Determining the Most Economical Formwork System, A Contractor's Perspective

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Abstract

This article discusses the steps involved when a contractor must decide the most economical formwork system for the reinforced concrete project at hand. The decision begins with a basic form design scenario and then economics are introduced that allows the contractor to make a final decision. Factors involved with the final decision are the cost of the labor and equipment for each type of form and the number of reuses that the forms will experience. Three form types will be used for this analysis. The engineering calculations will not be shared as this would take up too much precious paper space.

The costs used are from the state of California. This paper will illustrate that with temporary structures, there are often different "correct" solutions. However, without a detailed analysis, one cannot make an educated decision. Then, even the final decision cannot be validated as only one option is used. Three contractors were interviewed for the production rates and scenario circumstances. The labor production units are an average of these three companies and the names are protected.

This analysis uses a 200' x 80' concrete structure with a single center wall in the middle. The walls are 18 feet tall and all three formwork types will use the same structure and number of wall placements. This paper will only analyze the form system's material costs, labor and equipment costs, and fabrication costs. It is assumed that the placement and dry finish costs are relatively the same.

Key Words

Concrete, Formwork, Formwork Estimating, Formwork Design

1.0 Introduction

Every day in construction, cost analysis are performed by construction estimators, project managers, superintendents and engineers. These cost analysis' are the basis for decisions such as materials, equipment and crew size, amongst others.

This paper will use three systems that are common in the concrete construction industry today. These three systems are:

1. All wood form with snap ties
2. Composite form: Plywood, Aluma Beams and Double steel channels with taper ties or she-bolts
3. All steel form similar to EFCO or Dayton Superior

The author selected these three systems after interviewing 3 different heavy civil contractors in California. Many contractors use all wood systems even if they are not necessarily the most economical. The two reasons cited for this are the initial investment to purchase a more expensive system and crew familiarity with the wood form system.

The labor costs used in this paper were also accumulated through participants in the industry. However, the names of the companies are being protected. The quantities used for the analysis are the form fabrication, the erect and strip and the duration of the operation. The formwork quantities are mostly for labor and materials, whereas the duration of the operation is required for equipment utilization and for rental items.

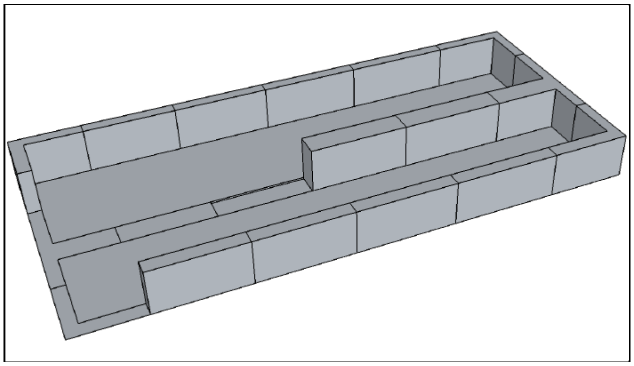

Figure 1: Typical Structure

This type of analysis can be used in the following Construction Management courses.

1. Heavy Civil Estimating
2. Cost Budgeting
3. Temporary Structures Estimating and Design
4. Methods Analysis

Curriculums can benefit from real world examples that span multiple subjects such as those mentioned above. The Construction Management student can visualize a construction process when he sees it from beginning to end. As costs are added to a method analysis, the estimating application of construction management comes to fruition.

1.1 Literature Review

A literature review was performed in both journals and general publications covering reinforced concrete construction with an emphasis on formwork systems and costs. There seems to be an abundance of material on formwork design and selection. In addition, it is agreed upon in the industry that formwork design should be a main consideration during early stages in the permanent design and continue throughout the Value Engineering (VE) process. The lack of cost data has inspired the purpose of this paper. It could be that the variety of economic regions throughout the world makes it difficult to compare costs between systems. This paper used a single economic region in order to avoid this confusion.

There was also a consensus that concrete as a material is the most commonly used building material in the world. Where concrete is used, it makes up 20-30% of the structures total cost depending on the structures intended use. Of the concrete's total cost, the formwork makes up between forty to eighty percent. Because of this commonality, literature on the subject suggests that any consideration to lower the cost of concrete construction should begin with ideas that lower the formwork costs.

In addition, much of the published work focuses on building designs and how VE and Design Build processes should be used that consider the formwork options a prospective contractor may use and incorporate these findings into the final design. This can be especially helpful for structures such and reinforced concrete building frames, parking garages and bridge construction, where the formwork methods are paramount to the overall concrete costs and success of the project. Some considerations include but are not limited to minimizing variations in the elements, minimizing formwork modifications and maximizing formwork reuse.

1.2 Formwork Costs

The cost of the form components makes up the unit price of each form design. Table 1 describes the high and low material costs used in this paper and what the today's cost would be in California. The higher costs tend to represent larger, heavier form systems and the lower costs represent the smaller, light form systems. Form ratio also plays a large part on formwork costs; however, since this comparison is based on the same structure type, this ratio will not affect the final costs (Bartholomew, 2000).

Table 1: Formwork Component Costs

Item	Unit	Rent or Buy	Low Unit Price ($/ unit)	High Unit Price ($/ unit)
MDO Plywood	**SF**	**B**	**1.25**	**1.50**
Studs	**LF**	**B or R**	**0.35**	**5.00**
Walers	**LF**	**B or R**	**0.70**	**11.00**
Ties	**EA**	**B or R**	**0.50**	**25.00**
Hardware	**EA**	**B or R**	**1.00**	**10.00**
Nails/Fasteners	**SF**	**B**	**1.00**	**2.50**

2.0 Method: Formwork Options

The basis for the formwork design is the sketch in Figure 1 and the following placement parameters.

1. Pour Height 18 feet
2. Rate of Placement at 5ft/HR
3. Temperature at placement of 70 Degrees Fahrenheit
4. Fabricate 2,232 SF of forms
5. Erect and strip 26,000 SF of forms
6. 18 placements: 16 each straight, 4 each corners and 2 each "T" sections (see Figure 1)

The formwork material costs consist of two categories. The cost of the material to fabricate the initial forms and the costs in order to erect and strip all 18 wall placements.

The design pressure from the information above can be derived from the ACI 347 formula for 1) Pour Rate less than 7 feet per hour, but 2) wall height greater than 14 feet. (Hurd, 2004) The pressure is as follows.

$$P = 150 + \frac{43{,}200}{70\ degrees} + \frac{2800\ (5\ ft)}{70\ degrees} = 967.2\ psf$$

This pressure calculation assumes there are no adjustments for chemicals C_c or concrete unit weight C_w. This formula was selected because the wall height exceeds 14 foot in height. If the wall was less than 14 feet and maintaining a pour rate of 5 feet per hour, the design pressure would drop to 793 PSF (Hurd, 2004).

Form fabrication is the process of building the form in a yard and preparing it for initial use. The cost of the form material is a one-time cost until possibly more money is spent to reverse the sheeting or rebuilding the frame work to extend the life of the form or to accommodate other elements with different shapes. Fabrication cost vary with each form system and in some cases, disassembly costs are added. For instance, an all wood form that has been used to its maximum life span is disposed into a pile of other wood forms. Several options are now available, such as burning, crushing and loading as is on a flatbed truck. On the other hand, composite and steel forms, because they are made of mostly reusable materials, are disassembled piece by piece as to preserve the reusable elements for storage or other uses.

Erecting and stripping the form is the actual placement of the form to support the intended concrete loads and then removing and preparing it for the next concrete placement. In this example, there are 18 wall placements. The forms used in this example are designed to maintain their quality throughout the scheduled time to complete the structure. The time allotment for this structure has been set at five months for all three scenarios. This time period includes initial form setting, cure time for each wall prior to form removal, rebar and concrete placement and the relocating of forms within the structure.

2.1 Wood Form Design

The wood formwork system is comprised of Medium Density Overlay (MDO) plywood, 2x4 studs, 2x4 walers, 5000# capacity snap ties, two levels of scaffold/hand rail and small turn-buckle style braces. Figure 2 shows this similar system for a Waste Water Treatment Structure in Roseville, CA. Scaffolding and the second level of bracing is not shown. The studs are orientated vertically and the double walers, horizontally. After a detailed design, the spacing of each member is determined. Table 2 summarizes the three designs.

Wood forms are more ideal for heights less than 20 feet. Curves are difficult to accomplish without the difficult and expensive option of cutting gussets to the proper shape, in which case, only large radii can be accomplished. On the other hand, wood formwork is lighter than the composite or steel, thus requiring a smaller crane or sometimes even an extendable boom forklift.

Figure 2: All Wood Form System with Snap ties

2.2 Composite Form Design (Aluma Beams and Steel Channels)

The composite system is comprised of MDO plywood, horizontal aluma beam studs, vertical double steel C5x6.7 channels, ¾" she-bolts with associated hardware, two rows of scaffold and handrail and steel pipe braces. Figure 3 shows a composite form system being use on a Water Treatment Plant project in Petaluma, CA. This type of system is ideal for re-use as long as higher quality plywood is used such as MDO or better. The tie and waler spacing are indicative to larger areas for each tie. This requires a larger tie do to the greater tributary area (Souder, 2015). Limiting the number of ties is very important in order to reduce the amount of labor costs installing, removing and patching these ties. Larger ties are heavier and harder to handle during the erect and strip process, but when there are fewer, this reduces the time handling the ties and patching the holes left by the ties.

A composite form, unlike the wood form, is more versatile for different designs. In other words, the waler and tie spacing can be adjusted depending on whether it is preferred to have larger beam elements with larger ties or the opposite. Typically, according to contractors that do this type of work regularly, it is preferred to minimize the number of pieces that are handled by the carpenters and laborers.

In a composite form, curves can be accomplished by turning the aluma studs vertically and having a steel shop roll a radius to the double steel channels and place them horizontally. This makes for a very light and economical curved form compared to its competition. The down-side to this method is the costs to have a steel fabricator roll the double channel shapes. This process can cost from $6.00 to $10.00 per linear foot, depending on the section weight required.

The ownership of the material that makes up a composite form is slightly more common to the average contractor. The materials are easier to store and the aluminum is not as susceptible to weather and water damage. Maintenance is still important however. The aluma beam "nailers" (a strip of wood attached at the top to allow the attachment of plywood) requires replacement approximately every five years. This involves removing this 2x2 nailer and attaching a new one. The steel channels need to be stored upright so water does not get trapped within the webbing.

Only one of the three contractors interviewed said they would purchase the aluma beams and steel channels. The other two said they would for the right amount of reuse, but it was decided on a case by case basis.

Figure 3: Composite Formwork with Aluma Beams and Steel Channels

2.3 Steel Form Design

Steel forms are pre-engineered by the particular manufacturer of the form. The form is typically rated for 1,200 lbs per square foot of concrete pressure. This limitation is typically adequate for the majority of concrete placement situations such as the one used in this scenario. Steel forms use 3/16" steel plate skin and "C" or "Z" shaped studs that are spaced at 12" on center (Ratay, 1996). The studs are supported by steel double channels or stiffener plates welded between the studs that support the ties. Ties for steel panels are typically she-bolts or taper ties, which have higher capacity to match the strength of the all-steel panel (AISC, 1989).

Figure 4 shows a steel form by Symons Corporation being used to form 32 foot high digester walls. The digester tank had a 50 foot radius. A steel form like this one shown in Figure 4 can weigh between 25 and 30 lbs per square foot with scaffolding and some braces attached. Therefore, a 20 foot by 18 foot panel could weigh as much as 10,800 lbs.

Steel forms are typically a rented form. It is very rare for a company such as those interviewed for this paper to purchase a steel form. Besides being very expensive, ownership requires storage and maintenance. If the form is not regularly used and properly stored, damage can set in quickly. When forms are rented, usually by the monthly period, a fee is paid all the panels, braces, scaffolding and sometimes the tie hardware. The expendable material, such as coil rod, would be an additional cost that the contractor would be responsible for.

Figure 4: All Steel System by Symon's Corporation

Steel forms can be more desirable when the wall heights exceed 24 feet tall and when there are curves to the geometry of the structure.

2.4 Design Comparison

Table 2 indicates the form design for the three formwork categories considered. Using the base pressure calculated above. The designs followed standard design protocol and the results were double checked by a third party.

Table 2: Formwork Design for 967 psf

Description	Wood Form	Composite Form	Steel Form
Sheeting	¾"MDO Plywood	¾" MDO Plywood	3/16" Steel Plating
Studs	2x4 @ 10 @ OC	Aluma Beams @ 10" OC	"Z" Plate @ 12" OC
Walers	Dbl. 2x4 @ 22" OC	Dbl. C8x6.2 @ 48" OC	Dbl. Channels @ 48" OC
Ties	Snap Ties	¾" She-Bolts @ 54" OC	¾" She-Bolts @ 36" OC

3.0 Results: Formwork Selection Based on Design

The form costs per square foot were derived from the updated material prices listed in Table 1. The Composite and Steel Forms utilize the more expensive, higher range and the Wood forms utilize the less expensive materials. The expendables are the ties and other materials that go to waste or get left with the final product. Table 3 shows the material unit price per square foot and the cost of expendables per category.

Table 3: Formwork Material Costs per Unit

System	**Unit**	**Unit Price**	**Weight per unit**	**Expendables ($)**
All Wood with Snap Ties	SF	$4.50 /SF	3-4 lbs/ SF	$3,250
Composite with Aluma Beams and Steel Channels	SF	$16.50 /SF	13-16 lbs/ SF	$3,900
All Steel	SF	$17.50 /SF	25-30 lbs/ SF	$4,300

Table 4 summarizes the major costs of the three formwork categories being compared herein. For the example used in this paper (rectangular, 18 placement structure with 18 foot high walls), the composite form system seems to be the most economical. These costs assumed that all three systems required little or no re-fabrication or re-applying/turning of form sheathing material (MDO plywood) for the wood or composite form. This was the reason MDO ply form was used. Traditionally, MDO ply form can achieve more than 15 uses before its condition warrants excessive dry finish costs.

Table 4: Total Formwork Costs per System Including Labor, Equipment and Materials

Expense	**Wood Form**	**Composite Form**	**Steel Form**
Labor - Form Fabrication	$10,747	$14,329	$21,494
Labor - Erect and Strip	$194,740	$111,280	$125,190
Equipment	$66,240	$73,404	$139,196
Form Materials	$10,135	$32,068	$39,060
Expendable Materials	$3,250	$3,900	$4,300
Total Expense	$285,112	$234,982	$329,240
Unit Expense per SF	**$10.97**	**$9.04**	**$12.66**

Labor Rate Average $53.50 per man hour; Erect and Strip Quantity of 26,000 SF

The labor rates for form fabrication and erect and strip, which traditionally make up the majority of formwork costs (with the exception of when equipment capacity drives costs) were averaged from three companies in the heavy civil industry. The names have been protected, but the rates used are as follows in Table 5.

Table 5: Labor Production Rates for Form Fabrication and Erect and Strip

Category	*Form Fabrication (MH/SF)	*Erect and Strip (MH/SF)
Wood Form	0.093	0.141
Composite Form	0.122	0.084
Steel Form	0.184	0.091

*Man hour factors used are company averages

4.0 Discussion: Formwork Selection Based on Economics and Design

4.1 Formwork Reuse

The overall cost of formwork for a particular project is very much dependent on the number of uses a form produces in its useful life, with or without re-sheeting depending if re-sheeting is part of the analysis. In this paper, re-sheeting is not part of the analysis. However, with 18 placements, a good sample size has been achieved. The form fabrication quantity was figured to be enough so that a typical straight section could be cycled throughout the majority of the wall placements and a second form would take care of the more intricate corners.

4.2 Duration of Placements

The eighteen placements of walls would occupy approximately 5 months of schedule time. This assumes that one complete form was fabricated for the straight walls and an additional form was used for the corners and intersections. This five month period was most instrumental on the support equipment used for hoisting and removing the forms into place. The heavier the forms, the larger the lifting devise, hence the higher the monthly rental rate. This paper did not compare company owned equipment with outside rented equipment. This may have swayed the numbers and given cost savings to larger companies that tend to own their equipment and reap the benefits of discounted rental rates. A cost guide was used for these rates so the analysis was consistent.

4.3 Estimated Production Rates

When costs analyses are performed for decision making reasons, one should remember that the production rates used for the labor (the most risky variable in construction costs) are estimated rates. Until the operation is in progress or complete, the final decision cannot be validated. For the same reason temporary structure design has so many options, until the work is complete, one does not know if the final decision was the best.

The man hours involved with the fabrication, erect and strip of the wood, composite and steel options were 3,841, 2,348 and 2,742 respectively. The composite form seems to produce the best erect and strip labor costs and is medium in weight, thus requiring a mid-size capacity crane. The composite form has the lease amount of ties when a large double steel channel and high capacity ties are used. The steel form comes close to the composite when it comes to the number of ties but the weight adds labor cost indirectly as shown in the average man hour factor (man hours/unit) form Table 5.

4.4 Equipment

As mentioned above, the three different categories of forms differentiate in weight enough that the equipment needed for hoisting into place and removing is significantly different. The difference is mainly in the lifting capacity of the equipment and with capacity differences, usually comes hourly rate differences, operator pay differences and potentially the requirement of an additional operator (oiler) to accompany the crane during usage.

This paper utilized the Cost Reference Guide published by EquipmentWatch in 2008 (EquipmentWatch, 2008) for the costs of the lifting devices for each formwork category. Three size cranes were sized for the application at hand. The following lifting assumptions were made:

1. Wood forms require a 25-40 ton Rough Terraine Hydraulic Crane
2. Composite forms require a 60-80 ton Rough Terraine Hydraulic or Truck Mounted Hydrauilic Crane
3. Steel Form require a 150 ton Fixed Boom, Crawler Crane

These three different style cranes rent for $69.58, $107.84 and $195.50 per hour respectively. These rates were translated to weekly rates and then projected for the required duration based on the schedule of time required by each system.

4.5 Other Applications

The steel formwork option in this example was not feasible. However, one might ask when a steel form is desirable. Steel forms would not be manufactured and used if there was not a feasible application. In the design section above, it was mentioned that wood forms were difficult in applications where the elements were very tall (exceeding approximately 20 feet in height) and when an element contained curves and other odd shapes that were difficult to achieve with straight, rectangular beams sections. Steel formwork can be shipped to the project site in any radius configuration greater than approximately a 10 foot radius. In addition, the strength of an all steel form allows it to be used up to a 30-40 foot high element without internal bracing or additional external braces.

For the same reason one could conclude that a composite formwork system would not be a wise selection for shape and maybe even element height. This fact could be argued, but not to the extent of the wood formwork system. Generally, when a contractor uses an aluma and steel channel system, the double channels are orientated vertically which allows for a taller and stiffer form design. Curved shapes can be achieved with a composite system if the aluma beams and steel channel orientation is rotated 90 degrees (alumas vertical and channels horizontal). The downside to this option is that the double channels need to be “rolled” into the radius/curve of the elements design and a steel mill uses special equipment to perform this operation. An estimate of this additional cost to the purchase price of the steel channels reveals an increase cost to the linear footage of the double steel channels by $6 to $10 per linear foot of double channel. Again, a steel form, for the additional price indicated in this paper, will solve at least one of these challenges. Sometimes, low cost is not always the final indicator. Means and methods may warrant the more expensive system and make the less expensive systems almost obsolete.

5.0 Conclusion

Three formwork scenarios have been discussed in this paper. Of the three categories, the composite system appeared to be the most economical, the wood and steel form were more expensive, but definitely competitive. Of the two best options, the composite form was the most economical using the data at hand. As mentioned, until the work is complete, the final selection cannot be validated. This is a phenomenon with most means and methods in construction. Brain storming and cost analyses are performed, output is analyzed and final decisions are made. Once the operation begins, adjustments are made; however it would be a rare case when the contractor would abandon the idea and change to one of the other options. After all, money has already been spent on what appeared to be the best option. The production rates used in an analysis like this one are derived from historical company cost data. However, the guarantee that the same costs or better costs can be made is not always reality. It should never be assumed that the costs on one project would be achieved on another project. A separate analysis should be done.

This analysis was performed on one structure containing 26,000 square feet of wall forming. The cost savings to utilize the composite form system as compared to its competition was $50,130 and $94,258 respectively. On one hand, one might look at this and realize that there is a potential of four times more quantity, thus making the savings four times as favorable. On the other hand, another project’s results could show one of the other options as more feasible.

Also, the components of a composite and steel form are not always a purchased item. Many contractors prefer to rent these components if they do not believe the forms will see adequate reuse on future projects. In addition, storage can be an issue for smaller contractors that do not have the allotted yard space.

Cost comparisons are typically the deciding factor except in cases where a contractor may own some material and would prefer paying its own company for the materials and transportation rather than a rental company. In a case where access is limited and a large crane may not be practical or available, a wood form (lighter) system may be selected even though the analysis showed otherwise. These are all additional factors a contractor would consider while analyzing the best formwork options.

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