Examining Methods of Concrete Construction in A Tadao Ando Private Art Gallery: Lincoln Park, Chicago, Illinois.

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***Abstract*—Creating high quality, smooth-finish architectural-grade concrete outside of Japan, using non-Japanese tools, equipment, and labor, requires a special degree of conviction and a lot of trial and error to achieve proscribed results. The definition of success, in this particular case study, was set forth by none other than architect Tadao Ando of Osaka. In order to attain a degree of fidelity mirroring what the master has already accomplished in his native homeland, within a society where precision and exactitude has reached cult-like status, most may consider a Sisyphean task elsewhere. However, it is the opinion of the author, who simultaneously was the on-site scribe and the Owner's Representative of this Ando-designed Chicago private museum project (Wrightwood 659), that an equivalent degree of design perfection was obtained. This paper will elaborate upon the myriad of architectural and construction methodological details required to attain excellency in site-cast architectural concrete.**

***Index Terms*—Chicago, private museums and galleries, Site cast concrete construction, architectural finish concrete, Tadao Ando.**

I. Introduction

This project, unlike most wholly new-construction works of master architect Tadao Ando, is not a stand-alone new building situated upon a virgin site commanding exclusivity. Instead, it exists mostly concealed, within the confines of an architectural nom-de-plume: a traditional early twentieth century four-story apartment building, built 1929-30, fashioned in a mild historicist style. Red wire-cut face-brick with symmetrical cut and tooled Indiana limestone accents convey a simplified American Federal revival style. The original building might be easily forgotten by the pedestrian casually passing by, walking through a largely residential enclave known as Lincoln Park, Chicago, about three miles (4.8 km) north of Chicago's downtown core, called 'The Loop.' The former apartment block, located at 659 West Wrightwood Avenue, is in fact easily overlooked, for a more prominent creation stands next door to the west, in stark contrast: the commissioner (owner) of the new private gallery (called 'Wrightwood 659,' named [1] after its post-1909 street address), was actually the first American client Ando built a residence for, outside of Japan. The "intensely private" [2] house was designed and built between 1993 and 1997. A repeat client has enabled the ferro-concrete master to envisage an architectural encore in the most complimentary manner, situated right next door, starting twenty years later!

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II. Structure Versus Architecture

A. Defining and Dividing Concrete Types

Other scribed compositions by the author has examined different components of this building, such as its aggressively hefty reinforced footing and foundation system along with an armature composed of a steel frame reinforced with structural concrete. This paper examines types of concrete casting methods that were employed in the creation of what is termed 'architectural concrete' for this project. The majority of the concrete work is comprised of interior bearing columns and some load bearing (as well as non-bearing) architectural-finish concrete walls. It must be noted that the insertion of a new Ando-designed gallery into an existing apartment building yielded a vast array of both structural and aesthetic solutions, insofar as some site-cast concrete walls are wholly non-bearing partitions, and others, partially concealed on the fourth floor, act as huge transfer trusses for a 13' (3.96 meter) deep cantilevered roof plane.

Fig. 1. Exterior (North, street-facing) view of Wrightwood 659.

B. What is Truly Bearing Weight?

All concrete columns within the new structure, in deed, act as true bearing elements; however they are not simply reinforced concrete, but instead technically classified as fire-proof cladding around a steel column. In these examples, site-cast concrete acts as a layer of fire-protection, poured in formwork enveloping new structural steel columns, with welded shear stud anchors (Nelson type, of Elyria, Ohio) to ensure adequate bonding strength between the concrete and

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steel. Adjacent to the steel columns are internal steel reinforcement bars with at least 1.5” (3.81 cm) of concrete coverage. Bonding between the two materials was of such concern to the structural engineer that when some of the steel I-beams arrived on site, accidentally painted in the fabrication plant, the engineer insisted that the paint coating be removed prior to the casting of concrete, with mild abrasive, high-pressure washing equipment. This ‘raw steel’ then conformed to the original plan (and computer model) that engineers from Thornton Tomasetti envisaged.

III. Defining Quality

A. *Meeting Client and Design Expectations*

Prior to execution of the most publicly-visible concrete elements, the general contractor, Norcon, and the concrete sub-contractor, Elliot Concrete (both of Chicago), exercised two major opportunities to practice different formwork application and bracing techniques on this job. The first of which was the casting of perimeter basement walls, which consisted of about 402 linear feet (122.53 linear m) of 9’-6” tall walls (2.9 m). These walls fortunately would never be visible to museum guests, for the basement was specifically reserved for only liquid-based mechanical systems and storage of non-valuable goods. The second opportunity for concrete casting practice was an off-site wall mock up (or full-scale construction of a variety of difficult casting conditions), which grew over time to three separate mock-up exercises in order to achieve the desired outcome quality.

Fig. 2. Inspecting recently-unveiled basement walls.

B. *Knowledge Transfer*

Timing was extraordinarily fortuitous, for another major Tadao Ando-designed museum project was finishing up its final stages of construction in 2013-15: The Clark Art Institute in Williamstown, Massachusetts, built by Turner Construction from construction documents executed by architect of record, Gensler (New York office). For this private-foundation run, publicly-accessible fine art museum project, Gensler’s Chicago office created a base set of permit drawings, followed by the extraordinarily talented local architecture firm, Vinci | Hamp, who created the finish design detailing drawings and performed exhaustive construction administration services. A series of construction-site tours to Massachusetts were arranged; the last one taking place on 5 August, 2015 [3] between the contractors working on both projects. This small summit was the most important one; it was held in a near-finished executive director’s conference room on the subterranean level of the Clark, where both general contractors (Turner of New York and Norcon of Chicago) and respective concrete sub-contractors were present.

Fig. 3. Making a site visit to the clark in Massachusetts.

C. *Builder Lore and Legend*

At the meeting, people jovially traded ‘war stories’ as well as discussed timing, production tips, and means and methods for achieving in-situ, high-quality concrete wall finishes that Ando approved of. One particular level of commitment to quality discussed at length, concerned patching ‘bug holes.’ These voids (trapped air between the formwork and the wet concrete) mars the surface of the exposed, smooth finished concrete walls. Turner indicated that in order to achieve equivalent color consistency when patching these voids, non-visible basement concrete walls were drilled with shallow-depth bits; the resultant dust and grit was collected and re-mixed with new concrete paste, to form a uniform base patch material to fill-in publicly visible bug holes. This high degree of labor generally yielded intended results, for the patches turned out ‘satisfactorily invisible’ to architectural inspectors from Ando’s office (long-time most-senior personnel Masataka Yano san, junior Kazutoshi Miyamura san, and junior Alex Iida san).

D. *Building the Basement*

Returning to the Chicago gallery project, the former apartment building was configured with what is commonly legally termed as an “English Basement” style. This half-sunken level can yield handsome garden-level apartment units—where the first story is submerged about 3’ (1 m) below grade, and the sills of the windows in these units are situated just above finished grade (earth) level. The new use of the building, configured as an art gallery with concomitant sustaining mechanical systems necessitated a near full-basement volume, whose depth limitation was dictated by the relatively high water table of nearby freshwater Lake Michigan. Test bore holes penetrating the thin layer of subsoil, drilled into the sand to the depth of 8’-1” (2.46 meters) below average grade, hit the water table. Hence, the new basement finished floor elevation was set at 14” (35.56 cm) above the mean water table. The basement walls (which protrude above grade) became 9’-6” (2.9 m) tall, after the mean basement floor elevation was set, and under advice from the mechanical engineers calling for appropriate ceiling head clearances for equipment sizing that was initially planned to be located in this space.

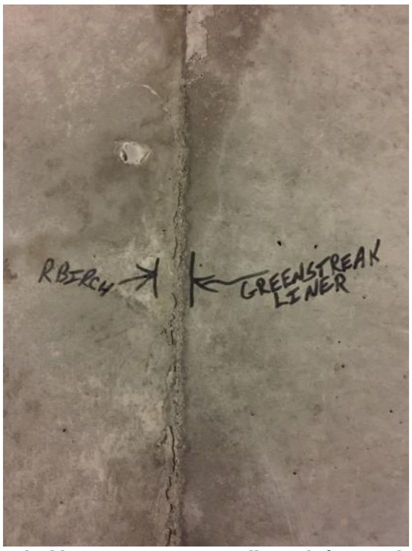

Fig. 4. Un-masked basement concrete walls, with formwork annotations.

IV. The Importance of Formwork

A. *Six Times A Charm*

Six different type of formwork were experimented with while forming the new poured-in-place architectural concrete basement foundation walls:

a) Rely-A-Form brand formwork which is made of Russian birch (field-labeled: 'RBIRCH') plywood with a phenolic film thermally fused to both faces.
b) Sika Greenstreak brand form liners.
c) Azdel Liner brand formwork from PPG, which is a glass-fiber reinforced plastic formwork.
d) High Density Overlay formwork (HDO).
e) Medium Density Overlay formwork (MDO).
f) FinnForm brand formwork.

Fig. 5. FinnForm laminated plywood formwork, section detail.

The last type mentioned, FinnForm, was found to produce optimal results. FinnForm is made from 12-ply (cross-grain layered) Finnish white birch lumber, with a phenolic resin surface coating on both sides that is dyed deep red in color. It is one of the rare imported products found on this all Union Labor (Chicago and Cook County) job site. Sourced through Plywood & Door Manufacturers Corporation of Union (no relation), New Jersey.

The thickness of FinnForm panels used was 3/4"-inch thick (19 mm). It must be noted that all architecturally-exposed concrete surfaces were formed exclusively with FinnForm. However, five-story shear walls hidden in the mechanical rooms, some loading dock partial-height walls, and some fourth-floor walls which would never be seen by the public, utilized industry-common Symons gang forms (a patented product, based in Elk Grove Village, Illinois). Most Symons gang forms require no formwork ties or cone nuts and use pre-assembled smaller panels reinforced with pre-attached steel angles for rigidity and re-usability. One "window" through the finish gypsum board (attached to concrete via thin-depth hat studs) was created at the top of the fourth floor north fire exit stairwell to facilitate a framed viewport onto the surface of the two types of concrete. This opening allows one to see, side-by-side, the remarkable differences in color and finish characteristics imparted by the two types of formwork. Symons gang forms (left side of Fig. 6) are of efficient utilitarian use to quickly build a concrete wall because they are "easy to assemble, easy to strip, and reusable. The (resultant) seams in the wall are very pronounced…" [4]. Hence, they are *not* intended for showcasing any sort of concrete aesthetic, and are only visible in the above mentioned "window" and not an experience that the general visiting public would ever witness.

Fig. 6. Left: Symons gang form impression; Right: FinnForm face.

B. *Excelsior*

The high-quality FinnForm formwork was not simply delivered as sheet-goods are, in 4' x 8' (121.9 cm x 243.8 cm) panels to the job site, raw and unfinished. Instead, all field cuts and site-configured specialty joints were minimized, for the vast majority of the formwork was cut and created in a controlled environment: in a cabinet-maker's wood-shop (which produces finished products known in the industry as 'millwork' and 'case goods'). The first, being Bernhard Woodwork of Northbrook, and the second being Parenti &

Raffaelli of Mount Prospect (both located in the suburbs of Chicago, Illinois). The latter company finished this job and coincidentally also created all of the finish woodwork for the owner's original adjacent Ando-designed home, completed about 1997. Jeff Jozwiak, owner of Norcon, the general contractor building the Wrightwood 659 gallery, commented, "This is the first time that we have had a millwork company custom cut the FinnForm (and) to do the edge banding."[5] Normally, butt joints involve simply using 'as-delivered' sheet goods, wedged against one another through the periodic application of brute force—whereby occasional formwork leakage is tolerated. Not at all on this job.

C. Seams and Joints

Standard friction-fit and silicone-caulked butt-joints were found to be unacceptable methods to join two pieces of FinnForm together, for too much liquid from the concrete (known as 'milk') leaked out between panels, yielding an uneven face surface with unacceptably rough markings. Instead, all edges of FinnForm panels received an added (gray or white) vinyl edge band, which was attached in-house (in their shop) by the millwork fabricator, using a two-part epoxy glue. This additional step illustrates the extreme degree of care taken to ensure fight-fits between formwork panel butt-joints, and the quest for precision that all parties worked towards in this project to yield the highest-quality concrete in America.

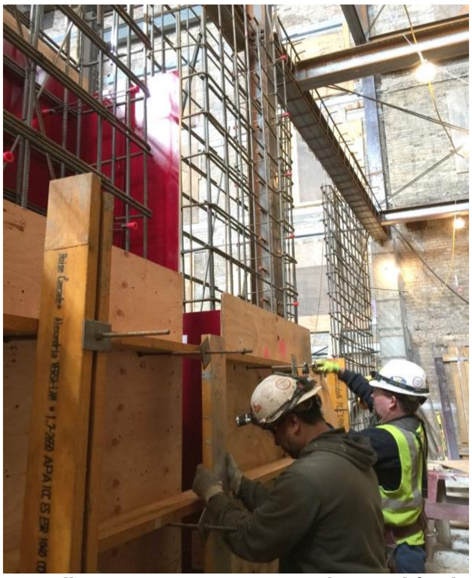

Fig. 7. Installing FinnForm to create an architectural finish wall.

Standard square 4"x4" (10.16 cm x 10.16 cm) wood posts (in varying lengths), although at first used as reinforcement to keep all the "experimental" basement formwork panels co-planar, were eventually found to be too inconsistent in quality (dimensional instability and excessive warpage), due to the fact 4x4's (square posts) are inexpensive fast-growth timber. Eventually, the team found Boise Cascade brand 'Versa-Lams' (manufactured Laminated-wood lumber beams, HQ in Boise, Idaho) worked best when used for both vertical and horizontal FinnForm reinforcement and support. These "glue-lams" as they are commonly called in the field, kept all formwork panels co-planar and true to their intended location, with minimal movement from the great hydrostatic pressures encountered when wet concrete is initially deposited in between the formwork panels.

V. The Importance of the Mock-Up

A. Trial One

A mock-up, configured in an irregular shape of approximately 238" (604.5 cm) long x 101" (256.5 cm) deep x 144" (365.7 cm) tall, was deemed adequate to contain most all nuanced geometric formwork conditions. A suitable outdoor vacant flat at-grade site was used about 1.6 miles (2.57 km) west of the new gallery building, whereupon a flat concrete slab was first poured to provide a level "floor" surface upon which the concrete mock-up could be created.

Fig. 8. Mock-up number one.

The first mock-up utilized modified 4'x4' (121.9 cm x 121.9 cm) and 4'x8' (121.9 cm x 243.8 cm) large gang form panels with additional tie-holes added to attain the desired aesthetic affect. Vertical control joints, construction joints and butt joints were all included in the mock-up. A long, wide 3/4" (1.905 cm) horizontal construction joint (visible above) was also incorporated. Recessed panels for both light fixture sconces and switch / outlet face plates were part of the mock-up. Corian (a DuPont brand homogenous acrylic polymer mixed with alumina trihydrate)[6] commonly used for solid-surface kitchen countertops, was anchored to the inside faces of the formwork panels to create both construction joints as well as desired recesses for electrical devices.

Fig. 9. Formwork samples and Corian insertions for mock-up.

Corian was chosen for its relatively superior dimensional stability, lack of absorption of most liquids including water, and easy ability for layers to be clamped and glued together (with epoxy) in the shop. Corian can also be cut and sanded to be formed to desired sizes and shape in a mill-work shop, and has ability to be coated with formwork release agent without adverse affect upon its surface, material degradation or de-lamination.

Upon stripping the formwork (as proscribed) on the third day after the pour, the results were immediately observed and noted. Unfortunately, the first mock-up was a relative complete failure, for the concrete displayed a full array of aesthetic (not structural) defects. For example, excessive air pockets had adhered to the surface of the formwork leaving irregular-shaped cavities or voids, commonly known in the field as "bug-holes." Secondly, concrete had not evenly settled around large horizontal construction joints, leaving twisted-ribbon-like linear voids on the surface of the wall where concrete should have filled in. Third, lift-lines were visible near the end of the last pour. Lift-lines are vaguely horizontal or slightly tilted lines of different shade or texture that indicate where one batch of concrete (although of the same mix from the concrete plant), was deposited into the formwork at markedly different internal or ambient temperatures, yielding both excessive air pockets as well as unacceptable contrast in face color of the finished, set concrete.

Fig. 10. Post-stripping of mock-up number 1; detail.

B. Second Time's A Charm

All three of the above common concrete defects needed addressing in terms of workmanship of formwork carpenters, concrete pourers, and coordination of teams at the plant mixing and delivering the concrete to the site. Fortunately, the yard utilized for building mock-up number one was vacant and had more space for a full re-creation of a second mock-up. All significant issues were fortunately resolved in mock-up number two. The chief change was the elimination of all modified gang form formwork panels, and the complete incorporation of cabinet-maker level of quality of FinnForm formwork, built in a millwork shop, and delivered with great care to the site. Secondly, notes for methods of assembly of the formwork were delivered to the job site, annotated by the architect's office in Osaka. Some notes were even detailed in Japanese, and were re-issued for this job with English annotations, clearly indicating that this project in Chicago was *not* the only one in the world experiencing such technical challenges to produce Ando-quality aesthetics in concrete.

It must be noted for an international audience, that in the United States of America, neither the architect of record, who is responsible for creating the construction and contract documents, nor the design architect (in this case, being Ando) ever typically issue drawings describing what is termed, "means and methods" of construction. This is due in part to a litigious society, and also regarding differences between the trades involved in building construction versus the architect's scope of design work (*excluding* describing 'how-to-do' the act of construction). Without pursuing a tangent that exists outside the range of this topic, it must be noted that the entire design and construction team, in the spirt of good faith and collaboration, worked together and accepted the "means and methods" details from Ando's office. Hence proscribed joint details from abroad were fully incorporated into drawings describing how to best assemble the formwork. The result was highly satisfactory upon inspection of mock-up number two.

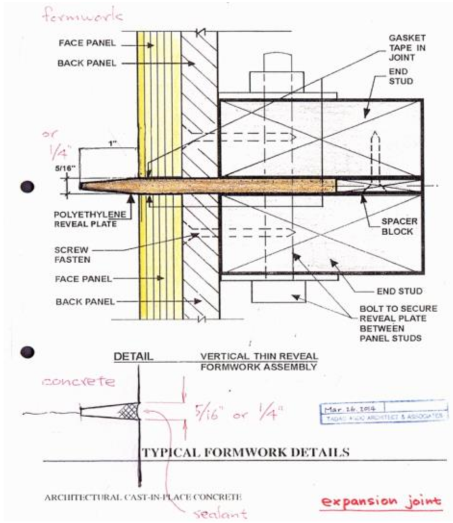

Fig. 11. Ando's 'means and methods' crack-control joint detail. [7].

VI. Mock-Up Number Three

A. Furtive Success

The third mock-up did not encompass the same geometric form as mock-up numbers one and two. Instead, mock-up number three occurred over two and a half years later, as a problem-seeking and problem-solving exercise. This mock-up came about as a result of the discovery issues involved in the pouring of the first staircase composed of architectural concrete. Previously on the project, extensive fire exit stairs had been poured (two separate sets, from basement up to the fourth floors), but out of structural concrete (since they are not viewable by the public on a regular basis). The problem arose when a long run of internal art gallery stairs (traveling from a landing just above floor level three to level four) exhibited major pour problems upon stripping of the formwork. This particular straight-run staircase possessed an exposed concrete underside, fully exposed stringer, and with what appears to be an ornamental (non-walkable) tread and riser—all constructed out of architectural concrete. Sadly, both the exposed stair-stepped stringer and the underside exhibited excessive bug-holes of a size not before witnessed on this project (some in excess of 2" or 3.81 cm in width). A much smaller mock-up, consisting of just seven risers, was created in a construction staging area, just across the alley from the gallery building, for further practice by the formwork carpentry team, and to identify a viable solution.

Fig. 12. Egregious bug holes (entrapped air) marked with blue tape.

B. *Exhaustive Search for A Solution*

This third mock-up, created after the cast-in-place permanent straight-run staircase exhibited the large bug hole issue, was done to ensure the next large set of a stairs, to be cast in the three-story atrium space (42’-1” tall or 12.8 m), would not possess similar air-entrapment issues. The solution found, made actually no modification to the formwork, nor steel rebar placement—but instead the actual mix ingredients were modified. The error which yielded excessive air bubbles or bug-holes was the improper ratio of add-mix to the concrete batch of superplasticizers, at the plant (in other words, not enough superplasticizers were added). This resulted in a more stiff mix, which the team at first desired, in order to properly pour a stepped riser/tread/stringer combination. (For if the mix had too low a viscosity, excessive hydrostatic pressure would build up in the first few steps of the staircase and potentially leak and “blow-out” the formwork, due to gravity and weight of the wet concrete). However, in this case, the mix was too stiff, not allowing entrapped air to escape from typical vibrator use. One solution remained in the idea stage and was not pursued: more vigorous vibrator use or vibration of actual formwork. In both cases, precision of the final cast concrete would be lost, and risk of damage to the formwork by unintentional vibrator contact would have resulted in a marred concrete face-finish. Hence, the amount of superplasticizer was adjusted; and the use of a hand-dipped vibrator continued with no change from previous procedural concrete casting methods.

Fig. 13. Extraordinarily useful mock-up number three: ‘stairs to nowhere.’

VII. Stripping the Formwork

A. *The Importance of Lubrication*

Briefly returning to the aforementioned brainstorming meeting between general contractors Turner and Norcon at the Clark in Massachusetts: one strange message that Turner’s concrete specialists and sub-contractors conveyed was that standard mineral oil-based formwork release agents did not produce satisfactory results. A release agent is a lubricant that is traditionally pump and spray-applied to the interior formwork surface, just prior to the depositing of the liquid concrete into the forms, which subsequently eases (or simply makes possible) the process of stripping the formwork off the curing concrete. For inexplicable reasons, standard mineral oil-based release agents did not enable the satisfactorily smooth removal of formwork; the finished face of the concrete was marred and degraded as a result. Turner explained that they experimented with many different substances and brands of release agent. The ultimate material they found that worked best was a very non-conventional material: a furniture polish commonly known under the brand name, ‘Lemon Pledge,’ made by Johnson Wax of Racine, Wisconsin (headquartered in Frank Lloyd Wright’s legendary modernist building of 1939). This material, sold in an aerosol can, is primarily used in hospitality and residential cleaning situations. It contains as its base carrier an isoparaffin, which “is a mixture of hydrocarbons (mineral oils) derived from petroleum…”[8] Turner adamantly expressed that they concluded Lemon Pledge, adapted for use as formwork release agent, yielded the least amount of vigorous labor, and left the finished surface of the concrete walls looking the best.

Fig. 14. In search of the highest-quality finish (pre-cone nut removal).

Norcon instituted Turner’s suggestion, using Lemon Pledge, with non-uniform and dissimilar results. Three additional formwork release agents (sold as such), all made by different vendors, were experimented with when forming the basement walls: a) Master Builder Preco brand release agent, b) Symons Thrift Kote E release agent, and c) W.R. Meadows Sealtight distributing Duogard Citrus release agent.[9] The third, Duogard-brand, yielded the best results, and the product was then continued throughout as the trusted formwork release agent for the entire building; happily with uniform results. In certain weather conditions, 1st Choice premium form oil-brand release agent was used, by McCann of Addison, Illinois. Once again, the entire team worked together, with altruistic out-of-state assistance from the larger construction industry, to search and find a specific solution to what could have become a big construction quality-control issue. The result was the Chicago team was able to deliver the highest-quality finish on the architectural concrete as possible, with acceptably smooth and visually consistent surface appearance, requiring the minimal amount of cosmetic post-pouring work possible.

VIII. Contents of Concrete

A. A Selective Mixture

Much greater detail must be elaborated upon with regards to the differences between the structural concrete poured between the Symons gang forms and the architectural concrete placed between the customized FinnForm formwork panels. Elliot Concrete, the aforementioned concrete sub-contractor, supervised and employed all three labor teams: a) the formwork carpenters (who assembled the millwork-joined FinnForm panels). b) the crew that poured the wet concrete into the formwork and vibrated the concrete to eliminate as much entrapped air as possible. c) the crew that carefully stripped the formwork off the curing concrete and removed the bright red plastic formwork cone-nuts (producing the deep tapered and truncated cylindrical holes at each formwork tie rod) after the third day of concrete curing.

The structural concrete was specified to perform at 6,000 psi (pound per square inch, or 41.36 MPa {megapascals} in metric) yield strength, in compression. This is slightly higher than standard structural concrete, which typically performs at 5,000 psi (34.47 Mpa). The structural concrete contains a maximum graded aggregate of about 1" (2.54 cm), which is larger than the architectural grade concrete. The structural concrete contains a greater amount of fly-ash, "an inexpensive material (admixture) that provides the finest level of gradation in the concrete." [10]. If the delivery truck is delayed in traffic, and arrives on site with an inadequate amount of viscosity (drier concrete than desired), water can be added to the mixer before being pumped to the delivery area. This can result in a color or texture change (but no alteration in strength); for obvious reasons, this is typically permitted on a job site where all structural concrete is hidden from view. The structural concrete specified by the engineer is categorized as a "lightweight concrete" (meaning, its in-place density or unit weight by volume is less than standard weight concrete). This specification was made for the sake of structural efficiency, for it "reduced the loads to the foundations and saved on overall structural costs by shrinking the column and foundation sizes." [11]. Hence, the use of lightweight concrete "lightened" the overall gross mass of the building, and created less of an extreme demand upon the micro pile and push (or jack-) pile foundation systems (reviewed in another article by the author). For reference, lightweight concrete is about 64% to 76% the weight of normal weight concrete. Lightweight ranges from 90 to 115 pounds/ft^3 (1,440 to 1,840 kg/m^3) and normal weight concrete ranges from 140 to 150 pounds/ft^3 (2,240 to 2,400 kg/m^3). [12]

B. Aggregate Matters

The architectural concrete, in contrast, contains a smaller gradation of aggregate, of which the maximum size was 3/4" (or 19 mm) in rough diameter. The aggregate for both mixes, crushed limestone, has its origin not more than 51 miles (82 km) away from the Chicago gallery job site, in an underground mine located 300 feet (91.4 m) beneath the village of Joliet, Illinois [13]. Here, Lafarge/Holcim (based in Zurich, Switzerland), operates a prime crushed limestone mine supplying raw materials that are eventually mixed to form concrete—to build the city of Chicago, and this particular Ando-designed gallery project. The architectural concrete was more in alignment with normal weight concrete, certified at weighing in around 145 pounds/ft^3 (2,323 kg/m^3). [14] The concrete exhibited a 9" (22.86 cm) slump test; the possible range is 1"~10" (2.54 cm~25.4 cm). "The high slump is a result of the superplasticizers used, which aid in flowability of the concrete." [15] There were several admixtures contributing to the overall workability and final appearance of the architectural concrete, which included: hydration stabilizers, air entraining agents, high range water reducer, and viscosity modifier, all manufactured by W.R. Grace and Company (of Columbia, Maryland), and specifically formulated, as per structural engineer, Thornton Tomasetti's specifications, for the architectural concrete for this project. [16]

Ozinga, the concrete supplier for this project, made sure to source both types of concrete mixes from only one of its two plants located in the City of Chicago (the 'Chinatown plant' was located in a more distant neighborhood, so the mix consistently came from the closer 'Goose Island plant'). A total of 363 concrete truck-loads were hauled to the site, with a cumulative 2,299 cubic yards of concrete were poured (1,757.7 cubic meters). [17] Approximately 30% of this concrete was the special architectural concrete mix. The remainder was structural concrete. The concrete budget was approximately USD$4.932 million (澳門圓 MOP$39.85 million). Contrary to typical operation, the concrete trucks were "thoroughly cleaned before each load was delivered." [18]. The general contractor also indicated that "greater care is taken in flushing the (concrete) pump and slick-line before the architectural concrete is sent through." [19] The final desired yield strength of the architectural concrete (measured at 28 days after pouring, industry standard) was designed to be 5,000 psi (34.47 Mpa), compressive strength, "but all the concrete tests were yielding much higher strengths." [20] Three different test cylinders (of concrete collected during different pours) yielded an average test strength of 9,308 psi (64.17 Mpa), yielding 86% greater strength than technically required. [21]

C. Concrete Specifications

The aforementioned structural engineering firm, Thornton Tomasetti (Chicago office) indicated that the architectural concrete specified was "normal weight" concrete. This decision was made "because normal weight has better finishing characteristics (looks better exposed)." [22] It must also be noted "that (at) many locations the Ando (architectural grade) concrete is acting structurally as well as aesthetically." [23]. The monumental staircase, for instance, in the aforementioned three-story atrium, is one such location.

A giant (but thin, measuring only 12" thick, or 30.48 cm) 'fin wall' extends 35'-5" tall (10.79 m) upward, and simultaneously acts in its core as a giant column (12" x 14.5' long or 30.48 cm x 4.41 m) bearing the weight of the majority of second and third floor balconies. At its center point is situated a pile cap covering a typical set of five micropiles. This fin wall does not extend upward to touch the ceiling/floor structure of the fourth floor however (a giant welded steel box-beam spans this distance). This fin wall also supports the staircase, of which, traversing from floors 2 to 3, is fully cantilevered off of three faces of the fin wall. The staircase from levels 1 to 2 are more conventionally supported; that is, the sloping ramp that supports the stone steps is supported on both sides by spread-footing braced partial-height walls. The unitary stone tread and riser unit rests in a bed of grout and is also permanently held in place by two stainless steel pins (stone type and use is elaborated in another paper by the author).

Fig. 15. Staircase cantilevered from 'fin' wall.

IX. Conclusion

In conclusion, the creation of a 37,000 square foot (3,437 square meter) private museum building in the city of Chicago, wholly using American labor, tools and building construction techniques, while adhering to a strict and thoroughly developed Japanese design aesthetic, is quite a formidable task. Through much on-site experimentation, coöperation and courage, the engineering, design, and construction teams in Chicago were able to achieve their ultimate goal: a stamp of approval and satisfaction issued by both the client and the master of concrete, Tadao Ando. This private museum / art, architecture and activism gallery called 'Wrightwood 659,' would not have been a success without a calculated degree of carefully staged and planned off-site mock-ups and on-site trials. Whereby, superior formwork assembly, concrete casting, and formwork removal means and methods would eventually prevail, after much controlled and recorded tests and trials. Patience was paramount, and not in surplus supply at many junctures in this project, due to the desire to deliver a completed building in a timely manner. Yet, nobody ever surrendered in the midst of the project, nor sacrificed the objective of delivering the highest quality concrete building, yet built in America.

Acknowledgment

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