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Vol. I

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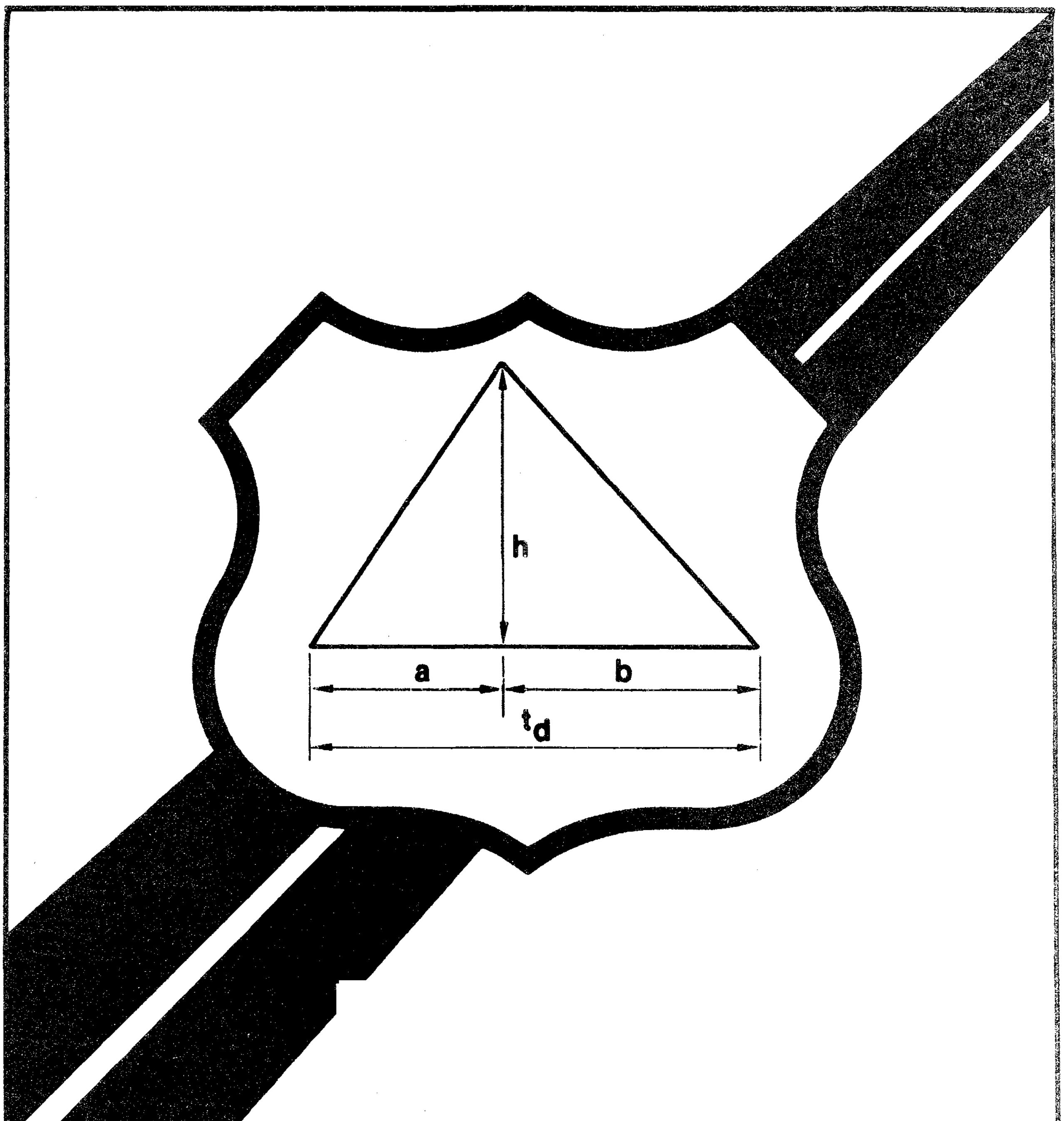

FOREWORD

This report summarizes the development of a simple triangular hyetograph method in deriving local design storms for use in the design of highway storm drainage structures. It is based on the statistical analysis of rainfall data from 235 raingage stations all over the United States.

Research in urban and rural highway storm drainage is included in the Federally Coordinated Program of Highway Research and Development as Tasks 2 and 3 of Project 5H "Protection of the Highway System from Hazards Attributed to Flooding."

Sufficient copies of this report are being distributed to provide a minimum of two copies to each FHWA regional office, one copy to each division office, and one copy to each State highway agency. Direct distribution is being made to the division offices.

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NOTICE

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16. Abstract

Recently developed improved methods for highway storm water drainage require information on the temporal distribution of rainfall (i.e., hyetograph) in addition to the average rain intensity. The triangular design hyetograph method is developed as a practical method to provide the local storm hyetograph for design of highway storm drainage facilities. The method is based on the methods of moments, using and preserving the statistical mean of the first time moment of rainstorms. The method is proposed as a trade-off between theoretical sophistication and practical simplicity. A total of 293,946 rainstorms from the hourly precipitation data of 222 National Weather Service stations and 5 to 60 minute data of 13 raingage stations of USDA Agricultural Research service were analyzed to provide the statistical values of the hyetograph parameters for the United States.

Volume I is the executive summary of the project report. It briefly describes the background and objectives of the research project, the methodology and procedure of the first-moment triangular design hyetograph method, and results of statistical analysis of the rainfall data.

The other three volumes of this report set are:

Vol. II Methodology and Analysis (FHWA/RD-82/064)
Vol. III User's Manual (FHWA/RD-82/065)
Vol. IV Tabulation of Sample Detail Results of Statistical Analysis (FHWA/RD-82/066)

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I. Background and Objective

The final report of the research project "Local design storm: Phase II" consists of a set of four volumes. This volume I is the executive summary. Volume II describes the theoretical background and methodology of the first-moment triangular design hyetograph method and discussion of the results of the statistical analysis of rainfall data. Presented in Volume III is the procedure to apply the triangular design hyetograph method to the hydrologic design of highway storm drainage facilities. User's guides for two computer programs to perform statistical analysis and frequency analysis of National Weather Service hourly precipitation data are also presented. The results of statistical analysis of hyetograph parameters of more than a quarter of a million rainstorms at 235 locations are summarized in a voluminous set of 3600 tables. Volume IV presents 84 tables containing the detailed results of two typical locations.

Properly designed storm water drainage facilities are important components contributing to successful performance of a highway system. For small watersheds the design flood usually cannot be determined directly from the storm runoff record because such data are usually unavailable or inadequate. Therefore, the design flood is normally obtained by converting the rainfall data to flood flow using a rainfall-runoff simulation model.

Conventionally, in highway storm drainage design using traditional simple methods such as the rational method, the required rainstorm information is the average rain intensity over a specific duration for the design return period. However, the effects and significance of the temporal and spatial distributions of the rainfall on the time distribution and peak rate of runoff have long been recognized. During the past decade concerns for highway storm water pollution and use of detention storage to control highway storm runoff have promoted the need of more detailed rainfall information. Recently developed improved methods that are adaptable to the design of highway drainage facilities, such as Storm Water Management Model (SWMM), Illinois Urban Drainage Simulator (ILLUDAS), and Illinois Stormsewer Design Model (ILSD), all require the time distribution of the rainfall, i.e., the local design storm hyetograph, as their input. But, so far there is no sound practical procedure for determination of the local design storm hyetograph.

The main objective of this project is to develop, on a sound theoretical basis, a practical procedure for the determination of the local design storm hyetograph to facilitate the use of these recently developed improved methods in the design of rural and urban highway storm drainage facilities. The basic criteria in developing the new procedure are: (a) the method must be theoretically sound, accounting for the physics of natural rainstorms and accurately and realistically preserving the statistical nature of natural rainfalls; (b) no matter how sophisticated and complicated the theory of the method is, the application procedure must be relatively simple and easy to use by engineers for design of highway storm drainage facilities, and the engineer should be able to apply the procedure without fully knowing the theory; (c) the method must be applicable to the entire United States for the determination of the design storms at individual locations; (d) the design storm hyetographs obtained from the new procedure must be compatible and applicable to various modern storm drainage design models, not restricted to only one or a selected few models, and it must be compatible with the existing commonly used traditional storm drainage design methods.

II. Methodology Development

In nature no two rainstorms are alike. They differ from place to place and from time to time, i.e., they all differ from one another in their temporal and spatial distributions of the different durations and volumes of rainfall. Thus, the amount, time of occurrence, and temporal distribution of future rainfalls is a matter of conjecture. This suggests that the design storm, presumably a critical rainstorm that could occur in the future, would best be determined through the use of probability theory. Since past rainstorms will not be repeated, observed past rainfall records can only be used as a basis for providing statistics in establishing the design rainstorm.

In view of the aforementioned project objective and methodology selection criteria, the first-moment nondimensional triangular hyetograph method is developed for the determination of the hyetograph to be used for the design of highway drainage facilities such as culverts, sewers, parking lots, detention storages, ditches, channels, and small bridge openings. The feasibility of the first-moment triangular hyetograph method was investigated in a previous FHWA project.[1]

The hyetographs of different rainstorms have different shapes. Therefore, their corresponding values of moments are different. However, if the data of an adequate number of rainstorms are available, the statistics of each of the moments of the rainstorms can be computed, and from probability theory, the mean values are the estimated expected values of the moments, and hence they can be used to construct the expected hyetograph. Since different rainstorms have different rain depths and durations, it is desirable to first normalize the individual hyetographs, i.e., nondimensionalize by using the duration and total depth of the rainfall so that the normalized hyetographs can easily be compared and evaluated.

III. Research Accomplishment

In view of the main objective of this project specified in Section I, the methodology described in Section II, and the findings of the previous project on the feasibility of the first moment triangular hyetograph method, the following goals have been set up and accomplished for this research project: (a) to reconfirm the feasibility and practicality of the first moment triangular hyetograph method for local design storms by using the results of statistical analyses of a large number of observed rainstorms from at least one location in each of the states; (b) to establish a national map of the nondimensional triangular design hyetograph parameter; and (c) to establish a standard procedure of the triangular hyetograph method to be used for the design of highway storm drainage facilities. In this project the following tasks have been accomplished:

(1) Acquisition and selection of rainfall data for analysis

The value of the nondimensional first time moment, which is the key value of the triangular design hyetograph, is established statistically. Therefore, a large number of recorded rainfalls must be available for analysis. Two primary U.S. rainfall data sources are utilized, namely,

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[1] Yen, B. C., and Chow, V. T., "Feasibility Study on Research of Local Design Storms," Report No. *FHWA-RD-78-65*, U.S. Dept of Transportation, Federal Highway Administration, Washington, D.C., 1977.

the U.S. National Weather Service (NWS) hourly precipitation data and the precipitation data of the agricultural experimental watershed network of the Department of Agriculture's Agricultural Research Service (ARS). The entire file of the NWS hourly precipitation data that are on magnetic tapes was acquired and screened. Stations unsuitable for the present investigation were rejected. Further screening of stations that were not rejected yielded 222 stations located in all the 50 states and Puerto Rico, and containing more than one million rainstorms for analysis. It is believed that this is the first time that the NWS hourly precipitation data of the entire United States have been so systematically acquired, compiled, and screened. Likewise, the entire file of the ARS break-point precipitation data was acquired and screened, from which 13 stations were suitable and hence selected for analysis. The ARS break-point was converted into clock-time data of 5, 15, 30, and 60 minute recording time intervals. The analysis of rainfall data of short recording time intervals provided by the ARS data is necessary because many convective type rainstorms are characterized by heavy intensity over a short duration often less than an hour. The NWS hourly data probably are the most refined data that an engineer would normally be able to acquire. Comparison of the statistical results of short-time-interval data to hourly data was used to assure that the hourly data can provide representative statistical results of the rainstorm parameters.

(2) Development of computer programs for statistical analyses

Two computer programs have been developed in this study which can be used by highway drainage design engineers. They are (a) SATH for statistical analysis of NWS hourly precipitation data for triangular hyetograph to compute the local statistical values of hyetograph parameters; and (b) FANHP for frequency analysis for NWS hourly precipitation data to establish the local rainfall depth-duration-return period relationship.

(3) Statistical analysis of rainfall data

Statistical analyses of 15 rainstorm parameters were performed on the 222 NWS stations for 274,884 rainstorms of 2, 3, 4, and 5-hour durations and the results of the computed mean, standard deviation, and range for each of the 15 parameters are reported in 2994 tables. The standard deviation and range provide an indication of the reliability of the expected hyetograph. One set of the results containing 12 tables for the NWS Washington, D.C. National Airport Station is presented in Volume IV of this report set as an example. Analyses were also performed on the 19,062 rainstorms at the 13 selected ARS stations (including 4220 storms for the 5-minute of recording time, 4663 storms for the 15-minute interval, 5341 storms for the 30-minute interval, and 4838 storms for the 60-minute interval) and the results are reported in 936 tables. One set of the results in 72 tables for the station near Coshocton, Ohio is presented in Volume IV as an example. Summary of statistical values of three key hyetograph parameters for the 235 stations analyzed is presented in Volume II of this report set.

(4) Evaluation of results and development of national map

The results of the statistical analysis of the 293,946 rainstorms at 235 locations are compared to evaluate the variations of the nondimensional values of the first time moment and the peak intensity time with rainstorm duration, rain depth, and geography. The results confirm that rain depth of rainstorms which is an indirect indication of the physical type of the rainstorm is a significant parameter affecting the nondimensional values of the first time moment and the peak intensity time of the triangular hyetograph. The decreasing value of the peak intensity time for increasing depth confirms the postulation that heavy rainstorms of the convective type, statistically speaking, tend to have peak rain intensity and a majority of the rain occurring in the early part of the duration of the raining period. For the durations and depth ranges analyzed, the nondimensional values of the first time moment and the peak intensity time fall within narrow ranges, in most cases.

Geographically, the results reveal that there is a general trend of these two nondimensional values to increase from Southeast United States towards the Northwest, and a relatively smaller increase in New England. Furthermore, the changes in these values for the central and mid-Atlantic States are rather small unless orographic effect becomes significant.

The results also indicate that the effect of rainstorm duration is insignificant provided the duration exceeds 15 minutes. However, this conclusion should not be considered as final because of the limitation on the accuracy of the data and the definition of rainstorm.

Based on this evaluation, a national map of the expected nondimensional values of the peak intensity time for triangular design hyetographs is developed.

(5) Formulation of standard procedures for application of triangular hyetograph method for local design storms

Simple, step-by-step procedures have been formulated for use by engineers to establish the local design storm using the triangular hyetograph method. These procedures are presented in Volume III.

IV. Conclusions

The triangular hyetograph method is applicable to design of storm drainage facilities in rural as well as urban watersheds up to 20 square miles (50 km^2) in size. It should not be used together with the rational method since the latter requires only the average intensity of the rainfall which is one half of the peak rain intensity of the triangular hyetograph.

The major advantages of the triangular design hyetograph in comparison with the existing hyetograph methods such as the Chicago method and SCS 6-hour and 24-hour rain mass curves are that it is relatively more theoretically sound, it preserves the primary time characteristics of the natural rainstorms and that its procedure of application is simple and straight forward. In comparison with the traditionally used intensity (depth)-duration-frequency anlaysis, the new method provides an entire hyetograph whereas the former gives only a design rain intensity, not the time distribution of the rainfall. In view of these advantages and the fact that evaluations have been conducted for all the 50 states, the triangular design hyetograph method is recommended for use in design of highway storm drainage facilities draining areas less than 20 square miles (50 km^2). Future refinements of the method based on new data and experiences of applications by engineers are also recommended.

The user's manual presents a procedure for rapidly developing a design storm (triangular rainfall hyetograph) to facilitate the use of rainfall-runoff models such as EPA's Storm Water Management Model (SWMM). Since these rainfall-runoff models can provide more accurate estimates of runoff characteristics than existing empirical methods such as the Rational Equation, highway engineers can develop more cost-effective storm drainage systems through their use.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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