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Highway bridge design and construction in Missouri

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HIGHWAY BRIDGE DESIGN AND CONSTRUCTION

IN MISSOURI

by

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A

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INTRODUCTION

The design and construction of highway bridges is a subject so broad and includes so many different specialized branches of engineering that volumes would be required to discuss the matter in any detail. With this in mind, the writer will attempt to cover in the following paper only a brief outline of the different phases of the work and to show how a number of the special problems are handled by the Bureau of Bridges of the Missouri State Highway Department. The writer, having had seven years experience as detailer, designer, engineer of construction assignments, and chief draftsman with this Bureau, is thoroughly familiar with the workings of the organization; and he feels that the information brought out in the following discussion will be of interest and value especially to students preparing themselves for engineering work.

DEPARTMENT ORGANIZATION

The business of designing and constructing the various sizes and types of bridges required for a state highway system necessitates the use of a large number of trained engineers. These men must be experienced and skilled in many of the distinctly different branches of the profession and yet work efficiently together, without friction, as parts of a well designed machine. Naturally a sound and properly directed organization is the first requisite. The Missouri Department is considered by many well known authorities to be one of the most efficient organizations of its kind in the country, and certainly many features of this Department are worthy of consideration. In order to understand and fully appreciate the necessary cooperation and the interlocking duties of the several bureaus of the Missouri State Highway Department and of the different units within each bureau, one should be familiar with the scheme of the general organization and its functioning. The organization chart shown on Plate I is self explanatory and is well worth studying in detail. The reader will obtain a more complete understanding of this Department

ORGANIZATION CHART

MISSOURI STATE HIGHWAY COMMISSION
JEFFERSON CITY

APPROVED JULY 1, 1929
MISSOURI STATE HIGHWAY COMMISSION
CHIEF ENGINEER

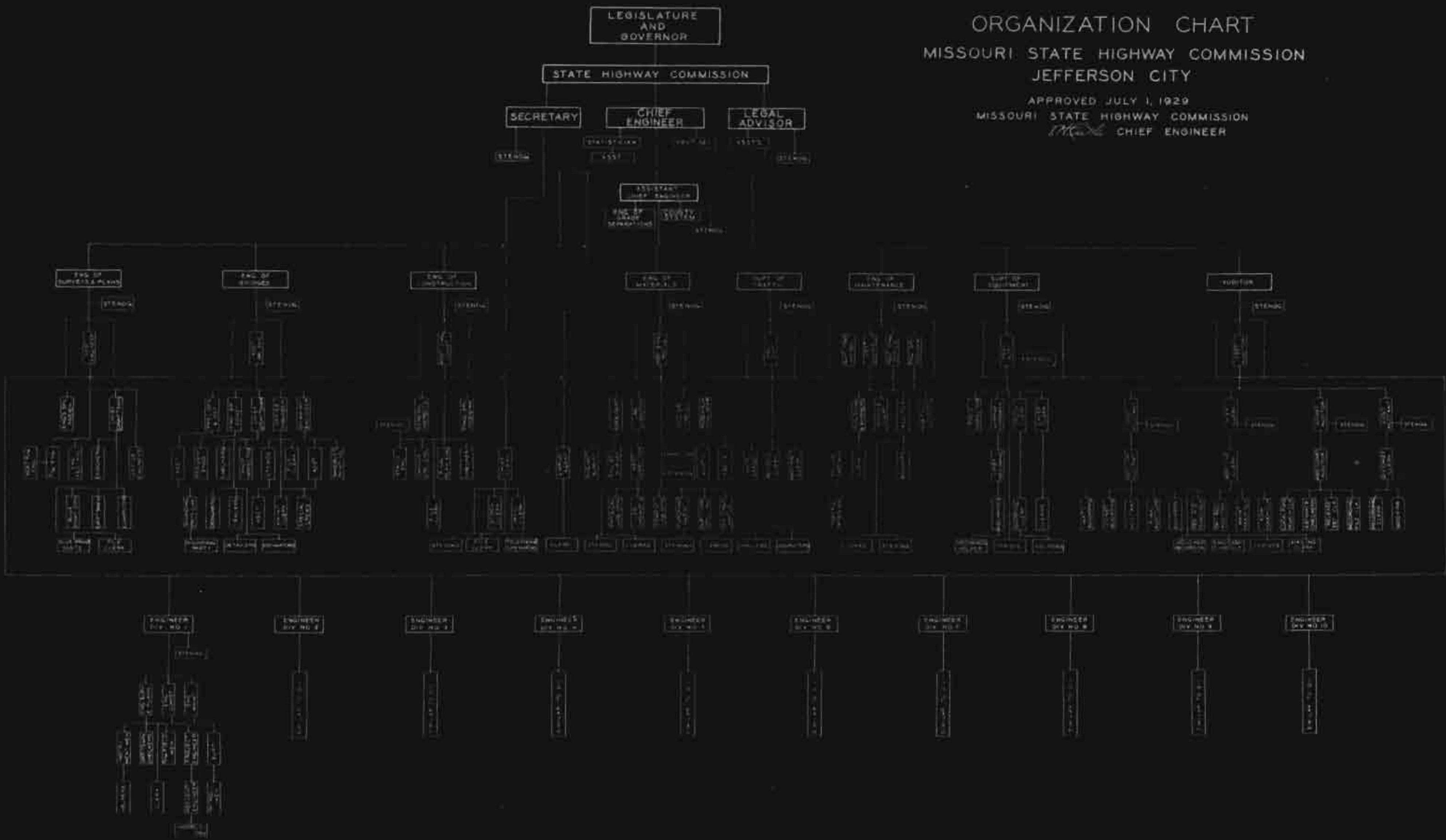

PLATE I

by noting the relation of the several activities as each particular phase of bridge design and construction are taken up and discussed in the following paragraphs.

BRIDGE SURVEYS

Special surveys of all bridge sites are necessary in order to obtain certain specific information upon which the layout of the structure must depend. This survey is made by the field parties operating out of the division offices and is taken care of at the same time they survey the road. The data collected and shown on these bridge survey reports and maps will largely determine the length, height, skew, and arrangement of spans; the type, size, and depth of foundations; and the estimated cost of construction. The bridge surveys are very complete showing many details which, to the layman, may seem irrelevant and unnecessary; yet they contain data of utmost importance for successful and economic design.

The topography at the bridge site is taken in detail and is shown on a large scale contour map. The contours are usually shown at two foot intervals and cover an area at least one thousand feet up and down the stream and over the full valley width. Any existing roads or bridges are shown on this map, and possibly several alternate alignments for the proposed new road. These contour maps are invaluable in studying the general trend and direction of the valley for the determination of skew angle and desired channel changes.

A profile is taken along the centerline of the proposed road extending each side of the channel to limits of extreme high water. Since the valleys are usually of considerable width, these profiles are plotted to contracted scale. Other profiles are taken of the particular portion of valley crossing to be occupied by the bridge. These are taken thirty feet right and left as well as at centerline of proposed road and are shown at equal vertical and horizontal scales, preferably one inch equaling ten feet.

A profile of the stream bed is also made. This extends at least one thousand feet each way from the bridge site and shows at a glance the channel grade, which is a most important function of stream velocity and channel capacity.

Supplementing these contours and profiles, every bridge survey includes a report giving a complete description of the stream. The stream may be comparatively straight or very crooked. The channel may be clear or obstructed with trees, or it may be cutting or filling. The banks may be caving or stable. A knowledge of the proximity of existing or proposed dams is also essential and is covered in these reports. The water stages are determined as accurately as possible from a study of the drift and from information furnished by local residents. The elevation, frequency, and duration of extreme highwater is given and described as either headwater or backwater. Drift is another item given special attention, and its characteristics are noted in this report. The extreme low water elevation shows the necessity for treating foundation piling, and it is no small item in fixing the cost of excavation.

Special care is taken to report all obtainable data in regard to any existing bridge or bridges at the proposed site of the new structure. The types of substructure and superstructure are noted, together with the number and length of spans, floor elevations, roadway widths, et cetera. Where possible, the construction dates are given and the effectiveness of structures for waterway and drift during past years are discussed. Similar data is obtained and furnished for any old structures up stream or down stream from the proposed bridge. It is obvious that a knowledge of the functioning of present bridges will be no small factor in the determination of types and lengths suitable for future construction.

In order to determine the required waterway, the drainage area is given special study. The area is computed by traverse or from the U. S. G. S. contour maps. The length and width of the valley is ascertained and the character of the area is classified as flat, rolling, hilly, or mountainous. After all possible information has been obtained in regard to the drainage area and the stream itself, the required waterway at the proposed bridge site is estimated by formulae. All survey reports show estimated discharge based on the following formulae: Dunn, Talbot, Kuichling, and Rational. Other estimates of discharge are based on special Missouri curves and on Missouri reports of rainfall and highwater. An estimate is made on probable discharge through the old structure, if any, and through the proposed new structure. A thorough analysis of all information obtained makes it possible to design structures that meet drainage requirements with reasonable margins of safety. Under these conditions a structure is rarely designed that proves disasterously too short or extravagantly too long.

In addition to a report of the above mentioned observations, each survey accurately locates in detail the proposed crossing. The route, county, township, range, and sections are given as well as the name of the stream and proximity of the bridge site to city or town. The locality and distance to shipping points will often effect estimated costs to such a degree as to determine the type and extent of construction.

All bridge survey reports and maps are made up on blank forms which are supplied with complete instructions to the survey party. These forms not only facilitate the tabulation of required data, but also serve to standardize this work, thereby adding much to its value for future reference and study. After completion, these reports and maps are signed by the chief of survey party, later approved by the division engineer, and then submitted to the Bureau of Bridges for use in making up preliminary layouts.

FIELD CHECK

Upon receipt of surveys in the Bureau of Bridges, they are turned over to the preliminary designer and estimator who makes a brief study of the data submitted. However, before proceeding with layouts and detail estimates, a field check is made. This field inspection is made by the preliminary designer and estimator, or his assistant, in company with the division engineer and his assistant in charge of surveys. Much of the information shown on the survey report is taken up, checked, and discussed on the site. Possible channel changes are located and their advantages and estimated costs considered. Alternate crossings are looked over together with any proposed changes in alignment on either side of crossings. These and other important questions are investigated during this field check, and any differences of opinion are usually threshed out here on the site where actual conditions can be observed and studied.

SOUNDINGS

After the field check has been made and a general idea obtained as to the amount of bridging and span lengths required, the next step is to secure soundings. For all of the smaller structures, the division offices make soundings with their own equipment; while for the larger and more important designs, soundings are made by a special sounding party from the Bureau of Bridges. The equipment used by the division offices consists of augers in four foot lengths for use through soft material and driving points for use through gravel and boulders. They also carry a jack to pull these augers and driving points. This equipment, while simple and comparatively inexpensive, is sufficient for use on the average crossing. The sounding party operating out of and under the direction of the Bureau of Bridges uses augers, driving points, pipe casings, core drills, jacks, gasoline motors, et cetera. With this special equipment, the party is prepared to take soundings for any job from one on the smallest stream to one on the largest river.

It is usually possible to determine in advance the approximate location of substructure, especially such units as may be placed in or near the channel. Where this is done, soundings are made at these predetermined points and are, of course, of much greater value than if taken at random. All soundings are logged in such a manner as to show the surface elevation, the classification and extent of each different material passed through, and the elevation and character of material at the lowest point reached. Where practical, all soundings are carried to rock and for special designs they are often carried one or two feet into solid hard rock. In addition to this carefully tabulated log, all soundings are plotted on the large scale profile map made by the survey party. The value of this information to the estimator and designer is almost incalculable. It eliminates one of the principle variables in estimating substructure costs by enabling the preliminary designer to compare a design with footings on rock with one on piling. This information also reduces to a minimum the necessity for a redesign of footings after excavation has been made during construction. These soundings are available and are studied by the contractor before he submits a bid for the construction work. This data furnishes him with a knowledge and an assurance of the kind of materials which are to be handled in excavating for substructure.

PRELIMINARY LAYOUTS

Now that the survey has been completed and field checked and that soundings have been made, the preliminary designer and estimator is ready to proceed with the making and estimating of alternate layouts for the proposed bridge. In making these layouts a number of factors must be considered in addition to the primary requirements of drainage. The required length and type of structure may be influenced by some special or unusual characteristic of the channel or of the stream valley. Unstable banks may make it wise to use U-abutments; a large channel with rock near the stream bed may favor concrete arch construction; suitable hardpan or fireclay may make possible some type of spread footings; solid rock not too far below stream bed may decide for some type of concrete bents or piers; or existing subsurface material may make it necessary to consider pile bents or piling under concrete bents. Certain facts relating to the channel, to navigation requirements, or to the quantity of drift during highwater may largely determine the span lengths and the location of substructure units. All of these items are vital and must be given careful study and consideration.

Besides the physical requirements of the stream, it is necessary to take into account the type of route, whether primary, secondary, traffic relief, additional primary and park connections, supplementary, or refund. The location of the bridge site must be studied with special reference to its proximity to a city or village. These facts will indicate the character and magnitude of present and probable future traffic as well as fix, to a large degree, the amount of money available to provide for such traffic. The type of road and the location of the bridge site with respect to a center of population will determine the roadway width and necessity for sidewalks as well as to fix the required loading for design. Other features of the design layout that are determined by location are provisions for lighting; for carrying water, gas, or sewer lines; or for supporting telephone or electric conduits.

Another fundamental economic factor entering into the design is the relative distances from the bridge site to the source of supply of the different materials of construction. In one section of the state local gravel may be available in such quantities as to make for cheap concrete masonry, while in another section a long expensive freight haul may be required to bring in all the concrete aggregates. It has been found that unit prices paid for steel and timber as well as the cost of concrete masonry vary considerably because of the bridge location and corresponding costs of material transportation. This influence on the final cost of structures is important because of the fact that the material constitutes a major item in the total construction costs.

To facilitate selection of types and span lengths, use is made of many charts, diagrams, and curves. Quantities are computed for variable heights and styles of open end bents, intermediate bents, dumbbell piers, U-abutments, and each of the other standard types of substructure. These quantities are then plotted against heights for each particular style and type. Other curves are plotted which show the costs of variable heights at certain unit prices for concrete, reinforcing steel, excavation, and any other items entering into the construction costs. By judicial selection of unit prices and careful interpolation between price curves, it is possible to prepare, in advance of design, a very accurate estimate of cost for any desired case. Similar curves are prepared and used for the different types and spans of superstructure. This completes the data necessary for estimating the total cost of a finished structure of any standard type and length.

However, the first cost alone is not used as a basis of selecting the most economical type. The useful life of the structure, maintenance costs, and the salvage value must be considered. While some of these items may be considered as highly problematical, it is possible to arrive at a reasonable and comparable estimate of their values, and they should not be neglected. It is often found that the amount of a sinking fund required to take care of repainting structural steel under maintenance is alone sufficient to swing the balance of economy in favor of some type of concrete construction. The first cost of a timber bridge is usually much less than one constructed of steel or concrete; yet with its comparatively short life and costly maintenance, it is not always the most economical type.

Aesthetics is another feature of design that should be considered by the preliminary designer, especially for structures in or near a city, in a park, or near some natural beauty spot. Results pleasing to the eye can usually be obtained without additional or extravagant expenditure.

Symmetry in the layout of spans, good general lines, and a consistent proportion of parts should be attained whenever practicable, while highly ornamental effects should always be avoided. The structure should be worked out along natural, simple lines to harmonize with its environment and not created to offend the landscape in which it occurs.

LAYOUT CONFERENCE

The next step is the layout conference held by the Bridge Engineer before approving any proposed layout for design. Those present and taking part in this informal discussion are, in addition to the Bridge Engineer, the Assistant Bridge Engineer, the Bridge Construction Engineer, the Chief Draftsman, and the Preliminary Designer and Estimator. All of the survey and sounding data and the preliminary layouts with estimates is submitted and explained by the Preliminary Designer and Estimator. Questions are asked and constructive criticism brought out in regard to every important or special feature of the proposed work. Some of the items given most consideration in these conferences are as follows: waterway, bridge lengths, bridge grades, span lengths and types, roadway widths and sidewalks, substructure types, footing elevations, pile lengths, channel changes, and channel cleanouts. After one of the proposed alternate layouts has been approved in this conference, the survey, with layout, is ready to turn over to the chief draftsman who will prepare detail plans for the work.

PREPARATION OF DESIGN PLANS

The preparation of the detail plans, which are required for letting and construction purposes, is all done by the Bureau of Bridges. This centralized drafting office under one direction makes possible an efficiency in operation and a standardization in design with the resulting uniformity in detail plans that could never be attained by any system of work under the division offices. One large organization can be developed and trained as a group of individual specialists working in combination to produce plans far more economically than a number of small organizations where each man must handle every step of the work. For instance, in a large office, tracers, detailers, estimators, designers, special designers, and checkers can be developed according to the individual's ability. Under this system it is possible to employ, at a comparatively low salary, a man untrained in design and develop him into a better tracer and detailer than the high salaried designer who, at most, would spend only a small per cent of his time tracing or detailing. However, specialization should not be carried to such a degree as to injure the morale of the personnel by destroying all ambition for promotion to higher grades of work. The individual should be given every possible opportunity and incentive to prove himself worthy of advancement. While not directly related to the technical side of bridge design, an efficient designing and drafting organization is no small factor in the economical phase of the work and has a well defined place in any general discussion of bridge design problems.

As already suggested, the cost of producing the detail design plans for a structure is an item of considerable importance; and, in addition to the development of an efficient organization, some thought should be given to the drafting office and its equipment. The Missouri office is sufficiently large, well lighted, furnished with comfortable desks and drafting tables, and supplied with the necessary electric calculators, adding machines, dictaphones, typewriters, and many other smaller labor saving devices. Electric erasing machines are used, and while comparatively inexpensive, they save many hours of high priced labor each day. The careful selection of supplies, even to the grade of pencils, has a direct relation to the efficiency and economy of design.

The use of standard types of superstructure and substructure saves much time and expense in the production of detail plans as well as furnishing a most valuable basis of costs for the preliminary estimator. Standard reinforced concrete deck girders, concrete slabs, I-beams, and structural steel trusses are designed in many different span lengths, roadway widths, and with different types of handrail. Each of these designs is drawn up on a standard sheet which can be used to supplement other details for any particular structure. These standards save not only the time required to design each bridge as a special case, but also the time necessary for detailing, tracing, and checking each design. Culverts are designed and details shown on standard sheets which, together with tabulated modifications, satisfactorily take care of each of the several standard sizes under various heights of fill. While it is granted that there is a possible danger of over-standardization, the judicial use of properly designed standards is one of the necessary means of attaining greatest efficiency in design.

Because of the fact that the substructure heights vary with almost every individual case, it is usually found impracticable to show details on standard sheets. However, considerable saving can be made by the use of "Brown Prints." These are made by first detailing and tracing the desired type of bent, pier, or abutment with all variable dimensions left blank. These tracings are then "Vandyked" and the "Brown Prints" made from the "Vandykes." The open dimensions are then filled in on the "Brown Print" to apply to a particular job and this sheet made a part of the detail plans for that job. "Brown Prints" are in this way made up and used for the various types of standard open bents, dumbbell piers, U-abutments, cantilever abutments, et cetera. It is sometimes possible to use practically all of the details of one job for another similar design. This is accomplished by "Vandyking" the original job, blocking out on these "Vandykes" such details and dimensions as do not apply to the second job, making a "Brown Print" of this corrected "Vandyke" and then adding on the "Brown Print" the required details and dimensions.

Before starting work on detail plans for a bridge, the chief draftsman studies the proposed layout with regard to possible use of standards and "Brown Prints." Similar designs, if available, are selected from the files for reference and, together with standards and "Brown Prints," are given to the designer or detailer assigned for the work. During the process of designing, detailing, and tracing, careful supervision is given by the chief draftsman or his assistant to see that standard methods and details are used where possible and that special features are properly handled. Supervision of the work during these stages is well worth while since at this time it is possible to catch and correct many errors and discrepancies in the making, and thereby avoid the necessity of making revisions after plans have been completed. All designs, details, and quantities are checked by men who are thoroughly familiar with the general design specifications and the standard office practice in regard to details. After necessary corrections have been made, the plans are approved and signed by the checker. They are next received by the chief draftsman who carefully reviews them to see that design features and plans in general are satisfactory. The plans are finally passed to the Bridge Engineer for his approval.

ENGINEERS' ESTIMATE

After the detail plans have been completed and all quantities checked, a careful estimate of cost is made. This engineers' estimate is necessary in order to determine the amount of funds required to handle the project and to reveal excessive or unbalanced bids which may be submitted by the contractors. In making these estimates it is necessary to consider the cost of materials required for the structure at their source and the transportation charges to the bridge site. It is also necessary to estimate the cost of all material required for falsework, forming, and cofferdams, as well as the rental charges on all equipment and tools. These, together with labor costs and a fair per cent of profit, form the basis for the unit prices used in the estimates which, within reasonable limits, are accurate and reliable.

AWARD OF CONSTRUCTION CONTRACTS

All work is advertised two weeks in advance of the letting date and the detail plans, specifications, and bidding blanks are furnished to anyone requesting them and making the required deposit of ten dollars ($10.00) per project. On the letting day the sealed bids are publicly opened and read, after which they are tabulated and checked. Upon recommendation of the Chief Engineer, the contracts are awarded by the Highway Commission at its next regular meeting and notices to proceed are sent out to the contractors getting the work.

CONSTRUCTION

Direct supervision of construction on all the smaller bridges is handled by project engineers working out of the division offices, while many of the larger and more important structures are handled by special project engineers. These special project men operate as a part of the division organization but are under the direction of the Bridge Engineer. In addition to the direct supervision of bridge construction, there is a general cooperative supervision taken care of by the Bureau of Bridges and the Bureau of Construction. Field inspections are made by representatives of these two bureaus. The Bridge Construction Engineer operates out of the Bureau of Bridges, and the General Inspectors operate out of the Bureau of Construction. At regular intervals detail reports are submitted by the project engineers so that it is possible for all concerned to keep in close contact with the job by reference to these reports and the general correspondence relative to the work.

In addition to taking part in the supervision of construction in the field, the Bureau of Bridges has direct charge of many other features of the work. Any proposed change in layout or in details must be referred to this Bureau and approved before such a change is made. Redesign, which may be made necessary because of errors in soundings or for any other reason, is prepared by this Bureau. All test pile data is analyzed and the required authorization is given to the contractor before he places the order for piling. These are only a few of the many design items taken care of by this Bureau during construction.

SHOP DRAWINGS

Complete detail shop drawings are required for all structural steel. These drawings are usually prepared by the shop furnishing this material and are submitted to the Bureau of Bridges for approval before fabrication is started. All of these details are checked and one set of prints, on which required corrections have been noted, is returned to the shop. After revisions have been made and the details found satisfactory, one set of prints is approved and returned to the fabricator who then furnishes the additional prints required for office files and for use in the field. The approved drawings furnish the necessary data for the final estimate of the structural steel. In making this estimate, all cuts and copes are deducted so that the resulting weights are the exact theoretical weights of material in the finished structure. In accordance with specifications, payment is always based on these theoretical quantities.

SHOP INSPECTION

In addition to checking the detail shop drawings for all structural steel, the Bureau of Bridges inspects and approves the fabrication of this material. This inspection is made at the various fabricating shops before the material is shipped. Experience has shown that it is far more economical as well as more satisfactory to handle this inspection out of this Bureau than to hire this work done by a representative of one of the commercial testing laboratories. As a further safeguard in the use of steel, the contractor or the fabricating shop is required to furnish certification of the chemical and physical properties of the material furnished.

PAINTING

One other item of construction taken care of by the Bureau of Bridges is the painting of all structural steel. This work requires several special painting crews each equipped with a sandblasting outfit for cleaning the steel and with both paint guns and brushes for applying the paint. All this work is done by experienced painters working under capable foremen. Painting handled in this way has proven very economical and far more satisfactory than that applied by the bridge contractor.

CONCLUSION

After painting, the bridge is complete and ready to serve its purpose as a very important and necessary connecting link in the state system of roads. While each major step of design and construction procedure has been mentioned and briefly explained, it has not been possible, in so short a paper, to discuss the many other interesting and instructive features of this work. However, it is the sincere desire of the writer that the information furnished herein will, in some way, help lead to a greater realization and fuller appreciation of the engineering problems involved in the creation of these structures.

I N D E X