ANALYSIS #2 PRECAST CONCRETE WALLS

C-5 Fuel Cell Facility

167th Airlift Wing

Martinsburg, WV

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ANALYSIS 2: PRECAST CONCRETE WALLS

BACKGROUND INFORMATION

Due to schedule acceleration techniques that were necessary to make up time, masonry work which was originally not supposed to begin until steel erection was complete, was taking place during the erection process. This created some site congestion issues and also forced the masons to work more quickly than initially scheduled. On the façade of the building, these conditions along with adverse weather conditions caused some problems with the quality of the finished product, including broken CMU's and the appearance of efflorescence in many locations around the building. Site congestion was also experienced during the construction of the interior CMU walls since other activities such as MEP rough-in were taking place simultaneously. These are problems that commonly occur with on-site construction, especially when the schedule must be accelerated.

The use of precast concrete walls for both the exterior façade and the interior walls would lessen the impact of these conditions. For the exterior façade, one of the most important factors to be considered when looking at the precast wall system is whether it is possible to match the aesthetic features that are present in the design with CMU's. The two existing hangars of almost identical design as the Fuel Cell Facility feature the same CMU façade around the bottom portion of the exterior walls, and it is critical that this design feature be maintained on this building. For the interior load-bearing walls, aesthetics is far less of an issue. The key factor for these will be the necessary thickness of the walls to handle the current loading. It is important that additional thickness is not necessary; otherwise valuable floor space will be consumed by a wall.

Based on discussions in various classes, some of the major benefits of using a prefabricated or precast system are the improved quality that can be obtained since the construction is done in a controlled environment, as well the reduction of site congestion since a portion of the work is taking place off-site. Another benefit which has been explained in class is the increase in productivity. Under controlled conditions the product can be built much more quickly, and then once the product arrives on site it is installed more quickly than if masons had been constructing it on-site. The validity of these potential benefits will be examined in the following analysis.

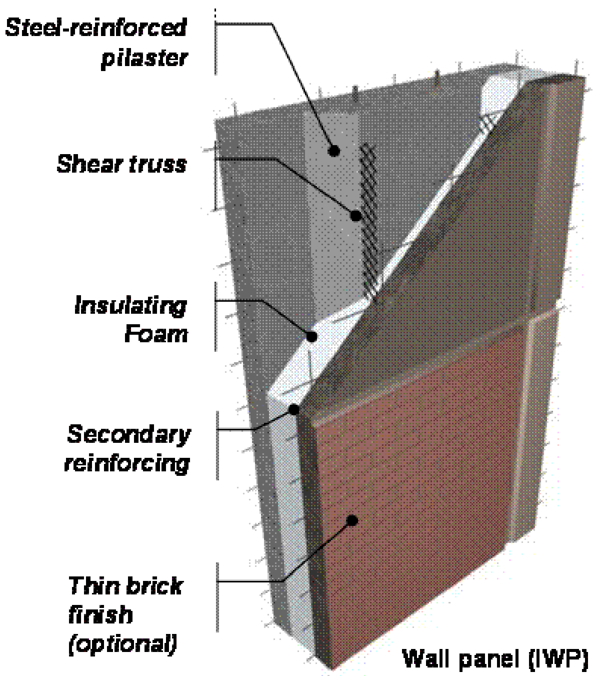
GOAL OF ANALYSIS

A Cost vs. Value review will be used to determine whether or not precast concrete would be a better option than the chosen option of CMU for the wall construction of the exterior façade and the interior load-bearing walls. Arrival of this decision is the main goal for this topic of analysis. The Cost vs. Value review will be based upon the pros and cons of the precast system as compared to the CMU system. Particular areas of comparison include: quality of the final product; cost impact; potential for added value; and schedule impact with respect to productivity and site congestion issues.

CARBON CAST PANELS

The portion of the exterior façade for the Fuel Cell Facility that is currently constructed with split-face CMU plays an important aesthetic role for the building. As mentioned above, there are two existing hangars of very similar design on the base, both of which implement the split-face CMU façade. Deviating from that style is not an acceptable option, thus making the usage of precast concrete walls somewhat restricted. The change in the system cannot cause a change in the architectural features. To be sure that a precast concrete wall could be made to look identical to the CMU wall that was designed, it was necessary to research various precast companies.

The results of this research were that a true precast concrete wall would not be able to match. However, several precast concrete companies also construct prefabricated walls which are composed of steel reinforcement, insulating foam, concrete, and a "thin brick" face. Specifically I chose to contact High Concrete Group LLC, located in Lancaster County, PA. High Concrete is a supplier of CarbonCast insulated wall panels, which is an example of the prefabricated wall system described above. According to my contact at High Concrete, the "thin brick" usage allows the façade to meet practically any set of specifications that a CMU wall can meet. A cutaway diagram of the CarbonCast system is shown below.



As mentioned in the *Background Information* section above, one of the major benefits of using a prefabricated system is the improvement in the quality of the product. The exterior façade of a building is the only part that many people ever see, thus making it very important that the impression it gives off is one of a quality-constructed building. Schedule acceleration and weather conditions were some of the causes of a reduced quality product in the CMU wall construction for the façade, both of which would not be factors in the construction of the CarbonCast wall system. The prefabricated system would be created in a controlled environment; one which has ideal temperature for working, ideal curing conditions for the concrete, and one which is not being rushed by the accelerated schedule on-site. Prefabricated construction of this type would also be done under much more stringent quality control requirements. Another benefit of using the prefabricated wall system is the increased productivity which would occur within the controlled environment. This is largely due to the fact that there are skilled workers performing repetitive activities; a learning curve is set and the workers will continuously be able to complete the work more quickly while maintaining the same quality. Productivity for the installation of the system on-site will be discussed in later sections of this analysis.

STRUCTURAL BREADTH STUDY

While changing the façade system for the Fuel Cell Facility has little affect on the structural demands of the building, changing the interior load-bearing masonry walls to precast requires structural analysis. As was briefly discussed in the *Background Information* section, one of the keys in switching to a precast concrete system is making sure the wall thickness is not increased. Due to the relatively low loads that these walls must support, the ideal situation would be to decrease the wall thickness and increase the usable floor space. There are two different conditions for the interior load-bearing walls, which are shown in the drawings included in Appendix I, but the only difference is the length of the joists which the walls must support. Therefore it was determined that the best solution would be to design for the two conditions separately concerning the wall thickness, and then use the more stringent condition for the design of the reinforcement. This design condition would then be applied for both sections of the wall in order to make construction uniform. The steps of the design process are discussed in the following sections.

LOAD DETERMINATION AND ASSUMPTIONS

The loads that the interior load-bearing walls must support were determined by contacting the Project Engineer for the 167th Airlift Wing, who happens to be an AE Structural Option graduate. I was informed that the loads could be assumed as follows:

Dead Load:	1-1/2" MTL Roof Deck	2.0 psf
	(2) layers of 5/8" Type X GWB	5.6 psf
	Suspended ACT	2.5 psf
	Collateral/Misc.	5.0 psf
	Steel Joists (avg. 4' oc spacing)	5.0 psf
	3" Batt Insulation	1.2 psf
	TOTAL DEAD LOAD	**21.3 psf**
Live Load:	Construction load	20 psf
	TOTAL LIVE LOAD	**20 psf**

Based on discussion with a fellow AE student in the Structural Option, the following assumptions were developed in order to complete the design of the interior concrete load-bearing walls:

Assumptions: Concrete wall is concentrically loaded – axial load only; horizontal load is carried by wide flange steel beam

Pinned-Pinned connection – k=1.0

f'c = 3000 psi; f'y = 60,000 psi

WALL DESIGN

It was determined that the most appropriate design method to use was LRFD or Strength Design and therefore the best load combination to use for each of the two conditions was:

$$1.2D + 1.6L$$

The complete calculations for design of each of the two conditions can be found in Appendix J, but the main parts of the design for Condition 1 are shown below. This condition is shown because it was determined to be the more stringent of the two conditions. The first step was to use the loads that were listed above and convert them into the axial load which the concrete wall is required to support.

$$P_D = 1193 \text{ lbs}$$

$$P_L = 1120 \text{ lbs}$$

$$\mathbf{P_U = 1.2P_D + 1.6P_L = 3223 \text{ lbs} = 3.22 \text{ kips}}$$

This calculated load is the amount that each of the steel joists is applying to the concrete wall at a 4' spacing. It was determined that the bearing plates on which the joists rest have an area of 67.5 inches squared each. It was also determined that the effective width for bearing is 38.75" based on a chosen wall thickness of 8". Next the wall was checked for both Bearing Capacity and Axial Load Capacity with respect to the ultimate load which was calculated above. These checks are as follows:

$$\text{Bearing Capacity: } Pu \leq \emptyset 0.85 f'cA_b;\ \emptyset = 0.65$$

$$\mathbf{0.65(.85)(3)(67.5) = 112 \text{ kips} \geq 3.22 \text{ kips} \ \ OK}$$

$$\text{Axial Load Capacity: } P_u \leq \emptyset P_n = \emptyset 0.55 f'cA_g\left[1 - \left(\frac{kl_e}{32h}\right)^2\right]$$

$$A_g = \text{effective width} \times h = 38.75 \times 8 = 310\ in^2;\ \emptyset = 0.70$$

$$\emptyset P_n = .70(.55)(3)(310)\left[1 - \left(\frac{16 \times 12}{32 \times 8}\right)^2\right]$$

$$\mathbf{\emptyset P_n = 157 \text{ kips} \geq 3.22 \text{ kips OK}}$$

Based on these results, a wall thickness of 8" is acceptable and capable in both bearing capacity and axial load capacity. From this point, it is now necessary to design the reinforcement for the wall. Although there is no steel reinforcement necessary to support the applied loads, there are minimum steel requirements that must be met. The calculations are included in Appendix J, but the resulting steel requirement for the concrete wall is as follows:

#4 reinforcing bars @ 18" oc in the vertical direction

#4 reinforcing bars @ 12" oc in the horizontal direction

INCREASED FLOOR SPACE

As was explained in the above calculations, a wall thickness of 8” was determined to be acceptable for meeting the design criteria. It can also be seen in the sections of the two different wall conditions that the CMU system requires a 12” wall thickness. A simple 4” reduction does not seem like much, yet when the length over which this 4” is gained is considered the additional floor space is fairly significant. The interior load-bearing walls have a length of approximately 356 lineal feet. When multiplied by the 4” reduction in wall thickness we find that 117 square feet of floor space is gained in the office areas. While 117 square feet still does not sound like much in comparison to the overall project, it becomes more significant when there is a price attached to it. According to the findings in the *Project Cost Evaluation* section, the Total Project Cost is $339.46 per square foot.

117SF x $339.46 = **$39,717**

The above equation shows that by decreasing the wall thickness from 12” with the CMU system to 8” with the precast concrete system, an additional $39,717 worth of usable floor space is gained. Though the aesthetic quality of the interior walls may not be as important as it was on the exterior façade, the same conditions leading to a quality product that were discussed previously still apply. The increased productivity benefits would be experienced for the precast interior wall system as well.

COST COMPARISON

It is no secret that one of the most important factors when considering a change of systems is the cost impact. To compare the costs of the system that was instituted on the Fuel Cell Facility project, the CMU system, to the costs of the prefabricated and precast wall systems, it was necessary to acquire information from individuals in the industry. The most accurate cost estimation for the implemented CMU system would be the actual construction costs, which were acquired from the Project Manager in the form of a Schedule of Values which can be found in Appendix K. It can be seen on this Schedule of Values that the total cost of all masonry work on this project is **$230,011** and even includes foundation work for which there is no precast concrete to compare with.

To create a cost estimate for the precast concrete and the prefabricated wall systems, I again conferred with my contact at High Concrete who provided me with a rough estimate for the two wall systems. The estimate I received stated that the production and installation of the two systems would average out at $38 per square feet of wall. The calculation for the total cost of the two wall systems is as follows:

$38/SF x (7622SF Façade + 5696SF Interior) = **$506,084**

It is apparent that the cost of the precast and prefabricated systems is far greater than that of the CMU system which was used on the Fuel Cell Facility. In fact the difference between the two options is $276,073. Stated in other terms, the precast and prefabricated combined system costs more than twice as much as the masonry system. However, to take a step back and look at this from a distance, this price differential is just slightly more than 1% of the total project cost.

SCHEDULE IMPACT

The affect that changing from a masonry system to a precast concrete system has on the schedule of the project must be examined in multiple dimensions. First of all, the duration of activities on site must be compared for the two systems. Clearly the shorter the schedule is the lower costs will be, specifically due to General Conditions costs which were discussed earlier. It can be seen in the *Detailed Project Schedule* in Appendix C that the total duration of the masonry work for both the exterior façade and the interior load-bearing walls is 25 days. Based on information provided by my contact at High Concrete, the total duration for erection of precast and prefabricated panels on-site would be 15 days. This duration was developed according to an estimated 125 panels that would be constructed off-site and then erected by means of a truck crane. It is quite obvious that there is a 10 day difference in the duration of activities on-site, so one would assume that the overall schedule could be reduced by this amount. In the form that the project was originally scheduled, the *Project Summary Schedule* in Appendix C, this assumption would have held true. Unfortunately, due to necessary schedule acceleration, the masonry work overlapped with the steel erection, an activity which was on the critical path and lasted beyond the completion of masonry work. Therefore, the reduction in duration that occurs by switching to the precast and prefabricated system is essentially negligible for the overall project schedule.

Other than the duration of the work itself, it is also necessary to examine the schedule impact in terms of site congestion and productivity, two issues which go hand-in-hand. As was mentioned in the previous paragraph, no matter which option is selected, the activities will be taking place simultaneously with steel erection. This obviously creates some site congestion concerns, which was one of the primary reasons for completing this analysis. The more congested the site becomes with equipment and manpower, the greater the potential for losses in productivity. To compare the logistical issues on the project site for each of the two options for wall construction, site logistics plans have been developed, each of which accounts for the ongoing steel erection process. These plans can be found in Appendix L.

It can be seen in these plans that by implementing the precast and prefabricated wall system instead of the masonry wall system, all scaffolding around the building would be eliminated as well as the mortar mixing station. The forklift traffic which is noted on the Masonry Site Logistics Plan is also eliminated for the precast option, but is replaced by the truck crane and delivery truck traffic which is necessary for erecting the concrete panels. Based on the information explained in this *Schedule Impact* section and prior knowledge, the following conclusions have been made concerning productivity and site congestion issues:

- The decreased duration on site means that site congestion does not last as long
- Fewer workers will be on-site for the precast erection than the masonry construction; less congestion and higher productivity
- Erection of interior walls during steel erection could cause significant congestion issues; more congestion and lower productivity
- Maneuvering the delivery truck and crane on the South end of the building may cause delays; productivity of the erection would be decreased

Overall, it seems that the site congestion level for the two options is almost equal. While the precast and prefabricated systems could be installed with fewer workers on-site and without the scaffolding, it would require the addition of two large vehicles to be maneuvering about the site. It seems reasonable to assume that the productivity rate of the precast and prefabricated system is still higher than that of the masonry system based strictly on the duration of the activities, and that productivity of other activities would be higher with a precast system since there would be less overlapping time.

CONCLUSIONS

As stated in the *Goal of Analysis* section, a Cost vs. Value review is necessary for determining whether or not the precast system is the best option for the Fuel Cell Facility. To do this, it is advisable to compare the pros and cons of changing to this system from the CMU system that was used. First, the main negative factor of switching systems is the additional cost of $276,073. The positive factors of the switch include: increased office floor space valued at $39,717; higher quality product for the façade; decreased duration of activity on site; and increased productivity. It is difficult to place a monetary value on quality as it is all a matter of perspective of the owner. However, since the owner seems to be happy with the final product that was achieved with masonry on the other two hangars, it is unlikely that they would attach a very high value to the improvement with the prefabricated system. As was mentioned earlier, the decreased duration does not affect the overall schedule and therefore does not provide any monetary savings through general conditions costs. The only chance of adding value through the increased productivity would be if other activities on-site were greatly affected and the overall project schedule would be decreased.

It seems that the use of precast concrete and prefabricated walls is not a better option than the masonry system that was used on the Fuel Cell Facility. Perhaps, if the CMU façade covered the entirety of the exterior walls instead of the base only, the cost of the prefabricated system would be more competitive. It is also possible that if there were a much greater amount of load-bearing walls, the increased floor space achieved through reduction in wall thickness would help overcome the increased cost. For the quantity of wall space on this project that could be potentially changed, it is clear that the design team chose wisely in selecting a masonry system rather than a precast concrete one.