



# NAC Executive Insights

## Bidding Unit Price Work – Low Bid Hoover Dam

### Key Points

1. The cost estimate serves as a guide for pricing bid items.
2. Items are priced to account for task risk.
3. It is necessary to identify which items should carry mark-up.
4. Always validate bid document quantities.
5. Use selective bid item pricing to finance the work.

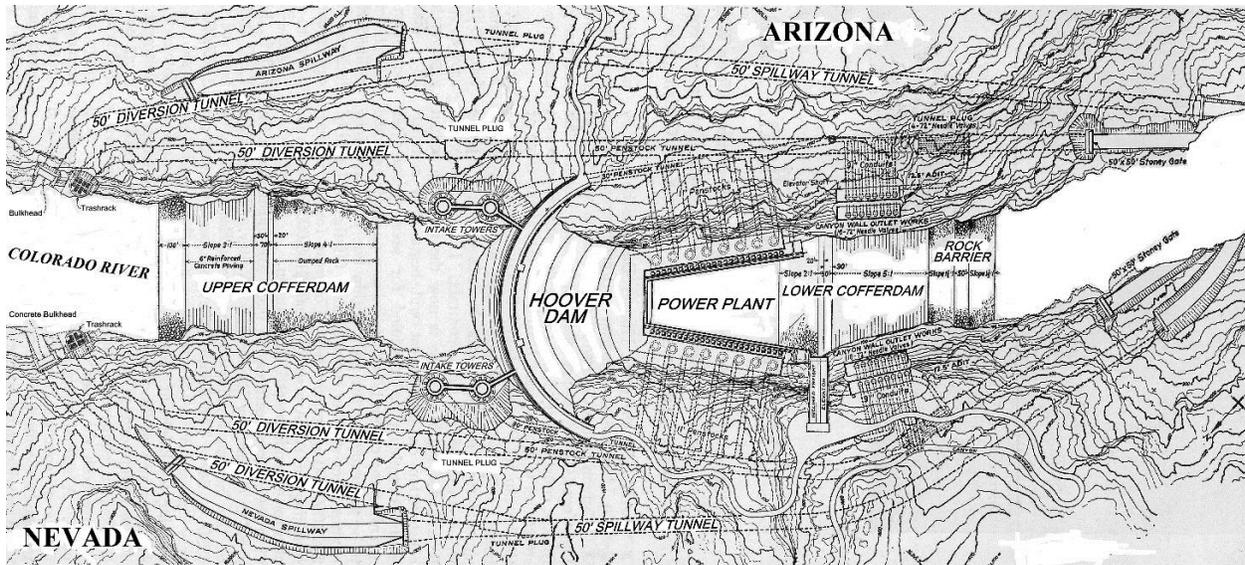
*A contractor's project cost estimate is only the first step in pricing work. The next step is to identify item payment risk and seek ways to insure receipt of project overhead cost and profit. Confidence about a bid item—a work item—not being eliminated or the quantity being reduced is an important criteria for selecting the bid items to carry project overhead and profit mark-up. Item bid prices should also reflect the risk of performing the work tasks at the estimated production rate. Furthermore, to gain working capital, early bid/work items usually carry a higher percentage of mark-up.*

### Introduction

Bidding a unit price contract to secure work is more than taking the cost estimate number for each bid item and adding profit and overhead.

The U. S. Bureau of Reclamation, on 4 March 1931, received three bids to construct Hoover Dam. The Great Depression had officially begun with the Wall Street Crash in October 1929 and one of the industries to suffer the most was construction, so the government's Hoover Dam work was a much sought after opportunity. The bid values for the items of work for this historic project provide a good example of thoughtful bidding practices.

The low bidder for the Hoover Dam project (Figure 1) was the Six Companies, Inc., a combination of Utah Construction Co.; Henry J. Kaiser and W. A. Bechtel; McDonald & Kahn Co., Ltd.; Morrison-Knudson Co.; J. F. Shea Co.; and Pacific Bridge Co. Their bid of \$48,885,995.50 was below the second bidder by almost \$5 million or 10.2 percent.



*Layout of Hoover Dam work (adapted from a drawing prepared by the U. S. Bureau of Reclamation)*

The project, as let by the Bureau of Reclamation, was basically a labor and equipment contract because the government furnished all permanent materials. Even the aggregate for the concrete was to come from a government owned pit eight miles upstream. As a result, the cost risk for the work was primarily in the assumed production rates for the work tasks.

There were 119 bid items with 13 of these or 11 percent of the total number accounting for 80 percent of the bid amount. The three major items, accounting for 53 percent of the contract revenue, were bid items:

- No. 4, diversion tunnels (excavation), 27 percent of the total bid amount by the low bidder.
- No. 52, concrete lining diversion tunnels, 7 percent.
- No. 54, concrete dam, 19 percent.

Items No. 4 and 52, besides representing 34 percent of the bid, controlled the project schedule because the tunnels had to be completed before building the dam could commence.

Was the contractors' Hoover Dam offer a smart bid? Even without the cost estimate prepared by the Six Companies, the bid numbers for the project work items provide a significant amount of information about how the contractor viewed project risk and then used bid item pricing to achieve a successful job.

## **Item Risk**

The contract for construction of the Hoover Dam was signed in Washington, D.C., on 20 April 1931. Bid item No. 1, stripping loose rock, was one of the 13 items making up 80 percent of the contract revenue. The quantity for that item was 150,000 cubic yards, but who knew for sure what the actual quantity

would be until workers scaled the slopes of the canyon above the dam site? Nonetheless, the more important question concerned work productivity. Six Companies was led by construction professionals, all of whom had years of experience building railroads and dams across the west and southwest. They were well trained and tanned from having personal experience working out of doors. Some had started behind a pair of mules grading railroad track beds. As a result, in a very personal way, they understood the work conditions of the Hoover Dam project.

Because of the desert climate and environment at the Colorado River Gorge, the productivity for bid item No. 1 was extremely unpredictable. Six Companies bid the item at \$4.50/cubic yard (cy), making their bid total for the item \$225,000 above the second bidder, who was at \$3.00/cy. The third bidder was at \$3.50/cy.

## **Recognizing Project Environment Risk**

Slightly less than three months after the signing of the contract, the stripping of the canyon wall above the intake portals of the tunnels on the Arizona side began. Two weeks later, the summer sun drove the temperature in the canyon to 126°F and there was difficulty in maintaining worker efficiency because of the heat. As July wore on, heat forced the contractor to schedule some of the work in the canyon during the night. Stripping, however, was so dangerous it could not be done in the dark.

When bidding work it is necessary to carefully consider the environmental conditions of the work location and adjust estimate production rates accordingly. Still, when making a final decision about bid item environmental risk, the probability of conditions outside the normal range must be considered.

Toward the end of July, temperatures in the canyon reached 140°F. As workers collapsed from heat prostration, a large turnover of the work force occurred and the work slowed. Productivity was so low the contractor suspended work and waited for cooler weather. It was mid-August before work resumed at a more normal pace. The contractor's higher prices for early outside work in the canyon can partly be attributed to a realization concerning labor productivity in the summer heat of the desert and the threat of flash flooding of the lower work areas by the Colorado River. Through the hot summer months, the underground tunnel work was not as severely impacted. The risks associated with environmental impacts are work-task specific.

To understand a work environment risk, spend some time on the jobsite with the men and women who actually perform the work.

## **Risks of Underground Work**

The first order of work for this dam, which was to be located in a narrow, rock-walled canyon, was excavation (bid item No. 4) and concreting of the four diversion tunnels (bid item No. 52). Once the tunnels were operational and could be used to pass the flow of the river, construction of the upstream and downstream cofferdams could proceed.

There are common risks are inherent with all underground work; handling explosives and having workers involved with multiple coordinated tasks in a confined space. As a result, both the Six Companies and the second bidder priced the 15,919 ft. (three miles) of 56-ft. diameter tunnel excavation at \$8.50 per cubic yard or \$781,500 above the third bidder. Both bidders undoubtedly recognized the risk of variable rock conditions. To mitigate the risk of unexpected rock conditions, they sought extra dollars for the work, resulting in higher item bid prices. Additionally, for the tunnel concrete item, Six Companies was \$936,000 higher than the second bidder. Delivering and properly placing 312,000 cubic yards of concrete in the space between the tunnel forms and the rock surface of the excavated bore was going to be a difficult task. It was done in three steps. First the invert, then the side walls, and finally the arch section, which had to be placed pneumatically. But the major challenge was scheduling the movement of the concrete mix into the tunnel because as the work progressed, it was necessary for trucks to travel over the previously constructed invert section and through the trailing arch and sidewall work, trailing the leading invert work.

The identification of item risk, particularly on a work item, serves to focus a contractor's attention on ways either to mitigate or eliminate the risk. Money added to a bid item is a risk mitigation technique applied during bidding. Planning the work and application of equipment or development of new equipment are ways to eliminate risk. While these may begin during the bidding process, they are usually not refined until a contract is secured.

## **Planning to Eliminate Risk**

Faced with the challenge of boring large diameter tunnels, the leadership of Six Companies set their minds to finding a better approach. Excavation of the four 56-ft. diameter diversion tunnels represented over 25 percent of the contract revenue. Moreover, the completion of the tunnels controlled the project schedule as the diversion of the river had to occur during the low river flows of early winter so the coffer dams could be completed before the spring floods. If the tunnels were not ready by the late fall of 1932, only 19 months from the start of work, the project would be delayed a full year. Eighteen months after the signing of the contract, the Colorado River flowed into the tunnels of the Arizona side of the canyon.

To accomplish this, the contractor spent funds on non-pay item work, including the boring of small tunnels (adits) horizontally into the side of the canyon walls at about mid-length of each set of tunnels. The adits, when they reached the center-line of the tunnels, opened two additional headings for each tunnel. However, the greatest time saver was the fabrication of two drill carriages mounted on large World War 1 truck bodies built for the U.S. Army. This time saver was devised by assistant superintendent Bernard "Woody" Williams. His innovation reduced labor and the risk. Two set-ups of the drill carriage covered the 56-ft. breadth of the tunnels at their full width mid-section.

The usual procedure was to drill one tunnel and then move to the adjacent tunnel while the drill holes were loaded, shot, and mucked. To speed the muck removal, the shovels were equipped with buckets a cubic yard greater than their rated size.

To compensate for the high tunnel work prices and to secure the project while accumulating needed capital, Six Companies priced the later dam concrete work \$4,930,000 below the second bidder.

## Profit and Overhead

Eight bid items represented 72 percent of the contract revenue, and 34 percent of this total was in the two tunnel items, No. 4 and 52. These were definitely work items that would not be reduced in scope/pay item quality. Tunneling always involves risk. Still, excavating the four diversion tunnels was an early work item and the only quantity unknown was the amount of rock breakage beyond the planned diameter of the tunnel, the over-break. Over-break is commonly caused by the irregular character of the rock.

Boring the tunnels accounted for slightly over 27 percent of the contract revenue, so it was a good item for carrying project overhead and profit. While Six Companies' bids were only \$0.50 greater than the third bidder's price, that 50-cent difference represented a \$780,000 increase in revenue.

## Check the Bid Quantities

The quantity of tunnel lining, Item No. 52, would vary with control of the rock blasting. This is a case where the estimator should back-calculate the bid quantity of 312,000 cy to check the amount of over-break included in the item.

When estimating a project, it is good practice to make an independent calculation of major bid quantities based on the project plans. The calculated values should then be compared to the bid item quantities.

The specifications required the contractor to achieve an average concrete liner thickness of 36 inches and also required a 24-inch minimum thickness. Additionally, there would be payment for concrete placed to a thickness of 42 inches. A back-calculation would have identified that the bid quantity was based on a 34.34-inch average thickness. If a 36-inch liner was constructed instead of the assumed 34.34-inch thickness, the pay difference based on the low bidder's price would be \$174,000 or \$50,000 more than the second bidder, who was \$3.00/cy cheaper. If the tunneling over-break was still greater but remained within the specification tolerance, then the difference to the low bidder could be as much as \$800,000 at the higher bid price. The decision on the tunnel lining's bid price required an assumption about tunnel over-break.

The dam concrete represented almost 19 percent of the low bidder's offer. The item quantity was probably fairly accurate because of the mass of the concrete was described by the dimensions of the dam and the only variable was volume of the base, which depended on the quality of the foundation rock. Six Companies, therefore, used it to gain advantage by bidding dam concrete \$1.45/cy below the second bidder and \$0.70/cy below the third bidder.

The Six Companies bid five of the other six major items at prices from 13 to 75 percent above the second bidder. These were all excavation items where the actual quantity would be determined by the conditions encountered. The prices indicate an expectation that the quantities for these excavation items would overrun. For the excavation of the feeder tunnels (penstocks) for delivering water to the

power plant turbines, Six Companies was 6 percent under the second bidder. This was a work item with well-defined dimensions.

## Sequence of Work

“Front loading” early work items allows a contractor to accumulate working capital for financing the project work.

A bid is said to be “front loaded” (unbalanced) when a contractor assigns higher bid prices to early project activities, and lower prices to later activities while keeping the total cost of the project to the owner unchanged. To meet payroll every week and other day-to-day operational expenses, a contractor needs working capital. While a project owner makes periodic progress payments as the work proceeds, these are usually not received until two or more months after the expenses are experienced. Even today it can take this long for a project owner organization to verify pay quantities for payment. Therefore, to avoid serving as a banker and financing the project for the owner, contractors “front load” the bid prices of early project activities.

When bidding private work, front loading is legal. However, if the project has federal money, a front loaded bid can be rejected. The Federal Acquisition Regulation (FAR) § 52.214-10(e) states:

*The Government may reject a bid as nonresponsive if the prices bid are **materially** unbalanced between line items or subline items. A bid is materially unbalanced when it is based on prices significantly less than cost for some work and prices which are significantly overstated in relation to cost for other work, and if there is a reasonable doubt that the bid will result in the lowest overall cost to the Government even though it may be the low evaluated bid, or if it is so unbalanced as to be tantamount to allowing an advance payment.*

"A bid is mathematically unbalanced if the bid is structured on the basis of nominal prices for some work and inflated prices for other work; that is, each element of the bid must carry its proportionate share of the total cost of the work plus profits."<sup>1</sup> (Howell Construction, Comp. Gen. B-225766, 1987)

Mathematically, unbalanced bids are not prohibited per se.

"A bid is materially unbalanced if there is a reasonable doubt that award to the bidder submitting the mathematically unbalanced bid will result in the lowest ultimate cost to the Government. Consequently, a materially unbalanced bid may not be accepted."<sup>2</sup>

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<sup>1</sup> “Bid Analysis and Unbalanced Bids,” FHWA Memorandum, May 16, 1988

<sup>2</sup> Ibid.

In the case of the Hoover Dam project, the work was so unusual that there were no bid averages to use for making price comparisons. There were few tunnels anywhere in the world of comparable size. The quantity of concrete for the tunnel lining alone was equivalent to many previously constructed dams.

Besides the boring and lining of the tunnels, there were five other bid items involving early work: No. 1, stripping loose rock; No. 9, common excavation, foundations; No. 10, rock excavation foundation; No.

11, all classes (meaning all classes of excavation), cutoff trench; and No. 12, all classes, open cut. The Six Companies bid these at \$1,986,530 above the second bidder (see Table 1). All of these early work items plus the diversion tunnels were used to generate working capital.

Considering the work conditions at the project site, the productivity for bid item No. 1, stripping loose rock, was extremely unpredictable. Therefore, some of the \$225,000 difference for this item can be attributed to labor productivity risk. The same is true for the tunnel work, in which there was significant work task risk driving the higher pricing.

**Table 1.** Prices for Early Work Items, Hoover Dam Project.

Bid Item	Quantity	Low Bidder's Price	Second Bidder's Price	Difference
1. Stripping loose rock	150,000 cy	\$4.50	\$3.00	\$225,000
9. Common exc. foundations	857,000 cy	\$2.20	\$1.26	\$805,580
10. Rock exc., foundations	400,000 cy	\$4.40	\$3.40	\$400,000
11. All classes, cutoff trench	35,000 cy	\$12.00	\$4.79	\$252,350
12. All classes, open cut	1,012,000 cy	\$2.60	\$2.30	\$303,600
<b>Total difference</b>				<b>\$1,986,530</b>

**Where was the Advantage?**

Six Companies obtained its bid advantage with the concrete production and placement items. There were 15 concrete bid items. Six Companies bid only two of the items above the second bidder's prices, and the difference for those items was only \$6,252. There were two other concrete items with the offered concrete prices being the same. However, for the other 11 concrete items, Six Companies was \$6,632,275 lower than the second bidder.

**Planning Delivery 3,400,000 Cubic Yards of Dam Concrete**

Six Companies gained its advantage by developing a system for delivering concrete to the dam. Their system permitted placement of over 6,600 cubic yards per day. The contractor invested in two concrete

plants, one in the canyon at the elevation of the upstream coffer dam, 720 ft, and one on the ridge above on the Nevada side at elevation 1,235 ft.

The lower plant produced all of the concrete needed up to elevation 720, about two-thirds of the dam concrete. The mix was delivered by train to one of five cableways spanning the canyon. At the plant, the concrete was dumped into 8-cy concrete bottom dump buckets as they rested on the flat cars of the train. The general superintendent, Francis T. Crowe, designed these large buckets. Project cost estimating is more than quantity take-off and costing of work tasks. It is development of construction operation–execution–plans. Good plans are often the result of extensive field experience and result in lower production costs. The final placement of dam concrete took place less than two years after first placement.

Crowe was a 1905 civil engineering graduate of the University of Maine. He first worked for the U.S. Bureau of Reclamation before joining the Morrison-Knudsen Company. At the Arrowrock Dam (1910-1915), he pioneered a system of overhead cables to deliver concrete to the construction site. Again at Hoover Dam, Crowe's concrete delivery ideas solved the problem of placing concrete in a narrow gorge and gave Six Companies its competitive advantage.

## **Be a Student of Construction**

Was Crowe a careful observer of construction practices? Four years after Crowe received his degree, cableways were used to place concrete at the Gatun locks of the Panama Canal. In Panama, the capacity of the cableways was six tons. What Crowe designed and used for the Hoover Dam work was a cableway with a 25-ton capacity. The planning to use both lower and upper concrete plants and the larger capacity cableway allowed Six Companies to complete the main dam concrete in less than two years.

## **Experience**

When a project owner uses the unit-price contract method, the contractor is paid for the actual quantity of each bid item performed. Payment is based on measured quantities of completed work as the project proceeds. The unit price for each bid item will encompass the expected labor, material, and equipment costs plus a percentage of overhead and profit.

Identifying and managing risks is the most important aspect of bidding unit-price work. The leadership of Six Companies who bid the Hoover Dam project applied selective higher item pricing to protect themselves from work task productivity risk and the unknowns of boring the diversion tunnels.

It also appears they used their concrete placement knowledge/advantage to selectively apply more profit to early work items and lower the price of the concrete work. While such front loading of early work items is common, the bid can be declared unbalanced if this practice is carried to an extreme.

**About the Author**

Cliff Schexnayder has been an NAC member since 2012. He is a construction engineer with over 45 years of practical experience, working with major heavy/highway construction contractors as field engineer, estimator, and corporate chief engineer.