Analysis II | Alternative Concrete Construction Process

Background

The concrete construction process has large implications on the successful progression of any project, especially a data center since there is such a complex construction schedule in very little time. All construction trades rely on the completion of concrete slab-on-grade in order to begin any interior installation work. Thus, it is imperative that the concrete subcontractor works as quickly and efficiently as possible.

Overall, the data center's existing use of concrete was quite typical, which involved foundations, equipment pits, slab-on-grade (SOG), trenches within the computer and mechanical rooms, raised slabs for engine-generator rooms (EG) and administration office area, and topping slabs on the roof. Since the building was predominately single-story, the SOG comprised of a majority of the work, covering medium voltage (MV) rooms, uninterruptible power supply (UPS) rooms, mechanical rooms, computer rooms, and the administration office area.

A key difference from typical SOG concrete designs involved large mechanical trenches along the computer room walls (See Figure 11 to the right). These trenches house mechanical main feeds that connect computer room air handlers (CRAH's) with the mechanical equipment in the mechanical rooms. Trenches were utilized to contain spills from the pipes, lower the piping so the access floor can easily clear the pipes, and provide ample underfloor space for other conduit, such as fire alarm and security.

Figure 11 - View of the SOG with Trenches

From start to finish, the concrete subcontractor was on-site from May 28, 2008 until October 28, 2008, totaling 110 days. The cost for this amount of work was approximately $7.2 million, not including overhead and profit, contingency, and other contractual costs.

Goal

The overall goal of this analysis focuses on reducing the amount of time that the concrete subcontractor is on-site, thus having a ripple effect on subsequent trades and the overall project duration. This analysis involves evaluating a redesign of the slab to be a continuous SOG in lieu of a SOG with trenches and its effect on the underfloor MEP layout. Other areas to evaluate include changing the UPS equipment pits from cast-in-place concrete to precast concrete and SOG pour sequences for UPS rooms, computer rooms, and transformer yard. The benefits of the new design, layout, and sequencing will be researched, including constructability impacts, schedule impacts, and the reduction of materials and cost savings.

Methodology

1. Review and analyze the current design.
2. Evaluate the constructability of the new design.
3. Perform take-offs associated with the new design to determine material, labor, and equipment savings.
4. Evaluate both the schedule and cost effects of the new design on the concrete subcontractor contract and the overall project contract.
5. Form conclusions and recommendations.

Resources

- DuPont Fabros Technology, contact– Joe Ambrogio
- Holder Construction on-site staff –Ashburn, VA (MADC5) and Chicago, IL (MWDC)
- EYP Mission Critical Facilities/Hill Mechanical, contact – Andrew Syrios
- RS Means 2008 Online
- Case Study of DuPont's Midwest Data Center

Constructability Analysis

First and foremost, since the design has been altered a thorough constructability analysis must occur to determine the design feasibility. Two significant alterations to be evaluated are the continuous SOG and precast UPS pits.

Continuous SOG

As mentioned in the Background and Goal sections above, the existing floor design involves a 6" continuous SOG with trenches located along the walls of the computer rooms. These trenches are typically 3'-0" deep and range from 3'-0" – 7'-0" wide throughout the computer rooms. The trenches house chilled water piping, ranging from 8" – 30" diameter, from the CRAH's to the chillers. Leak containment and providing additional room below the access floor are the two main reasons for utilizing trenches.

Case Study: Midwest Data Center, Elk Grove Village, IL

The idea for a complete continuous SOG originated from DuPont's Midwest Data Center (MWDC), which was constructed throughout 2007. In fact, the original design for MWDC included trenches with the continuous SOG. However, shortly into the design it was determined that the trenches would be removed as a result of value engineering. According to an owner's representative, "Labor costs for certain trades in Chicago were in some cases almost double what they are in Ashburn. The construction team was asked for ideas on how to trim costs and this one was accepted." Furthermore, MWDC was an existing building and trenches would have pushed the electrical ductbanks and underground plumbing another 4'-0" – 6'-0" lower than the actual installation elevation. Doing so would have created a tremendous amount of haul-off, thus very costly.

MWDC and MADC5 are both extremely large buildings, 425,000 SF and 360,000 SF respectively, with a similar interior design concepts. Since a building has been successfully constructed without trenches, it is obvious that the design is possible. Nevertheless, the design still needs to be evaluated based on the given circumstances of the Mid-Atlantic Data Center 5, especially since the MADC5 piping is much larger and the room layouts are completely different.

The new floor design maintains the continuous SOG for the entire building, removing the trenches within the computer rooms. In doing so, there is a significant decrease in the concrete contractor's scope, which ultimately saves materials, time, and money on the entire project, especially since there are fewer obstacles with making deliveries and setting equipment. As far as constructability is concerned for the concrete, pouring a continuous SOG is not only feasible but much easier than having to deal with trenches too. In contrast, making such a modification will cause a ripple effect on other trades, thus requiring a thorough analysis to be certain that such a design is viable.

Underground Conduits

A disadvantage of the trench design is that all trenches have to be coordinated with the underground electrical system, underground plumbing system, storm lines, and sanitary lines. Any lines that run perpendicular to the trenches must be lower than the bottom elevation of the trench, which creates added excavation. This takes time and money to draft and review with all parties. By removing the trenches, the overall underground coordination process is significantly less since the trenches are no longer in the way. In addition, the conduit does not have to be buried as deep which could reduce excavation haul-off. Lastly, plumbing drain lines would not be run as deep, thus allowing the possibility of eliminating lift stations. All of these constructability issues presented with the trenches would no longer be an issue with the flat slab.

Chilled Water Piping

Figure 12 - Chilled water piping support

Figure 12 to the left demonstrates the support mechanism for the chilled water piping within the trenches. Steel beams are required to support the piping. By removing the trenches, this steel is no longer necessary to hold up the piping. The piping is merely resting on slab mounted tube steel, which is less laborious to install. The figure also clearly illustrates the tight space available to install the piping, requiring more labor due to the difficulty.

Despite seeming like the perfect choice, resting the chilled water piping on the slab does have its constructible issues to take into consideration. As mentioned above, the pipes must be lifted off of the slab and rest on slab mounted tube steel. Fortunately, since the system is pressurized, there is no need to slope the piping. Another issue involves crossing pipes over each other. With a 42" underfloor space to work with, some design tweaking and further coordination may need to occur when the larger mains must cross over each other. One possible solution is to have the crossovers in the corners of the rooms or at least out of the way of any airflow.

Lastly, the most important constructability issue involves leak containment. An extremely important advantage to the existing design is the inherent leak containment provided by the trenches. Should there ever be a leak, the trenches could contain a large volume of water, 3-4 feet versus 6 inches, and the leak would not affect any other major equipment within the rooms, especially electrical wiring and equipment. As such, the owner and tenants are much more at ease knowing that in an emergency situation, their equipment and business would be protected. On the other hand, the flat slab design added design ingenuity to protect against a leak. Six inch steel angles, which were non-corrosive to moisture due to air humidity from the CRAH's, must be fastened and caulked to the slab surrounding all water filled pipes and coils. Additionally, it was even more vital that floor flatness and levelness were maintained to prevent water from ponding near major equipment. Most of all, the drywall around the computer rooms need to be waterproof in order to contain any water leaks as well.

Access Floor

Access floor installation is greatly affected by altering the concrete floor design. With the existing design the trenches pose an issue with the placement of pedestals for the access floor. Steel or aluminum channels must bridge the trenches to provide support for the pedestals. This requires a large amount of steel to cover all trenches since the trenches are much wider than the actual piping. In turn, such work requires more coordination and labor. Additionally, once tenants move into the space, the power distribution unit (PDU) layout may occur over the trench, requiring additional steel channels to support the PDU stands. This underfloor area, above the trenches and below the access floor, becomes quite cluttered with the abundance of steel and aluminum.

Unfortunately, after much research, the new design experiences similar problems clearing the piping. The maximum size access floor tile is 24"x24" where the piping on this job ranges from 8"-30" plus insulation. It is obvious that the tile and pedestals will not be able to clear all of the piping. Therefore, similar metal channels must be used to bridge the piping. However, as shown in Figure 13 to the right, less bridging is required since it just barely spans the piping as opposed to having to span the entire trench. Further, it is easier and quicker to install the access floor on a continuous surface because there are fewer worries about falling into a trench or having to carefully maneuver around the trenches.

Figure 13 - Bridging over the chilled water pipes

Precast UPS Pits

According to the original design, all UPS pits were to be cast-in-place (CIP) concrete pits (see Figure 15 on the following page). As the construction began on the Phase I UPS rooms 1-8, it was determined that the UPS pits would be changed from CIP to precast (see Figure 14 on the following page) for Phase II UPS rooms 9-16. Therefore, the proposed design includes substituting CIP pits to precast pits for all UPS rooms at the beginning of the design process.

Figure 14 - Precast UPS pits

Figure 15 - Cast-in-place UPS pits

Fortunately, the constructability of precast UPS pits is quite straightforward and requires less arduous labor for the workers. There are two options when installing precast pits, which are pre-coordination or post-coordination. Pre-coordination involves gathering the MEP trades and the precast trade prior to fabrication in order to coordinate all underground MEP rough-ins on the pits. It is highly important that the conduit and pits are exactly aligned to ensure a proper installation. On the other hand, post-coordination, which occurred in the actual design for UPS rooms 9-16, requires core-drilling into the precast pits and sealing around the conduit once it has been placed. Both options are quite viable; however, according to the superintendent, the optimum choice would be to coordinate all pit and conduit locations prior to fabricating the pits.

Schedule Analysis

In analyzing the original schedule, every concrete sequence, except for the EG rooms, mechanical room 1, and equipment yard, could be altered to allow the subcontractor to be onsite for a much shorter duration. The biggest change in the schedule, however, was the ability to bring the subcontractor onsite later, June 18, 2008, since the sequences were tighter and moved smoother. The original schedule required that the subcontractor begin May 28, 2008 in the computer rooms because that was the earliest opportunity to work following precast. However, since the precast dictated the schedule, the concrete pours occurred sporadic throughout the project depending on when certain precast pieces were erected and out of the way. Starting later allows for the precast to get ahead enough so that the concrete does not catch up and can work continuously. [Note: All other underground MEP work began as soon as possible.]

As previously mentioned, several sequences could altered to produce a short schedule, such as computer room, UPS room, mechanical room 2, administration office area, Phase II SOG, topping slab, and transformer yard. The following is a breakdown of the changes made to the original schedule. Please see Appendix B for the original schedule and Appendix E for the revised schedule.

- Computer Rooms
  - Overall duration for computer room sequence was lengthened due to starting the prep/pour activities later while the underground MEP work began as soon as possible.
  - The prep/pour sequence changed from 13 days to 5 days by removing the trenches.

- Able to overlap prep/pour and establish a start-start relationship after completing half of the previous prep/pour sequence. (5 day prep/pour = SS+2 days…10 day prep/pour = SS+5 days)
- Duration Comparison:
  - Original = 5/28/08 – 8/15/08 (50 days)
  - New = 7/2/08 – 8/6/08 (26 days)

- UPS Rooms
  - UPS pits changed from cast-in-place concrete to precast concrete because it is a faster and easier installation. As a result, the only concrete work was the SOG. (Phase II was changed after initial design and work had begun on Phase I)
  - Able to pour 2 rooms at the same time because the crew was available.
  - Duration Comparison:
    - Original = 6/12/08 – 8/15/08 (47 days)
    - New = 6/23/08 – 8/1/08 (30 days)
- Mechanical Room 2(Phase 2)
  - Changed the SOG and trench prep/pour sequence to a finish-start relationship with Plumbing/Electrical underground. There is no need for a lag between these activities.
  - Duration Comparison:
    - Original = 8/1/08 – 8/22/08 (16 days)
    - New = 8/1/08 – 8/14/08 (10 days)
- Administration Office Area
  - All of the above changes pushed this area back by a few days, but has no ultimate effect on the overall project.
  - The slight time savings results from moving the prep/pour sequence to a finish-start relationship with Electrical R/I. Again, the previously scheduled lag is unnecessary.
  - Duration Comparison:
    - Original: 8/4/08 – 9/16/08 (32 days)
    - New: 8/13/08 – 9/19/08 (28 days)
- Phase II SOG
  - Includes computer rooms, UPS rooms, EG rooms, MV2, and some small miscellaneous areas (everything else was done with Phase I).
  - Durations affected the same way as Phase I. Additional time savings for these sequences because more man power is available to attend to the areas.
  - Duration Comparison:
    - Original: 9/11/08 – 2/10/09 (109 days)
    - New: 9/18/08 – 12/2/08 (54 days)
- Topping Slabs
  - In the original schedule, topping slabs were waiting on precast, thus creating a large amount of idle time between pours. After discussions with the superintendent, it is possible to prep/pour all topping slab sequences one after another with a finish-start relationship.

- Delayed the start time of the prep/pours sequence to not catch up to the precast.
- Building would still be watertight because CM had its own concrete crew seal all joints between precast pieces enough to be watertight.
- Duration Comparison:
  - Original: 6/4/08 – 10/14/08 (95 days)
  - New: 8/14/08 – 10/14/08 (44 days)

- Transformer Yard
  - Original schedule had an extremely large lag between precast and underground electrical installation. Precast was done with the first section in Phase II (EG 9 and 10) when underground work started in Phase I. It was discovered and realized that underground work could start much sooner, when precast was finished with Phase I (EG 7 and 8).
  - Starting the underground electrical work earlier results in all subsequent activities starting earlier, especially the turndown footings & SOG.
  - Duration Comparison:
    - Original: 10/17/08 – 10/28/08 (8 days)
    - New: 8/28/08 – 9/8/08 (8 days)

As to be expected, several other activities were equally affected by the new concrete sequencing. In fact, no trade will be waiting on concrete per the new schedule. For example, the all of the computer rooms will be done much earlier, which allows for additional time, should it be needed, without delaying other activities.

- Sealing Concrete
  - Concrete SOGs could be sealed sooner, which affects computer rooms, UPS rooms, mechanical rooms, and MV rooms. (The EG rooms have epoxy floors and the administration offices have carpet or ceramic tile.)
- Access Floor
  - There is a shorter installation time, 5 days to 4 days, since the crew has less difficulty bridging the trenches as opposed to bridging the piping.
- Chilled Water Piping and Insulate Chilled Water Piping
  - There is a shorter installation time without the trenches since there is more room to maneuver. The install duration changes from 15 days to 12 days to 10 days and the insulation duration changes from 5 days to 4 days to 3 days, which is a result of the learning curve after the first room.
- Medium Voltage 1
  - The medium voltage equipment for the MV1 room can be installed earlier as well since the room is done sooner. As a result, Level 3 commissioning can begin sooner since it cannot begin until MV1 has been installed.
- Set CRAH Stands/Units
  - All delivery dates could be sooner due to the rooms being ready earlier.
- CRAH Testing

- In the existing schedule, access floor held up the CRAH tester from performing any tests. CRAH testing depends on computer rooms being dried in, complete, and having power. Per the new schedule, the CRAH tester will be waiting for power instead of room readiness. In addition, since computer rooms will be done faster than the original schedule, the CRAH tester will be able to work much faster and not be held up waiting for rooms to finish. Overall, the new schedule provides for an easier Level 3 process.

Upon evaluating and altering the overall project schedule accordingly, it has been determined that the concrete subcontractor can save **65 days** off of his schedule, which significantly reduces his time on the jobsite. Furthermore, the overall project duration has been reduced by 15 days. There is an obvious discrepancy between 15 days and 65 days, however, this can be accounted for due to critical path items and other trade sequences. For example, the computer room construction can be completed earlier; however, since it is not on the critical path, the overall project duration has not been largely impacted. There is a slight impact because Level 3 testing can begin earlier and there is now some "fluff" time for testing the CRAH's depending on power. Likewise, having computer rooms done earlier could allow for a larger manpower shift over to more critical path items such as UPS rooms, but since UPS rooms are so small, adding a large amount of people will only crowd the area and there would be a limited reduction or adverse effect on the overall project schedule.

Cost Analysis

The following assumptions were made throughout the take-off:

- Cost breakdown values provided by RS Means 2008 Online.
- Fairfax, VA was used as the location factor (0.92). It was the closest city to Ashburn; however, the cost may be higher due to a slightly higher cost of living in Fairfax. The calculations include this factor within the unit costs.
- Overhead and profit are omitted from the cost estimate
- Rebar cost derived by applying a factor to the original value.
    - A ratio of the amount of concrete used on the trenches versus the total amount of concrete used on the project [Ratio = (1405 CY)/ (9790 CY) = 0.14].
- Formwork unit cost provided by Superintendent.
- Open Shop labor
- Trench fall protection value provided by concrete subcontractor.
- All concrete is pumped.

By implementing precast UPS equipment pits and removing the mechanical trenches, the concrete subcontractor has saved **$627,828**, which is a 9**% reduction** in price. This savings value includes materials, labor, equipment, and trench fall protection. Several other cost savings can be also be attributed to the concrete contractor finishing earlier, such as overhead and profit, personnel, and a reduction in contractual fees. However, due to confidentiality issues, an actual amount could not be derived. Please see Table 19 below for a comparison of the two processes. Likewise, please refer to Appendix E for a further cost breakdown.

Table 19 - Existing and New Design Cost Comparison

	Material	Labor	Equipment	Total
Original Process	$ 5,488,661	$ 1,142,884	$ 325,848	$ 7,227,393
Alternative Process	$ 5,140,523	$ 1,096,322	$ 316,720	$ 6,599,565
% Savings	**6%**	**4%**	**3%**	**9%**

In addition to evaluating the cost effect of removing the trenches for the concrete subcontractor, it is necessary to assess other trades that may be financially affected. The two most effected trades are access floor and mechanical. Initially it was assumed that there may be a cost additive for the access floor since the piping is quite large and would require either customized flooring or a unique design layout. Fortunately, after discussions with an access floor subcontractor, it was concluded that having to bridge the piping would not have any cost effect on the access floor budget because the steel channels used to bridge the trenches would be used to bridge the piping. Likewise, for the mechanical subcontractor there is also minimal to no cost effect. It is difficult to estimate the exact amount since it is merely dependent on labor. Installing piping on a flat slab would be much easier and take less time than installing within a trench, however that saved time could be allotted to another activity.

In addition to evaluating the cost effect of removing the trenches for the concrete subcontractor, it is not only necessary to assess other trades that may be financially affected, but also the overall general conditions cost savings for the owner.

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For the owner, it is important to look at the general conditions for the three main contracts and evaluate the effects of the alternative concrete process. As mentioned in the schedule analysis, by altering the slab design and resequencing, the overall schedule has been shortened by 3 weeks. Though it is not a large change, it does still have significant implications. The total savings amounts to **$543,000**, which is a **3% savings** on the construction manager contract and a **5% savings** on both the electrical and mechanical contractor contracts. Please see Table 20 on the following page for the savings breakdown.

Table 20 - General Conditions Cost Savings

Company	Total Cost	Duration (wk)	Unit Cost ($/wk)	Savings (wk)	Savings ($)
Holder Construction *Construction Manager*	$ 7,025,338	58	$ 121,000	3.0	$ 363,000
Dynalectric (Dyna) *Electrical Contractor*	$ 1,756,335	58	$ 30,000	3.0	$ 90,000
John J. Kirlin (JJK) *Mechanical Contractor*	$ 1,756,335	58	$ 30,000	3.0	$ 90,000
				TOTAL	$ 543,000
				HCC % Savings	**3%**
				Dyna % Savings	**5%**
				JJK % Savings	**5%**

**Dyna and JJK total GC value is approximately 25% of HCC's value (per HCC estimate)*

Overall, the new design remains to be strictly a cost savings for everyone involved. Taken as a whole, the owner has the ability to save **$1,170,828.**

Conclusions and Recommendations

Though the existing design of a continuous slab with trenches holds significant value with leak containment; overall, the continuous slab design is much more beneficial.

- The continuous slab system requires much less coordination efforts than constructing trenches due to a simpler design and less material.
- The construction for the concrete subcontractor is 65 days faster, resulting in significantly less time on the jobsite and less overhead on the contract. The overall construction schedule has also been reduced by 15 days.
- This system saves the owner $1,170,828 in construction costs. Of that amount, there is a $627,828 savings on the concrete contract and a $543,000 savings on the project general conditions.

Based on this analysis of constructability, schedule, and cost, the continuous slab design is the recommended system. Every aspect of this design surpasses the existing design for it is easier to construct, quicker, and it is less expensive for the owner.