

TECHNICAL GRANT REPORT

**The Next Generation Bechtel Concrete
Design and Delivery System to Improve Cost,
Schedule, Quality and Sustainability**

BECHTEL CONCRETE

*"The Goal - green concrete of consistent quality and workmanship on
all projects across GBUs at optimum cost and efficient schedule"*

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Executive Summary

This report provides a road map for next generation concrete design and delivery system to improve cost, schedule, quality and sustainability. It is a multi-disciplinary effort that involves engineering, construction, procurement and innovation to address all aspects of concrete procurement, production and placement. The new delivery system includes use of standardized self-consolidating mixes, software Apps connected with a Unifier system to electronically order, track and approve concrete batch tickets, use of sensors in the truck to monitor its fresh properties and in-place concrete sensors to track its temperature and strength gain to optimize curing and protection as well as allow early form removal. All the above materials and processes are selected and designed with a focus on reducing the carbon footprint by reducing use of cement, water, field labor, unnecessary idling of trucks and above all, wastage of concrete due to quality issues. Several mockups and field trials were carried out to verify the use of software Apps, sensors etc. Based on the experience and feedback received from projects, this new design delivery system is ready to be rolled out on projects across all GBUs and expected to be a great success in improving our concrete production costs and schedule while improving quality and sustainability at the same time.

The report describes how the concrete production, procurement and placement process at Bechtel is being improved to achieve better cost efficiencies, schedule improvement and sustainability by utilizing the following latest industry trends, technologies and innovations. Chapter 1 discusses the use of standardized concrete mixtures of self-consolidating concrete to reduce labor for vibration and consolidation issues. Chapter 2 describes the use of software Apps to automate and streamline the process of concrete production, supply, quality and software approval. Chapter 3 discusses the use of sensors to monitor concrete rheology, and fresh properties including temperature and air, along with the use of sensors for in-place concrete for early form removal and identification to concrete batches and test records. Chapter 4 considers the optimization of curing and protection to improve schedule. Chapter 5 describes roles of green materials (to replace cement), recycled aggregate and water, and reduction of waste and truck idling time in improving sustainability. Lastly, Chapter 5 presents conclusions.

CHAPTER 1

STANDARDIZED CONCRETE MIXES

The objective of this task was to develop a limited number of standardized mixes that can be used on all projects across all GBUs to improve consistency of concrete performance and reduce overall cost and schedule impact due to use multiple mixes that vary from project to project. For this task, Georgia Tech University was engaged because of their expertise in concrete mix development especially the self-consolidating (SCC) mixes. The idea was to develop general proportions for self-consolidating concrete (SCC), with early (e.g., 3-day) strength attaining 80% of 28-day design strength. Two design strength targets of 5000 psi (35MPa) and 7300 psi (50MPa) were chosen to cover both the normal strength concrete used in most concretes and the high-strength high performance mix that is required for some infrastructure projects. Generally, mixtures with design services lives of at least 50 years are desired, but options for 100-year service life are also covered to account for many projects now requiring extended service life. Guidance on mix adjustment for flowable (high slump) concrete (FC), air entrained concrete, hot weather placement, cold weather placement, and mass concrete is also sought. Mixtures should be producible using local aggregate.

The mixtures provided can be tailored to account for local materials availability, increase early strength, and to account for high- or low-temperature production.

Options to account for materials availability:

- Class C fly ash can be used in place of slag, likely pound-for-pound, although ~25% reduction in HRWRA dosage should be attempted.
- Class C fly ash can be substituted for Class F fly ash. However, Class C fly ash concrete is less resistant to alkali silica reaction and sulfate attack, compared to Class F fly ash concrete.
- Calcined clay can be used in place of silica fume, likely pound-for-pound, at similar HRWRA dosage. However, based on recent literature, larger calcined clay (i.e., metakaolin) dosages – up to 2x - may be required for equivalent durability.
- SCC and FC mixtures can be developed using fine limestone powders, instead of SCMs.

Options to increase early strength, which are also suitable for cold-weather concreting, include:

- Use steam curing and/or insulated formwork
- Use warm mix water
- Swap Type III cement for Type I or I/II. This may require a slight increase in HRWRA dosage.
- Swap in slag or Class C fly ash for Class F fly ash.
- Replace 5-10% of Class F fly ash with silica fume or metakaolin and increase HRWRA dosage to compensate for workability.
- Reduce water content, and increase HRWRA dosage to compensate for workability

SCC-N-3/4 and FC-N-3/4, with their high Class F fly ash contents, are good options for hot-weather concreting. Additional adjustments to these or other mixtures for hot-weather concreting:

- Use a retarding admixture
- Use chilled mix water (blend with ice)
- Swap Type I/II cement for Type I.
- Swap in Class C fly ash or Class F fly ash for slag.

- Increase SCM content, as replacement for cement.
- Replace 5-15% of cement with limestone powder (25um, 40um) and reduce HRWRA by same percentage.

Air-entrainment may not be required to impart freeze-thaw resistance due to the low permeability of some of these concretes. However, when required, manufacturer's recommendations for dosages should be followed to achieve adequate air volume and spacing.

As noted previously, SCC can be readily produced from a variety of materials, using a range of mix proportions. Due to regional and day-to-day variability in materials and environmental conditions and with varying production equipment, it is difficult to anticipate what adjustments to the sample SCC and FC mixtures will be required. However, advice given here for tailoring mixtures should be helpful in lab batching. Bechtel should be aware that as the mixtures are scaled up from the lab to the field, additional adjustments may be necessary and ongoing adjustments may be required.

Georgia Tech has produced 100+ SCC and FC mixtures and thousands of mix designs have been published. Given this broad availability of data, a data-driven approach to mixture design could be explored. Such an approach could result in a tool that could (1) develop mixture designs for projects with prescriptive and/or performance constraints and (2) adjust mixtures to account for the regional and day-to-day variability in materials and site conditions. As we carry out trials SCC mixtures in the lab and in the field, data collected could be used to develop a predictive tool for SCC mix design and adjustment.

The team also collected data on SCC mixes used on Bechtel projects across all GBUs. Also, ACI 237R for SCC also provides a list of successful SCCs.

REFERENCES

Appendix A – Self-Consolidating Mix Development Report from Georgia Tech, October 2019

ACI 237R-07, Re Approved 2019, Self-Consolidating Concrete

Application of Self-Compacting Concrete in Japan, Europe and the United States, 2003 IHSPC

CHAPTER 2

SOFTWARE APPs AND PORTAL

The objective of this task was to introduce a paperless tracking system of concrete from batching through transit in the truck and testing of fresh properties of concrete for quality control acceptance. The software App would replace a paper batch ticket that could be accessed on a hand-held device or via a portal for mix details batched, any water added and admixtures during mixing in the truck and record of all testing in the field. The process would be integrated with our Unifier portal to tie the batch tickets/quantities to the pour cards and cost coding for ease of the invoicing process.

There are many options of varying capacities available in the market that were evaluated through detailed conversation with each vendor and a demo of their software. Some of these are discussed below:

Ordering/Pour Management

Ready Set Pour – Small Startup out of Dallas

Batch Plant/Truck Management

- Sysdyne
- Command Alkon
- Libra Systems
- Stonemont
- GivenHasco
- Trimble – Concrete Fleet Management

Based on the above screening process, Command Alkon was selected as a best fit both in terms of its capabilities and possible integration with our enterprise software system. We also have some experience of using this system on previous projects with good feedback.

In order to evaluate Command Alkon further, a field demo of the software was carried out. Some of the considerations included the following:

1. Difference between electronic batch ticket process and paper process
2. Understanding of needed integrations between Command Alkon and Unifier
3. Evaluations of downstream integrations between DSC and Command Alkon for invoicing purposes
4. Establishment of criteria for a business case for implementation
5. Discussion of possible set up on Southfield project moving forward

The performance of this software App was exceptional. The field was very excited about this and the possible integration with Unifier and DSC. Test pilot of Command Alkon may be carried out on CCLNG

and Southfield projects. A Demand Management Request has also been made and the security requirements are being evaluated.

Unifier Pour Card was developed. The ability to fill out your form on the phone and get multiple signatures in parallel is very powerful.

CHAPTER 3

CONCRETE SENSORS

The purpose of this initiative is to evaluate current concrete sensor technology offerings that would allow us to actively monitor and calibrate quality, productivity, and schedule from batching through transportation and placement. Both truck mounted sensors used to monitor and calibrate the rheological (slump and flowability), air and temperature properties of fresh concrete and embedded sensors to identify and provide real time temperature and strength gain of in-place concrete are evaluated in this report.

Evaluation Criteria:

1. Wireless Application set up and configuration
2. Installation of sensors
3. Durability of sensors during concrete pour
4. Data collection process
5. User interface on phone/web Application
6. Out of the box data configuration and presentation

Process

1. Cross GBU site visits/meetings to discuss the initiative with concrete personnel, Superintendents/FE's and craft personnel to see what issues they are experiencing and how technology may be able to assist them.
2. Consolidate list of features that would provide value to the field.
3. List assumptions for application integration requirements
4. Set up demonstrations, either in person or remote, to allow each company to showcase their product and answer any questions related to the offering.
5. Consolidate the features of each offering and summarize the value of each feature.
6. Prioritize the features in terms of business value to the enterprise overall
7. Review the technology to evaluate the possibility of internal development or integration with the hardware or technology companies.
8. Short list the companies and set up hands on demonstrations either at the WATC or at projects to test the overall offering and ensure that the features operate and deliver the value showcased previously in the demonstrations.

Summarize the offerings and make recommendations for selection and path forward for implementation.

Results

After reviewing our research, decision matrix, field test results, and our head to head comparison we recommend that Bechtel adopts *Concrete Sensors* for in-place concrete. They are the most well-established name in the sensor industry, having secured many major clients, including ourselves in the past. They offer everything that we are looking for in sensors as well, where some of the other vendors fell short. While their pricing may be higher than the other vendors, they make up for that in the best sensors and dashboard on the market in addition to a proven track record of success. We believe that these sensors will help increase efficiency on all job sites, saving Bechtel time and money. They are very excited about the prospect of working with Bechtel and improve their systems to meet our specific needs.

For the truck mounted sensors for fresh concrete properties, we have not come to a clear conclusion as a path forward for Bechtel to pursue. This technology is still developing and there does not seem to be a clear choice that has a proven record of performance and would suit all our needs. Bechtel should keep engaged with the players in this market and continue its evaluation for the right technology.

CHAPTER 4

CURING AND PROTECTION

Bechtel concrete specification require at least 7 days of wet curing or application of curing compound to allow adequate hydration. These requirements are in line with the industry standards. Concretes with higher percentages of fly ash and/or slag require longer curing periods. Temperature is an important parameter that needs to be kept above 50°F during the curing period. Since process of hydration generates heat, it is important to control the maximum temperature for mass concrete and depending upon the ambient temperature also the temperature differential between the core and surface to within limits to avoid thermal cracking. Reference 1 (CIP 11 NRMCA) provides some practical ways of maintaining moisture and temperature of concrete after placement.

References 2 and 3 (CIP 12 and 27 NRMCA) provide guidelines for concrete placement, curing and protection during hot and cold weather concreting, respectively. In-place sensors, as proposed in Chapter 3 can be used to monitor temperature of concrete and regulate its protection both in terms of required insulation and time period, as necessary.

Curing compounds have been shown to provide nearly equivalent durability to continuous wet curing, and can minimize thermal shock caused by cold water on hot concrete surfaces. Thermal shock can lead to thermal cracking.

Wet curing of low water cementitious ratio (w/cm) concrete generally has little or no effect on the cement paste quality more than a few millimeters deep (Ref. 5.) This is due to the reduced transport properties of the concrete (especially when SCMs are used), which significantly inhibit the rate of water penetration into the concrete. Curing is still useful to prevent moisture loss at the surface, which can reduce the quality of the near-surface layer cement paste. Quality surface paste is the first line of defense against corrosion, so it follows that preventing moisture loss at the surface is helpful for durability. Unless a coating is planned, a membrane-forming compound is generally considered equivalent to wet curing.

Further, moisture loss with low w/c has been found to mostly occur in the first 24 hours. This is because the early-age hydration rate is higher than conventional concrete, leaving less long-term hydration potential. The required curing duration, after the initial moisture protection has been applied, has been found to have little effect on long term chloride permeability of HPC containing silica fume or fly ash.

ACI 301 (Ref. 6) recommends a minimum curing period corresponding to concrete attaining 70 percent of the specified compressive strength. The often-specified seven-day curing commonly corresponds to approximately 70 percent of the specified compressive strength. The 70 percent strength level can be reached sooner when concrete cures at higher temperatures or when certain cement/admixture combinations are used, as will be achieved in this case. It should be noted that application of curing compound is proposed in this case, and not complete removal of curing.

Water curing of structural reinforced mass concrete is not advisable due to a risk of thermal cracking. Therefore, moisture-retention curing methods such as maintaining forms in place (form curing), plastic sheeting, and/or membrane curing are recommended, as specified for mass concrete by ACI 301. For locations where water curing is necessary, it is recommended that, in lieu of continuous wetting, damp

burlap covered by plastic should be installed, once the surface of the concrete is cured enough to receive burlap without damage. Insulation (if required) would then be installed over the plastic.

Applying membrane-forming curing compounds

Membrane-forming curing compounds are used to reduce evaporation of moisture from concrete. Curing compounds should be applied immediately after final finishing. Generally, specified curing compound shall comply with ASTM C309 (Ref. 7) or ASTM C1315 (Ref. 8). They can be clear, translucent, or white-pigmented. White-pigmented compounds are recommended for hot and sunny weather conditions to reflect solar radiation, so they are not generally required in cold weather climates.

Application rate for curing compound should be determined and communicated to project staff prior to concrete placement. To achieve a properly executed uniform application, curing compound should be applied by a roller (similar to how paint is software Applied). If the material is spray-applied, a power sprayer should be used (instead of a hand sprayer) to achieve manufacturer's recommended coverage rates. Curing compound should then be uniformly spread with a roller that immediately follows the sprayer. Regardless of the curing method that is used, it must be properly executed to fully cover the surface with an appropriate thickness.

Curing compound will need to be removed from surfaces that will be covered by additional concrete or will receive a coating. Curing compound should not generally be used on construction joints so that bond to adjacent concrete is not affected. If curing compound does get applied to these joints, it should be removed prior to placement of adjoining concrete by approved methods.

Use of Curing Compound on Other Projects

Many owners specify the use of curing compound. For example, Texas Department of Transportation (TxDOT) 2014 Specification Item 420 Substructure Concrete Paragraph 4.10 states the following:

Cure all concrete for 4 consecutive days except as allowed for the curing options listed below. Use form or membrane curing for vertical surfaces unless otherwise approved. Use only water curing for horizontal surfaces of HPC or mass concrete. Use water or membrane curing for horizontal or unformed surfaces for all other concrete.

Use one of the following curing options for vertical surfaces, unless indicated otherwise.

- *Form cure for 48 hr. after placement.*
- *Form cure for 12 hr. after placement followed by membrane curing.*
- *For HPC Concrete, form cure for 48 hr. after placement followed by membrane curing.*
- *For mass concrete, form cure as required by the heat control plan followed by membrane curing if forms are removed before 4 days.*
- *Apply membrane curing, if used, within 2 hr. of form removal.*

Many state DOT's have similar requirements for substructure concrete.

Recommendations

Based on the information provided above, the use of the membrane forming curing compounds is recommended in most software Applications to ensure concrete is appropriately cured without concerns for hot weather or cold weather effects and thermal shock. This curing method also reduces demand for water and improve schedule thus contributing to sustainability of the project.

Forms can generally be removed as early as 3 days depending upon the concrete element and early strength gain of concrete. Concrete mixes proposed in this report (Chapter 1) can be tweaked for early strength gain to allow for a 3 day form removal to accelerate the schedule. Sensors proposed in Chapter 3 can be used to monitor the in-place temperature and strength gain of concrete to supplement results of field cure cylinders to allow form removal.

It is recommended that a comprehensive concrete curing, protection and form removal plan be established for the concrete mixes, applications and environments that are to be encountered on a project. This plan can be verified with mockups, if necessary.

References

1. CIP 11 Curing In-Place Concrete, NRMCA
2. CIP 12 Hot Weather Concrete, NRMCA
3. CIP 27 Cold Weather Concrete, NRMCA
4. Nassif, Hani & Suksawang, Nakin. (2002). Effect of Curing Methods on Durability of High-Performance Concrete. Transportation Research Record. 1798. 31-38. 10.3141/1798-05.
5. ACI 308 Guide to External Curing of Concrete, ACI International, Farmington Hills, MI, 2016
6. ACI 301-16, Specifications for Structural Concrete. American Concrete Institute (ACI), Farmington Hills, MI, 2016
7. ASTM C309-11, Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete, ASTM International, West Conshohocken, PA, 2011, www.astm.org
8. ASTM C1315-11, Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete, ASTM International, West Conshohocken, PA, 2011, www.astm.org

CHAPTER 5

SUSTAINABILITY

Bechtel's Corporate Policy 115 provides the sustainability mission of the Bechtel group of companies ("Bechtel") - to protect people and the environment, partner with communities and society, and promote economic development. To these we have more recently added *pioneering through innovation*. Some of the broad goals include:

- Apply our proven processes, experience and innovation in engineering, environmental safety and health, procurement, construction, and operations to develop, design, and execute projects with care for the environment, as well as for the safety and well-being of the people who can be affected by our projects.
- Be supportive to the communities that host our projects and offices and use inclusive, participatory engagement by which local cultures and values are respected, dialogue is promoted and mutual trust is built.
- Build and enhance the capacity of workers and businesses through local procurement and hiring and by stimulating long-term economic development beyond the projects we deliver.

Concrete is the major commodity and common work product for all our projects across all GBUs that involves all aspects of sustainability indicated above from material selection, procurement and production process, yet concrete is a significant source of greenhouse gas emissions. Thus improvements to decrease the embodied carbon in our projects will be welcome in the marketplace.

This Tech Grant initiative aims to improve sustainability in all these aspects which include:

- Standardized mix development - to minimize number of mixes across projects and improve consistency of performance to reduce duplication of effort, quality problems and waste
- Material selection which aims at reduction of cement and use of SCMs to reduce CO₂ emissions,
- Use of self-consolidating or highly flowable concretes to reduce field labor costs involved in vibration and also reduce concrete placement problems requiring evaluation and repair
- Automation of procurement, batching, QC, acceptance and invoicing using an software App or a Portal – to reduce paperwork, streamline communication, reduce labor and improve efficiencies
- Sensors to measure fresh concrete properties to improve quality and acceptance and reduce rejection of concrete and schedule impacts
- In-place sensors to track temperature and strength gain of concrete to allow early termination of curing and protection and afford form removal – which again helps reduce field labor, materials used for curing such as water and protection and monitoring period and insulation
- Use of high-strength rebar and/or fiber reinforcement to minimize transportation and field labor associated with conventional reinforcement

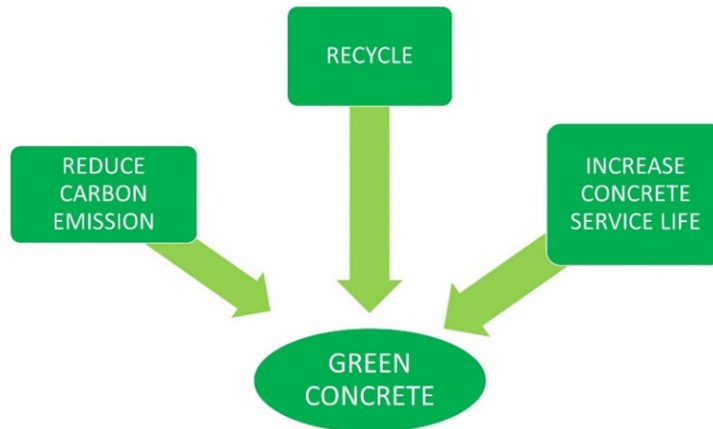
Each of the above measures contributes to cost savings, reduction of waste (where the embodied emissions within waste concrete serve no purpose), fewer truck transport loads reduce diesel-related emissions, with both local air quality and emissions benefits, and reduction of potable water. The UK Environment Agency infrastructure carbon emissions tool recommends that full accounting of carbon from building materials to reduce material quantities, embedded carbon, transportation-related emissions and waste be included. They recommend efforts to reduce embodied carbon such as reduction of cement, use of recycled aggregate, productive reuse of recycled concrete instead of crushed stone where possible, and batch plants close to production will reduce transport-related emissions. Replacing Portland cement is often characterized as reducing the embodied carbon as it results in a roughly 1:1 ratio for cement production resulting in CO₂ emissions. We have established use of at least 25% fly ash and a maximum of 50% slag in our concrete specifications which automatically results in reduction of embodied carbon by about 25-50% in our concrete mixes. In addition, we also provide alternate guidelines for achieving higher goals of sustainability in our specifications which allow use of recycled aggregate and wash water, use of limestone cement etc based on a Tech grant study carried out in 2014 on green concrete (see Exhibit 1). We propose tracking quantities of materials, water, reduction from typical usage to specifically quantify the sustainability benefits from adoption of these proposals.

In summary, this Tech Grant addresses sustainability at every level of concrete production and placement from procurement to material selection to batching and transportation and curing and protection to provide a comprehensive and significant improvement in sustainability.

References:

1. UK Environment Agency Carbon Calculator
2. Inventory of Carbon and Energy, University of Bath

Green Concrete for Sustainable Construction



LIMESTONE CEMENT	<ul style="list-style-type: none"> MANUFACTURED BY INTERGRINDING CEMENT CLINKER WITH BETWEEN 6% AND 15% LIMESTONE REDUCES CARBON EMISSION BY DIRECTLY INTERGRINDING
HIGH VOLUME FLY ASH CONCRETE	<ul style="list-style-type: none"> CONTAINS HIGH AMOUNTS OF FLY ASH UP TO 60 % BY REPLACEMENT OR HIGHER RECYCLES BY REUSING FLY-ASH, AN INDUSTRIAL BY-PRODUCT, REDUCES CARBON EMISSIONS BY REPLACING CEMENT, AND INCREASES CONCRETE SERVICE LIFE
INTERNAL CURING	<ul style="list-style-type: none"> USES PRE-WETTED LIGHTWEIGHT AGGREGATES TO SUPPLY CURING WATER FROM INSIDE THE CONCRETE INCREASES CONCRETE SERVICE LIFE
SLAG CEMENT	<ul style="list-style-type: none"> USES BLAST FURNACE SLAG FORMED AS A BYPRODUCT DURING PRODUCTION OF IRON RECYCLES BY REUSING SLAG, AN INDUSTRIAL BY-PRODUCT, REDUCES CARBON EMISSIONS BY REPLACING CEMENT, AND INCREASES CONCRETE SERVICE LIFE
CRUSHED CONCRETE AGGREGATE	<ul style="list-style-type: none"> USES AGGREGATES MANUFACTURED BY CRUSHING OF CONCRETE RETURNED AT CONCRETE MIX PLANT RECYCLES BY REUSING RETURNED CONCRETE
SELF CONSOLIDATING CONCRETE	<ul style="list-style-type: none"> HIGHLY FLOWABLE AND NON-SEGREGATING CONCRETE ABLE TO BE PLACED WITHOUT ANY MECHANICAL CONSOLIDATION REDUCES CARBON EMISSIONS INDIRECTLY BY CONSERVING ENERGY DURING CONSTRUCTION OPERATIONS
RECYCLED PROCESS WATER	<ul style="list-style-type: none"> FULLY RECYCLED TO MEET ASTM C94 LIMITS OR PARTIALLY RECYCLED REPRESENTING CLARIFIED WATER RECYCLES BY REUSING WASHWATER AT CONCRETE MIX PLANT
RETURNED CONCRETE	<ul style="list-style-type: none"> USE S PLASTIC CONCRETE RETURNED FROM CONSTRUCTION SITE BY BLENDING IT WITH FRESH CONCRETE RECYCLES BY REUSING RETURNED CONCRETE
BUILDING INFORMATION MODELING	<ul style="list-style-type: none"> CREATES 3-D VIEW OF THE BUILDING, INCLUDES PROCUREMENT, COSTS, AND SCHEDULING INFORMATION REDUCES REBAR AND CONCRETE WASTAGE BY INCREASING ACCURACY OF QUANTITY TAKEOFFS AND OPTIMIZES USE OF FORMWORK BY BETTER PLANNING

By
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POWER TECHNOLOGY FAIR 2014

Exhibit 1 From Tech Grant Report on Green Concrete, 2014

CHAPTER 6

CONCLUSIONS

This report provides a road map for next generation concrete design and delivery system to improve cost, schedule, quality and sustainability. It is a multi-disciplinary effort that involves engineering, construction, procurement and innovation to address all aspects of concrete procurement, production and placement. The new delivery system includes use of standardized self-consolidating mixes which were developed in consultation with Georgia Tech University. Command Alkon was selected as a software App which is configured with our Unifier system to electronically order, track and approve concrete batch tickets. To monitor/regulate fresh properties of concrete, several truck sensor systems were evaluated but no decision could be made because the technology has not matured yet. Concrete Sensors were selected for in-place concrete application to track its temperature and strength gain to optimize curing and protection as well as allow early form removal. All the above materials and processes were selected and designed with a focus on reducing the carbon footprint by reducing use of cement, water, field labor, unnecessary idling of trucks and above all, wastage of concrete due to quality issues. Several mockups and field trials were carried out to verify the use of software Apps, sensors etc. Based on the experience and feedback received from projects, this new design delivery system is ready to be rolled out on projects across all GBUs and expected to be a great success in improving our concrete production costs and schedule while improving quality and sustainability at the same time.