Can Using Form Ratios Improve the Accuracy of Estimating Structural Concrete?

Chris Souder, MS
California State University, Chico
Chico, California

This paper discusses the concept of using concrete formwork ratios to assist in estimating structural concrete construction. Concrete construction costs vary between structure types. The structure types have different geometrical characteristics that can be compared to one another by the form ratio (square feet of form area divided by the volume of concrete). The author will illustrate how this ratio can assist and act as a cross-check during the estimating process. This paper will examine the key aspects of concrete construction estimating and summarize total labor costs. At a minimum labor costs include form erect and strip, placement of concrete and dry finish work. This paper will also discuss how the ratio can categorize historical cost data so it can be used effectively for estimating accuracy which will ultimately lead to more profitable projects. Although the author emphasizes heavy civil construction, all types of concrete structures can utilize these ratios. The main types of structures covered in this paper are bridges, water and sewage treatment containment structures, and building foundations both commercial and industrial.

Key Words: Concrete Construction, Reinforced Concrete, Formwork, Form Factors, Form Ratios

Introduction

Reinforced concrete construction estimating requires a great deal of labor and temporary structure knowledge. When the finish product is delivered, one may not realize how much work went into the creation of the structure. Competently estimating this work involves a great deal of past project experience and form ratios can be the link that brings past experience to the estimator.

Reinforced concrete estimating utilizes several categories of costs. Labor is one of its largest if not the largest cost element. The formwork, the placement of the concrete, the finishes, some additional miscellaneous items and the reinforcing steel are the other cost categories. Materials are also required in two categories; permanent and temporary. STS (small tools and services or supplies) is another cost category. Finally, the cost of construction equipment, such as forklifts, cranes and pickup trucks must be included.

For consistency, any examples shown in this paper will use labor rates at $40.00 per labor hour. Other costs shown are from the San Francisco Bay Area and the Central Sacramento Valley (Northern California). Also, the examples used in this paper have been taken from actual project costs but altered slightly to preserve confidentiality. The alterations do not affect the objectives of this paper.

What is a Form Ratio?

A form ratio (FR) is developed by dividing the neat volume of concrete in cubic yards (CY) for a structural element into the total contact area of formwork in square feet of the same element as shown below (Bartholomew, 2000):

F.R. = Total Forms (SFCA) / Total Volume (CY)

The formwork quantity should include any concrete surface that requires a form to support the plastic concrete during its curing process. This should include footing and slab-on-grade edge (SOG) forms, all wall surfaces, the formed area of all elevated concrete surfaces (excluding additional surfaces for access platforms), construction joints, miscellaneous curbs and equipment pads and all other formed surfaces. The volume of concrete should include all concrete elements except fill concrete and other concrete not requiring a form. However, unformed concrete volume is still accounted for in the estimate because the unformed concrete must be purchased and there may be some incidental costs associated with this volume in the estimate. During actual construction, it is crucial the project staff record actual costs in this same manner. This will be discussed more in the “Historical Cost Data” section of this paper.

Table 1 illustrates that the larger the element's thickness, the smaller the ratio. Also, if an element is supported by the ground (as an example footings and SOGs) the ratio is lower due to the fact that there is no formwork required beneath the concrete. Wall concrete requiring forms on both sides generate higher ratios because twice the formed surfaces are required. Other surfaces, such as the top of the wall and top surfaces of slabs are not formed. These unformed areas require a "wet" finish. A wet finish is applied by cement masons who strike off and smooth the surface before the concrete takes final set. Between the elements with high and low ratios are supported slabs and beams soffit (bottom) must be supported by falsework.

Table 1: Formwork Ratios for Different Elements of Concrete Structures

	L(FT)	W(FT)	HT(FT)	FORMS(SF)	CONCRETE(CY)	FORM RATIO
Bridge Footings	18	18	6	432	72	6.00
Slab-on Grade (SOG), with CJs 1	100	40	1	280	148	1.89
Small Walls (thin)	100	20	1	4100	74	55.35
Large Walls (thick)	100	20	2.5	4100	185	22.14
Bridge piers	6	6	40	960	53	18.00
Small Columns	1.5	1.5	20	120	1.7	72.00
Elevated Slabs	100	20	1	2240	74	30.24
Misc Curbs & Pads	20	20	0.5	40	7	5.40
TOTALS				12402	632	19.60
Notes: 1. CJs-Construction Joints						

Historical Cost Data

Historical cost data are the actual costs or production rates that are achieved by a construction company self - performing similar work from project to project. These costs are recorded as the project is completed and the final data used for determining the project's financial success and for estimating similar projects in the future. Successful companies prefer to use these historical costs over published cost manuals because they are what they have achieved on an actual project. Published cost and production rates are based on documented equipment and labor rates and may be obtained from various sources. These rates may be representative of what is expected on an industry wide basis, but they have not necessarily been achieved by the estimator's own company. Published data is an accumulation of records from companies throughout the industry doing the same type of work. It is usually preferable for a company to rely on its own historical cost data when it is available.

Historical costs should take into account safety ordinances, the capabilities and availability of a company's supervisory personnel and craft workforce, the area's available workforce and how much similar work the company has previously performed. Historical costs also include the cost of daily shutdown periods such as water breaks, ten minute breaks and bathroom breaks. The production rates generated by this data take into account all the above which, when applied to accurate work quantity data, results in a good depiction of actual overall labor costs. These do not include interruptions by the owner or subcontractors, or delays resulting from adverse weather, labor strikes or other abnormal interruptions to the work. Published cost manuals which attempt to take into account all the above using multiplying factors are not company specific, therefore, not as accurate.

Costs Associated with Reinforced Concrete Construction

Reinforced concrete construction requires performance of many different items of work resulting in several categories of costs. The major costs are permanent materials, formwork erection and fabrication, small tools and services or supplies (STS), furnishing and placing reinforcing steel and placing and finishing of the concrete (Ratay, 1996). Of these, the ones directly affected by the form ratio are the activities related to the formed contact area. These specific activities are the labor for erecting and removing formwork, the placement of the concrete and the dry finishes required to the concrete surfaces.

Formwork Labor Costs

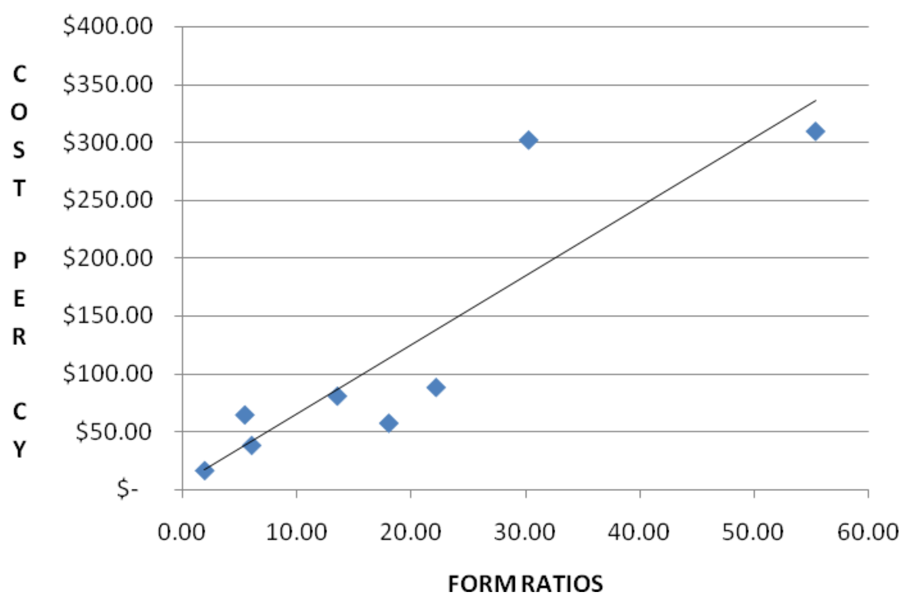
Formwork is the largest contribution to concrete labor costs. As the formwork ratio increases the costs per cubic yard associated with formwork also increases. For example, if the cost of formwork per cubic yard of a structural element is $50 and the form ratio for that element is 15, one would expect the cost of an element with a form ratio of 25 to be higher ($50 x 25/15=$83.33). Table 2 and Figure 1 indicate how formwork labor costs increase with the higher ratios. When these graphs are used it is helpful to develop a linear trend line so that the approximate concrete labor costs can be easily interpolated from a graph. Figure 1 is the result of actual costs obtained from several heavy civil projects in the Northern California region.

Table2: Formwork Costs per CY for Different Elements of Concrete Structures

ELEMENT TYPE	FORM RATIO (sf/cy)	AVERAGE LABOR FACTOR (mh/sf)	COST PER SF ($40/mh)	COST PER CY
Bridge Footings	6.00	0.16	$ 6.40	$ 38.40
Slab-on Grade, with CJs	1.89	0.22	$ 8.80	$ 16.63
Small Walls	55.35	0.14	$ 5.60	$ 309.96
Large Walls	22.14	0.10	$ 4.00	$ 88.56
Bridge piers	18.00	0.08	$ 3.20	$ 57.60
Small Columns	13.50	0.15	$ 6.00	$ 81.00
Elevated Slabs	30.24	0.25	$10.00	$ 302.40
Misc Curbs & Pads	5.40	0.30	$12.00	$ 64.80
TOTALS (AVG)	**19.60**		**$ 7.00**	**$ 119.92**
Above costs are for labor only; materials and equipment are not included				

Another significant phenomenon is the trend that occurs in placing and removing forms by the square foot as the ratio changes. For small and detailed structures, when the ratio increases, the man hours required per square foot decreases and the opposite happens when the ratio goes up. A sample of past costs of a form erect and strip operation were analyzed. From this data a form ratio of 16 yielded 0.195 man hours per square foot and as the form ratio reached 34 the demand on erecting and removing the forms reduced to 0.148 man hours per square foot. This is caused by the amount of area produced by the forms being different for almost the same amount of effort. Also, forms associated with low ratios such as slab-on grades, curbs and equipment pads produce higher form costs.

Figure 1: Graphical Representation of Formwork Costs per CY



In addition to the erect and strip labor costs, formwork fabrication labor and material costs need to be considered for every square foot of formwork area required to be fabricated (Hurd, 2004). As form ratios increase, formwork usually has narrower elements and can become more complicated; this can increase the necessity for forms which reduces the reuse factor. The reuse factor is how many times the same form can be used before it is thrown away or modified significantly (erect and strip quantity divided by form fabrication quantity), or simply the number of times a form is reused (Bartholomew, 2000). However, the amount of forms required to be produced does not have a direct relationship with the ratio. Form fabrication should be determined on a case by case basis. It should not be assumed that a higher or lower form ratio produces higher or lower form reuse.

Concrete Placement

As mentioned earlier, low form ratios are typically associated with slab-on-grades and thick elements particularly those that are formed on one side only. When concrete is placed in these elements, more concrete can be placed per hour for the same size placing crew (Hurd, 2004). The more concrete placed per hour, the less the labor hours required per cubic yard. As a comparison high form ratios are associated with thin walls and elevated slabs and beam/girder elements (falsework supported). Thin walls have to be poured slowly, therefore, for every vertical foot of concrete, fewer cubic yards are placed. This can be compared to wider walls, where there is much more volume for every vertical foot of placement. If a wall thickness doubles, the ratio and the labor cost per cubic yard are reduced to half. Elevated slabs and beam elements produce slower concrete placements because they are typically thinner than on-grade elements and they sometimes have to be placed in a particular sequence to satisfy falsework design requirements. All forms are above grade designed with specific pour rates which must be followed to avoid form failures.

Concrete conveyance costs go hand-in-hand with placement costs (Ratay, 1996). An example situation in which the concrete is conveyed to the forms by a concrete pump/boom system costing $180/hr and is placed at a rate of 72 cy/hr would require adding $2.50 per cy to the placing costs. The longer a pour takes combined with how many cubic yards are actually being placed per hour greatly affects the placement cost. Consequently, if the pump is on site longer, the placing crew is also there longer. The setup and cleanup would be the same at the beginning and end of the pour regardless of the time to place the concrete.

Concrete Finishes

There are two common classifications of finishes in concrete work. Wet finishes are applied shortly after the concrete is placed but prior to the initial concrete set (Cal Trans, 1995). Dry finishes are required on formed surfaces after the forms are removed in order to achieve the requirements of the specifications for smoothness and other aesthetics. Wet finish costs do not fluctuate with form ratios as dry finishes do. Dry finishes have a direct relationship to the formed surfaces. Almost all specifications require either a point and patch or sack finish. Surfaces that will not be exposed to view when the structure is put into service generally require a much less stringent dry finish requirement. These types of finishes would also apply to surfaces that are backfilled and buried underground. The labor costs for these finishes range from 0.008 – 0.015 man hours per square foot depending on the specification requirement. On the other hand, concrete surfaces exposed to view, such as the outside surfaces of structures and public area exterior surfaces will produce labor costs from 0.02 to 0.06 man hours per square foot. Therefore, when the form ratio fluctuates from a 5 to a 10, the finish costs will range from $1.00 to $10.00 per CY ($40.00/labor hour).

Architectural finishes that are formed typically require a more expensive form and dry finish. There are also additional costs for the form liner material to produce the different patterns in the concrete. These form liners are attached to the face of the formwork in order to achieve the architectural design surface. There are various patterns available on the market cost $5.00 to $40.00 per SF. The inexpensive material is hard PVC and the higher quality, more expensive material is made from an elastomeric and can resist wear from multiple concrete placements (Cal Trans, 1995). Form liner costs vary with the surface area and are related to the form ratio.

Small Tool, Services and Supplies (STS)

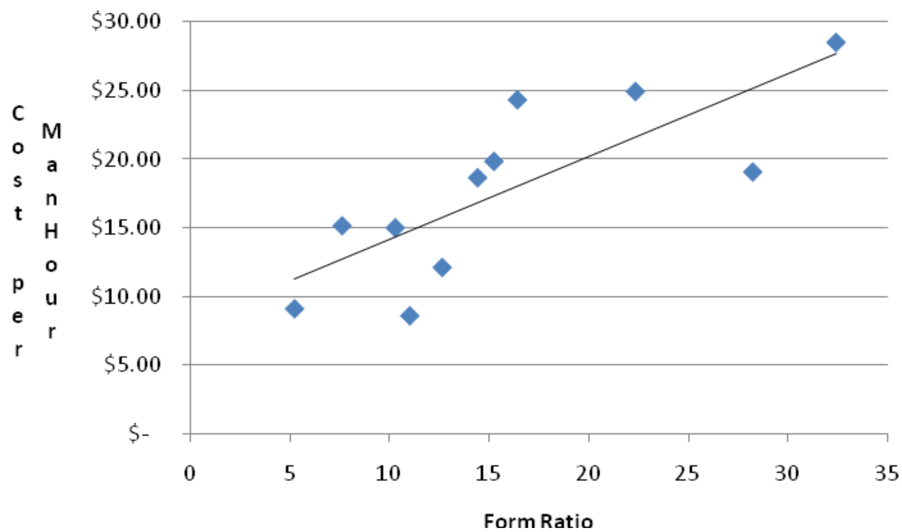
In addition to the labor costs for reinforced concrete estimates, small tools and services are required to be considered for purchase to support formwork materials, formwork placement tools and incidentals and concrete placement and finishing tools. Formwork STS includes plywood, dimensional lumber, form ties and hand power tools. Concrete placement STS includes vibrators, shovels, curing hoses, fittings and blankets, rubber gloves and boots, construction joint preparation equipment such as sandblast pots, nozzles, hose, respirators and goggles. Finishing STS include trowels, floats, cement and sand for dry patch and personal protective equipment.

Formwork ratios fluctuate up and down and affect the items associated with SFCA. Of the above mentioned labor items, certain ones are directly related to the SFCA. The ones affect are formwork placing and removing, dry finish and wet finish. Typical costs for these items are as follows:

Form Erect and Strip	\$0.30 -\$0.40/SF all forms that are placed and removed, regardless of reuse
Concrete Placement	\$1.70-\$2.00/CY of concrete placed
Dry Finish Concrete	\$0.10 -\$0.15/SF of concrete which requires some type of dry finish

Higher form ratios produce higher STS costs per cubic yard and labor hour. For example, a ratio of 5.0 would result in \$1.50 -\$2.00/SFCA of formwork STS (\$0.30/SF x 5.0 or \$0.40/SF x 5.0). On the other hand, a form ratio of 20.00 would produce \$6.00 - \$8.00/SF of formwork erect and strip respectively (\$0.30/SF x 20.0 or \$0.40/SF x 20.0). Figure 2 shows the relationship between STS costs and concrete labor man hours. The trend line indicates the increase in STS costs with an increase to the form ratio. The data points represent past project costs collected from the same projects mentioned earlier in the Northern California region.

Figure 2: Small Tools, Supplies and Service Cost as it relates to Form Ratio



Reinforcing Steel

Reinforcing steel can vary by structure type and project. However when concrete ranges from 8 to 60 inches in thickness, the reinforcing steel ratio (pounds of steel per cubic yard of concrete) can vary in a similar fashion to the form ratios. For instance, a 12 inch wall will typically have reinforcing steel at both surfaces (1 ½" to 2" form the surface). In comparisons, a 5'- 0" thick wall or column would also have two planes of reinforcing steel, except this larger element would have at least 4'- 0" of unreinforced concrete between the two layers of reinforcing steel. The 12 inch wall would have a greater weight of reinforcing steel per cubic yard than the larger element. If it is assumed that these two elements have a form ratio of 5 to 20 respectively, than it would be expected that the reinforcing weight per cubic yard would increase with the ratio. As an example, a 6 foot square column that is 20 feet tall and reinforced with #5 bars two inches from the face, all around and 12 inches on center each direction would produce 36 pounds of rebar for every cubic yard of concrete. However, a 12 inch thick wall, six foot long and 20 feet tall with the same reinforcing layout produces 108 pounds of rebar for every cubic yard of concrete. Structures that are more heavily reinforced would achieve higher ratios proportionately.

When a concrete quantity takeoff is complete, an estimator can "plug" a dollar amount for the reinforcing subcontractor. To do this, he often relies on the volume of concrete and a review of the size and spacing of the reinforcing steel. The size and spacing is going to indicate to an estimator approximately how many pounds of reinforcing steel there may be for every cubic yard of concrete, similar to the above example. Once the weight is estimated, the cost (plug) can be obtained by historical project data ranging from \$0.75 to \$1.25 per pound of placement (\$1.10 to \$ 1.75 if the reinforcing steel is epoxy coated).

Overall Costs

The costs mentioned so far are estimated as individual components. Once they are analyzed individually, they can be combined into total costs. Table 3 shows some sample costs for the total concrete estimate. These total costs are an accumulation of the costs previously mention in this paper that fluctuate with form ratios. For instance, the purchase of the actual concrete has been left out since the volume of concrete is not affected by the form ratio by itself. Margins (company profits) and indirect costs were also left out of these costs. In other words, the costs shown are an estimate of only the direct labor costs that are affected by form ratios.

Table 3: Portions of Concrete Costs that are related to the Form Ratio

ELEMENT TYPE	FORM RATIO (sf/cy)	ERECT & STRIP LABOR	STS	PLACE & FINISH LABOR	TOTAL LABOR COST PER CY
Bridge Footings	6.00	$ 120.00	$ 11.50	$ 24.00	$ 155.50
Slab-on-Grade	1.89	$ 140.00	$ 5.34	$ 7.56	$ 152.90
Small Walls	55.35	$ 320.00	$ 85.53	$ 221.40	$ 626.93
Large Walls	22.14	$ 180.00	$ 35.71	$ 88.56	$ 304.27
Bridge piers	18.00	$ 160.00	$ 29.50	$ 72.00	$ 261.50
Small Columns	13.50	$ 360.00	$ 22.75	$ 54.00	$ 436.75
Elevated Slabs	30.24	$ 400.00	$ 59.86	$ 120.96	$ 580.82
Misc Curbs & Pads	5.40	$ 375.00	$ 10.60	$ 21.60	$ 407.20
TOTALS (AVG)	**19.60**				$ 365.73
Margin and Indirect Costs are not included in the above estimates					

Types of Structures

Structure types vary between the different uses of the structures. The geometry, size and shape of each structure determine the form ratio. The following are categories of concrete structures and their elements that have been the focus of this paper.

Highway Bridges	Footings, Abutments, Piers and Superstructure
Water/Sewage Facilities	Slabs-on-Grade, Walls and Elevated Slabs
Commercial & Industrial Buildings	Slabs-on-Grade, Columns, Walls, Elevated Slabs

Bridges in California, like many other western states, are typically the concrete box-girder type. The substructure (footings and columns/piers) and the Superstructure (spans from pier to pier) are all cast-in-place reinforced concrete with post-tensioning strand. The substructure form ratio is below 12. The superstructure form ration is above 20. Water treatment structures and commercial and industrial buildings have form ratios greater than 12. The foundations and walls of the latter are less in thickness and exhibit elements that do not have to support high dead loads; therefore, they consist of smaller elements (Peurify, Schexnayder & Shapira, 2006). Refer back to Table 1 for typical form ratios as they apply to these elements.

When estimating different types of structures, the estimator should categorize the types of elements within the project type and keep these cost estimates separate. This would eliminate the chances that costs for the low ratio structures are not mixed with cost of the higher ratio structures. Once the elements are categorized, the quantity takeoffs should remain separate and only combined when intending to represent the overall project.

Estimating with Formwork Ratios

The Work Quantity Take-off and Labor Work-Hours

The construction specifications will assist in how to categorize the takeoff in the cost estimating process. A quantity takeoff is performed for all the individual work items that involve labor and materials. It is recommended to categorize the structure types and the elements of the structures prior to the actual takeoff (Peurify, Schexnayder & Shapira, 2006). Once it is determined which categories contain which structures and their specific elements, the estimator can begin quantifying the square feet of form contact area, the cubic yards of concrete and the wet and dry finishes. Spreadsheets are often used to break the elements down further into components within an element. The spreadsheet (whether done by hand or with a computer) should show subtotals for each element and for each structure type. It is very common for a company to require two separate quantity takeoffs, performed by two different takeoff engineers, when projects are bid by lump sum. This assures accurate quantities and reduces the risk exposure to monetary loss.

When the structure takeoff is complete, the form ratio for each of the work activities can be calculated. Then the estimator can determine the work-hour production rate for each of the work activities that must be performed for each structural element.

Table 3: Example-Completed Project Quantity and Labor Hour Factors

	THIS ESTIMATE				PAST PROJECT #1		PAST PROJECT #2		PAST PROJECT #3	
DESCRIPTION	QTY	UNIT	MH/ SF	TOTAL MH	QTY	MH/SF	QTY	MH/SF	QTY	MH/SF
ERECT AND STRIP SLAB-ON-GRADE FORMS	3200	SF	0.163	800	2000	0.185	5500	0.124	350	0.234

As an example, if an estimator was pricing slab-on-grade formwork, data would be tabulated as shown in Table 3. Three past projects are listed next to an actual work quantity for the project being estimated. Production rates of 0.185, 0.124 and 0.234 man hours per square foot are shown in the table as an example. The estimator must then decide what production rate to apply to the present project slab-on-grade activity. The three past projects can be used to determine the appropriate production rate. One way to do this would be to average the three past project production rates. However, this method would not consider the differing work quantities of the three past projects. For instance, if the first project required 2000 square feet of forms, the second 5500 square feet and the third 350 square feet, the average would not properly weigh the higher quantity projects accordingly.

What is the effect of the differing quantities? Larger work quantities such as those for the project with 5500 square feet produce a better production rate because the operation generally continues to improve with time. On the other hand, the project with 350 square feet did not experience enough repetition to refine the process and produce better unit rates. In this case, it is not a surprise that the unit rate of 0.234 exceeds the others. The 2000 square foot project falls somewhere between the other two projects.

If the project being estimated has a slab-on-grade quantity of 3200 square feet, and the estimator has no reason to believe that the project elements are much different from the projects in the past cost summary, then the estimator would look at the two larger quantities (5500 square feet and 2000 square feet) and choose a production rate somewhere in between. In this case, it would be appropriate to interpolate the unit rate between the other two, resulting in a rate of 0.163 man hours per square foot.

When this is done, the results for each structure element can be totaled to represent the entire project. These totals will include the total cubic yards of concrete and the total square feet of contact form area resulting in the total labor hours per cubic yard of concrete for a given form ratio. The corresponding information for the present project can then be plotted for a comparison between the historical rates and anticipated performance. If the plots for the present project fall above or below the “trend line”, then it is evident that the estimate is either high or low when compared to historical data.

When the activities have all been compared to past costs individually and their production rates have been determined, a final comparison is done. Since we know the form ratio for the current estimate and the total concrete quantities, we should be able to line them up with historical costs of other projects and their totals. The totals that are compared are the form ratio, the total man hours per cubic yard and the place and remove man hours per the total place and remove formwork quantity. It would not make sense to compare costs between a project with a form ratio of 12 and a project with a form ratio of 22. This would defeat the purpose of using these ratios and comparing job totals. The form ratios of the project being compared should be within 10-15 percent higher or lower than the trend line of similar projects. Greater variations are cause for concern with regard to the present estimate. It should be noted that the above analysis pertains only to cost of labor and associated STS. A similar analysis can be performed for other concrete costs.

Tracking Project Costs

Everything that has been discussed so far would be irrelevant if the project staff did not do an accurate job tracking costs at the project level. A system should be in place to record quantities completed, labor hours spent and total activity costs, including equipment and materials. A system like this is almost always used so that companies can document the actual costs as compared to the estimated budget.

In addition, it is very important that the project staff be accurate in the cost coding of individual activities. Project personnel are sometimes enticed to make an activity seem better than it is or claim quantities for work not actually performed producing inaccurate results. The results, if used on future estimates, would generate an unrealistic estimate and eventually jeopardize the financial health of the company. The project reporting system needs to match the estimating system by category. These categories are similar to the estimating activities mentioned in the above example.

Conclusion

The form ratio, the relationship between the square feet of form contact area (SFCA) and the volume of the concrete being formed, characterizes each type of concrete structure and its elements. This ratio is achieved by dividing the volume of concrete into the SFCA. Each type of concrete structure and the use of that structure dictate the ratio being higher or lower than other structures.

Effective concrete estimates utilize past cost experiences to insure the estimated costs are consistent with historical costs. Form ratios make it possible to determine similarities and differences between projects. An estimator should be careful not to simplify estimates by assuming one project is exactly like another. By comparing form ratios this risk can be eliminated.

Accuracy is significantly improved when the estimate includes past cost experiences. Emphasis has been placed on the importance of relying on costs that have only been demonstrated by the company. Every project should be treated differently as far as access, local requirements and labor wage rates. Form ratios bring pieces of different projects together for a side by side comparison regardless of geographical location. Labor hours are used to eliminate the local cost variations.

This paper has illustrated a technique to accurately compare concrete estimate costs while comparing results to those experienced on like past projects. It has also defined major concrete estimating categories for different types of concrete projects. Finally this paper emphasizes that these comparisons should not be made between projects with significantly different form ratios.

References

Bartholomew, Stuart H, Estimating and Bidding for Heavy Construction, Published by Prentice-Hall, Inc. (2000)

CalTrans Standard Specifications, State of California, Department of Transportation, Published by the State of California, Publication Distribution Unit (1995)

Hurd, MK ACI SP-4, Formwork for Concrete, 7th Edition, Published by the American Concrete Institute (2004)

Peurify, Schexnayder and Shapira, Construction Planning, Equipment and Methods, McGraw Hill Publishers (2006)

Ratay, Robert T, Handbook of Temporary Structures in Construction, McGraw Hill Publishers, (1996)