REPORT

FLOOD PROTECTION AT BRIDGES AND CULVERTS

by

D.B. Simons and G.L. Lewis

Prepared for

Wyoming State Highway Department

Planning and Research Division

in cooperation with the

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AUTHORIZATION OF PROJECT

The problems to be investigated were formulated by the staff of the State Highway Commission of Wyoming in consultation with personnel of Colorado State University and the Bureau of Public Roads. The project was initiated by the signing of the agreement "Engineering Investigation Pertaining to Flood Protection of Bridges and Culverts", dated February 16, 1966. This agreement was modified in an addendum to the agreement October 8, 1969.

DISCLAIMER

The opinions, findings, and conclusions in the publication are those of the authors and not necessarily those of the State Highway Commission of Wyoming or the Bureau of Public Roads.

ABSTRACT

FLOOD PROTECTION AT BRIDGES AND CULVERTS

This report is an introduction to two separate research reports, "Flood Protection at Culvert Outlets" and "Flood Protection at Bridge Crossings". Descriptions of the sponsors and investigators for the research program, and outlines of the research conducted for each report are included. The report is directed at advising management staffs and potential users of the nature and application of the research results presented in the two reports.

Details of the experimental programs, hydraulic analyses, theoretical considerations, design procedures, and design examples can be found in each of the two reports, which are listed in the Bibliography.

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The research and design techniques in the two reports are outlined herein. Reference should be made to the Phase I and Phase II reports for descriptions of the data collected, the experimental results, and the development and presentation of the design procedures.

OUTLINE OF RESEARCH

The Phase I and Phase II reports are presented as design manuals for use by hydraulic engineers. Both reports contain experimental and theoretical descriptions of the hydraulic properties and the relationships between hydraulic properties and stabilization requirements. Step-by-step design procedures are presented in both reports, and prototype design examples are included to assist the designer in interpreting the data.

Phase I - Culvert Research

The design procedures presented in the culvert report are derived from extensive investigations of the hydraulic and scour characteristics of model and small prototype outlet basins. Three types of rigid outlet basins and three types of riprapped basins were studied for circular and rectangular culverts and are offered as possible economical and practical structures. Figure 1 was taken from Reference 1 in the Bibliography and summarizes the geometric properties of the suggested basins. A brief description of each basin follows:

a) Smooth-Floor Flared Basin - This basin has a smooth, rigid, horizontal or sloping floor with vertical side-walls flared at an angle matching the expansion angle of the jet. A hydraulic jump is induced in the basin, causing energy dissipation and a reduction of the basin exit velocity to subcritical level.

b) Smooth-Floor Rectangular Basin - This basin differs from the smooth-floor flared type only in that it is rectangular in plan with no guides for the expanding jet.

c) Rough-Floor Rectangular Basin - This basin is similar to the smooth-floor rectangular basin with roughness elements attached to the floor. Increased energy dissipation forces the hydraulic jump to occur closer to the culvert outlet than for the smooth-floor case.

d) Combined Basin - This basin is a composite smooth-floor flared basin and rough-floor flared basin along zones A and C, respectively, in Figure 1. The depth of flow and velocity at the end of zone A are used as initial values for the zone C design.

e) Standard Non-Scouring Riprapped Basin - This basin has boundaries formed from riprap which has adequate size and size distribution to withstand the design flow with no scour.

f) Standard Hybrid Riprapped Basin - This basin is similar to the non-scouring basin with smaller rock sizes and a thickened apron. Slight scour of the smaller rock occurs near the culvert outlet resulting in improved energy dissipation.

g) Standard Scoured Basin - This basin is designed so that the jet will form a scour hole and deposit a mound of material downstream of the hole. The scour hole and mound significantly increase the effectiveness of the basin by assisting in the energy dissipation of the jet.

h) Non-Scouring and Scouring Basins with a Metal End Section - These basins are suggested for certain restrictive cases (described in the culvert report) to reduce the depth of scour in the riprapped basin. The metal end section provides a transition from circular culverts to rectangular outlet basins.

Research for the rigid outlet basins was performed in a specially constructed laboratory flume 20 ft wide and 180 ft long capable of discharges up to 100 cfs. Rectangular and circular approach culverts were used to supply water to the outlet basins. Extensive depth, velocity, and pressure data were collected and are presented in the form of graphs showing relationships among dimensionless parameters. The dimensionless parameters were varied so that the ranges encompassed values encountered in many prototype culverts.

Research for the riprapped basins was also performed in the 20 by 180 ft flume. Rectangular and circular culverts were used to supply water to riprapped basins having effective riprap sizes ranging from 0.049 ft to 0.613 ft. Riprapped outlet basins were extensively tested (270 runs) with variations in riprap sizes, culvert slopes, culvert sizes, apron slopes, side-wall slopes, basin widths, and end sections. Scour data for these tests are presented in dimensionless-parameter design curves in the Phase I report.

Additional tests (190 runs) of rectangular riprapped basins with rectangular culverts were performed in the 6 ft wide by 64 ft long recirculating laboratory flume. Variations of riprap sizes, culvert widths, and culvert slopes were included to extend the ranges of the dimensionless parameter graphs obtained from the tests in the larger flume.

Phase II - Spill-Through Bridge Research

The design procedures presented for stabilization of spill-through bridge structures are derived from extensive hydraulic and scour data obtained from a survey of the pertinent literature and the experimental work at CSU. This large amount of available data and the time and cost of experimentally evaluating the numerous variables relevant to flow through model and prototype bridge crossings were felt to be adequate reasons for omitting additional data collection. The majority of the research for the bridge phase involved laboratory tests of spill-through bridge abutments stabilized from a design procedure developed from hydraulic considerations and the data presented by other investigators.

Model spill-through abutments were constructed in both the flumes mentioned above. Bridge abutments for two types of channel geometry were constructed with riprap-protected central cores of river sand. Figure 2 (from Reference 2) summarizes the geometric properties of the model abutments, and the two channel types are described as follows:

a) Wide Channel Flow - The channel bed is horizontal across the channel with vertical side walls.

b) Overbank Flow - The channel bed consists of a wide horizontal flood plain extended to the bank of a centrally located low-flow channel. The flume walls are vertical.

Research for the Phase II report consisted of tests of the stability of riprap protection placed on model spill-through abutments. Six bridge crossings with spill-through abutments were tested in the 20 ft wide flume. The approaches were constructed at different angles to the flow direction with different sizes of riprap protection, and wide channel conditions were utilized with both rigid and alluvial beds.

Overbank flow conditions were tested in the 6 ft wide flume. Bridge embankments with spill-through abutments were constructed normal to the flow direction from one flume wall, and were placed on smooth and artificially roughened flood plains. For the overbank tests, the abutment approach length on the flood plain was varied from a point at the bank of the low-flow channel to a point two feet from the opposite flume wall. Variations of abutment height and width, flow depth, and riprap size and angularity were included in the overbank tests.

For the tests in both flumes, effective riprap sizes ranging from 0.016 ft to 0.208 ft were placed on the abutment sand cores using a thickness equal to twice the maximum riprap particle diameter. The models were then subjected to flowing water applied as incremental discharge increases until failure of the abutment riprap occurred. Comparisons of actual and theoretical failure conditions produced the verification of the design procedures presented in the Phase II report.

Stabilization techniques derived from the literature review for portions of the crossings other than the abutment slopes are also presented in the Phase II report. Recent scour information at abutment toes and piers was obtained from the literature review and is included to assist the engineer in designing protection for the total bridge crossing.

APPLICATION OF THE RESEARCH

The research for both reports is presently the most complete and extensive investigation of stabilization techniques at culvert outlet basins and bridge crossings. The various types of culvert outlet basins and riprapped bridge abutments are accepted as economical structures, and the designs are based on sound engineering fundamentals and extensive experimental data obtained from model and prototype structures.

The complexity of flow and geometric conditions at various prototype structures do not allow complete analytical solutions, and reliance must be placed on experimental approaches. These approaches limit the application of the research results to designs having parameters which fall in the range of the experimental data. Extrapolation of experimental data may be accomplished only through sound engineering judgment and experience.

Ranges of the experimental parameters for both reports encompass most field conditions. For extreme conditions which are not included in the experimental ranges, larger safety factors will be necessary. It is felt that the ranges studied are wide enough that extreme conditions are either scarce or non-existent.

Application of the design techniques presented in either report requires values for certain hydraulic and geometric variables as input to the design. Design techniques for culvert outlets require values for the size, shape, and slope of the culvert, in addition to estimates of the design discharge, brink depth, and tailwater elevation. Any of the outlet basins shown in Figure 1 may be selected for the design site depending on local labor and material costs and availability.

Necessary input for the Phase II report includes the design discharge and the natural channel properties. Selection of riprap sizes for protection of spill-through abutments is made from a knowledge of the hydraulic and geometric properties of the natural channel before the beginning of construction. Among the required values are the flow stage at design discharge, the cross-sectional geometry of the original channel, and the distribution of the unconstricted design flow across the channel.

Output from both reports includes the required size and extent of riprap protection for the structures. Concrete or other forms of protection may be more economical when rock riprap is not available. Also, for certain designs, it may be more economically desirable to utilize structures capable of handling the design flood with protection designed for smaller flood events. Increased maintenance costs for these designs should be considered in the economic analyses.

Repeated application of either design technique to field conditions will undoubtedly suggest modifications in the design procedures. After using the techniques in several field installations, the designer will be in a better position to formulate the best design.

IMPLICATIONS OF THE RESEARCH

The three rigid culvert basins and the rock riprapped basins and various bridge crossings offer several options to the design engineer. Riprap protection for culvert outlets and bridge abutments appears to be the most economical choice whenever riprap is available. If a limited size of riprap is readily available, its use may be economically justified even if larger culverts or longer bridge spans are required to reduce flow velocities.

Use of the design techniques in both reports for riprap protection may require eventual updating and revision of construction and quality control specifications. For example, the Phase I report successfully utilizes the effective diameter of the riprap. This parameter is a combined measure of the size and distribution of the riprap, and field installations will require the same gradation in order to insure successful uses of the experimental data. Improved methods of sampling and controlling riprap sizes and gradation will therefore be required for field installations. Other specifications for control of specific gravity, hardness, angularity, surface conditions, and placement of riprap may require revisions evolving from additional research and repeated applications of the design techniques.

Additional research into other forms of protection and especially into locating and classifying natural or quarried rock riprap will be helpful. Relationships among blasting parameters and riprap size and gradation for various rock formations would provide geologists and potential users with better design tools whenever riprap has to be quarried. Simplified methods of determining size and gradation of natural riprap sources and suggestions for specification revisions also need additional research.

Among the benefits of implementing the research findings are the savings in initial investments, savings in maintenance costs throughout the life of the structures, and savings in the maintenance repairs of existing structures. The savings in the cost of maintenance required annually in the state of Wyoming alone should more than cover the expenditures for the research.

In summary, both research reports allow economic considerations to enter the design by providing estimates for the initial size and extent of protection required at culvert outlets and bridge crossings. Local variations in labor costs and material availability will need to be considered in selecting the most economical structure. Repeated application of the design techniques and additional research should provide the designer with data for improvements in the performance, control, and economy of flood protection for culvert outlets and bridge crossings.

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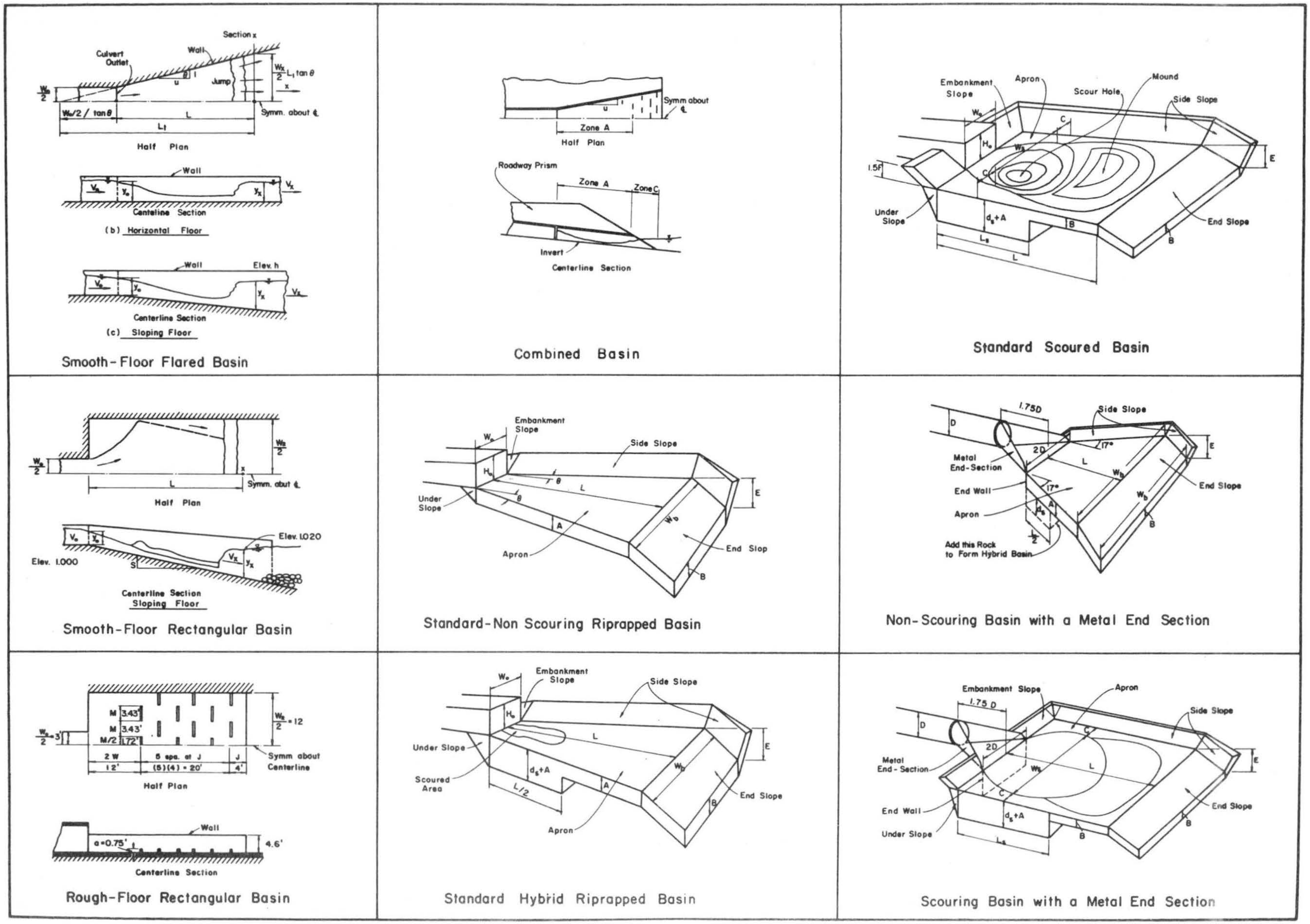
2. Simons, D.B., and G.L. Lewis, "Flood Protection at Bridge Crossings." Report prepared for Wyoming State Highway Department, Planning and Research Division, in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, 1970.

APPENDIX A

FIGURES



Smooth-Floor Flared Basin

Combined Basin

Standard Scoured Basin

Smooth-Floor Rectangular Basin

Standard-Non Scouring Riprapped Basin

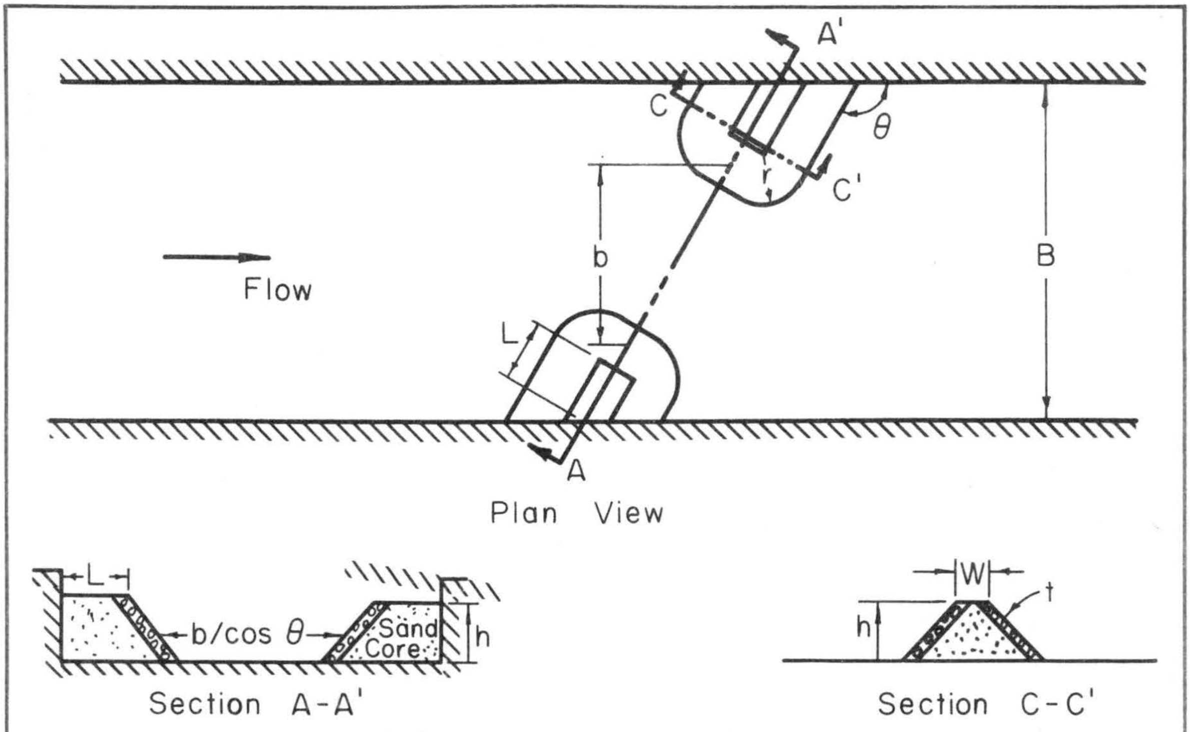
Non-Scouring Basin with a Metal End Section

Rough-Floor Rectangular Basin

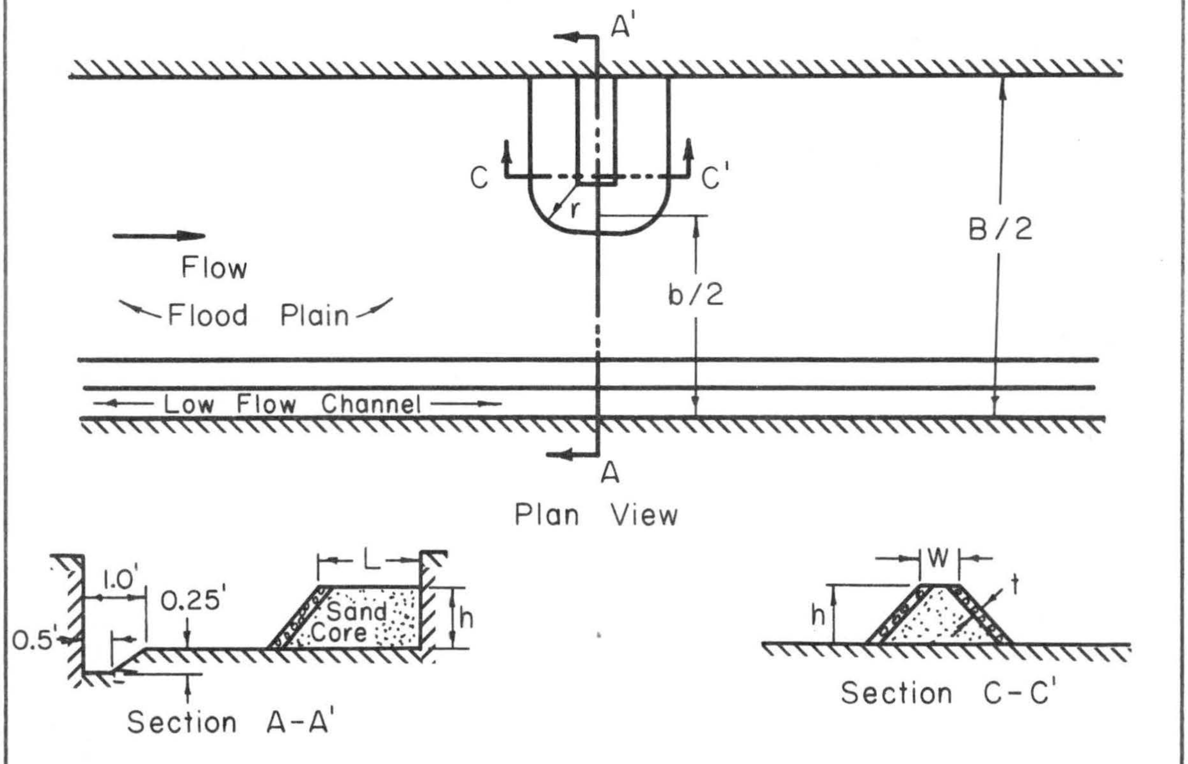
Standard Hybrid Riprapped Basin

Scouring Basin with a Metal End Section

Fig. 1 - Rigid and Riprapped Culvert Outlet Basins



(a) Wide Channel Flow



(b) Overbank Flow (Setback Abutment)

Fig. 2 - Model Spill-Through Abutments for Wide Channel and Overbank Flow