 160 K=2,12
DO 160 L=1,25
TABLE1(L,K)=TABLE1(L,2*K)
160 CONTINUE
WRITE (6,170) TABLE1(1,1),TABLE1(1,2),TABLE1(1,3),TABLE1(1,2),(TAB
LE1(1,1),L=5,24,2),(TABLE1(1,M),M=3,12)
170 FORMAT ('5X,13,F4.2,1X,F4.3,13,1X,10(F3.2,5X),140,10(13,5X))
DO 400 K=2,25
WRITE (6,200)TABLE1(K,1),TABLE1(K,2),(TABLE1(K,M),M=3,24,2),(TAB
LE1(K,M),M=2,12)
200 FORMAT ('15X,13, F4.2,1X,11(F3.2,5X),132,11(13,5X))
400 CONTINUE
500 WRITE (6,500)
500 FORMAT ('1')
CALL EXIT
END
    
```

```

9 MAR 78 0135149      MODULE: *MAIN*
61516-02 ENHANCED SAU FORTRAN COMPILER
                                OPTIONS:
                                REVISION LEVEL 31.011878      SOURCE INPUT:      SP# 429
SURROUTINE IAHFR1 (R,D,C,C1,C2,C3)
C=2*R*SIN(D/2*.0174533)
C1=2*R*SIN(D*.0174533)
C2=2*R*SIN(2*D*.0174533)
C3=2*R*SIN(5*D/1*.0174533)
RETURN
FND

```

```

3 00000
4 00000
5 00020
6 00032
7 00045
8 00060
9 00061

```

9 MAR 78 0:35:40 MODULE: *MAIN*
 61516-02 ENHANCED SAU FORTRAN COMPILER

SUBROUTINE YAHF2 (R,D,C,C1,C2,C3)
 C =2*R*SIN(D/4*.0174533)
 C1=2*R*SIN(D/2*.0174533)
 C2=2*R*SIN(D*.0174533)
 C3=2*R*SIN(5*D/2*.0174533)
 RETURN
 END

OPTIONS:
 REVISION LEVEL 31.011878 SOURCE INPUT: SP## 429

10 00000
 11 00000
 12 00020
 13 00033
 14 00045
 15 00061
 16 00062

```

9 MAR 78 0:35:49      MODULE: *MAIN*      OPTIONS:
61516-02 FMIANCFD SAI FORTRAN COMPILER  REVISION LEVEL 31.011878  SOURCE INPUT:  SP## 429

SUBROUTINE TAHR3 (R,D,C,C1,C2,C3)
C =2*R*SIN(D/8*.0174533)
C1=2*R*SIN(D/4*.0174533)
C2=2*R*SIN(D/2*.0174533)
C3=2*R*SIN(5*D/4*.0174533)
RETURN
END

```

```

17 00000
18 00000
19 00020
20 00033
21 00046
22 00062
23 00063

```

9 MAR 78 08:35:49 MODULE: *MAIN*
 61516-02 ENHANCED SAI FORTRAN COMPILER
 SURROUTINE TAHERA (R,D,C,C1,C2,C3)
 C =2*RR* SIN(D/20*.0174533)
 C1=2*RR* SIN(D/10*.0174533)
 C2=2*RR* SIN(D/5*.0174533)
 C3=2*RR* SIN(D/2*.0174533)
 RETURN
 END

OPTIONS:
 REVISION LEVEL 31.011878 SOURCE INPIJT: SP## 429

24 00000
 25 00000
 26 00020
 27 00033
 28 00046
 29 00061
 30 00062

```

9 MAR 78 0135:49          MODULE: *MAIN*      OPTIONS:
61516-02 ENHANCED SAU FORTRAN COMPILER      REVISION LEVEL 31.01187A      SOURCE INPUT:      SP## 429

      DIMENSION CNST1(4),CNST2(4)
      DATA CNST1/572.9578,1145.916,2291.832,5729.578/
      DATA CNST2 /10.,20.,40.,100./
      DO 410 K4=1,4
      ISW1=0
      1 WRITE (6,5)
      5 FORMAT ('1')
      WRITE (6,10)
      10 FORMAT(40X,'TABLE II'//22X,'RADIOI,DEFLECTIONS AND CHORDS "ARC DEFINI
      INITIUM"')
      WRITE (6,20)
      20 FORMAT (15X,'DFGREE',2X,'RADIUS',2X,'DEFLECTIONS',11X,'CHORD FOR')
      WRITE (6,30)
      30 FORMAT (17X,'OF',6X,'OF',9X,'FOR')
      WRITE (6,40)
      40 FORMAT (15X,'CURVE',3X,'CURVE',3X,'1 M.',3X,'20 M.',2X,'10 M.',2X
      '120 M.',2X,'40 M.',3X,'100 M.')
      WRITE (6,50)
      50 FORMAT (31X,'OF ARC',4(1X,'OF ARC'),2X,'OF ARC')
      60 FORMAT (16X,'0',11,'4X','METER',4X,'0',11,'4X','0',11,'3X','METER',2X,'M
      IETER',2X,'METER',3X,'METER')
      IF (ISW1) 200,65,200
      65 WRITE (6,70)
      70 FORMAT (16X,'0',11,'4X','0',11,'4X','0',11,'3X','METER',2X,'M
      ISTOP=0
      ICONT=0
      IA=0
      IF=0
      IB=0
      IC=0
      NI=2
      NJ=5
      75 DO 95 K2=1,N1
      IF=JF+10
      ICONT=ICONT+5
      AK2=K2
      AIR=IR
      D=AK2/6+AIR
      R=CNST1(K4)/D
      DELT20=D/2
      DELTA1=DELT20/(CNST2(K4))
      80 TO (700,701,702,703),K4
      700 CALL TAHER1 (R,D,C,C1,C2,C3)
      80 TO 76
      701 CALL TAHER2 (R,D,C,C1,C2,C3)
      80 TO 76
      702 CALL TAHER3 (R,D,C,C1,C2,C3)
      80 TO 76
      703 CALL TAHER4 (R,D,C,C1,C2,C3)
      76 WRITE (6,R0)IF,R,DELTA1,ICONT,C,C1,C2,C3
      80 FORMAT (18X,12,2X,FR,3,1X, F5.2,4X,12,3X,3(F6.3,1X),1X,F7.3)
      95 CONTINUE
      IF (ISW2) 88,97,88
      97 IF=0
      ISW2=1
31 00000
32 00000
33 00000
34 00000
35 00004
36 00005
37 00011
38 00016
39 00022
40 00022
41 00056
42 00062
43 00110
44 00114
45 00130
46 00134
47 00134
48 00177
49 00203
50 00224
51 00230
52 00230
53 00271
54 00272
55 00277
56 00312
57 00313
58 00314
59 00315
60 00316
61 00317
62 00320
63 00322
64 00324
65 00326
66 00332
67 00334
68 00336
69 00341
70 00344
71 00350
72 00356
73 00361
74 00364
75 00376
76 00405
77 00405
78 00415
79 00415
80 00425
81 00425
82 00435
83 00471
84 00512
85 00515
86 00516
87 00520

```



```

9 MAR 78 0:35:49      MODULE: *MAIN*      OPTIONS:
61516-02 ENHANCED SAU FORTRAN COMPILER    REVISION LEVEL 31.01187A      SOURCE INPUT:      SP# 429

ICNT=ICNT+5
IB=IR+1
D=IR
P=CNST1(K4)/D
DELTA=D/2
DELTA1=DELTA/(CNST2(K4))
GO TO (710,711,712,713),K4
710 CALL TAHER1 (R,D,C,C1,C2,C3)
GO TO A6
711 CALL TAHER2 (R,D,C,C1,C2,C3)
GO TO A6
712 CALL TAHER3 (R,D,C,C1,C2,C3)
GO TO A6
713 CALL TAHER4 (R,D,C,C1,C2,C3)
86 WRITE (6,87) IR,IF,R,DELTA1,IA,ICNT,C,C1,C2,C3
87 FORMAT(/15X,I2,I1X,I2,2X,F8.3,I1X, F5.2,I1X,I2,I1X,I2,3X,3(F6.3,I1X),1
1X,F7.3)
GO TO 75
88 IF=0
ISW2=0
IA=IA+1
ICNT=0
IB=IR+1
D=IB
P=CNST1(K4)/D
DELTA=D/2
DELTA1=DELTA/(CNST2(K4))
GO TO (720,721,722,723),K4
720 CALL TAHER1 (R,D,C,C1,C2,C3)
GO TO 100
721 CALL TAHER2 (R,D,C,C1,C2,C3)
GO TO 100
722 CALL TAHER3 (R,D,C,C1,C2,C3)
GO TO 100
723 CALL TAHER4 (R,D,C,C1,C2,C3)
100 ISTOP=ISTOP+1
IF (ISTOP=3) 200,400,200
200 WRITE (6,90) IR,IF,R,DELTA1,IA,C,C1,C2,C3
90 FORMAT(/15X,I2,I1X,I2,2X,F8.3,I1X, F5.2,I1X,I2,I1X,I2,3X,F6.3,I1X,F6
1.3,I1X,F6.3,2X,F7.3)
GO TO 75
400 IF (IB=51) 405,410,410
405 ISW1=1
ISTOP=0
GO TO 1
410 CONTINUE
600 WRITE (6,600)
600 FORMAT ('1')
CALL EXIT
END

```

```

88 00522
89 00524
90 00525
91 00530
92 00536
93 00541
94 00544
95 00556
96 00565
97 00565
98 00575
99 00575
100 00605
101 00605
102 00615
103 00657
104 00657
105 00705
106 00705
107 00707
108 00710
109 00711
110 00712
111 00713
112 00716
113 00724
114 00727
115 00732
116 00744
117 00753
118 00753
119 00763
120 00763
121 00773
122 00775
123 01003
124 01004
125 01006
126 01046
127 01046
128 01077
129 01077
130 01102
131 01105
132 01106
133 01106
134 01112
135 01116
136 01123
137 01124

```

```

ISTOP=0
IDELTA=0
D=1.
5 WRITE (6,10)
10 FORMAT ('1')
WRITE (6,20)
20 FORMAT (55X,'TABLE III - A/')
WRITE (6,30)
30 FORMAT (47X,'FUNCTIONS OF SIMPLE CIRCULAR CURVE')
WRITE (6,40)
40 FORMAT (21X,'A UNIT CURVE OF LENGTH 10 METERS OF ARC',13X,'A UNIT
    1 CURVE OF LENGTH 20 METERS OF ARC/')
WRITE (6,50)
50 FORMAT (19X,'DELTA',5X,'R',6X,'T',6X,'L',6X,'H',5X,'E',6X,'C',6X,'
    DELTA',4X,'R',6X,'T',9X,'L',5X,'M',5X,'E',6X,'C')
WRITE (6,60)
60 FORMAT (20X,'0',48X,'0')
70 IDELTA=IDELTA+1
IF (IDELTA-51) 75,200,75
75 RELTA=IDELTA
IV=0
ISW1=0
DO 100 K=1,6
DV=IV
DELTA=RELTA+DV/60
R1040=572.9578/DELTA
T1040=R1040*TAN(DELTA/2*.0174533)
DL1040=10.*DELTA/D
DM1040= R1040*(1-COS(DELTA/2*.0174533))
E1040=T1040*TAN(DELTA/4*.0174533)
C1040=2*R1040*SIN(DELTA/2*.0174533)
R20100=1145.9167/DELTA
T20100=R20100*TAN(DELTA/2*.0174533)
D20100=20.*DELTA/D
A20100=R20100*(1-COS(DELTA/2*.0174533))
E20100=120100*TAN(DELTA/4*.0174533)
C20100=2*R20100*SIN(DELTA/2*.0174533)
IF (ISW1) 76,79,76
76 WRITE (6,77) IV,R1040,T1040,DL1040,DM1040,E1040,C1040,
1 IV,R20100,T20100,D20100,A20100,E20100,C20100
77 FORMAT (18X,3X,1X,12,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F
    16,3,4X,13,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F6.3/)
IV=IV+10
GO TO 100
79 WRITE (6,80) IDELTA,IV,R1040,T1040,DL1040,DM1040,E1040,C1040,IDELT
    1A,IV,R20100,T20100,D20100,A20100,E20100,C20100
80 FORMAT (18X,13,1X,12,2X,F7.2,2X,F5.2,2X,F7.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F
    16,3,14,13,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F6.3/)
IV=IV+10
ISW1=1
100 CONTINUE
ISTOP=ISTOP+1
IF (ISTOP-4) 70,190,70
190 ISTOP=0
GO TO 5
200 CALL TAHER
WRITE (6,205)
    
```

31 JAN 76 15:29:09 MODULE: *MAIN* OPTIONS: 267
61516-02 ENHANCED SAU FORTRAN COMPILER REVISION LEVEL 31.121677 SOURCE INPUT AREA: SP# 206 RECORD: 267

267	00710
268	00715
269	00716

205 FORMAT ('1')
CALL EXIT
END

```

SUBROUTINE TAHER
  ISTOP=0
  IDELTA=0
  N=1.
  5 WRITE (6,10)
  10 FORHAT ('11')
  WRITE (6,20)
  20 FORMAT (55X,'TABLE III - R1/')
  30 FORMAT (47X,'FUNCTIONS OF SIMPLE CIRCULAR CURVE')
  40 FORHAT (21X,'A UNIT CURVE OF LENGTH 40 METERS OF ARC',13X,'A UNIT
    1 CURVE OF LENGTH 100 METERS OF ARC')
  50 FORMAT (19X,'DELTA',5X,'R',6X,'T',8X,'L',11,6X,'M',5X,'E',6X,'C',4X,'
    1 DELTA',4X,'R',8X,'T',9X,'L',5X,'M',5X,'E',6X,'C')
  WRITE (6,60)
  60 FORHAT (20X,'0 11,4AX,10 111')
  70 IDELTA=IDELTA+1
  IF (IDELTA-26) 75,200,75
  75 RELTA=IDELTA
  IV=0
  ISW1=0
  DO 100 K=1,6
  DV=IV
  DELTA=RELTA+DV/60
  R1040=2291.830/DELTA
  T1040=R1040*TAN(DELTA/2*.0174533)
  L1040=40.*DELTA/D
  DM1040= R1040*(1-COS(DELTA/2*.0174533))
  E1040=T1040*TAN(DELTA/4*.0174533)
  C1040=2*R1040*SIN(DELTA/2*.0174533)
  R20100=5729.578/DELTA
  T20100=R20100*TAN(DELTA/2*.0174533)
  O20100=100.*DELTA/D
  A20100=R20100*(1-COS(DELTA/2*.0174533))
  E20100=T20100*TAN(DELTA/4*.0174533)
  C20100=2*R20100*SIN(DELTA/2*.0174533)
  IF (ISW1) 76,79,76
  76 WRITE (6,77)
  1 IV,R20100,I20100,O20100,A20100,E20100,C20100
  16.3,4X,I3,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F
  IV=IV+10
  GO TO 100
  79 WRITE (6,80) IDELTA,IV,R1040,T1040,DL1040,DM1040,E1040,C1040,IDELT
  1A,IV,R20100,I20100,O20100,A20100,E20100,C20100
  80 FORHAT (18X,I3,1X,I2,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F
  16.3,4X,I3,2X,F7.2,2X,F5.2,2X,F7.2,1X,F5.2,1X,F5.2,2X,F6.3/)
  IV=IV+10
  ISW1=1
  100 CONTINUE
  ISTOP=ISTOP+1
  IF (ISTOP-4) 70,190,70
  190 ISTOP=0
  GO TO 5
  200 RETURN
  
```

31 JAN 78 15129109

MODULE: TAHER
6151A-02 ENHANCED SAU FORTRAN COMPILER

OPTIONS1

REVISION LEVEL 31.121677

SOURCE INPUT AREA: SP# 206 RECORD# 209

END

209 00705

```

DIMENSION TABLE5(11),TABLEE(4)
DATA TABLE7,.17,.16,.15,.14,.13,.12,.12,.11,.10/
DO 300 M=1,4
WRITE (6,10)
10 FORMAT ('1')
WRITE (6,20)
20 FORMAT (45X,'TABLE V ')
WRITE (6,30)
30 FORMAT (30X,'MAXIMUM DEGREE OF CURVE AND MINIMUM RADIUS')
WRITE (6,40)
40 FORMAT (30X,'DETERMINED FOR LIMITING VALUES OF E AND F')
WRITE (6,50)
50 FORMAT (45X,'1',14X,'MAX DEGREE OF',07X,'MAX. D.C.1')
WRITE (6,60)
60 FORMAT (15X,'DESIGN',1X,'MAXIM-',1X,'MAXIMUM-',2X,'TOTAL',3X,'MINIM
1UM',7X,'CURVE FOR',11X,'ROUNDED')
WRITE (6,70)
70 FORMAT (15X,'SPEED',2X,'UM',5X,'UM',15X,'RADIUS')
WRITE (6,80)
80 FORMAT (15X,'K.P.H.',3X,'E',6X,'F',7X,'E+F',6X,'IN',5X,'10M',3X,'2
10M',3X,'40M',3X,'100M',2X,'10.',20',40',100')
WRITE (6,90)
90 FORMAT (46Y,'METER',4X,4('ARC',3X))
IV=30
DO 200 L=1,11
IV=IV+10
TOTAL=TABLE5(L)+TABLEE(M)
R=0.007874*IV**2/TOTAL
D40=D100/2.5
D20=D100/5
D10=D100/10
IR=R
D1100=D100+.5
D140=D40+.5
D120=D20+.5
D110=D10+.5
WRITE(6,100) IV, TABLE(M),TABLE5(L),TOTAL,IR,D10,D20,D40,D10
10 ,D10,D20,D40,D100
100 FORMAT (16X,I3,3X,F3.2,6X,F4.2,5X,F4.2,6X,I3,2X,3(F6.2),F7.2,3(I3)
1,X,I3)
200 CONTINUE
WRITE (6,210)
210 FORMAT(30X,'*RADIUS ASSUMED SAME FOR ALL ARCS, I.E.1')
WRITE (6,220)
220 FORMAT (31X,'DEGREE OF CURVES ARE CHANGED.1')
300 CONTINUE
WRITE (6,10)
CALL EXIT
END
  
```

438	00000
439	00000
440	00000
441	00000
442	00004
443	00010
444	00015
445	00021
446	00031
447	00035
448	00060
449	00064
450	00110
451	00114
452	00116
453	00142
454	00142
455	00205
456	00211
457	00232
458	00236
459	00236
460	00307
461	00313
462	00327
463	00331
464	00335
465	00337
466	00347
467	00355
468	00365
469	00370
470	00373
471	00376
472	00401
473	00405
474	00411
475	00415
476	00421
477	00421
478	00505
479	00505
480	00532
481	00535
482	00541
483	00564
484	00570
485	00607
486	00612
487	00616
488	00617

```

SUBROUTINE TAHER1
COMMON METERS(4), IHOLD(16), IDG(19), IMIN(19), EXTRA(4), K4, DDIV(4)
WRITE (6,10)
10 FORMAT (11)
WRITE (6,20)
20 FORMAT (1X,20X,37X,'TABLE VI SELECTED SPIRALS',//)
WRITE (6,30) METERS(K4)
30 FORMAT (1X,20X,43X,13,'-METER=ARC')
WRITE (6,50)
50 FORMAT (1X,20X,23X,'0',13X,'X0')
WRITE (6,60)
60 FORMAT (1X,20X,2X,'LS',4X,'DELTA',37X,'X',6X,'Y',7X,'L T',4X,'S T
-',6X,'L C',4X,'T 9',5X,'E 9')
WRITE (6,70)
70 FORMAT (1X,20X,16X,'D A',5X,'C 8',5X,'D A',4X,'C 8')
WRITE (6,80)
80 FORMAT (1X,20X,9X,'0',5X,'111')
RETURN
END
    
```

522	00000
523	00000
524	00000
525	00005
526	00012
527	00016
528	00037
529	00052
530	00066
531	00072
532	00105
533	00111
534	00111
535	00152
536	00156
537	00177
538	00203
539	00216
540	00217

```

COMMON METERS(4),I HOLD(16),IDG(19),IMIN(19),EXTRA(4),K4,DDIV(4)
DATA DDIV/200.,60.,40.,20./
DATA I HOLD/100,125,150,200,250,300,350,400,450,500,550,600,700,800
  ,900,1000/
DATA IDG/0,0,0,1,1,1,1,2,2,2,3,3,4,5,5,6,6/
DATA IMIN/30,40,50,60,70,80,90,100,110,120,130,140,150,160,170,180,190/
DATA METERS /100,40,20,10/
DATA EXTRA/5729,5780,2291,8312,1145,9156,572,9378/
C=57,2957795
DO 400 K4=1,4
IFLOW=0
CALL TAKER1
I1=1
I2=5
I3=1
I4=16
DO 130 L=11,12
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
35 FORMAT (1X,19X,41X,101,3X,1111)
WRITE (6,85) IDG(L),IMIN(L),R100
85 FORMAT (1X,20X,36X,101,12,1,1,12,1X ,2X,'R=',F6.2,' METERS')
CALL TAKER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 130,125,125
125 CALL TAKER1
IFLOW=0
130 CONTINUE
I HOLD(13)=650
I HOLD(14)=700
I HOLD(15)=800
I HOLD(16)=900
I1=6
I2=7
I3=1
I4=16
DO 131 L=11,12
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAKER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 131,126,126
126 CALL TAKER1
IFLOW=0
131 CONTINUE
I HOLD(13)=700
I HOLD(14)=800
I1=8
I2=10
I3=1
I4=14
DO 132 L=11,12

```

```

541 00000
542 00000
543 00000
544 00000
545 00000
546 00000
547 00000
548 00000
549 00000
550 00002
551 00006
552 00007
553 00010
554 00012
555 00014
556 00016
557 00020
558 00024
559 00025
560 00031
561 00036
562 00043
563 00047
564 00062
565 00105
566 00132
567 00142
568 00144
569 00146
570 00147
571 00152
572 00154
573 00156
574 00160
575 00162
576 00164
577 00166
578 00170
579 00172
580 00176
581 00177
582 00203
583 00210
584 00215
585 00221
586 00244
587 00254
588 00256
589 00260
590 00261
591 00264
592 00266
593 00270
594 00272
595 00274
596 00276
597 00300

```



```

IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAHER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 132,127,127
127 CALL TAHER1
IFLOW=0
132 CONTINUE
11=11
12=13
13=1
14=13
DO 133 L=11,12
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAHER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 133,128,128
128 CALL TAHER1
IFLOW=0
133 CONTINUE
IHOLD(13)=650
11=14
12=15
13=1
14=13
DO 134 L=11,12
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAHER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 134,129,129
129 CALL TAHER1
IFLOW=0
134 CONTINUE
11=16
12=17
13=1
14=12
DO 135 L=11,12
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAHER (11,12,13,14,D,R100,C)
IF (IFLOW-3) 135,200,200

```

598 00304
 599 00305
 600 00311
 601 00316
 602 00323
 603 00327
 604 00352
 605 00362
 606 00364
 607 00366
 608 00367
 609 00372
 610 00374
 611 00376
 612 00400
 613 00402
 614 00406
 615 00407
 616 00413
 617 00420
 618 00425
 619 00431
 620 00454
 621 00464
 622 00466
 623 00470
 624 00471
 625 00474
 626 00476
 627 00500
 628 00502
 629 00504
 630 00506
 631 00512
 632 00513
 633 00517
 634 00524
 635 00531
 636 00535
 637 00560
 638 00570
 639 00572
 640 00574
 641 00575
 642 00600
 643 00602
 644 00604
 645 00606
 646 00610
 647 00614
 648 00615
 649 00621
 650 00626
 651 00633
 652 00637
 653 00662
 654 00672

31 JAN 76 15130126 MODULE: *MAIN* OPTIONS: SOURCE INPUT AREA: SPM# 206 RECORD: 655
 61516-02 ENHANCED SAU FORTRAN COMPILER REVISION LEVEL 31.121677

```

200 CALL TAHER1
IFLOW=0
135 CONTINUE
I1=10
I2=19
I3=1
I4=11
DO 500 L=I1,I2
IFLOW=IFLOW+1
AIMIN=IMIN(L)
D=IDG(L)+AIMIN/60.
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,85) IDG(L),IMIN(L),R100
CALL TAHER (I1,I2,I3,I4,D,R100,C)
IF (IFLOW-3) 500,495,495
495 CALL TAHER1
IFLOW=0
500 CONTINUE
I1=7
I2=18
I3=1
I4=11
DO 220 L=I1,I2
IFLOW=IFLOW+1
D=L
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,210) L,R100
210 FORMAT (I1,20X,36X,'D=',I2,7X,'R=',F7.2,' METERS')
CALL TAHER (I1,I2,I3,I4,D,R100,C)
IF (IFLOW-3) 220,410,410
410 CALL TAHER1
IFLOW=0
220 CONTINUE
I1=19
I2=25
I3=1
I4=10
DO 230 L=I1,I2
IFLOW=IFLOW+1
D=L
R100=EXTRA(K4)/D
WRITE (6,35)
WRITE (6,210) L,R100
CALL TAHER (I1,I2,I3,I4,D,R100,C)
IF (IFLOW-3) 230,450,450
450 CALL TAHER1
IFLOW=0
230 CONTINUE
IHOLD(13)=700
IHOLD(14)=600
IHOLD(15)=900
IHOLD(16)=1000
600 CONTINUE
WRITE (6,900)
900 FORMAT ('I1',

```

655 00674

656 00676

657 00677

658 00702

659 00704

660 00706

661 00710

662 00712

663 00716

664 00717

665 00723

666 00730

667 00735

668 00741

669 00764

670 00774

671 00776

672 01000

673 01001

674 01004

675 01006

676 01010

677 01012

678 01014

679 01020

680 01021

681 01024

682 01031

683 01035

684 01047

685 01070

686 01100

687 01102

688 01104

689 01105

690 01110

691 01112

692 01114

693 01116

694 01120

695 01124

696 01125

697 01130

698 01135

699 01141

700 01153

701 01163

702 01165

703 01167

704 01170

705 01173

706 01175

707 01177

708 01201

709 01203

710 01206

711 01212

31 JAN 78 15:30:26 MODULE: *MAIN* OPTIONS: SOURCE INPUT AREA: SPMM 206 RECORD: 712
61516-02 ENHANCED SAU FORTRAN COMPILER REVISION LEVEL 31.121677

CALL EXIT
END
712 01217
713 01220

```

DIMENSION WN(3),C(3),TABLE1(9),TABLE2(8),TABLE3(6),ITYPE(4),IMETER
1(4),Z(9),CONST(4)
DIMENSION TREAD(80)
DATA WN/7.40,6.80,6.20/
DATA C/0.92,0.76,0.61/
DATA ITYPE/'A','B','C','D'/
DATA IMETER/10,20,40,100/
DATA CONST/572.958,1145.916,2291.825,5729.578/
DO 600 K1=1,4
  ID1=0
  DO 550 K2=1,3
    WRITE (6,10)
  10 FORMAT ('1')
  20 WRITE (6,20) ITYPE(K1),IMETER(K1)
  21 WRITE (6,21)
  21 FORMAT (5X,'PAVEMENT WIDENING ON OPEN HIGHWAY CURVES'//)
  22 WRITE (6,22)
  22 FORMAT (5X,'2-LANE PAVEMENTS ONE-WAY OR TWO-WAY'//)
  23 WRITE (6,23)
  23 FORMAT (17X,'DEGREE',27X,'W = WIDENING IN METERS FOR 2-LANE P
    PAVEMENTS ON'//)
  24 WRITE (6,24)
  24 FORMAT (50X,'CURVES FOR WIDTH OF PAVEMENT ON TANGENT OF '
    1//)
  25 WRITE (6,25)
  25 FORMAT (19X,'OF',16X,'WN = 7.40 METERS',21X,'WN = 6.80 METERS',1
    13X,'WN = 6.20 METERS'//)
  26 WRITE (6,26)
  26 FORMAT (35X,'DESIGN SPEED IN KPH',16X,'DESIGN SPEED IN KPH',
    16X,'DESIGN SPEED IN KPH'//)
  27 WRITE (6,27)
  27 FORMAT (17X,'CURVE 50 60 70 80 90 100 110 120 130
    150 60 70 80 90 100 110 120 50 60 70 80 90 100'//)
  DO 500 ID=1,15
    ID1=ID1+1
    V=50.
    A=CONST(K1)/JD1
    U=2.592+A-SORT(A**2-37.179)
    FA=SQRT(A**2+5.0 )-A
    DO 100 L=1,9
      Z(L)=V/(3.7 *SQRT(A))
      V=V+10.
  100 CONTINUE
    DO 200 L=1,9
      WC=2*(U+C(1))+FA+Z(L)
      TABLE1(L)=WC-WN(1)
  200 CONTINUE
    DO 300 L=1,9
      WC=2*(U+C(2))+FA+Z(L)
      TABLE2(L)=WC-WN(2)
  300 CONTINUE
    DO 400 L=1,6
      WC=2*(U+C(3))+FA+Z(L)
      TABLE3(L)=WC-WN(3)
  400 CONTINUE
    WRITE(6,410)ID1,(TABLE1(L),L=1,9),(TABLE2(L,2)=1,8),(TABLE3(L,3

```

```

31 JAN 78 15:29:42      MODULE: MAIN*  OPTIONS:
61516-02 ENHANCED SAU FORTRAN COMPILER  REVISION LEVEL 31.121677  SOURCEF INPUT AREA: SP# 206  RECORD: 329

1),L,3=1,6)
410 FORMAT (18X,12,5X,9(F3.1,2X),8(F3.1,1X),1X,6(F3.1,1X)/)
500 CONTINUE
550 CONTINUE
600 CONTINUE
    WRITE (6,510)
510 FORMAT('1')
650 READ (7,700) IREAD
700 FORMAT (A0A1)
    IF (IREAD(1).EQ.'9') GO TO 800
    WRITE (6,710) IREAD
710 FORMAT (1X,80A1)
    GO TO 650
800 WRITE (6,801)
801 FORMAT ('1')
805 READ (7,810) IREAD
810 FORMAT (80A1)
    IF (IREAD(1).EQ.'9') GO TO 900
    WRITE (6,820) IREAD
820 FORMAT (1X,80A1)
    GO TO 805
900 WRITE (6,910)
910 FORMAT ('1')
    CALL EXIT
    END

```

```

329 00607
330 00670
331 00711
332 00714
333 00717
334 00722
335 00726
336 00733
337 00742
338 00747
339 00754
340 00764
341 00772
342 00772
343 00777
344 01004
345 01013
346 01020
347 01025
348 01035
349 01043
350 01043
351 01050
352 01055
353 01056

```

Note: This program includes a printout of Table IV and VII.

```

SUBROUTINE TAKER2
DIMENSION ISPEED(11),F1(11),F2(11)
COMMON ISSD(11)
COMMON ISUB(28),R(4),PW(11)
DATA ISPEED/31,47,54,63,70,78,87,91,97,104,111/
DATA F1/.34,.36,.34,.32,.31,.30,.29,.28,.27,.27/
DATA F2/.64,.62,.60,.58,.57,.56,.55,.54,.53,.53/
WRITE (6,10)
10 FORMAT ('11')
WRITE (6,20)
20 FORMAT (16X,27X,'TABLE IX - A'/)
WRITE (6,30)
30 FORMAT (16X,14X,'MINIMUM STOPPING SIGHT DISTANCE (S.S.D)'/)
WRITE (6,40)
40 FORMAT (16X,1X,'DESIGN RUNNING PERCEPTION AND COEFFICIENT BRAK
ING STOPPING SIGHT'/)
WRITE (6,50)
50 FORMAT (16X,2X,'SPEED SPEED BRAKE REACTION',15X,'DISTANCE DIS
TANCE IN METERS')
WRITE (6,60)
60 FORMAT (16X,37X,'0F')
WRITE (6,70)
70 FORMAT (16X,3X,'KPH',3X,'KPH',5X,'TIME',3X,'DISTANCE',16X,'METERS'
,15X,'COMPUTED ROUNDED')
WRITE (6,80)
80 FORMAT (16X,35X,'FRICTION')
WRITE (6,90)
90 FORMAT (16X,17X,'SECOND METERS')
WRITE (6,100)
100 FORMAT (16X,27X,'S1',9X,'F',10X,'S2',11X,'SSD1'/)
WRITE (6,110)
110 FORMAT (16X,10X,'DESIGN CRITERIA-WET PAVEMENTS'/)
IV=40
T=2.5
DO 120 L=1,11
S1=0.279*ISPEED(L)*T
S2=ISPEED(L)**2/(255*F1(L))
SSD=S1+S2
ISSD(L)=SSD+.5
WRITE (6,111) IV,ISPEED(L),T,S1,F1(L),S2,SSD,ISSD(L)
111 FORMAT (16X,5X,13,4X,13,4X,F3.1,6X,F5.2,5X,F4.2,6X,F6.2,4X,F6.2,5X
,13/)
IV=IV+10
120 CONTINUE
WRITE (6,130)
130 FORMAT (/16X,15X,'COMPARATIVE VALUES-DRY PAVEMENTS'/)
IV=40
DO 140 L=1,11
S1=0.279*IV*T
S2=IV**2/(255*F2(L))
SSD=S1+S2
JSSD=SSD+.5
WRITE (6,111) IV,IV,T,S1,F2(L),S2,SSD,JSSD
IV=IV+10
140 CONTINUE
RETURN
END

```

716 00000
 717 00000
 718 00000
 719 00000
 720 00000
 721 00000
 722 00000
 723 00000
 724 00005
 725 00012
 726 00016
 727 00031
 728 00035
 729 00062
 730 00066
 731 00066
 732 00125
 733 00131
 734 00131
 735 00165
 736 00171
 737 00200
 738 00204
 739 00204
 740 00243
 741 00247
 742 00260
 743 00264
 744 00277
 745 00303
 746 00324
 747 00330
 748 00351
 749 00353
 750 00355
 751 00361
 752 00367
 753 00401
 754 00404
 755 00414
 756 00463
 757 00463
 758 00510
 759 00512
 760 00515
 761 00521
 762 00544
 763 00546
 764 00552
 765 00557
 766 00571
 767 00574
 768 00600
 769 00640
 770 00642
 771 00645
 772 00646

```

SUBROUTINE TAHER4 (LNECNT, IPAGE)
COMMON ISPFED(11),F1(11),F2(11), CSSD(11)
ICNT=1
GRADE=ICNT
GRADE=GRADE/100
CALL TAHER1 (GRADE)
WRITE (6,180) ICNT,( CSSD(L),L=1,11)
180 FORMAT (16X,3X,12,4X,11F7.1/)
LNECNT=LNECNT+2
ICNT=ICNT+1
GRADE=ICNT
GRADE=GRADE/100
CALL TAHER1 (GRADE)
WRITE (6,190) ICNT,( CSSD(L),L=1,11)
190 FORMAT (16X,3X,12,4X,11F7.1,3X,'DECREASING'//)
ICNT=ICNT+1
LNECNT=LNECNT+2
GRADE=ICNT
GRADE=GRADE/100
CALL TAHER1 (GRADE)
WRITE (6,200) ICNT,( CSSD(L),L=1,11)
200 FORMAT (16X,3X,12,4X,11F7.1,6X,'FOR,/')
ICNT=ICNT+1
LNECNT=LNECNT+2
GRADE=ICNT
GRADE=GRADE/100
CALL TAHER1 (GRADE)
WRITE (6,210) ICNT,( CSSD(L),L=1,11)
210 FORMAT (16X,3X,12,4X,11F7.1,4X,'UPGRADE'//)
DO 240 L=4,25
LNECNT=LNECNT+2
IF (LNECNT-55) 220,220,230
220 ICNT=ICNT+1
GRADE=ICNT
GRADE=GRADE/100
CALL TAHER1 (GRADE)
WRITE (6,180) ICNT,(CSSD(11),M=1,11)
GO TO 240
230 WRITE (6,231)
231 FORMAT ('11')
IPAGE=IPAGE+1
WRITE (6,250) IPAGE
250 FORMAT (16X,79X,'PAGE',13///)
LNECNT=3
240 CONTINUE
RETURN
END

```

895 00000
896 00000
897 00000
898 00007
899 00012
900 00015
901 00017
902 00044
903 00056
904 00060
905 00061
906 00064
907 00067
908 00071
909 00116
910 00136
911 00137
912 00141
913 00144
914 00147
915 00151
916 00176
917 00213
918 00214
919 00216
920 00221
921 00224
922 00226
923 00253
924 00272
925 00276
926 00300
927 00302
928 00304
929 00307
930 00312
931 00314
932 00341
933 00341
934 00346
935 00353
936 00354
937 00363
938 00377
939 00401
940 00404
941 00405

942

RECORDS

SOURCE INPUT AREA: SP# 206

REVISION LEVEL 31.121677

OPTIONS:

MAIN

MODULE: SAU

61516-02

31 JAN 78 15134816

```

SUBROUTINE TAMER3 (GRADE)
COMMON ISPEED(11),F1(11),F2(11), CSSD(11)
DO 170 L=1,11
  CSSD(L)=ISPEED(L)**2/(255*(F1(L)-GRADE))-ISPEED(L)**2/(255*F1(L))
170 CONTINUE
RETURN
END

```

942	00000
943	00000
944	00000
945	00007
946	00043
947	00046
948	00047


```

COMMON ISPEED(11),F1(11),F2(11), CS80(11)
DATA ISPEED /37,47,54,63,70,76,87,91,97,104,111/
DATA F1 /,38,,36,,39,,32,,31,,30,,30,,29,,28,,27,,27/
DATA F2 /,64,,62,,60,,50,,57,,56,,56,,55,,54,,53,,53/
WRITE (6,10)
10 FORMAT ('1')
LNECNT=0
IPAGE=1
WRITE (6,20) IPAGE
20 FORMAT ('16X,4HX,'TABLE-IX-R',36X,'PAGE',I3//)
LNECNT=LNECNT+2
WRITE (6,30)
30 FORMAT ('16X,26X,'EFFECT OF GRADE ON STOPPING SIGHT DISTANCE'
//)
LNECNT=LNECNT+3
WRITE (6,40)
40 FORMAT ('16X,41X,'WET CONDITIONS'//)
LNECNT=LNECNT+3
WRITE (6,50)
50 FORMAT ('16X,28X,'CORRECTION IN STOPPING SIGHT DISTANCE IN ME
TERS'//)
LNECNT=LNECNT+3
WRITE (6,60)
60 FORMAT ('16X,1X,'DESIGN')
LNECNT=LNECNT+1
WRITE (6,70)
70 FORMAT ('16X,12X,' 40 50 60 70 80 90 100
1 110 120 130 140')
LNECNT=LNECNT+1
WRITE (6,80)
80 FORMAT ('16X,2X,'SPEED'//)
LNECNT=LNECNT+2
WRITE (6,90)
90 FORMAT ('16X,1X,'ASSUMED'//)
LNECNT=LNECNT+2
WRITE (6,100) (ISPEED(L),L=1,9),ISPEED(10),ISPEED(11)
LNECNT=LNECNT+1
WRITE (6,110)
110 FORMAT ('16X,89X,'CORRECTION')
LNECNT=LNECNT+1
WRITE (6,120)
120 FORMAT ('16X,2X,'K.P.H.'//)
LNECNT=LNECNT+2
WRITE (6,130)
130 FORMAT ('16X,1X,'FRICTION',80X,'CHANGES')
LNECNT=LNECNT+1
WRITE (6,140) (F1(L),L=1,11)
LNECNT=LNECNT+1
WRITE (6,150)
150 FORMAT ('16X,2X,'FACTOR'//)
LNECNT=LNECNT+2
WRITE (6,160)
160 FORMAT ('16X,2X,'GRADE %'//)
LNECNT=LNECNT+2
CALL TAHERA (LNECNT,IPAGE)

```

```

SUBROUTINE TAMER1 (L, IDGREE)
COMMON ISSD(11)
COMMON ISUR(28), R(4), DM(11)
ISW1=0
WRITE (6,20) ISUB (L*7-1), ISUR(L*7)
20 FORMAT (16X,4X, 'TABLF-X-',2A1/)
WRITE (6,30) ISUB(L*7-6), ISUB(L*7-5), ISUB(L*7-4)
30 FORMAT (16X,4X,5A1, '-METER OF ARC: /)
WRITE (6,40)
40 FORMAT (16X,50X,1M',32X,'>')
WRITE (6,60)
60 FORMAT (16X,1X, 'DGREE',3X, 'RADIUS',22X, 'CENTERLINE INSIDE LANE TO
ISIGHT OBSTRUCTION-METERS, 9 = L',133,' LENGTH ' /)
WRITE (6,70)
70 FORMAT (16X,3X, 'OF',7X, 'OF',11X, 'V 40 50 60 70 8
10 90 100 110 120 130 140',133,' OF ' /)
WRITE (6,80) (ISSD(K),K=1,11)
80 FORMAT (16X,1X, 'CURVE CURVE',10X, '9',4X,12,5X,12,5X,12,5X,12,5X
1,13,4X,13,4X,13,4X,13,4X,13,4X,13,4X,13,133,' CURVE ' /)
WRITE (6,83)
83 FORMAT (16X,2X, '0 ' /)
IF (IDGREE) 84,81,84
81 WRITE (6,90)
90 FORMAT (16X,2X, '0 00' /)
IMIN=10
GO TO A5
84 IMIN=0
85 DO 170 M2=1,6
DJMIN=IMIN
D=IDGREE+DIMIN/60
R10=R(L)/D
C10=0.0174533*D*R(L)
DO 150 M=1,11
DM(M)=C10*(2*ISSD(M)-C10)/(R*R10)
150 CONTINUE
IF (IDGREE) 146,145,146
146 IF (ISW1) 153,155,153
155 WRITE (6,165) IDGREE, R10, (DM(M),M=1,11),C10
165 FORMAT (16X,13, ' 00',F9.2,11X,11F7.1,133,F7.2/)
ISW1=1
IMIN=IMIN*10
GO TO 170
145 IF (M2-6) 153,170,153
153 WRITE (6,160) IMIN,R10, (DM(M),M=1,11),C10
160 FORMAT (16X,3X,13,F9.2,11X,11F7.1,133,F7.2/)
IMIN=IMIN*10
170 CONTINUE
ISW1=0
RETURN
END

```

773	00000
774	00000
775	00000
776	00000
777	00006
778	00034
779	00050
780	00107
781	00125
782	00131
783	00143
784	00147
785	00147
786	00216
787	00222
788	00222
789	00276
790	00320
791	00320
792	00372
793	00376
794	00406
795	00407
796	00414
797	00425
798	00427
799	00427
800	00431
801	00435
802	00440
803	00445
804	00452
805	00456
806	00462
807	00500
808	00503
809	00504
810	00506
811	00542
812	00560
813	00562
814	00564
815	00564
816	00567
817	00623
818	00640
819	00642
820	00645
821	00646
822	00647


```

31 JAN 78 15:32:39      MODULE: *MAIN*      OPTIONS:
61516-0P ENHANCED SAU FORTRAN COMPILER      REVISION LEVEL 31.121A77      SOURCE INPUT AREA: SP# 206      RECORD: 880

      IMIN=IMIN+10
170 CONTINUE
      ISW1=0
      WRITE (6,200)
200 FORMAT (//)
      CALL YANEN1 (L, IDGREE)
      IDGREE=IDGREE+1
      IF (IDGREE=26) 5,400,5
400 CONTINUE
      WRITE (6,150)
150 FORMAT ('1')
      CALL EXIT
      END

```

```

880 00662
881 00664
882 00667
883 00670
884 00674
885 00701
886 00704
887 00705
888 00707
889 00713
890 00717
891 00724
892 00725

```

```

DIMENSION IV(11),IS(11),IP(11),ISAVE(11)
DATA IV/37,47,54,63,70,78,87,91,97,104,111/
DATA IS/40,57,71,93,111,134,160,175,199,230,256/
DATA IP/170,350,420,490,560,630,680,740,790,850,900/
A=.25
5 WRITE (6,10)
10 FORPAT ('1')
WRITE (6,20)
20 FORMAT (1X,19X,27X,'TABLE XI-A-METRIC'/)
WRITE (6,30)
30 FORMAT (1X,19X,7X,'DESIGN CONTROLS FOR CREST VERTICAL CURVES-STOPP
-ING SIGHT DISTANCE'/)
WRITE (6,40)
40 FORMAT (1X,19X,4X,'DS-KPH',3X,'40',4X,'50',4X,'60',4X,'70',4X,'80',
-,3X,'90',3X,'100',3X,'110',3X,'120',3X,'130',3X,'140',/)
WRITE (6,50)
50 FORMAT (1X,19X,4X,'V-KPH',3X,'37',4X,'47',4X,'54',4X,'63',4X,'70',
-,4X,'78',4X,'87',4X,'91',4X,'97',3X,'104',3X,'111',/)
WRITE (6,60)
60 FORMAT (1X,19X,4X,2X,'SSD',4X,'40',4X,'57',4X,'71',4X,'93',3X,'111
-,3X,'134',3X,'160',3X,'175',3X,'199',3X,'230',3X,'256',/)
WRITE (6,70)
70 FORMAT (1X,19X,4X,'A IN %',12X,'L=MINIMUM LENGTH OF VERTICAL CURVE
- IN METERS',/)
IFLOW=12
125 DO 130 L=1,11
SAVE =2.*18(L)-(426.11558/A)
IF (SAVE ) 131,131,135
131 ISAVE(L)= ABS( SAVE )
134 CONTINUE
WRITE (6,140) A,(ISAVE(M),M=1,11)
140 FORMAT (1X,19X,4X,F5.2,1116)
141 IFLOW=IFLOW+1
600 A=A+.25
60 TO 5
135 DO 145 M=L,11
ISAVE(M)=A*18(M)**2/426.11558
145 CONTINUE
WRITE (6,140) A,(ISAVE(H),H=1,11)
GO TO 141
151 A=A+.25
IF (A-.20) 125,125,155
155 A=.25
160 WRITE (6,10)
WRITE (6,170)
170 FORMAT (1X,19X,27X,'TABLE XI-B-METRIC'/)
WRITE (6,180)
180 FORMAT (1X,19X,7X,'DESIGN CONTROLS FOR CREST VERTICAL CURVES-PASSI
-NG SIGHT DISTANCE'/)
WRITE (6,40)
WRITE (6,50)
WRITE (6,190) (IP(L),L=1,11)
190 FORMAT (1X,19X,6X,'PSD',1116'/)
WRITE (6,70)
IFLOW=12
200 DO 210 L=1,11

```

1089 00000
1090 00000
1091 00000
1092 00000
1093 00000
1094 00002
1095 00006
1096 00013
1097 00017
1098 00035
1099 00041
1100 00041
1101 00077
1102 00103
1103 00103
1104 00156
1105 00162
1106 00162
1107 00235
1108 00241
1109 00241
1110 00314
1111 00320
1112 00320
1113 00353
1114 00355
1115 00361
1116 00372
1117 00373
1118 00404
1119 00407
1120 00433
1121 00444
1122 00445
1123 00447
1124 00453
1125 00453
1126 00460
1127 00473
1128 00476
1129 00522
1130 00522
1131 00526
1132 00530
1133 00533
1134 00537
1135 00543
1136 00561
1137 00565
1138 00565
1139 00623
1140 00627
1141 00633
1142 00654
1143 00667
1144 00673
1145 00675

```

SAVE      =2.*IP(L)-(1004./A)
IF ( SAVE ) 215,215,220
215 ISAVE(L)= ABS( SAVE )
210 CONTINUE
WRITE (6,140) A, (ISAVE(M),M=1,11)
216 IFLOW=IFLOW+1
216 IF (IFLOW-55) 226,226,650
650 A=A+.25
GO TO 160
220 DO 225 M=L,11
ISAVE(M)=A*IP(M)*2/1004.
225 CONTINUE
WRITE (6,140) A, (ISAVE(M),M=1,11)
GO TO 216
226 A=A+.25
250 A=.25
255 WRITE (6,10)
255 WRITE (6,270)
270 FORMAT (1X,19X,27X,'TABLE XI-C-METRIC'//)
280 FORMAT (1X,19X,7X,'DESIGN CONTROLS FOR SAG VERTICAL CURVES-STOPPIN
      -G SIGHT DISTANCE'//)
WRITE (6,40)
WRITE (6,50)
WRITE (6,60)
WRITE (6,70)
IFLOW=12
300 DO 310 L=1,11
SAVE      =2*IS(L)-(400.+11.4828*IS(L))/(3.2808*A)
IF ( SAVE ) 315,315,320
315 ISAVE(L)= ABS( SAVE )
310 CONTINUE
WRITE (6,140) A, (ISAVE(M),M=1,11)
311 IFLOW=IFLOW+1
311 IF (IFLOW-55) 329,329,700
700 A=A+.25
GO TO 255
320 DO 325 M=L,11
ISAVE(M)=(3.2808*A*IS(M)*2)/(400.+11.4828*IS(M))
325 CONTINUE
WRITE (6,140) A, (ISAVE(M),M=1,11)
GO TO 311
329 A=A+.25
350 A=.25
355 WRITE (6,10)
355 WRITE (6,360)
360 FORMAT (1X,19X,27X,'TABLE XI-D-METRIC'//)
WRITE (6,370)
370 FORMAT (1X,19X,7X,'DESIGN CONTROL FOR SAG VERTICAL CURVES-FOR COME
      -ORI'//)
WRITE (6,40)
WRITE (6,50)
WRITE (6,60)
WRITE (6,70)
IFLOW=12

```

1146 00701
1147 00712
1148 00713
1149 00724
1150 00727
1151 00753
1152 00754
1153 00756
1154 00762
1155 00762
1156 00767
1157 01002
1158 01005
1159 01031
1160 01031
1161 01035
1162 01037
1163 01042
1164 01046
1165 01052
1166 01070
1167 01074
1168 01074
1169 01131
1170 01135
1171 01141
1172 01145
1173 01151
1174 01153
1175 01157
1176 01176
1177 01177
1178 01210
1179 01213
1180 01237
1181 01240
1182 01242
1183 01246
1184 01246
1185 01253
1186 01276
1187 01301
1188 01325
1189 01325
1190 01331
1191 01333
1192 01336
1193 01342
1194 01346
1195 01364
1196 01370
1197 01370
1198 01421
1199 01425
1200 01431
1201 01435
1202 01441

```

31 JAN 78 15:35:22      MODULE: *MAIN*      OPTIONS:
61516-02 ENHANCED 8AU FORTRAN COMPILER      REVISION LEVEL 31.121677      SOURCE INPUT AREA: SP# 206      RECORD: 1203

375 IA=40
   DO 380 L=1,11
   ISAVE(L)=A+IA**2/394.95244
   IA=IA+10
380 CONTINUE
   WRITE (6,140) A, (ISAVE(M),M=1,11)
   IFLOW=IFLOW+1
   IF (IFLOW-55) 390,390,800
800 A=A+.25
   GO TO 355
390 A=A+.25
   IF (A-20) 375,375,490
490 A=.25
495 WRITE (6,10)
495 WRITE (6,500)
500 FORMAT (1X,19X,27X,'TABLE XI-E-METRIC'/)
510 FORMAT (1X,19X,7X,'DESIGN CONTROL FOR SAG VERTICAL CURVES-FOR UNDE
      -RP88'/)
   WRITE (6,40)
   WRITE (6,50)
   WRITE (6,60)
   WRITE (6,70)
   IFLOW=12
400 DO 410 L=1,11
   SAVE =2.*IS(L)-(2499.39/A)
   IF ( SAVE ) 415,415,420
415 ISAVE(L)= ABS( SAVE )
410 CONTINUE
   WRITE (6,140) A, (ISAVE(M),M=1,11)
411 IFLOW=IFLOW+1
   IF (IFLOW-55) 429,429,750
750 A=A+.25
   GO TO 495
420 DO 425 MEL,11
   ISAVE(M)=(A*IS(M)**2)/2499.39
425 CONTINUE
   WRITE (6,140) A, (ISAVE(M),M=1,11)
   GO TO 411
429 A=A+.25
450 IF (A-20) 400,400,450
450 WRITE (6,10)
   CALL EXIT
   END

```

```

1203 01443
1204 01445
1205 01451
1206 01463
1207 01465
1208 01470
1209 01514
1210 01515
1211 01517
1212 01523
1213 01523
1214 01527
1215 01531
1216 01534
1217 01540
1218 01544
1219 01562
1220 01566
1221 01566
1222 01617
1223 01623
1224 01627
1225 01633
1226 01637
1227 01641
1228 01645
1229 01656
1230 01657
1231 01670
1232 01673
1233 01717
1234 01720
1235 01722
1236 01726
1237 01726
1238 01733
1239 01746
1240 01751
1241 01775
1242 01775
1243 02001
1244 02003
1245 02010
1246 02011

```

APPENDIX B

DEFINITIONS

APPENDIX B

DEFINITIONS

- Metric System:** Based primarily on the "Metre," a length defined as a small portion of the earth's circumference (approximately 4×10^7 metres)
- Customary American:
(Foot System)** Based on Foot-Pound System of units.
- System International:** Based primarily on the "Metre" a length equal to 1 650 763.73 wave lengths in vacuum of the radiation of Krypton 86 (Kr 86).
- Advantages of Metric System (SI):**
- Easy to use.
 - Universal System.
 - Based on 10 and its multiple logical.
 - Practical for world trade .
 - Easier to teach and learn.
- Soft Conversion:** Implies that the conversion only takes place on paper and the object remains unchanged e.g. a pipe of (6") diametre could be "Soft" converted to (152.4) millimetres.
- Hard Conversion:** Is the process of choosing a "rational" metric size for a product e.g. the above 6" pipe could be "Hard" converted to a (150) millimetres instead of (152.4 mm).

- Curve:** A curve can provide the required changes in direction of movement around it in the form best suited to the operating characteristics.
- Circular Curve:** A circular curve is a part of a circle with constant rate of change.
- Simple Curve:** A simple curve is a circular arc joining two tangents (5) as shown in Figure No. 15.
- Compound Curve:** A compound curve consists of two or more consecutive circular arcs (6) as shown in Figure No. 16.
- Reversed Curve:** A reversed curve is composed of two simple curves turning in opposite directions (6) as shown in Figure No. 17
- Parabolic Curve:** Is a curve connecting two different grades to provide smooth transition. Also it provides a constant rate of change of grade. (See Figure No. 18.
- Transition Spirals:** These curves provide a gradual change in curvature from a "straight" to a "circular" path. (See Figure 19. There are several transition spirals, some of them are in common practice

as listed below:

- . Talbot spiral (ten chord or arc spiral)
- . Euler (American Spiral, adopted in this research)
- . Fronde's Parabola (Cubic)
- . Clothoid (European Spiral)

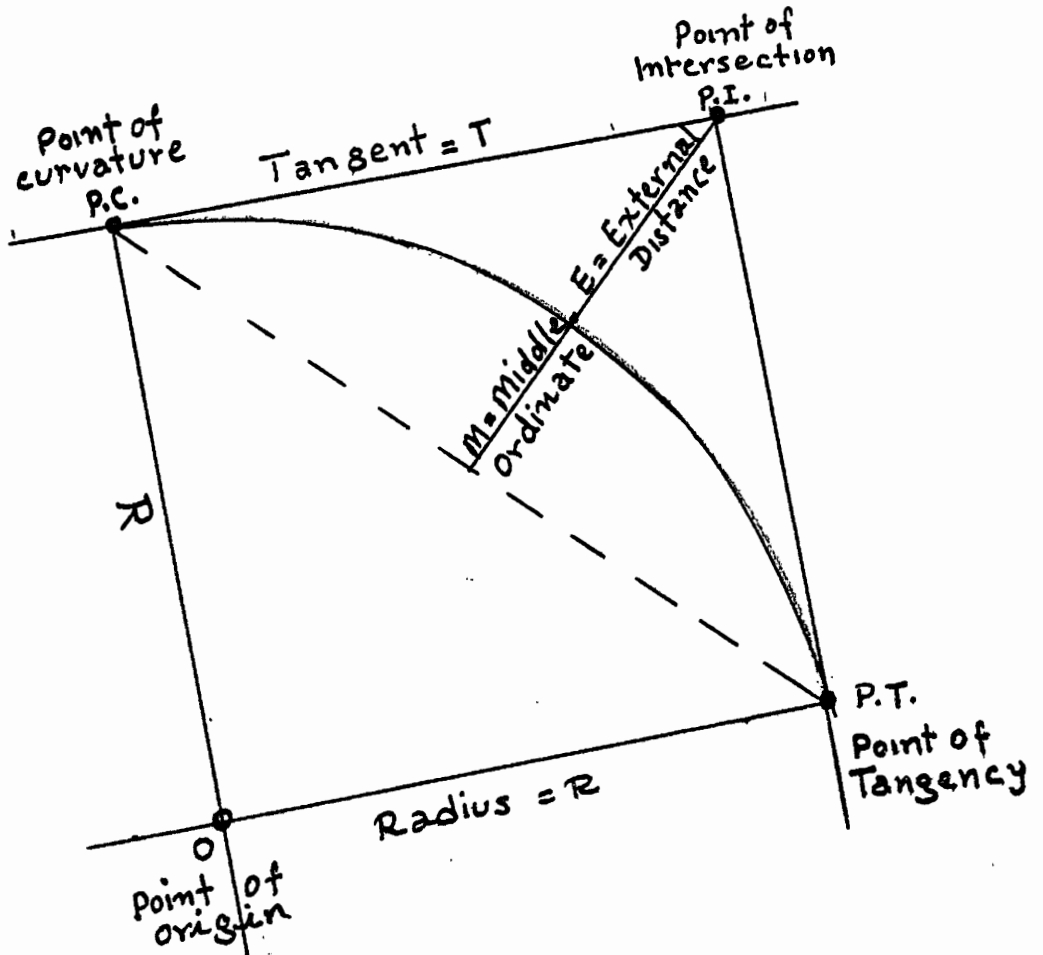


Figure 15.

Simple Curve Definition.

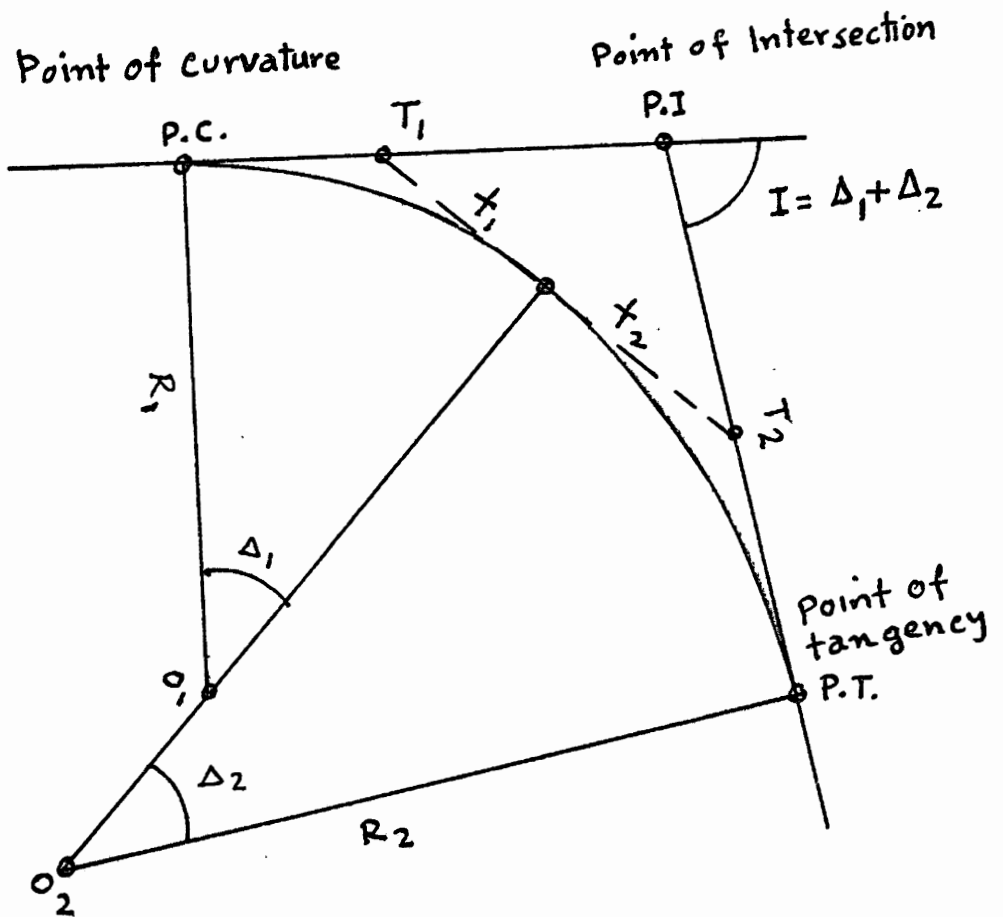


Figure 16.

Compound Curve Definition.

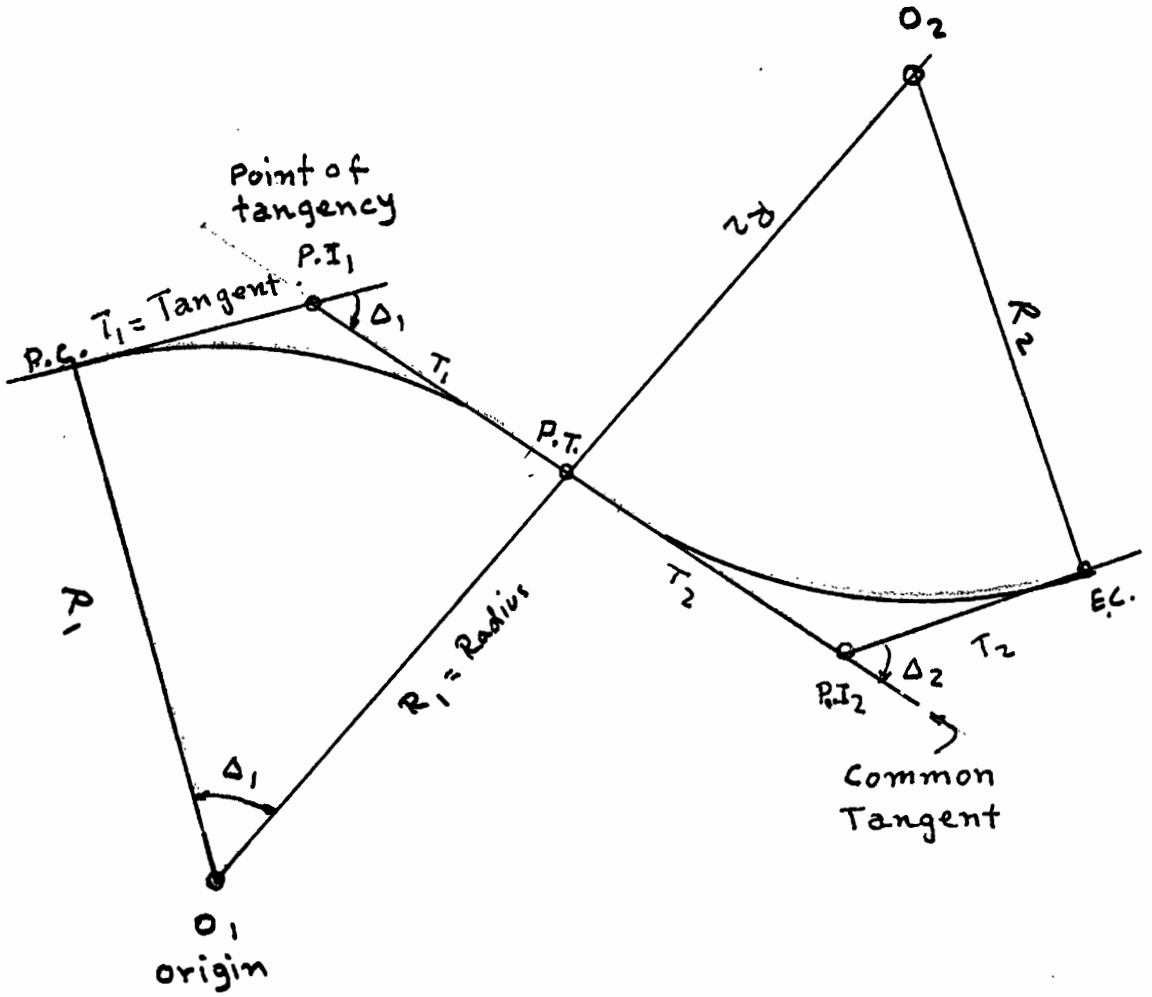


Figure 17.

Reversed Curve Definition.

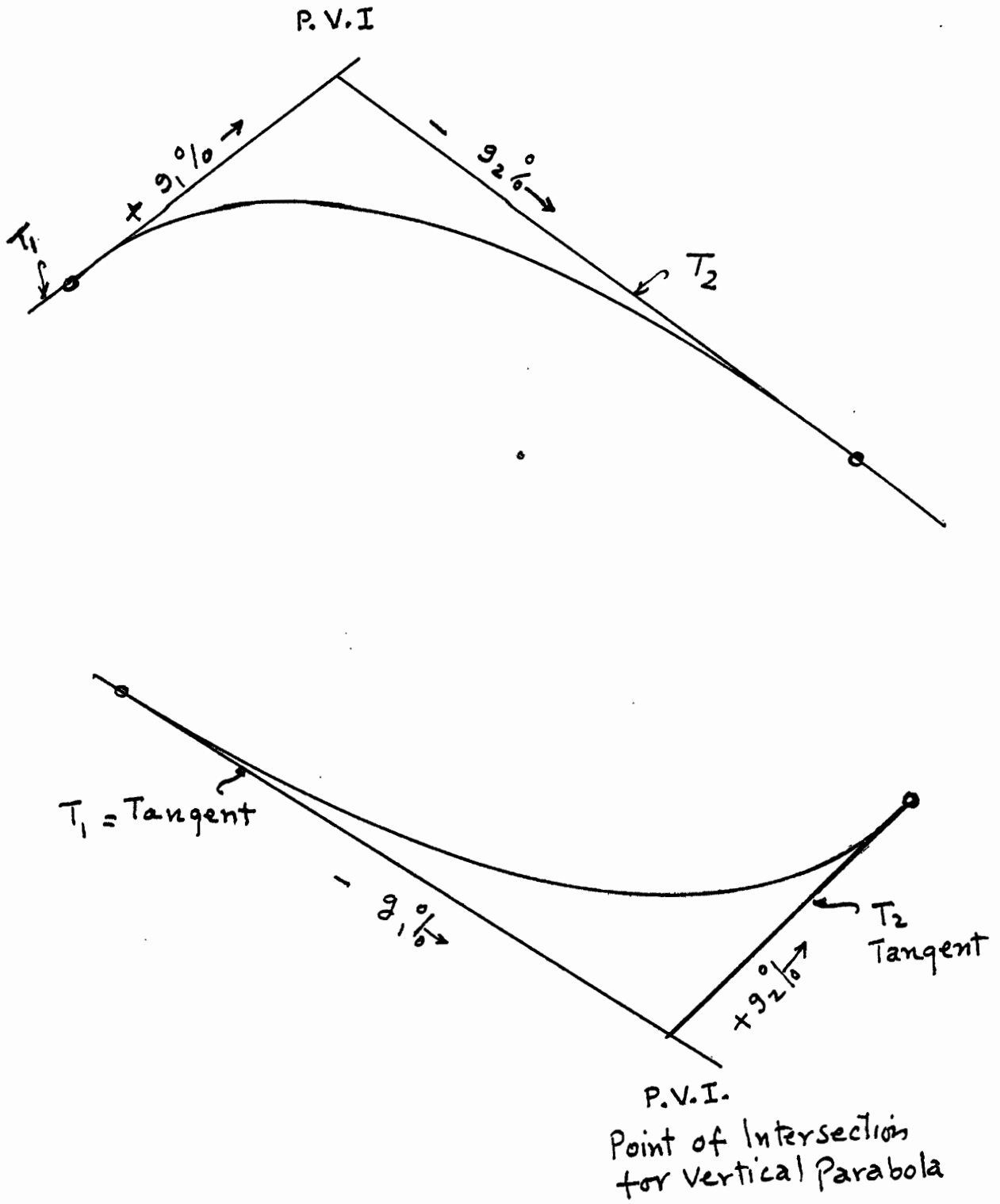


Figure 18.

Parabolic Curve Definition.

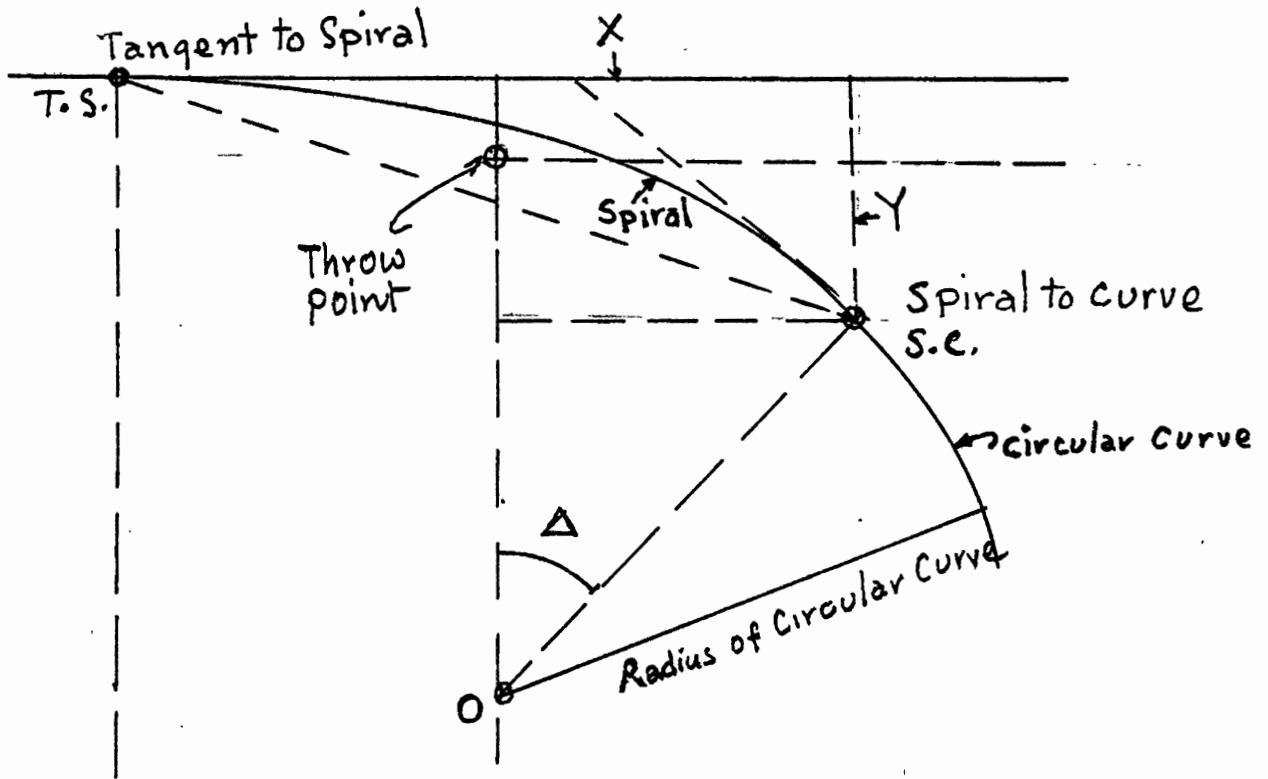


Figure 19.

Transition Spiral Definition