Engineering for Modern Contracts and Construction

By

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Introduction

In this article engineering practices followed in the United States, for the design of an engineering project to be constructed under a fixed unit-price type contract by highly mechanized construction methods, will be discussed. These may be compared with practices conventionally followed in West Pakistan, where only a limited degree of mechanization has been introduced. It will be shown, that more specialized field investigations and design practices are necesssary to efficiently and economically carry out the construction of a project utilizing the most recent advances in a high speed mechanized construction.

All engineering projects, carried to completion, pass through three phases. These are planning, design and construction, and maintenance. Despite great advances in techniques for high speed mechanised construction, the planning procedures for a major project have evolved very little through the years. Planning procedures followed in the United States are generally similar to these followed in West Pakistan. They may result in findings of feasibility which, in turn, are used to secure financing of the project from Government or other sources. Substantial differences do arise. however, in the design phases of the engineering work. Minor differences also arise in operation and maintenance procedures, but these will not be discussed herein.

Assuming that a given project has passed through its planning stage, including financing, and is entering its design and construction stage, and that a fixed unit-price type of contract is to be used in connection with high-speed mechanized construction methods, all work carried out during design must be tailored to the goal of obtaining the best possible prices for construction of the works required. To prepare a bid or tender a capable well-equiped modern contractor must know exactly all the work

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to be done and all the conditions affecting the execution of the work. Any unanswered questions or uncertainties in the drawings or specifications naturally forces the contractor to bid or tender a higher price to protect himself against these uncertainties. It becomes necessary, then, to issue many more drawings and more information in the specifications than is conventionally done in Pakistan, so that a contractor can determine exactly and fully the work and conditions, thereby ensuring lower costs for the project. This in, turn, results in an added burden on both investigation and design, as will be discussed more fully later.

Fixed Unit-Price Contract

Before going into a detailed discussion on what is requried in the investigation and design phase let us examine the advantage of a fixed unit-price type contract based on international tenders and see why it is being used. A fixed unit-price contract differs from the unit-price contracts normally used in West Pakistan ; and before discussing advantages of one over the other, we should understand this difference. The difference is best explained by using an illustration. It is a normal practice in West Pakistan to accept a tender, for, say, canal excavation at a tendered price and then make additional allowances for hardness, wetness, height and lead. With a fixed unit-price contract, on the other hand, a tender for excavating and moving the soil would be accepted and no extra allowance would be given for any conditions encountered. There is one advantage in the latter, in that the finances of the project can be programmed much more accurately after the contract has been awarded as the cost of the project will depend only on the accuracy of the quantities estimate, without variables which may enter as a result of extra allowances. The greatest advantage of a fixed unit-price contract, however, is that it forces the contractors to make their own estimate of the cost of constructing the project. They may plan on using any and all of the modern construction equipment at their disposal. Modern contractors must be truly experts in this field or they don't survive financially ; and as there are many of them in the world competing with one another, they are forced to tender the very lowest possible price in order to get construction jobs and continue successfully in their field. Thus, by using the fixed unit-price type of contract the owner is assured of getting the project constructed for the best possible price.

Final Location

Now, let us discuss the previously mentioned investigation and design procedures for a fixed unit-price type contract. It has been found in the United States, that the practice of locating the various structures or other components of a project on topographic maps in the design office and then checking their location in the field as advantageous from the standpoint of economics, time involved, and results in better final design. This is a different concept from what is normal in West Pakistan, so a few reasons for it will be discussed. With topographic maps personnel in a design office can observe the overall project site, and at the same time perceive many of the economic and natural factors that will influence the design and location of the project ; whereas a location engineer in the field can only see a limited distance in any direction, and many of the factors that should influence location are hidden from his view. The use of large high-speed construction equipment results in greater lattitude in use of such things as cuts and fills ; so that many design features, desirable from an operational point of view may be economically included in a project. All such special design features, and the choices between possible alternate locations, require comparative economic studies for individual justification. The design office is the logical place to make these studies. The design office, following United States practice, has personnel specialized in design and overall studies of this type, and is equipped with electric calculators, reference libraries, drawing equipment and other facilities for this type of work. Another not as obvious advantage, that comes as a by-product, is that preliminary estimates of quantities are produced as the studies have been made to justify the final design and locations. Final location in the design office required accurate topographic maps, with as small a contour interval as is economically justifiable. It is rare that existing published topographic maps can be obtained that will meet these requirements; and it becomes a part of the project engineering task to obtain them.

Topographic Maps and Aerial Surveying

In most parts of the world aerial surveys are presently the cheapest means of getting these maps. In those parts of the world where this statement may be debated, the elements of time and accuracy still make aerial surveys desirable. Aerial surveying is a highly specialized technical field,

that requires expensive equipment and highly trained specialised personnel. There are a large number of companies in the world who specialize in this field. As with construction contracts, it is usually most economical to put project mapping requirements out on competitive tenders and have the work done by a firm of specialists.

Since aerial mapping is somewhat new to West Pakistan and is becoming such an important part of modern engineering, we should discuss it a little further. It would be unrealistic to attempt to discuss photogrammetry technically in a paper of this nature, as entire textbooks and manuals have been written on the subject. Photogrammetry is the verv core of mapping from aerial photos, but it will have to suffice here to mention what is done, without delving into the subject of how it is done. The mapping contractor starts with large scale conventional maps on which the area to be surveyed has been outlined. He then plans how he will cover the area with aerial photography and plots flight lines on these maps. The maps are then turned over to the navigator of an air crew. The navigator guides the pilot on the required flight lines and tells the cameraman when to start and stop photography during the time each flight line is being flown. The distance above the ground maintained by the airplane during these flights depends on the desired scale of the finished topography maps and the focal length of the camera lens. The pictures are spaced so that there is about fifty per cent overlap between each two successive pictures in a flight line and the flight lines are spaced so that adjacent pictures overlap about thirty per cent. Overlap is necessary in order to get a stereoscopic effect from which vertical dimensions can be determined from the photographs. Some conventional ground control surveys must also be made on the site so that maps can be dimensionally controlled. Actually, two different surveys must be made. One is a form of triangulation network for horizontal distance control, and the other is an elevation network for vertical control. The horizontal control may be obtained with conventional triangulation using theodolites and computing distances. More recently many companies are using tellurometers by which distances are measured directly. The vertical control is done with conventional levelling equipment. Both types of control surveys are made after prints of the aerial photographs have been obtained. The surveys are tied to physical features visible on the prints. With both photographs and control surveys completed, plotting of the topographic maps may be started. Positives of the

pictures are made from the film, and placed in adjustable projectors above a table. On this table is a co-ordinate grid system plotted to the desired scale and plotted on this coordinate gird is the data obtained from the horizontal control surveys. The projectors are then adjusted, so that the images projected on the table are corrected to fit the points plotted from the horizontal control data.

Several of these projectors may be arranged in a row down long tables and alternate projectors may be fitted with different filters, so that different images are projected. Stereoscopic relief is obtained from the two images. Elevations of known points are taken from the vertical control survey. Contour lines are traced from the stereoscopic relief and points of known elevation by photogrammetic methods. The planimetric cultural features can be traced from either two overlapped images or a single image.

Accurate topographic maps, whether acquired by aerial surveys or otherwise, are essential to the drawings submitted to contractors for tenders and should not be construed as merely an aid to design,

Field surveys made to control the photography for aerial mapping are tailored specifically to that end, and some additional conventional field surveys must be made by engineering personel to determine sizes, capacities, etc.. of existing cultural features. This includes canals, ditches, culverts, bridges, roads, drainage ditches, graveyards and any other man made features that may affect the project.

Foundation Investigatious

Whenever excavation becomes one of the important items of work for a project, the prospective contractors are vitally interested in the materials that they will have to excavate. Foundation investigations, necessarily, become more extensive and complete, than is conventionally done in West Pakistan, so that this information can be included in the drawings for tenders. These investigations are done in the conventional manner *i. e.*, auger holes, test pits, core drills and spoon samplers. However, the use of power driven augers and bulldozers greatly facilitate ease and speed in conducting these investigations. Of course, samples taken in the field are tested in a laboratory to determine their engineering properties. A word of caution here : poorly trained personnel or carelessness, in either sampling or laboratory techniques, can result in entirely erroneous foundation data, and resulting monetary claims by the contractors.

Drainage Investigations

Drainage investigations remain essentially an item investigated for the design of a project and except for noting swampy areas and effects on accessibility of the site, do not concern prospective contractors. Weather, however, is a concern of prospective contractors ; so that the process of gathering rainfall data for drainage studies must be enlarged to include temperature, humidity, and wind data. The reasons for a contractor's concern about weather may not be readily apparent ; but it must be realized that he has a considerable investment in equipment, and that this investment in equipment is not drawing interest as it could be, and that the equipmeut is depreciating through obsolescence as well as usage. This equipment is costing the contractor a certain amount whether it is producing or sitting idle. Therefore, he is interested in keeping his equipment in production as much of the time as is possible. Aside from the necessary of collecting more weather data, the process of drainage investigation and design is similar in the United States to what is used in West Pakistan with equivalent results, *i.e.*, the determination of the amount of storm water discharge that must be incorporated into the project design.

Materials Investigation

Knowledge about available construction material is a pre-requisite for design of a project under any conditions, and becomes even more important in fixed unit-price contracts since such data must be included in the specifications and shown on drawings. Sources of materials, such as aggregates, cement, and steel must be shown on appropriate maps as well an indication of the quality and quantity available at each source. The costs of materials must be indicated, and in cases such as aggregates, where the materials must be produced, enough information must be given to enable the contractor to estimate production costs. Other data that is included in the tender documents are ; availability and costs of fuels and lubricants required for the operation of equipment, and in the case of international tenders the custom duties and taxes on imported equipment, materials, and spare parts and the taxes rendered on profits.

Design Office

We have discussed the effects that fixed unit-price contracts and high speed mechanized construction have had on investigation for design

and certain phases of design. Now let us discuss the overall effects they have had on design. To utilize a fixed unit-price contract, the entire design of a project, with the exception of construction drawings which will be discussed later, must be completed before tenders for construction may be let, and this has in general reduced the allowable time for design. This means that more design work must be done in a shorter period of time. To do this, a design office must increase efficiency and production and at the same time limit the personnel to a reasonable economic number. Part of this increase in efficiency is accomplished by using topographic maps and the other aids previously discussed. These allow the design engineers to remain in the office without having to waste both time and money travelling back and forth to the site trying to get data. The remaining increase in efficiency is accomplished by utilizing specialized design engineers, who are accustomed to designing under these conditions. A specialized design engineer for these conditions must, in addition to being competent in design theory, be adept at visualizing a structure, any part of a project, and the entire project. He must understand how it will function and be adept in the production of accurate, informative engineering drawings.

Engineering Drawings

Engineering drawings and specifications have been mentioned several times throughout this article. Their importance cannot be over-emphasized for a fixed unit-price type contract. They are the link of communication between design and construction. They are the basis on which the cost of the construction contract is predicated. Since engineering drawings are vitally important, it may be asked how are they different from conventional drawings as used in Pakistan? The difference is that there are many more drawings used and they have to show much more detail.

In order to evaluate engineering drawings, three important questions should be asked. Is it clear? Is it complete? Is it accurate? To get affirmative answers to these three questions about a drawing is a very difficult accomplishment. It can be said without reservation, that "a perfect engineering drawing does not exist." However, drawings for fixed unit-price contracts should be as near perfect as possible, for their imperfections will be reflected in higher prices tendered. The best and about the only way to get really good drawings is to have design engineers,

who fully understand both design and drawing, draw them and then have other dasign engineers, with the same qualifications, check and re-check them.

Engineering Specifications

Engineering specifications, for fixed unit-price type contracts, like the drawings, are not greatly different from those commonly used in West Pakistan, except, they must be so much more comprehensive. The same three questions asked for drawings may be asked of specifications. To get affirmative answers is just about as difficult. The main difference between specifications and drawings is that only a few people can work on specifications, because everyone writes a little differently and with a lot of people writing small portions it is difficult to get continuity in the overall specifications. In the United States, most design offices have a few engineers who specialize in writing specifications and these people write all the specifications for the office. Good specification writers are rare anywhere in the world.

Contract Documents

The people who write the specifications, usually, also prepare the contract documents for tenders. Engineering contract documents are normally more law than engineering, and have been written for so long that they are more or less standardized in any particular country. The author is not fully acquainted with engineering contracts as written in West Pakistan, so no comparison will be made. Contracts, in the United States, have clauses in them making the drawings and specifications part of the contract.

Construction Drawings

To stop the discussion here would leave the impression that design is completed when the tenders are issued. This is not true, as there remain detailed construction drawings, such as reinforcing steel details, hand rail details that are not required for issuance with tenders, but which are required for actual construction. These are left until after the tenders have been issued, unless there is ample time to prepare them before hand, They must be finished as required for construction,

Summary

This article has discussed the fixed unit-price contract used for high-speed mechanized construction, and how engineering practices followed in the United States fit these construction practices. The discussion followed a step-by-step procedure through investigation and design, with the most emphasis placed on those points that differed considerably from practices normally followed in West Pakistan. A major portion of the Indus Basin Replacement Plan will be constructed by these methods ; so it was assumed that most of the engineers would be interested in a discussion of this type. The conclusions that may be derived, which have been repeatedly verified by experience in the United States and elsewhere through the world, are :

that these methods result in a better project, more quickly and economically than other known methods.

Recommendations

The author recommends that more fixed unit-price contracts be used on a smaller scale to encourage the development of competitive private contracting enterprise within Pakistan. Competitive private contractors will import more equipment and produce better projects, quicker and more economically. It is also recommended that the design methods discussed herein be adopted for they have proven to be invaluable elsewhere in the world where high-speed construction methods have been used.