Handbook of Drainage and Construction Products

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HANDBOOK OF DRAINAGE AND CONSTRUCTION PRODUCTS

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PREFACE

SINCE THE FIRST EDITION of this drainage handbook appeared nearly a quarter century ago, under the title of *Handbook of Culvert and Drainage Practice*, tremendous changes have taken place in engineering construction—in materials, products and methods.

What is written today by engineers is more of a backsight or a bench mark from which to measure future progress. Armco engineers throughout the world have contributed of their experience and know-how to make this the only book of its kind. As before, it was prepared for engineers in private practice and public service as well as for students in municipal, highway, railway and other branches of engineering.

The following table of contents quickly reveals the wide scope of this handbook. Most of the chapters are briefly summarized to enable the user to conserve his time in searching for information. The Index has been carefully planned for the same purpose. All illustrations are referrred to in the text, thereby helping to clarify many points.

Acknowledgment is made to the various engineering societies and journals, text-book writers, engineering college experiment stations and to others for source material. Thanks is extended to the various engineering authorities who gave of their time to review the texts and who offered valuable suggestions.

Special acknowledgment is made to the Armco Drainage Engineers who wrote the chapters on which they were best versed, including G. E. Shafer, J. M. Robertson, W. T. Adams, H. L. White, M. H. Bailey, R. L. Mueller, W. J. Kropf and W. B. Roof. All of the Armco Drainage Division Engineers aided by their review of the copy, but special help was given by J. E. Kunkler, R. N. Tracy (deceased), K. E. Seppa and T. A. Bither.

Your help in suggesting changes or improvements for future editions will be greatly appreciated.

W. H. SPINDLER, *Editor*
MARKET DEVELOPMENT DIVISION
ARMCO STEEL CORPORATION

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INTRODUCTION

Development of Modern Construction

ONE OF THE most significant changes in the construction field during the past half century has been the swing from heavy, massive materials to lighter weight but stronger flexible materials. Fifty to 100 years ago the engineer and builder had but little choice. To cite a few examples:

Timber: Large timbers were plentiful and skilled labor was available for converting them into covered bridges, high trestles, buildings, foundation grillages and many other structures.

Stone: Pipe culverts were practically unknown. Not only culverts but many large bridges were built of stone because of its availability and because labor was plentiful and cheap. Tunnels, too, were lined with stone. Nowadays stone is used more for adornment than as the basic structure.

Brick: Sewers and culverts of brick, as in the case of stone, have largely passed out of the picture in favor of materials more quickly placed and better adapted to present service conditions.

Cast Iron: Once used extensively for culverts under railroads, cast iron pipe for this purpose has been supplanted almost entirely by lighter-weight, stronger materials.

Twentieth Century Problems

The turn of the century brought new problems to the engineer and builder—new and improved means of transportation. The slow "horseless carriage" has changed to streamlined, high speed automobiles, trucks and buses. Railroads have become a roller-bearing, streamlined, high speed means of transporting people and goods.

From a fragile "kite" first flown by the Wright Brothers at Kitty Hawk, N. C., in 1903, the airplane has become a flying behemoth—ranging up to 200 tons for the latest bomber. We have indeed become nations on wheels and wings.

Time is money. As distances have shrunk and the volume of traffic stepped up, the time element in construction has become a more important and costly consideration. Interruptions to heavy traffic and delays to costly fleets of construction equipment are sufficient causes to influence the choice of construction methods and materials.

Mechanization of construction processes has changed the picture, too. Old arts and skills have been lost. Builders of covered bridges and stone arches would now be hard to find or to train.

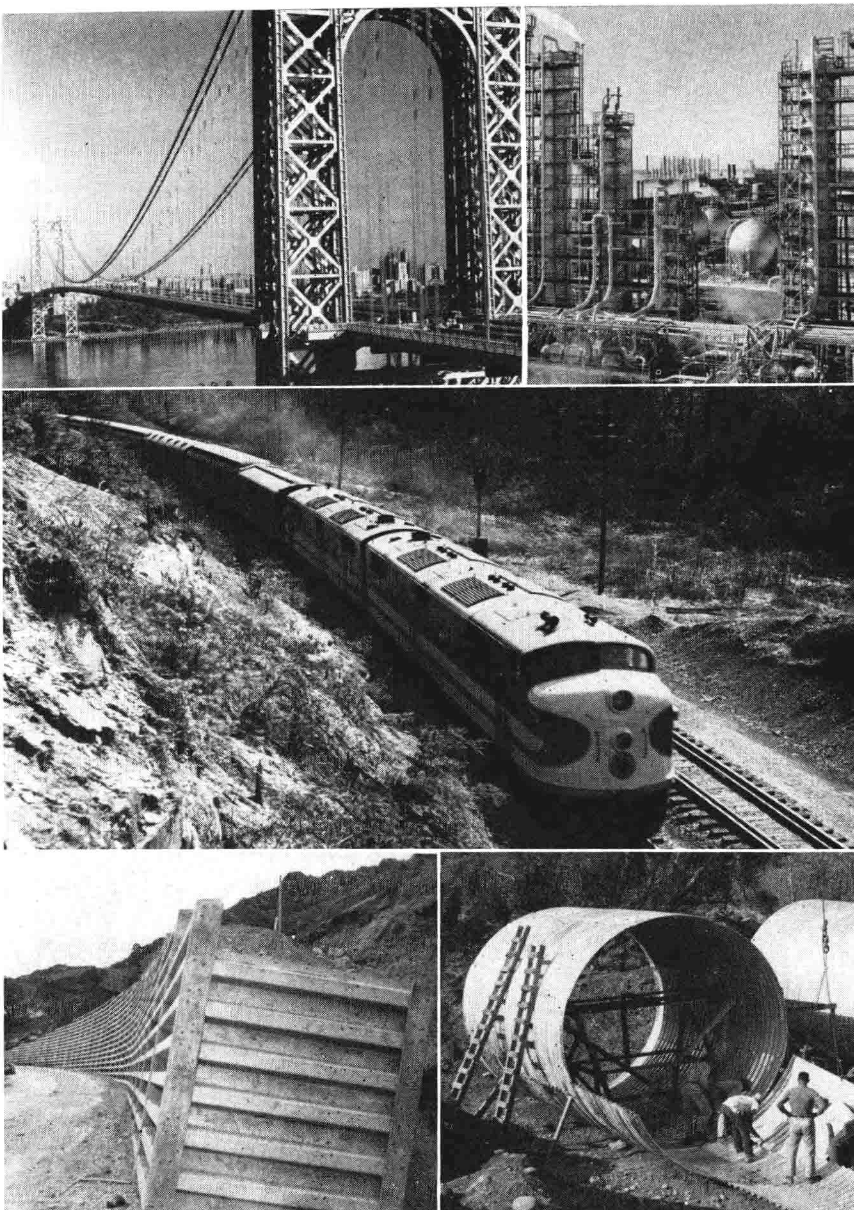

Fig. 2. Steel means economical construction of many kinds. *Upper left:* Geo. Washington suspension bridge. *Upper right:* Oil fractionating unit of Humble Oil & Refining Co. *Center:* Diesel-electric locomotive, Southern Ry. (3 photos courtesy Stand. Oil Co. of N. J.) *Bottom left:* Bin-type steel retaining wall. *Bottom right:* Multi-Plate pipes.

New Materials and Processes

With the new problems fortunately have come new materials and methods of using them. Research, both fundamental and commercial, has kept in step with the needs. Fig. 3.

Metallurgists, chemists, physicists and research engineers have contributed by developing many new grades and alloys of steel—to say nothing of rubber, petroleum products, cements, plastics, electronics and a host of other items. In this handbook we are concerned mostly about new steels, new protective coatings, new products and new methods of installation as they apply to engineering construction.

Research has played an important part in the growth of Armco Steel Corporation, largest manufacturer of specialty sheet steels, and also of its subsidiaries, Armco Drainage & Metal Products, Inc. and The Armco International Corporation. In this field, Armco has found its greatest opportunity to be of service to mankind.

Better controlled manufacturing conditions, more prefabrication, and less on-the-job labor has had a tremendous effect on speeding up engineering construction and reducing costs. Fig. 2.

Future Developments

Without attempting to prophesy the future, certain things are evident to the discerning builder. Nothing is static. Nothing is permanent in the sense that changing conditions will not make it obsolete or outmoded. This ever-changing scene makes it desirable to look for *adaptability* even more so than for permanence.

This "atomic age" calls for continuous progress. If the past is any indication, man's resourcefulness combined with God's providence will find and develop new materials, new processes to meet the builder's needs.

Fig. 3. Planned research in laboratory and field leads to development of better materials and construction methods. Armco's main research laboratories.

SECTION ONE

STRENGTH RESEARCH

CHAPTER ONE

Dead Loads

EXTERNAL LOADS AND EARTH PRESSURES ON UNDERGROUND CONDUITS

Summary

Each year millions of feet of conduits are placed underground for culverts, sewers, water mains, gas lines and other purposes.* However, only during the past four decades has the subject of soil mechanics progressed toward analyzing the loads reaching these conduits.

Extensive loading research has been carried on by engineering organizations and individuals. This has been supplemented by planned studies of the performance of many hundreds of culverts and sewers under the widest variety of actual service conditions—in Nature's laboratory.

Not all elements of loading research and design have been mastered, but much progress has been made toward a rational method of design. This progress is summarized in a paper entitled "Underground Conduits—An Appraisal of Modern Research," in Appendix A,[1] this handbook.

Early Load Theories and Practices

History records the use of underground conduits for the past 3,000 years. Some have lasted for centuries. Evidently these conduits were built as a result of experience, observation or by guess, rather than on the basis of rational design. No doubt there were many failures due to poor construction or to the disregard of simple engineering principles. On the other hand, many were built wastefully strong for similar reasons.

Before an engineer can design an underground conduit properly, he must consider the conditions surrounding its use:

1. The character, direction and magnitude of the loads;
2. The physical properties of the material from which the conduit is to be constructed;

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*Conduits also include tubes for receiving electric wires or cables; "utilidors"; underpasses or tunnels for pedestrians, livestock, conveyors, materials or utility lines.

[1]References to literature are given at end of chapter, page 21.

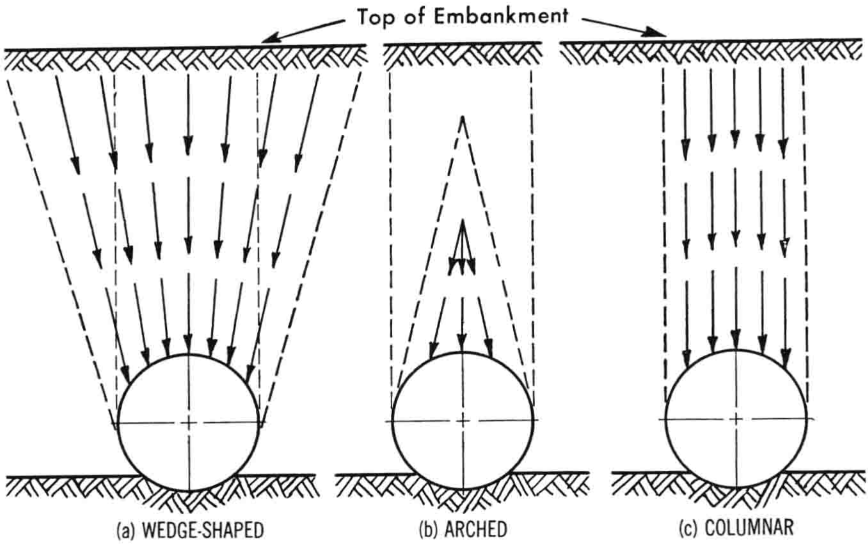

Fig. 4. Three theories of loads on underground conduits—wedge-shaped, arched, vertical.

3. The behavior of the material under the loads to which it is to be subjected; and
4. The size of opening required.

The first three items are necessary from a strength standpoint; the last requirement is to assure the conduit having adequate capacity. It is always advisable, however, to be guided by a study of existing installations. This study applies particularly to the behavior of the existing structures in regard to their ability to carry the superimposed loads without failure, the ability of the soil to carry the structure without excessive settlement, as well as the determination of the correct size of opening to accommodate the material to be carried through it.

Until Dean Anson Marston, in 1913, published the results of his work on conduit loadings,[2] there were only vague ideas of the loads acting on buried structures. One theory was that the load was equal to the weight of the earth directly over the structure, and that it varied only with the height. Some contended that arch action caused the load to be less. Others believed the load, for various reasons, was greater. These three theories are roughly illustrated in Fig. 4.

None of these theories was completely correct because they failed to recognize modifying factors such as installation conditions. Now it can be demonstrated by rational principles of mechanics that the load on a conduit is greatly influenced by:

1. Settlement of the soil directly over the conduit in relation to
2. Settlement of the soil at the sides of the conduit.

These settlements are in turn influenced by settlement of the original ground line under and adjacent to the conduit, the width of trench, the type of bedding, compaction of the fill, deflection of the conduit, and other factors. See description on following pages and in Appendix A.

Research Progress

Extensive loading research at Iowa State College, the University of North Carolina, and by the American Railway Engineering Association, included the weighing of loads over conduits, measuring the pressures, and determining relative settlements. This research led to:

1. Classifying conduits as to degree of flexibility.
2. Differentiation between conduits installed in a trench or under an embankment ("ditch" or trench conduits and "projecting" conduits).
3. Recognition of importance of bedding conditions, along with relative settlement of soil above, alongside, and under a conduit.

Iowa State College, 1908–1952

Most notable of all load research has been that of the Iowa Engineering Experiment Station of Iowa State College, Ames, Iowa. Begun in 1908 by Anson Marston, Dean of the Engineering Division, the research has been carried on almost continuously since then. W. J. Schlick participated in the work in the late 1910's and early 1920's, and M. G. Spangler beginning in 1926 has aided greatly in this research and in publishing its results. Much of the work has been in cooperation with the United States Bureau of Public Roads.

Cracking and failures of many drain tile and sewer pipe in Iowa led to this research. Apparatus was developed for actually weighing the load over pipe *in ditches* (trenches), resulting in the discovery that "the side pressure of filling materials against the sides of the ditch develops frictional resistance which helps to carry part of the weight."[2]

Next, Marston weighed the loads under a 20-ft *embankment* of top soil (1919–1920) and under a 16-ft sand and gravel embankment (1922). The maximum load was 1.92 times the weight of the fill material directly over the rigid pipe.

This research led to the discovery and publication by Dean Marston in 1922[3] of what is widely known as Marston's Theory of Loads on Underground Conduits. Although some factors still are not fully understood, this theory helps make it possible to estimate more rationally the loads on buried structures. Marston also developed methods of determining the strength of underground conduits, and methods of installing conduits to increase their load-carrying capacity. See Appendix A.

Kinds of Conduits

Conduits are of many shapes and materials, but one major distinction—degree of *flexibility*—is important in classifying from a load standpoint:[4]

1. *Rigid conduits*, such as concrete, cast iron or clay, fail by rupture of the pipe walls. Their principal load supporting ability lies in the inherent strength or stiffness of the pipe.
2. *Flexible conduits*, such as corrugated metal pipes and thin-walled steel pipe fail by deflection. Flexible pipe relies only partly on its inherent strength to resist external loads. In deflecting under load, the horizontal diameter increases, compresses the soil at the sides and thereby builds up "passive resistance" which in turn helps support the vertically-applied load.

On the basis of construction conditions under which they are installed, conduits are divided into three main classes: (1) *trench conduits*, (2) *projecting conduits*, and

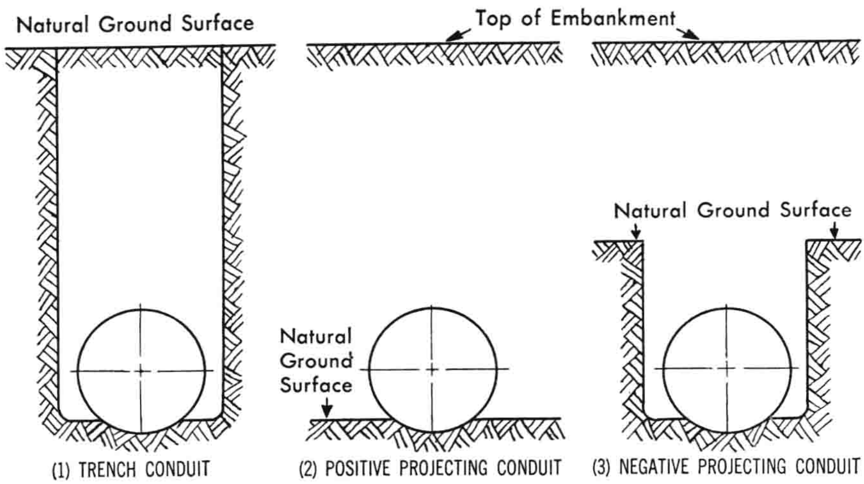

Fig. 5. Conduits are classified according to three construction conditions.

(3) *negative projecting conduits,* a variation of (2). See Fig. 5.

1. *Trench conduits* are structures installed and completely buried in narrow trenches in relatively passive or undisturbed soil. Examples are sewers, drains and water mains.
2. *Projecting conduits* are structures installed in shallow bedding with the top of the conduit projecting above the surface of the natural ground, and then covered with an embankment. Railway and highway culverts are good examples. Conduits installed in ditches wider than two or three times their maximum horizontal breadth may also be treated as projecting conduits.
3. *Negative projecting conduits.*[5] Highway or railway culverts are sometimes placed in a shallow ditch at one side of the existing water course, with the top of the conduit below the natural ground surface and then covered with an embankment above this ground level.

Bedding conditions affect settlement and thereby affect the supporting strength of conduits. These bedding conditions, illustrated for trench conduits in Fig. 6, are: (a) impermissible, (b) ordinary, (c) first class and (d) concrete cradle, used only for rigid conduits.

Field Measurement of Settlement

Two series of field measurements of settlement ratios were made by M. G. Spangler on twenty-four culverts in Iowa. The culverts included rigid and flexible prefabricated pipe and monolithic box and arch culverts. Height of fill over these various size culverts ranged from 8 to 61 ft.

Quoting Spangler's report,[6] "In the present state of knowledge it is difficult to predict the values of the settlement ratio, which has such an important effect on the relationship between load and height of fill. Nevertheless it is present and effective in every culvert installation and scientific progress demands that it be recognized and studied. This same comment applies to the projection ratio, except that the latter factor is more easily determined for a specific pipe installation."

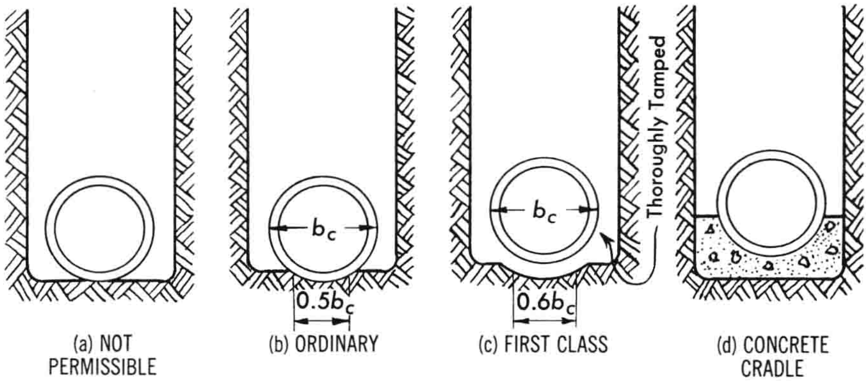

Fig. 6. Typical bedding specifications for trench conduits.

Check on Box Culvert

Pressure cell readings made by Wilson V. Binger of the U. S. Corps of Engineers, on a concrete box culvert 9 ft wide by 10 ft 10 in. high under 50 ft of clay fill on a relocation of the Panama Railroad, gave results comparable to those computed by Marston's theory for "incomplete projection condition."[7] See Fig. 7.

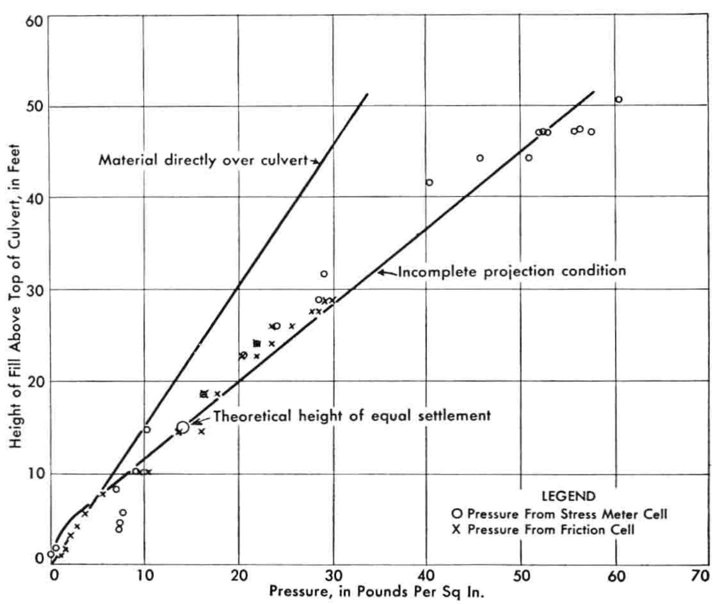

Fig. 7. Pressures versus heights of cover over culvert on Panama Railroad verifies the Marston theory of loads on underground conduits.

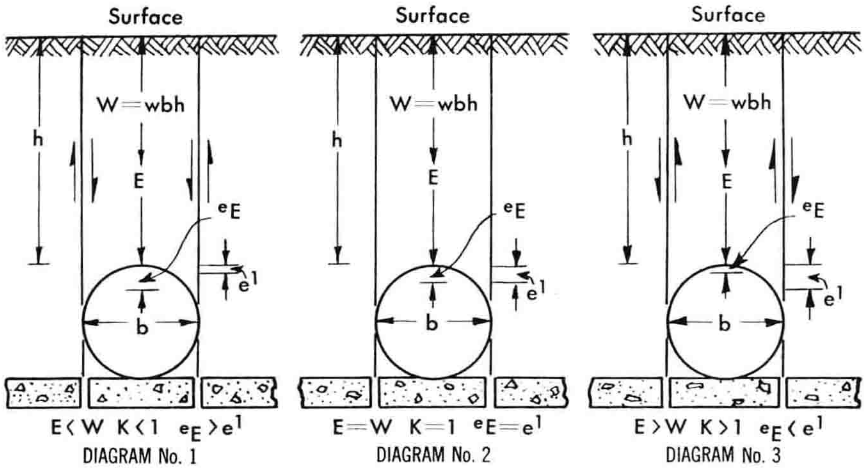

Fig. 8. Action of earth pressures on culvert pipe according to Dr. Wm. Cain of University of North Carolina. (After Public Roads.)

Special Cases

There are cases where the classifications "trench conduits" and "projecting conduits" do not apply. These may occur where either the terrain at the site or the designer will produce conditions other than those defined.

(a) In *wide ditches*, the load on a rigid conduit increases in accordance with the trench-conduit theory until it equals the load predicted by the projecting conduit theory. (b) For *rock foundations*, it is possible to reduce the vertical load on the conduit by excavating a trench in the rock material and refilling with a compressible soil. (c) *Rock fills* are found to act similar to earth embankments in producing loads on conduits. (d) Loads on projecting conduits may be reduced by the *imperfect trench method of construction* in which the soil on both sides and above the conduit for some distance is thoroughly compacted by rolling, tamping, or other suitable means. Then a ditch or trench is excavated over the conduit in this compacted fill and refilled with loose compressible material after which the embankment is completed in a normal manner. (e) *Negative projecting conduit*[5] is a term applying when a highway or railway culvert is installed in a trench dug through an old embankment or at one side of a channel and then covered over with a fill of considerable height. The load on such a conduit will be between that on a trench conduit and the weight of the prism of earth directly above the conduit.

Spangler advances the theory that loads on negative projecting conduits provide a sound approach to the study of loads on this class of structures and leads to proper design and construction of conduits that can safely withstand the loads produced by high fills. This theory may also be used to estimate loads on conduits installed by the *imperfect trench method*, described above. Spangler states that "there is no factual basis at the present time upon which design values of the settlement ratio can be recommended. Further extensive studies are needed."