TOLERANCE MANAGEMENT OF ALUMINUM-FRAMED CURTAIN WALL

SYSTEMS: A CASE STUDY

A Thesis

by

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ABSTRACT

The aluminum-framed curtain wall is one of the most applied building cladding systems due to its versatility and reasonable costs for low to high-rise constructions. The curtain wall system demands high-quality control and proper tolerance management with other building components to achieve adequate performance. However, the fragmented nature of the construction industry often results in poor interface management and creates problems making the installation process inefficient. Most sections in the construction industry have been utilizing emerging Information and Communication Technologies (ICT), including Building Information Modeling (BIM), to enhance communication and remove clashes between building components in advance. However, those practitioners working on the curtain wall installation do not appear to communicate effectively with project participants to resolve clashes between the curtain wall and other building components in advance. Therefore, they still experience low productivity in curtain wall installation.

What does hinder curtain wall subcontractors from utilizing ICT to enhance communication between parties in the course of the curtain wall installation? In response to the question, this study monitored the curtain wall installation process of one commercial building construction project in Texas. It also interviewed key practitioners with semi-structured open questions, to gain an in-depth understanding of the issues that may affect their productivity.

The results show that the general contractor nor the cladding subcontractors working for the target project see the immediate need of using ICT to solve clashes between cladding components. They thought the interface between cladding systems was not as complex as other building components such as mechanical, electrical and plumbing systems. The cladding subcontractors did not want to invest resources in adopting the ICT or hiring a third party to provide the service, because they were not sure if the use of ICT would guarantee the productivity improvement in the field. The interviewees recognized the overall productivity improvement that the construction industry gained from using ICT. They also admitted that the use of ICT may help them better manage the interface issues in cladding installation. However, the need of front-end investment and their doubts about the impact on the field crews hindered them from trying to use ICT in the course of the cladding installation process.

ACKNOWLEDGEMENTS

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Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the industry professionals, which provided access to the data for this research and were willing to participate in the study.

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NOMENCLATURE

#	Number
AAMA	American Architectural Manufacturers Association
ALUM	Aluminum
AVG	Average
B.O.	Bottom Of
BIM	Building Information Modeling
BTM	Bottom
CMHC	Canada Mortgage and Housing Corporation
CONC	Concrete
CONT	Continuation
CTRL	Control
CW	Curtain Wall
CWCT	Center for Window and Cladding Technology
DSTC	Distance
DWGS	Drawings
EXT	Exterior
F.F.	Finish Floor
GANA	Glass Association of North America
GC	General Contractor
H	Hour

INCL	Included
INST	Installed
INT	Interior
LF	Lineal Foot
LN	Line
LOC	Location
N.A.	Not Applicable
NMF	Not Measured in the Field
O.S.	Opening Size
PNL	Panel
QTY	Quantity
REF	Reference
SF	Square Foot
SSG	Structural Silicone Glazing
T.O.	Top Of
TYP	Typical
UFGS	United Facilities Guide Specifications
W/	With

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1. INTRODUCTION

1.1. Introduction and Background to the Problem

The aluminum-framed curtain wall system is used extensively from low to high-rise constructions. There are two types: stick and unitized. The stick curtain wall system allows complex configurations, field crews can modify the system in the field, and the cost of the materials is low. However, the quality control is subject to site variables, and the assembly process is slow which increases the field labor cost (Murray 2009). The unitized curtain wall system is pre-engineered, and factory assembled, enhancing the quality control and improving the installation process and reducing the labor cost. However, the unitized system cannot be modified in the field and demands smaller tolerances to guarantee an adequate integration of its components to ensure a proper performance of the system (Peevey 2011).

One of the main challenges that faces the glass and glazing industry relates to interface management (Waring and Gibb 2001). First, curtain wall subcontractors have to produce specialized designs (shop drawings), but they are not part of the design team, and there is poor coordination of their design inputs (Pavitt and Gibb 2003). Second, those subcontractors cannot often take measurements of the primary structure of the building, as well as building envelope components before the curtain wall fabrication starts. The curtain wall components have to be pre-ordered and the panels assembled in advance before the building is even built. The tolerances required for the curtain wall fabrication are measured in fractions of an inch, whereas other components of the building are often in the range of inches (Klein 2013). And third, the curtain wall subcontractor does not have control over the outcome of other trades' work that may affect the installation process. These problems can lead to the improper performance of the curtain wall, due to modifications of the system or adjacent building components, or inadequate integration between the curtain wall and other systems (Peevey 2011).

1.2. Research Problem

Curtain wall subcontractors, as well as other trades, are responsible for delivering the final product, but the installation process is not efficient. They do not usually participate in design decisions. The fragmented essence of the construction industry hinders the integration of construction knowledge among contractors (Thompson et al. 1996). Management and supervision are inadequate and work disruptions may occur (Proverbs et al. 2000). Subsequently, each participant passes the risks to the next stage in the supply chain. Each of them may become adversarial, more self-seeking and distrustful (Egan 1998). Therefore, the efficiency and costs can be compromised due to possible conflicts between numerous interfaces (Gray and Flanagan 1989). These issues show the need to employ efficient communication and interface management in early stages of the project.

Most sections of the construction industry utilize emerging Information and Communication Technologies (ICT), including Building Information Modeling (BIM) to improve the communication and remove clashes between building components in advance. These technologies enhance the communication and coordination of the design and can schedule information to all project participants (Wood and Alvarez 2005). ICT have the ability to interchange information with other systems and employ the data exchanged (Grilo and Jardim-Goncalves 2010). However, practitioners working on curtain wall installation do not appear to communicate effectively with other project participants to resolve clashes between the curtain wall with other building components in advance. As a result, they still experience low productivity in curtain wall installation. Therefore, one may be wondering what hinders the curtain wall subcontractors from utilizing ICT to enhance the communication between the parties in the course of the curtain wall installation.

1.3. Motivation

Studies addressing the inefficiencies installing the curtain wall system seems to be nonexistent in academia, although the curtain wall industry still face challenges improving their productivity in curtain wall installation. Most of the literature about the system refers to its performance, cladding procurement, strategies for managing cladding interfaces, and tolerance requirements for the installation of the building components.

1.4. Research Objective

The objective of this study was to identify the reasons that hinder the curtain wall subcontractors from utilizing ICT to enhance their communication with other project participants in the course of the curtain wall installation. To achieve the objective, this study monitored the curtain wall installation process of one commercial building construction project in Texas. It also interviewed key practitioners with semi-structured open questions, to gain an in-depth understanding of the issues that may affect their productivity.

1.5. Significance

This study intends to provide an initial view of the challenges faced by curtain wall subcontractors from adopting ICT to improve the communication with other project participants and enhance their productivity during the curtain wall installation. The results of this study may encourage future researchers to track down the cost resulting from the inefficiencies in the course of the curtain wall installation and quantify the overall impact in the construction industry. It could also encourage software vendors to develop applications and tools capable of overlaying the input of the cladding subcontractors with other trades and the design team within a collaborative environment.

1.6. Thesis Outline

The thesis has five sections. Section one provided an introduction and background to the problem. It explained the motivation, research question, objective and significance of the study. Section two reviewed pertinent literature, including definitions, types of curtain walls by erection techniques, tolerance conflicts installing the curtain wall system, and emerging information technologies applied in construction. Section three stated the research methodology, research tools, and data collection processes and analysis. Section four presented an analysis of the data and results. Section five concluded with a research summary, the limitations of the study and suggested future work about how to improve the productivity erecting the aluminum-framed curtain wall systems.

2. LITERATURE REVIEW

This section reviews published literature, including types and characteristics of the aluminum frame curtain wall systems, the challenges specialized contractors face installing the curtain wall system, and current emerging information and communication technologies applied in construction.

Due to the limitations of academic literature in this field, the author employed broad resources including associated organization symposium papers, catalogs prepared with funding from government agencies, and technical notes. The researcher carefully selected the sources to ensure objectivity and veracity in preparation for their use establishing the current picture of the curtain wall industry and its challenges.

2.1. Definitions

2.1.1. Curtain wall system

Curtain wall system is a non-load-bearing building envelope that carries only its weight and environmental forces, which act upon it. It protects the interior of the building from the exterior environment and can be independently framed, outboard of the primary building structure (Simpson 1999).

2.1.2. Cladding

Cladding is the covering of one material with another, but the definition changes depending on the context. Regarding building construction, the Centre for Window and Cladding Technology (2000) defines cladding as a comprehensive term for the envelope of a building that provides an aesthetic effect and protection from the weather. It may carry its weight, but it is usually transferred with the environmental loads to the structure of the building.

2.1.3. Interface management

Interface management is a methodology that manages and controls the flow of information between contractors, subcontractors, and clients. Its primary purpose is to identify potential issues early and address them properly to minimize or remove the impact to the cost and schedule of the project.

2.1.4. Building information modeling (BIM)

BIM is the process of designing and analyzing a construction project life span through the integration and documentation of the information. BIM produces an intelligent computer-generated preliminary model of the project, utilizing a databases (Leicht and Messner 2007).

2.1.5. Interoperability

Interoperability is the capacity of components or systems to interact mutually, interchange information, and employ the data exchanged (Radatz 1997).

2.2. Types of Curtain Wall Systems by Erection Techniques

2.2.1. Stick curtain wall system

The stick curtain wall system is commonly used in low and mid-rise constructions (Figure 1). The system components displayed in Figure 2 and Figure 3, are machine cut in the factory and supplied in a knockdown form to be assembled and installed on-site. They allow modifications in the field (cut-to-fit), and the system can be glazed at the job site (Simpson 1999). The stick curtain wall system is economical and extremely reliable if it is properly designed and installed. Its assembling facilities and shipping requirements are minimum, and it requires short lead times to arrive on-site. However, the assembly process is slow, which increases the labor cost. Its quality control is subject to site variables, and it requires exterior access for installation (Simpson 1999).

Figure 1. The stick curtain wall system. 211 W. 18th Street. New York, NY. Image: Andres Martinez.

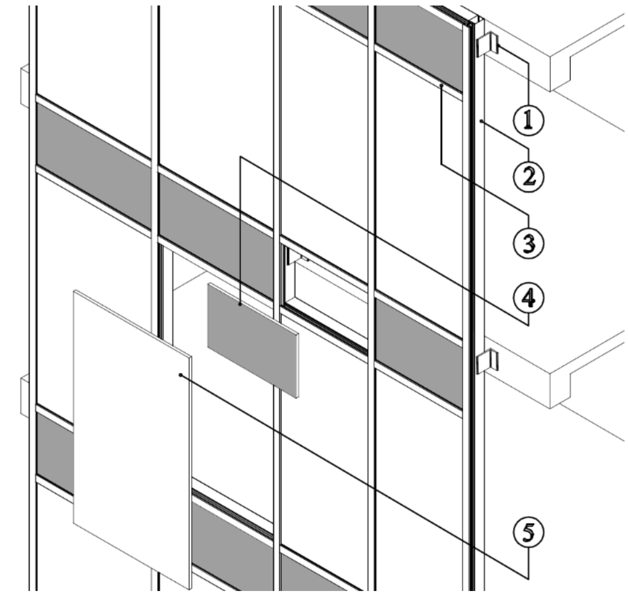

Figure 2. Stick curtain wall assembly. 1. Anchor, 2. Vertical mullion, 3. Horizontal mullion, 4. Spandrel Panel, 5. Glass Lite. Adapted from Kawneer 1600 Wall System 1, Kawneer Inc. (2014).

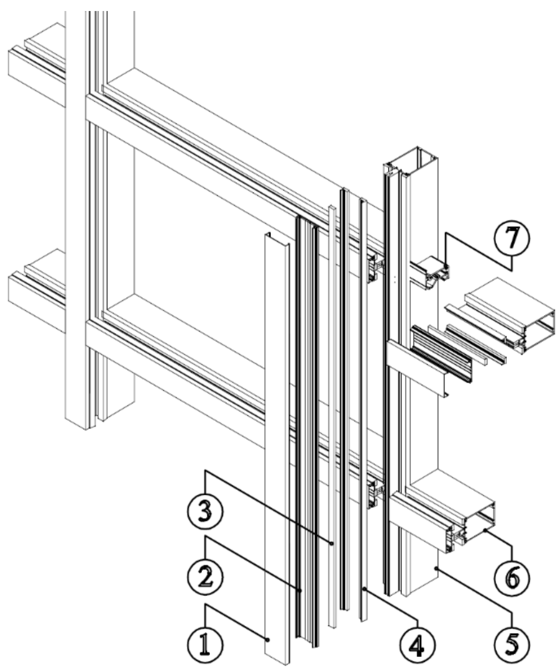

Figure 3. Stick curtain wall components. 1. Snap cap, 2. Pressure plate, 3. Thermal break, 4. Gasket, 5. Vertical mullion, 6. Horizontal mullion, 7. Shear block. Adapted from Kawneer 1600 Wall System 1, Kawneer Inc. (2014).

2.2.2. Unitized curtain wall system

The unitized curtain wall system is used in large high-rise buildings (Figure 4). The system frames and glass are pre-engineered, and factory assembled (Figure 5 and Figure 6), improving the quality control. This system can be installed from the interior. Its labor and installation cost is lower than stick curtain walls because its installation is faster. However, the use of this system increases storage and shipping cost because it requires expensive lifting equipment on site, careful site handling and longer lead times (Simpson 1999).

Figure 4. Unitized curtain wall system. 8th Avenue, New York, NY. Image: Andres Martinez.

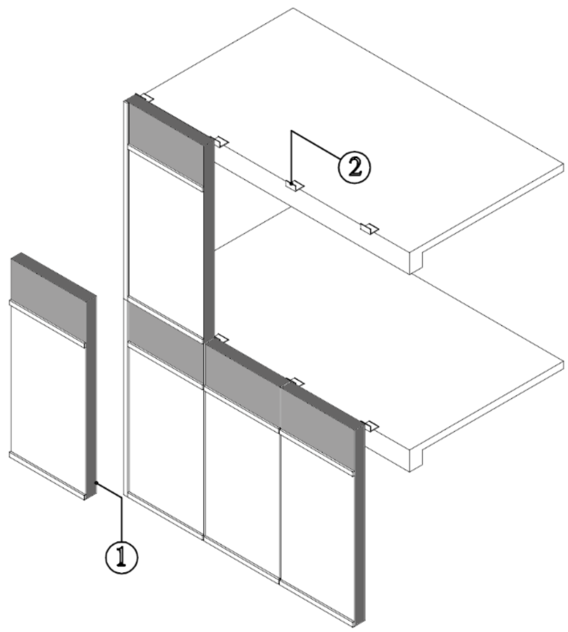

Figure 5. Unitized curtain wall assembly. 1. Anchor, 2. Prefabricated, pre-glazed frame. Adapted from Kawneer 2500 PG Wall™ System, Kawneer Inc. (2014).

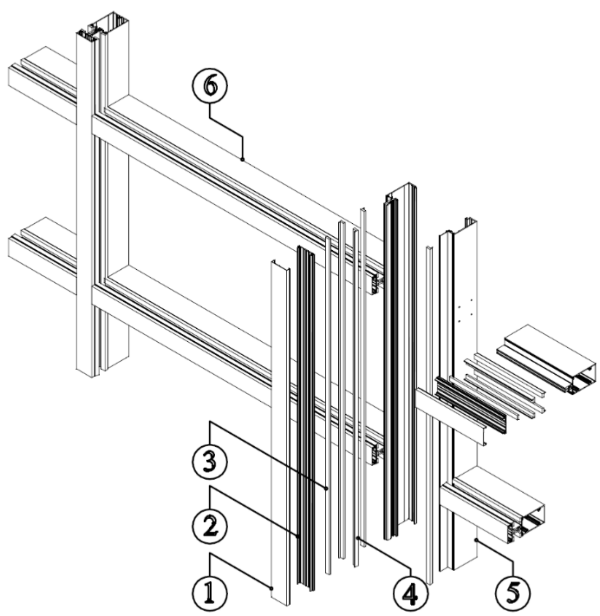

Figure 6. Unitized curtain wall components. 1. Snap cap, 2. Pressure plate, 3. Thermal break, 4. Gasket, 5. Split mullion, 6. Horizontal mullion. Adapted from Kawneer 1600 SS System, Kawneer Inc. (2014).

2.3. Tolerance Issues Installing a Curtain Wall System

The Metal Curtain Wall Manual of the American Architectural Manufacturers Association (AAMA MCWM-1-89) and the Section 08 44 00 of the Master Format, mention the strict tolerance requirements of the curtain wall system in order to ensure its proper performance (Ballast 2007). However, the supporting structure and the surrounding systems have much larger tolerances. Usually, larger or out-of-tolerance systems are adjusted to accommodate the curtain wall system, but often there are adverse results such as alterations to the original design and schedule delays. Inadequate edge distances for the curtain wall framing or supporting structure, over shimming of connections, improvised non-engineered structural connections, and improper waterproofing are results of construction tolerance issues. If the tolerance problems of adjacent systems surrounding the curtain wall system are not properly addressed, this result in system failure. (Peevey 2011).

2.4. The Challenge Installing a Curtain Wall System

One of the main challenges that faces the glass and glazing industry relates to interface management (Waring and Gibb 2001). First, curtain wall subcontractors have to produce specialized designs (shop drawings) but they are not part of the design team. Further, there is poor coordination between the architect's blueprints and the subcontractor's shop drawings (Pavitt and Gibb 2003). Second, the subcontractors often cannot often take measurements of the primary structure of the building or building envelope components before the curtain wall fabrication starts. The curtain wall components have to be pre-ordered, and the panels assembled before the building is even built. The tolerances required for the curtain wall fabrication are measured in fractions of an inch, whereas other components of the building are often in the range of inches (Klein 2013). And third, the curtain wall subcontractor does not have control over the outcome of other trades work that may affect the installation process. These problems can lead to the improper performance of the curtain wall, due to modifications of the system or adjacent building components, or inadequate integration between the curtain wall with other systems (Peevey 2011).

2.5. Emerging Information and Communication Technologies (ICT) Applied in Construction

Technology is evolving fast; economic success and market competitiveness for construction industry relies on technological developments. However, the construction sector still is not effectively using emerging information and communication technologies to integrate its design, construction, and operational processes (Wood and Alvarez 2005). Emerging Information and Communication Technologies (ICT) have the potential of improving the efficiency of executing construction-related processes and the inherent value added to the construction industry participants (Gallaher et al. 2005).

FIATECH™, an international community of stakeholders that promotes research on new technologies and innovation, prepared a catalog recognizing and documenting emergent ICT applicable to construction and facility management. The catalog was contracted by the National Institute of Standards and Technology under the auspice of the Physical Structures and Systems Interagency Working Group of the National Science and

Technology Council. The emerging ICT highlighted by Wood and Alvarez (2005) in the catalog are:

- Construction Simulation Technologies (Building Information Modeling),
- RFID for Construction Materials Management,
- Wireless Networks for Construction Sites,
- Mobile User Interface Devices,
- Technology Training Tools,
- Automated Tool and Supply Management,
- Sensing Technologies for Facility Performance,
- Materials Logistics Management and
- Subsurface Mapping Technologies.

Among the emerging ICT, "Construction Simulations Technologies combine 3D models with construction planning and management tools, information dependency between the 3D model and the schedule, support design, procurement, subcontracting, and external restraints to produce a dynamic, visual image of planned path of construction options and actual construction progress" (Wood and Alvarez 2005). In addition, the visual combination of design and project schedules allows the parties involved in the project to analyze and visualize several aspects of the construction sequence in advance, reducing errors from the beginning. These tools enhance the coordination and communication of the design and schedule information to all project participants (Wood and Alvarez 2005).

2.5.1. Construction simulation technologies

Building Information Modeling (BIM) adoption and implementation by construction industry have increased significantly since 2007 because contractors prioritize the attention on their advance in the job site. The direct benefits of using BIM in the job site are reduction of rework, which increases costs and schedule overruns, reduction of overall project duration, promotion of new business, reduction of inaccuracies and oversights in documents and retaining recurrent clients and businesses are the benefits that BIM directly impact the job site productivity (Bernstein et al. 2012). BIM improves the interface management through communication, coordination, cooperation and collaboration due to its ability to communicate with other systems, interchange information with other systems and utilize the data exchanged (Grilo and Jardim-Goncalves 2010).

2.6. Summary

The literature review covered relevant definitions related to this study, aluminum-framed curtain wall system types, and tolerance conflicts installing the curtain wall system. Issues installing the curtain wall system were identified as well as emerging information and communication technologies applied in construction that are improving the efficiency of designing and delivering a construction project. However, there is need of systematic literature on the challenges faced by curtain wall subcontractors to enhance their productivity. The lack of literature demonstrates the importance of research in this field and the considerable potential that could be gained from its results.

3. METHODOLOGY

3.1. Research Design: Case Study

A commercial building construction project in The Woodlands, Texas served as a case study to monitor the curtain wall installation process. Collected data included in-depth interviews, daily notes, and field measurements. The interviews used semi-structured open questions to allow the research participants to develop their answers, provide details, and express their perspectives. That allowed this study to gain an in-depth understanding of the productivity related issues in the industry.

The building complex consist of two office buildings and one garage. The office buildings comprise a 13 story core and shell building, called the “East Office Building”, and another 12 story core and shell building called the “West Office Building”. The parking garage was a 12 story building. This study only considered the “West Office Building” (Figure 7) because the curtain wall system was being installed at the time this research was being conducted, and the general contractor provided the data necessary for this study.

3.2.1. Interviews

Table 1 shows the list of semi-structured questions asked during the interviews. These kinds of questions allowed more flexibility during the interview because they could be modified according to the direction of the conversation. Semi-structured questions allowed the participants to expand freely their answers, offer details, and other viewpoints.

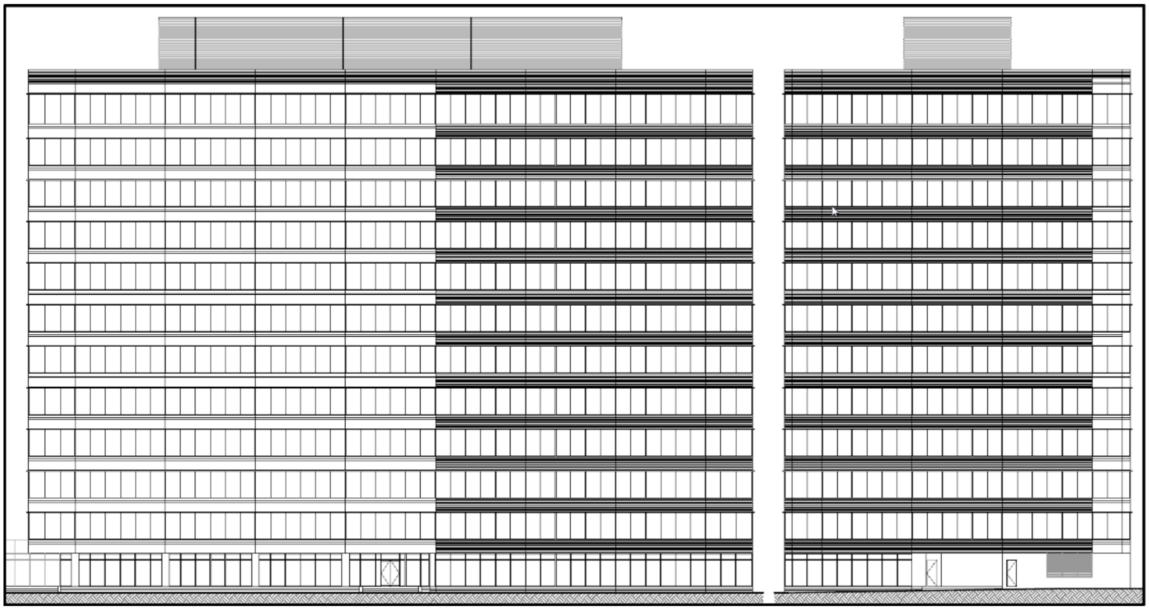

Figure 7. The “West Office Building”. North (left) and West (right) façades. Curtain wall layout similar on South and East façades. Adapted from Adapted from Dietzmann, J. M., Jr. (2014).

Table 1 List of questions asked in the interviews.

Questions to the General Contractor	
1.	Prior to the construction phase, how was planned the coordination and communication between trades to avoid clashes during the installation process?
2.	Was always the communication between subcontractors through the General Contractor?
3.	How was the quality control of the installation of the cladding systems?
4.	Did you experience any delay in your schedule due to any issues related to the façade of the building?
5.	Did you receive change orders from the cladding subcontractors, related to any conflicts or problems during the installation process?
6.	Did the Superintendent keep any daily report about issues faced by the cladding subcontractors?
Questions to the Curtain Wall Project Manager	
1.	Did you place requests for information to the designers due to discrepancies conflicts found on construction documents during the construction phase?
2.	If the answer to the question 1 is YES, could you explain to me what kind of conflicts did you find?
3.	If the answer to the question 1 is YES, did you find those conflicts in the construction documents or in the field?

Table 1 Continued

Questions to the Curtain Wall Project Manager
4. Did you place requests for information to the designers due to discrepancies conflicts found on construction documents during the construction phase?
5. If the answer to the question 1 is YES, could you explain to me what kind of conflicts did you find?
6. If the answer to the question 1 is YES, did you find those conflicts in the construction documents or in the field?
7. Based on question 3, where do you thing was the problem between the communication and coordination among the parties?
8. Did you have the opportunity to talk with the precast subcontractor before you start the fabrication of the curtain wall system?
9. How your productivity can be affected in terms of time, schedule and cost of personnel?
10. Did you receive from the General Contractor information from other subcontractors to adjust your drawings previously to begin the fabrication or installation?
11. Did you submit any change order due to conflicts between cladding systems found in the field?
12. In general, how the productivity can be improved during the fabrication and installation process of the curtain wall system?
Questions to the Curtain Wall Field Supervisor
1. Did you find the measurements provided on the Construction Documents accurate with the measurements found on the job site?
2. If the answer to the question 1 is NO, please indicate what kinds of discrepancies were found?
3. Did you use the exact measurements provided on the approved shop drawings to fabricate the curtain wall system? If no, why?
4. Did you take any measurements in the field before start the fabrication of the curtain wall system? Or everything was based on construction drawings?
5. Did you take into account information provided by General Contractor and other cladding subcontractors to fabricate the frames and prepare the installation of the curtain wall system?
6. Did you modify the curtain wall frame or its anchor in any way during the installation process?
7. What are the challenges in the field that affect your productivity during the installation of the curtain wall?
8. How can be improved the productivity during the installation process?
9. Did the precast subcontractor move or adjust the panels to allow you to install the curtain wall panels?

The data collected through the interviews involved two phases:

Pre-production/pre-installation phase: this phase addressed the discrepancies found between the construction documents and the shop drawings of the curtain wall system before its installation. That helped determine how the participants addressed the clashes between cladding systems prior to the construction phase.

Delivery phase: this phase established the challenges faced by the parties during the installation of the curtain wall system. Specifically, the modifications or adjustments of the system in the field and the efficiency of the crew installing the system. Tolerance conflicts between the curtain wall with other building components caused modifications or adjustments on the system and affected the productivity of the curtain wall installers in the job site. This phase also provided understanding and knowledge about the decisions made by the participants when they encountered tolerance-related problems.

Several pictures recorded the different tolerance issues between the curtain wall and other building components in the “West Building”. They also helped the interviewees recall their experiences with those issues, improving the quality and accuracy of the collected data. The interviews were digitally recorded to facilitate the informality of the dialogs with the participants. The transcripts of the interviews are attached in Appendix A.

3.2.2. Project diary

The project diary described the number of workers, their actions and time spent installing the curtain wall system (Appendix B). With this information, it was possible to analyze the performance of the curtain wall installers and the challenges that affected their productivity. It was not always possible to record data daily due to logistical issues. For example, access to areas where the curtain wall crew was working was restricted due to safety policies, and scheduling conflicts existed with the general contractor and the curtain wall subcontractor. Nevertheless, the collected field measurements allowed this study to determine tolerance conflicts between cladding components. Conclusions made with that data used the acceptable tolerance ranges following industry standards.

3.2.3. Field measurements

Field measurements of clean openings, which are ready for curtain wall installation, and installed curtain wall frames provided information about tolerance issues between the building cladding components. The Metal Curtain Wall Manual of the American Architectural Manufacturers Association (AAMA MCWM-1-89), the Glazing Manual of the Glass Association of North America (GANA), and the Section 08 44 0 of the United Facilities Guide Specifications (UFGS) provided the tolerance boundaries accepted by the industry. For curtain wall erection tolerances, the industry standards indicate that the difference in the length of the diagonals should not be more than 1/8 inch on any rectangular framing opening. Similarly, 1/8 inch should be the maximum deviation from the location showed on the shop drawings (Ballast 2007).

To measure the openings in the field, a standard laser level (mounted on a tripod) was the tool utilized to establish a reference based on the control lines drawn in the field. A measuring tape and a 6-foot aluminum ruler were used to determine the distance between the laser level and the adjacent cladding system. This study includes measurements of all curtain wall openings where the precast panels and/or curtain wall panels were already installed and where safety constraints allowed the general contractor to grant access. Table 2 presents the details of those measurements.

Table 2 Curtain wall area covered by the data collected in the field.

Floor	Precast Panels + CW System	Precast Only (Clean Opening)	Clean Opening Area / CW Area Measured	Total CW Area
1st	Not Measured	Not Measured	Not Measured	5,993 SF
2nd	Yes	-	6,224 SF	6,546 SF
3rd	Yes	-	6,224 SF	6,546 SF
4th	Yes	-	6,224 SF	6,546 SF
5th	Yes	-	6,224 SF	6,546 SF
6th	Not Measured	Not Measured	Not Measured	6,546 SF
7th	Yes	-	6,224 SF	6,546 SF
8th	-	Yes	6,224 SF	6,546 SF
9th	-	Yes	6,362 SF	6,546 SF
10th	-	Yes	6,178 SF	6,546 SF
11th	-	Yes	6,362 SF	6,546 SF
12th	Not Measured	Not Measured	Not Measured	7,258 SF
		Total Area Measured	**56,246 SF**	**78,711 SF**
		Percentage Measured	**71.45%**	**100%**

This study measured the cladding systems along the perimeter of the concrete slabs (Figure 8). It also measured the location of the curtain wall and other cladding components using the control lines drawn by the General Contractor (Figure 9). On floors where the curtain wall panels were installed (2nd to 7th Floor), the vertical mullions of the system helped locate the measuring instruments. Appendix C includes the measurements collected in the field.

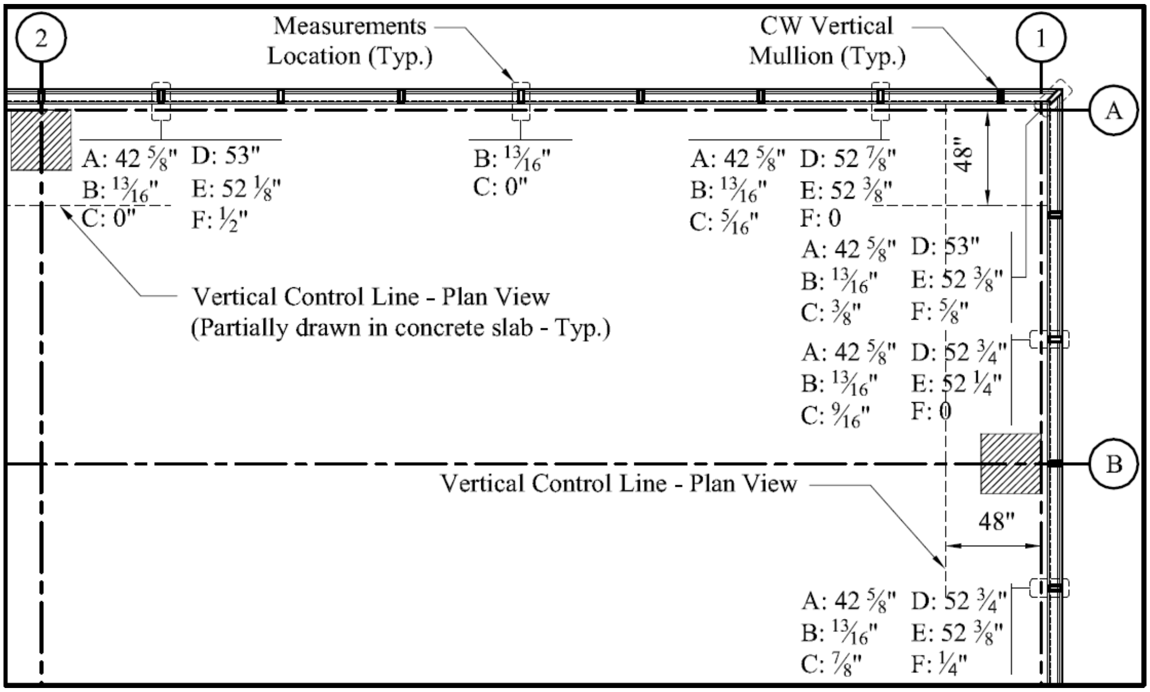

Figure 8. Example of data collected from 2nd to 7th floor. Letters A, B, C, D, E and F denote de measurements gathered in the field according to the façade section showed in Figure 9. Partial floor plan (Typ.). Adapted from Dietzmann, J. M., Jr. (2014).

Figure 10 and Figure 11 show the measurements collected between cladding systems, to determine any tolerance conflicts that could have affected the productivity installing the curtain wall system. To reach a great level of accuracy in such critical points, standard plastic horseshoe shims employed by the curtain wall installers were utilized. The standard shims come in 1/16″ (Blue), 1/8″ (Red), and 1/4" (Black) thickness. Filling the gap with shims provided the gap size (Figure 12).

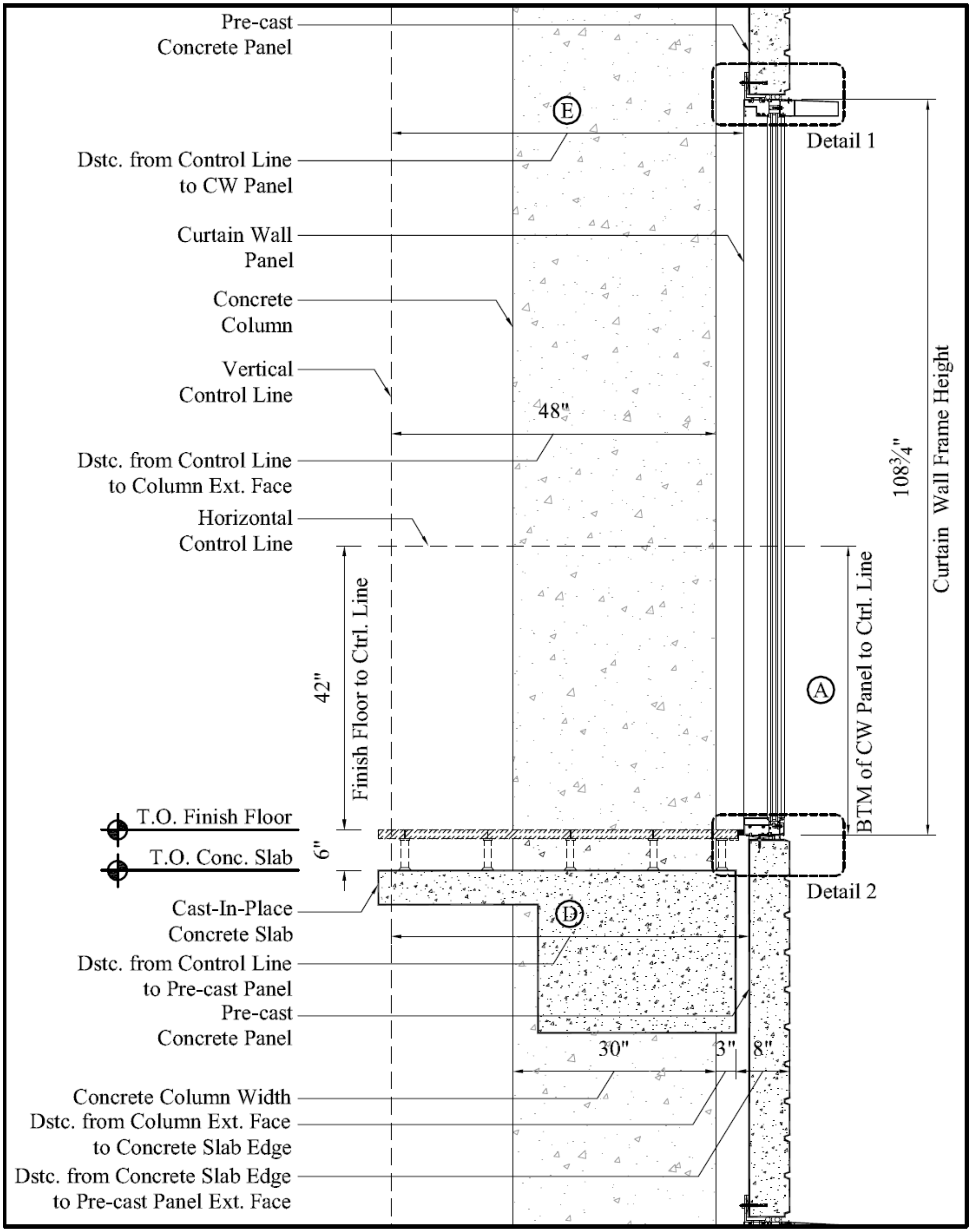

Figure 9. Partial façade section from 2nd to 7th floor. Letters A, D, and E denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

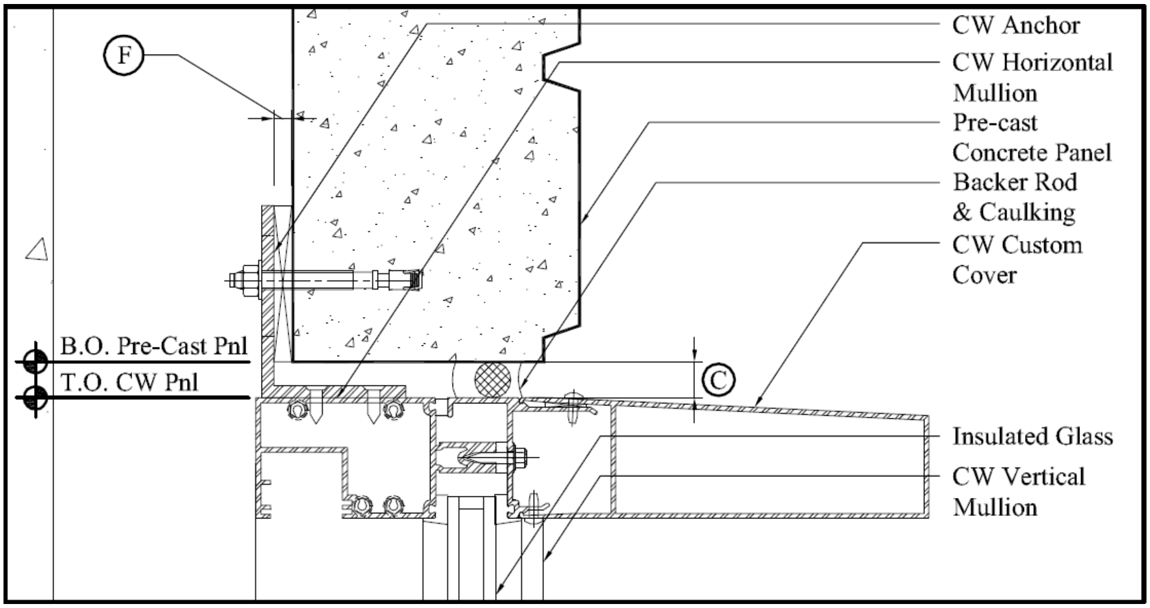

Figure 10. Detail 1: head of the curtain wall panel. Refer to Figure 9. Letter F indicates the distance between the curtain wall anchor clip and the precast panel, and letter C the distance between the top of the curtain wall and the bottom of the precast panel. Adapted from Diaz, O. (2014).

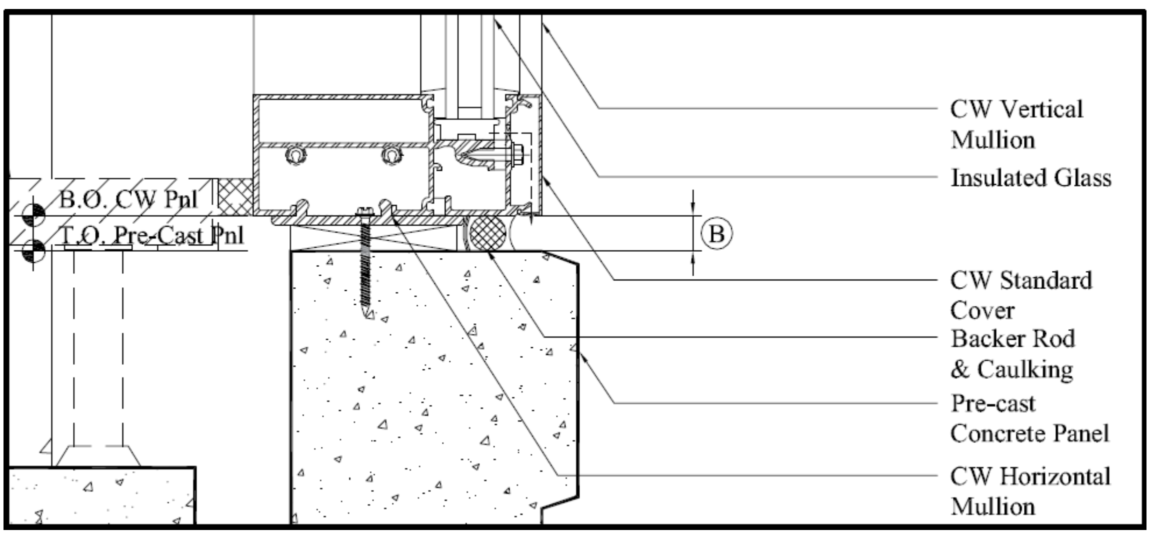

Figure 11. Detail 2: sill of the curtain wall panel. Refer to Figure 9. Letter B indicates the distance between the top of the precast panel and the bottom curtain wall system. Adapted from Diaz, O. (2014).

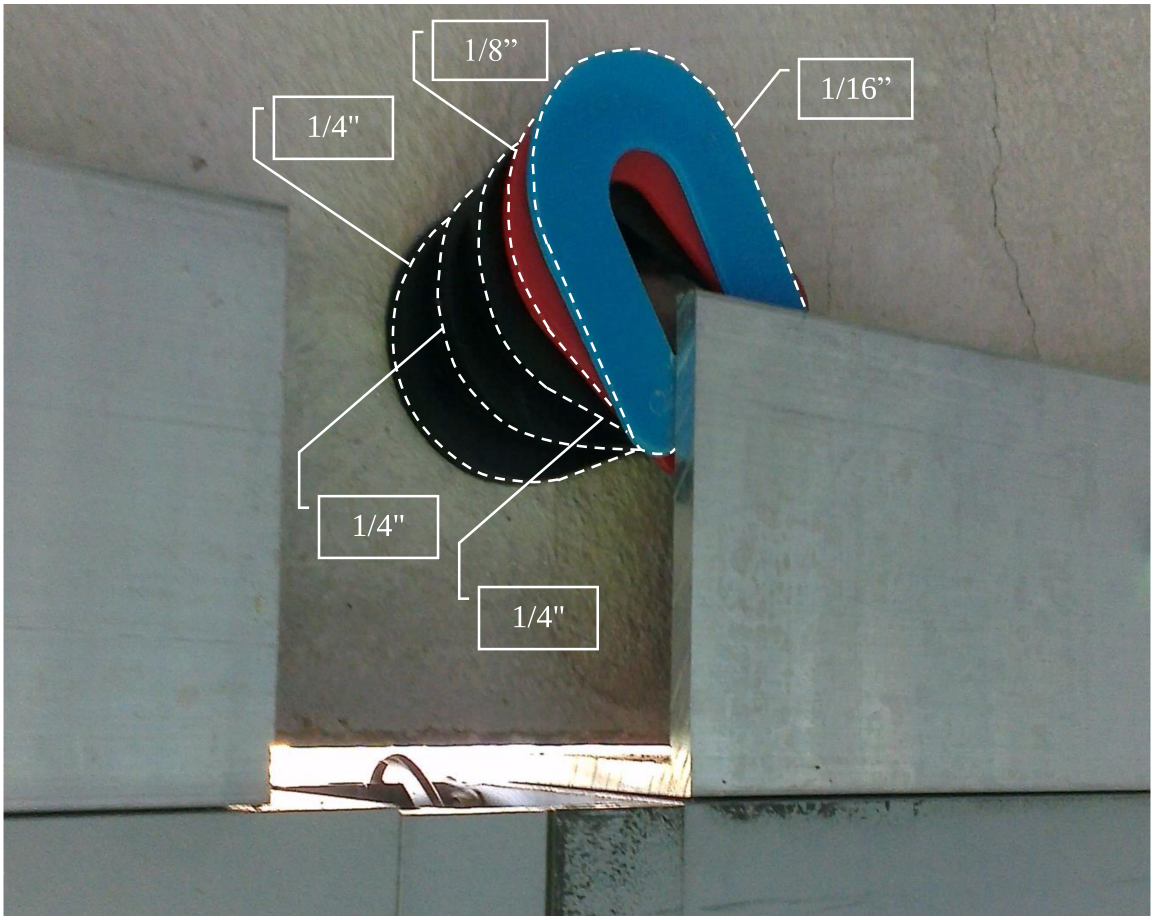

Figure 12. Example of measurement utilizing horseshoe shims. The picture shows the measurement process between the curtain wall anchor clip and the precast panel. Three (3) 1/4” shims, plus one (1) 1/8” shim, plus one (1) 1/16” shim. The total distance between cladding components is 15/16”. Image: Andres Martinez.

On floors where the curtain wall panels had not been installed (8th to 12th Floor), this research included measurements made along the concrete slab edge of the openings delimited by the precast panels (Figure 13). The existing control lines (Figure 14) were the reference used for the measuring instruments. A long range rotary laser with a 6-foot ruler were the tools used to measure openings. These tools overcome the challenges caused by daylight brightness, wind, construction materials, and the mechanical equipment dispersed by different trades in the floors.

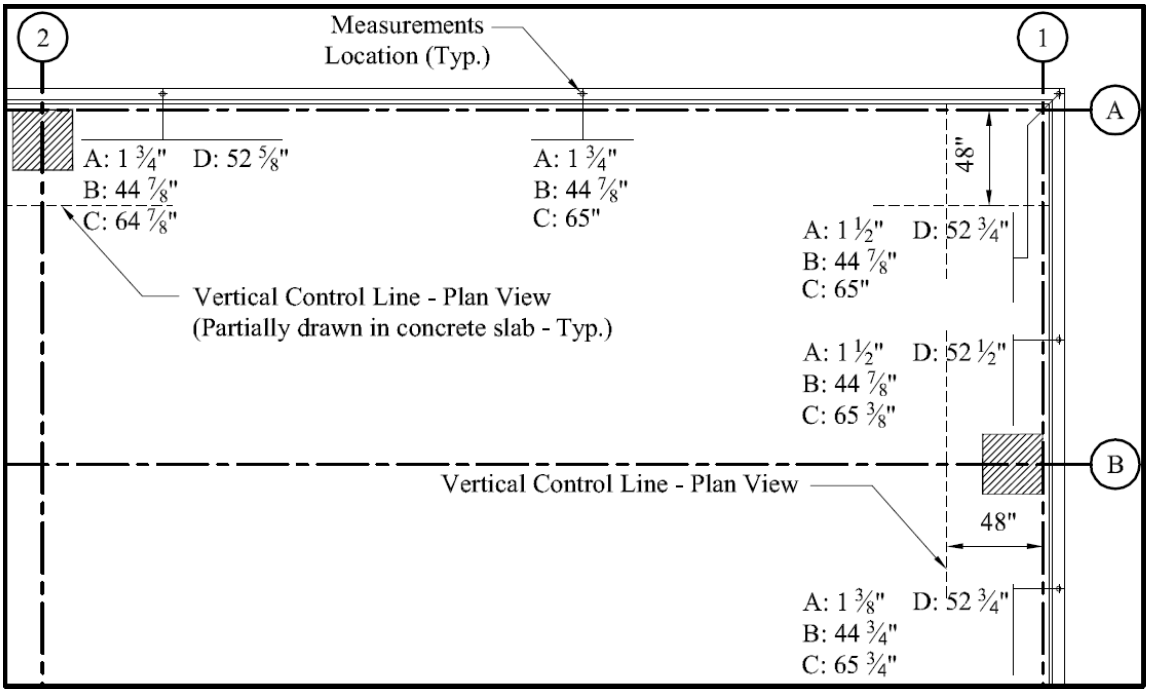

Figure 13. Example of data collected from 8th to 11th floor. Letters A, B, C and D denote de measurements gathered in the field according to the façade section showed in Figure 14. Partial floor plan (Typ.). Adapted from Dietzmann, J. M., Jr. (2014).

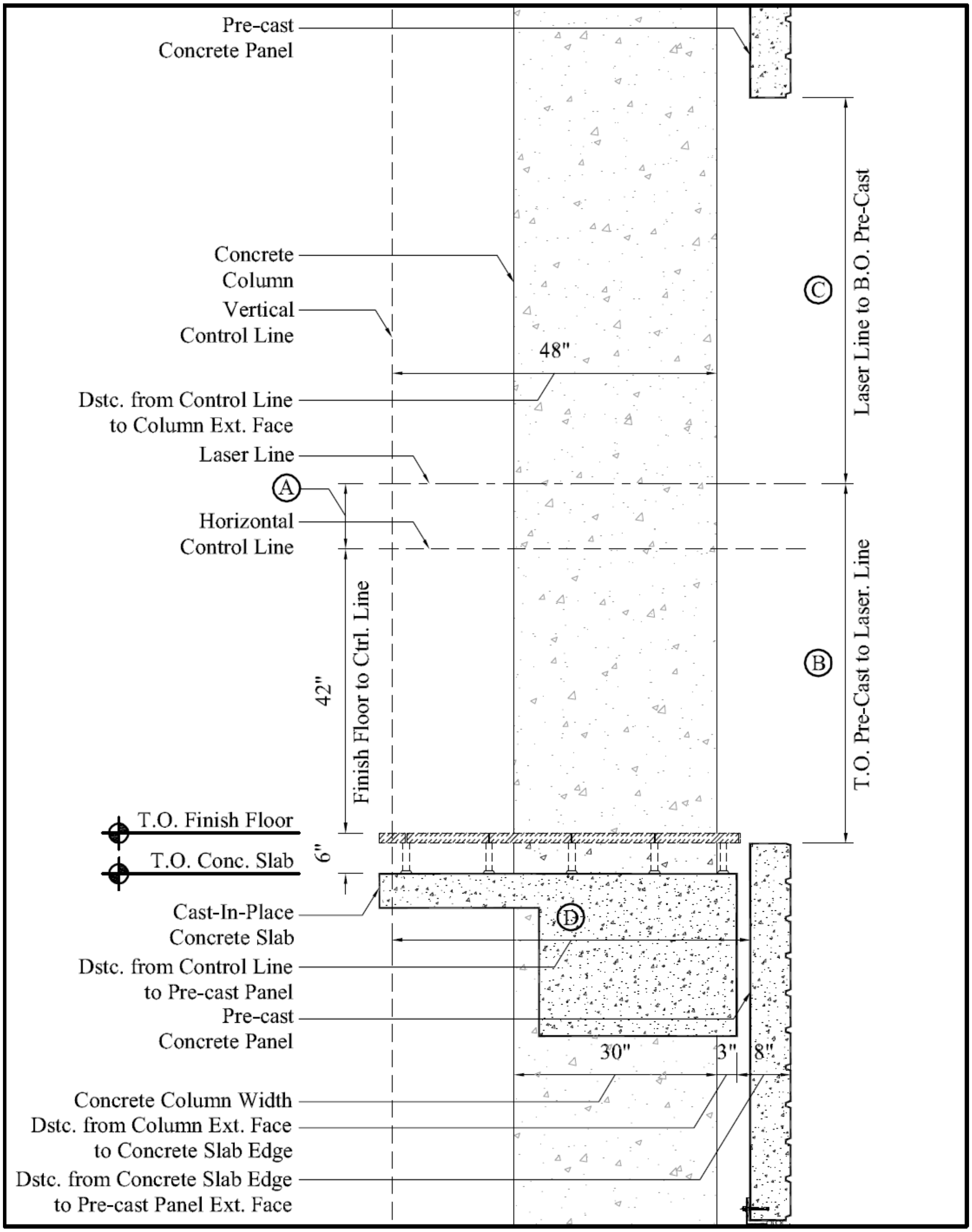

Figure 14. Partial façade section from 8th to the 11th floor without curtain wall. Letters A, B, C and D denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

3.3. Validity and Reliability

Triangulation techniques guaranteed the internal validity of this research study. The data included several sources, comprising field observations, and interviews. The case study corresponds to “a real-life setting” and the measurements correspond to a “representative sample”, as defined by Leedy and Ormrod (2013). The information collected through the semi-structured interviews can be precise and reliable because the interviewer was certain of the data source (the interviewees). Misunderstandings and misinterpretations were reduced because of the casual interaction between the interviewer and the research participants (Leedy and Ormrod 2013).

3.4. Data Analysis

This research analyzed the data collected in the field using the steps described by Leedy and Ormrod (2013):

1) Organization of the details about the case.

   This step involved arranging the data in a logical order. The project diary followed a chronologic order. Field measurements were arranged floor by floor, starting at the same location and following the same direction in each floor plan. And the interviews were organized depending on the hierarchy of the interviewee in the chain of command.

2) Categorization of data.

   It consisted of identifying and categorizing the data into meaningful groups. The content of the project diary was classified by processes. The field measurements were classified by the location of the interface between the curtain wall panels with other building components. And the content of the interviews was classified by recurrent keywords identified in the transcripts.

3) Identification of patterns.

It included the analysis of particular themes in the data, their interpretation, and the examination of specific topics and patterns.

4) Synthesis and generalizations.

This step used the information gathered in previous steps to understand what prevented the curtain wall subcontractors from increasing their productivity during the installation of the curtain wall system. Then, the overall description was examined to draw conclusions and identify whether emerging information and communication technologies can enhance communication between parties in the course of the curtain wall installation.

3.4.1. Interviews analysis

The primary task in the course of the interview analysis was to ascertain common topics in the participants descriptions of their understandings. This study transcribed the interviews and followed the steps suggested by Leedy and Ormrod (2013):

1) Identify statements related to de topic:

This step was achieved by the identification of statements describing how the interviewees were involved and their understanding during the curtain wall installation process.

2) Group statements into “meaningful units” or topics:

This step was implemented by examining the transcripts to identify how the interviewees perceive the adoption of emerging ICT to enhance the communication with other project participants in the course of the curtain wall installation.

3) Seek divergent statements

This step was achieved by examining the transcripts to identify how the interviewees perceive the adoption of emerging ICT to enhance the communication with other project participants in the course of the curtain wall installation.

4) Construct and composite

In this step, the identified viewpoints were used to develop an overall description of their experiences and opinions about the curtain wall installation process. Then, the overall description was examined to see what does hinder curtain wall professional from using ICT.

3.4.2. Project diary analysis

This research used a diary to describe the number of workers, their actions and time installing the curtain wall system to establish the efficiency of the crew installing the curtain wall system. The data collected in the field was chronologically organized, and records detailed descriptions and the time required to perform certain processes.

The diary also included pictures to illustrate and explain the nature of the tolerance conflicts between cladding systems. These pictures were important when interviewing the field supervisor of the curtain wall subcontractor because they reminded the interviewees about the processes, challenges, and decisions made executing the curtain wall installation.

3.4.3. Field measurements analysis

The construction documents and The Glazing Manual published by the Glass Association of North America were the reference documents used to determine the level of tolerance accuracy achieved by the subcontractors installing the cladding components. According to the aforementioned manual and Ballast (2007), erection tolerances for aluminum curtain wall installation should not be more than 1/8-inches. As a consequence, this study used a tolerance range between minus (-) 1/8-inch and 1/8-inch, and only the processed data that lay within the range was considered to be within the acceptable tolerance. The results are subject to further analysis in this research.

The curtain wall system of this case study was partially installed because the project was under construction. Collected data included clean openings ready for curtain wall installation and curtain wall panels already installed. The data also comprised measurements of the interface with other cladding systems (precast panels).

The variables considered when measuring tolerance discrepancies in floors with installed curtain walls were: A) Distance from existing horizontal control line to the bottom of curtain wall panel; B) Distance from top of precast panel to bottom of curtain wall panel; C) Distance from top of curtain wall panel to bottom of precast panel; D) Distance from control line to precast panel; E) Distance from control line to curtain wall panel; and F) Distance from curtain wall anchor to precast panel (Figure 15, Figure 16 and Figure 17).

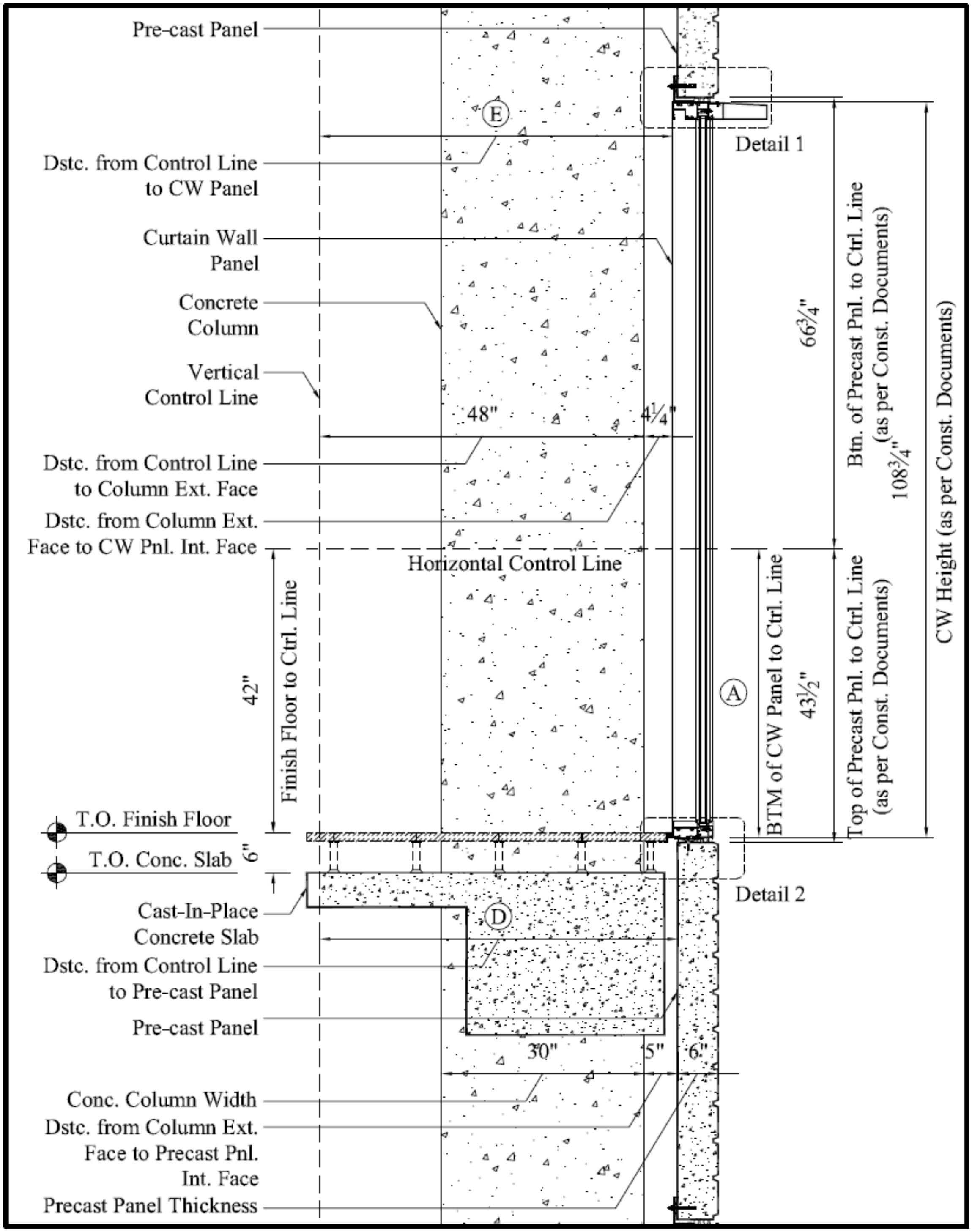

Figure 15. Measurements on partial façade section from 2nd to 7th floor as per construction documents. Letters A, D, and E denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

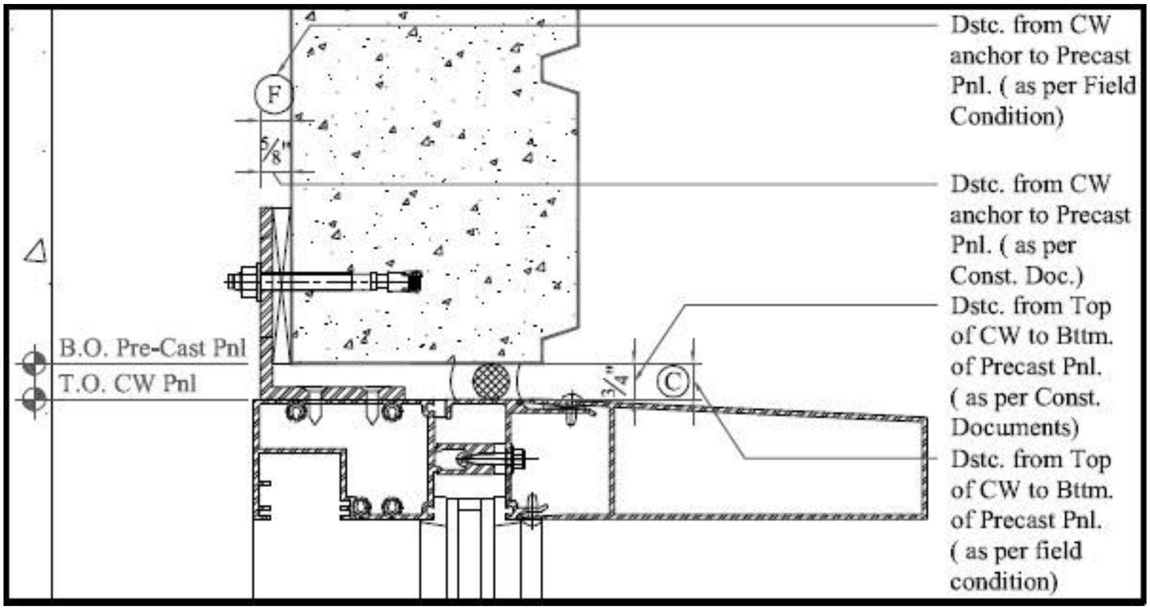

Figure 16. Measurements on detail 1 as per construction documents. Refer to Figure 15. Letter F indicates the distance between the anchor clip and the precast panel, and letter C the distance between the top of the curtain wall and the bottom of the precast panel. Adapted from Diaz, O. (2014).

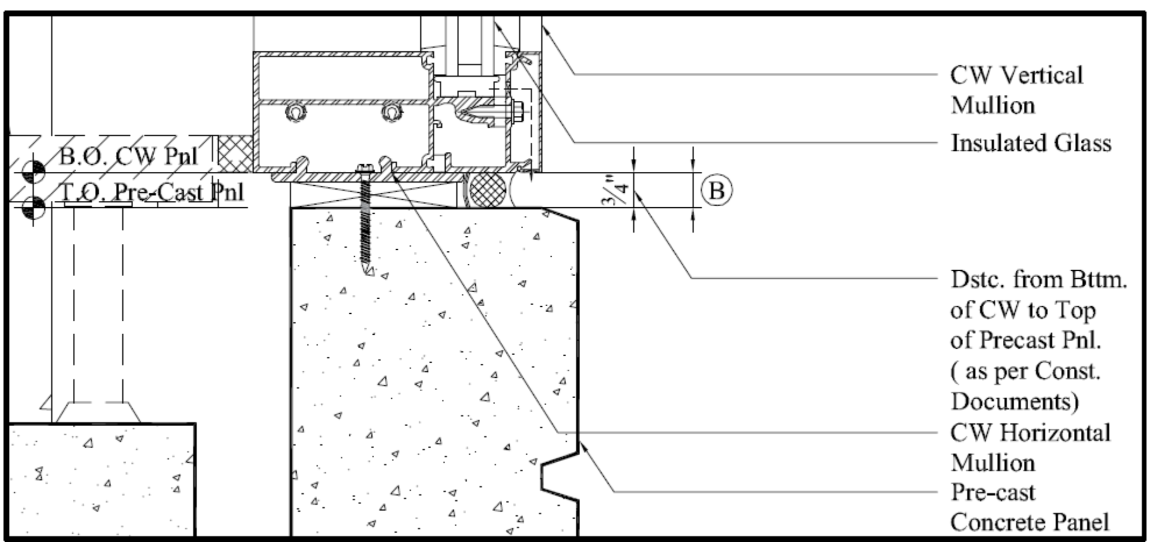

Figure 17. Measurements on detail 2 as per construction documents. Refer to Figure 15. Letter B indicates the distance between the top of the precast panel and the bottom curtain wall system. Adapted from Diaz, O. (2014).

Similarly, where clean openings were ready for curtain wall installation, the variables to be considered were: A) Distance from laser line to horizontal control line; B) Distance from top of precast panel to laser line; C) Distance from laser line to bottom of precast panel; and D) Distance from control line to precast panel (Figure 18).

Table 3 shows the information obtained from the construction documents used in this study to determine the level of accuracy achieved by the subcontractors installing the cladding components.

Table 3 Measurements obtained from construction documents.

Nom.	Location	Measurement
G	Distance from Finish Floor to Horizontal Control Line (Established by General Contractor for subcontractor use)	42-inches
H	Distance from Column Exterior Face to Vertical Control Line (Established by General Contractor for subcontractor use)	48-inches
I	Gap Size for Caulking at Top and Bottom of CW Panel.	¾-inches
J	Distance from curtain wall anchor to precast panel	3/8-inches
K	Curtain Wall Panel Height	108 ¾-inches
L	Opening Height	110 ¼ -inches
M	Distance from Top of Curtain Wall Panel to Control Line. (110 ¼" O.S. – ¾" gap for caulking at top – 42" height of Ctrl. Ln. from F.F. – ¾" gap for caulking at bottom)	66 ¾-inches
N	Distance from Bottom of Curtain Wall Panel to Control Line. (110 ¼" O.S. – 66 ¾" Top of CW Pnl. to Ctrl. Ln.)	43 ½-inches
O	Distance from Vertical Ctrl. Line to CW Panel Int. Face (48" Column Ext. Face to Vertical Ctrl. Ln. + 4 ¼" Column Ext. Face to CW Pnl. Int. Face)	52 ¼-inches
P	Distance from Vertical Ctrl. Ln. to Precast Panel Int. Face (48" Column Ext. Face to Vertical Ctrl. Ln. + 5" Column Ext. Face to Precast Pnl. Int. Face)	53-inches

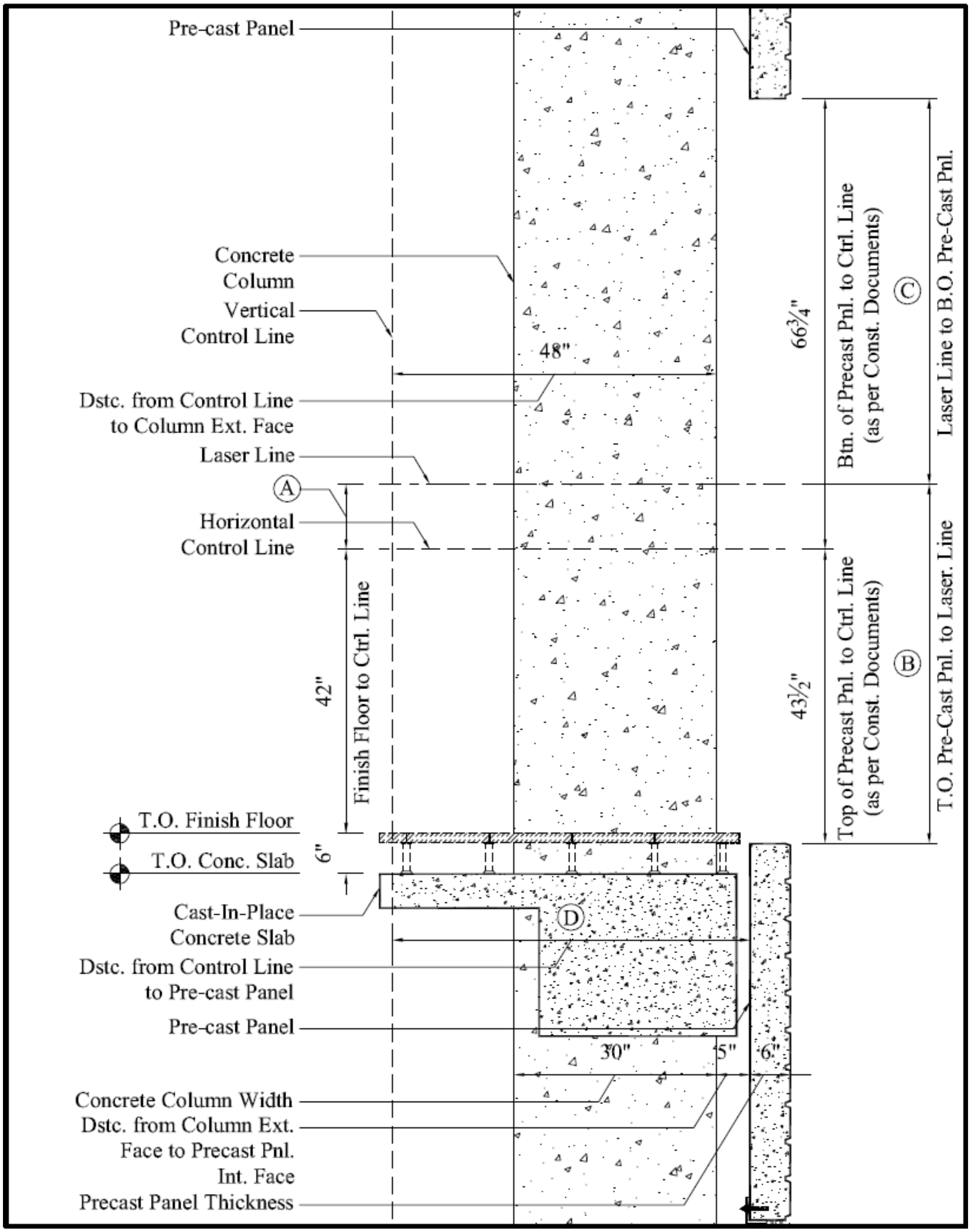

Figure 18. Measurements on partial façade section from 8th to the 11th floor as per construction documents. Letters A, B, C and D denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

On places where the curtain wall panels were installed, this study utilized the nomenclatures and equations showed in Table 4 and Table 5 to calculate the tolerance between the curtain wall panels and other building components.

Table 4 Nomenclature utilized to formulate the equations.

Data Collected in the Field	
Nomenclature	**Location**
A	Distance from existing horizontal control line to the bottom of curtain wall panel.
B	Distance from top of the precast panel to the bottom of curtain wall panel.
C	Distance from top of curtain wall panel to the bottom of the precast panel.
D	Distance from control line to precast panel.
E	Distance from control line to curtain wall panel.
F	Distance from curtain wall anchor to the precast panel.
Data Obtained from Construction Documents	
Nomenclature	**Location**
G	Distance from finish floor to horizontal control line
H	Distance from column exterior face to vertical control line
I	Gap size for caulking at top and bottom of curtain wall panel
J	Distance from curtain wall anchor to precast panel
K	Distance from curtain wall panel height
L	Opening height
M	Distance from top of curtain wall panel to control line.
N	Distance from bottom of curtain wall panel to control line.
O	Distance from vertical control line to curtain wall panel interior face
P	Distance from vertical control line to precast panel interior face

Table 5 Equations utilized to identify tolerance between the curtain wall and other building components.

Tolerance Discrepancy Location	**Equation**
At Bottom of Curtain Wall	*N-(B-A)*
At Top of Curtain Wall	*M-((K-A)+C)*
Control Line to Concrete Panel	*(P-D)*
Control Line to Curtain Wall	*(O-E)*
Curtain Wall Anchor to Precast Panel	*(F-I)*

On clean openings where the curtain wall panels were not installed, this study used the equations showed in Table 6 (refer to Figure 18 and Table 4 for reference and nomenclature). The measurements collected in the field and the tolerance results are included in Appendix C.

Table 6 Equations utilized to calculate tolerance conflicts on clean openings.

Tolerance Discrepancy Location	Equation
At Bottom of the Opening	*(A+B)-N*
At Top of the Opening	*M-(C-A)*
Control Line to Concrete Panel	*(P-D)*

The results of the tolerances between the curtain wall panels and other building components were analyzed graphically through range plots created utilizing a MATLAB script (Figure 19). These plots establish the data lying between -1/8-inch and 1/8-inch, and above or below this range. The information extracted from the plots allowed this study to determine the amount and type of tolerance conflicts that may influence the efficiency of the crew during the curtain wall installation.

```
%% Check range
allListing = dir('Data Thesis/');
listing = allListing(3:11);
% strings = {listing.name}'; %
% floor_nums = [];
% for i = 1:length(strings)
%     floors_nums(i) = str2num(strings{i}(1:2));
% end
% [strings_sort, ixs_strings_sort] = sort();
% listing_sort = listings(ixs_strings_sort);

%%
close all;clc;
titles_2_7 = {'Bottom CW', 'Top CW', 'Ctrl Ln to Conc. Pnl', 'Ctrl Ln to CW', 'CW
Anchor to Conc. Pnl'};
titles_8_11 = {'At Btm of Opening', 'At Top of Opening', 'Ctrl Ln to Conc. Pnl'};
for j = 1:length(listing)
    if str2num(listing(j).name(1:2))>=2 && str2num(listing(j).name(1:2)) <=7
        titles = titles_2_7;
    else
        titles = titles_8_11;
    end
    ndFloor = xlsread(['Data Thesis/',listing(j).name]);
    plotFigure(ndFloor, titles, listing, j);
end

%%
close all;clc;
titles_2_7_total = {'Bottom CW', 'Top CW', 'Ctrl Ln to Conc. Pnl', 'Ctrl Ln to CW',
'CW Anchor to Conc. Pnl'};
titles_8_11_total = {'At Btm of Opening', 'At Top of Opening', 'Ctrl Ln to Conc.
Pnl'};
floorName = {'2-7 Floor', '8-11 Floor'};
cnt = 1;
ndFloor_2_7 = [];ndFloor_8_11 = [];
for j = 1:length(listing)
    ndFloor = xlsread(['Data Thesis/',listing(j).name]);
    if str2num(listing(j).name(1:2))>=2 && str2num(listing(j).name(1:2)) <=7
        ndFloor_2_7 = [ndFloor_2_7;ndFloor];
    else
        ndFloor_8_11 = [ndFloor_8_11;ndFloor];
    end
end

ndFloors{1} = ndFloor_2_7; ndFloors{2} = ndFloor_8_11;
% totalTiels = {'2-7', '8-11'};

for j = 1:length(ndFloors)
    ndFloor = ndFloors{j};
    if j == 1
        titles = titles_2_7;
    else
        titles = titles_8_11;
    end

    plotFigure_total(ndFloor, titles, floorName{j}, j)

end
```

Figure 19. MATLAB script to determine tolerance accuracy between cladding components in the construction site (Huang 2015).

3.4. Limitations

The limitations of this research were:

- Time and resources constrained this research to a single case study. Therefore, it is hard to generalize the findings of a single project to all the glass and glazing industry.
- This study did not interview other cladding subcontractors. The access to their knowledge may help understand the challenges faced during their product installation, which later may affect the efficiency during the curtain wall installation.
- This research did not interview the project superintendent. The person that held this position was no longer available. His knowledge about issues between the cladding trades and the decisions made to address the problems would have been valuable for the research.
- The project location, construction schedule, and coordination with the general contractor, and the curtain wall subcontractor did not facilitate the researcher to record daily the project diary.

4. RESEARCH RESULTS

The following section comprises four subsections. The first one describes the curtain wall system employed in the case study and its advantages during the installation process. The second one describes and analyzes the data collected through the project diary. It presents actions, types of activities and number of workers involved in the curtain wall installation, to identify the level of productivity reached executing each action. The third one analyzes field data about the tolerances between the curtain wall and other cladding components collected in the field. With this data, the author determines the frequency of occurrences that may cause inefficiencies during the curtain wall installation. The fourth and last section analyzes interviews done to the participants of the case study.

4.1. Analysis of the Curtain Wall System

The construction documents of the project required the installation of a stick aluminum-framed curtain wall Kawneer 1600 Wall System 5®, (Figure 20, left). However, the curtain wall subcontractor suggested the use of a custom-made unitized curtain wall system based on the standard Kawneer 1600 SS® unitized system (Figure 20, right). The curtain wall factory modified certain system components to facilitate the installation of that custom-made curtain wall. According to the subcontractor, the use of the custom-made curtain wall system decreases the installation time, because the anchors come attached to the curtain wall panels (Figure 21). In contrast, the standard unitized system requires the installation of the each anchor in the construction site before each curtain wall panel is mounted (Figure 22). Another advantage, indicated by the subcontractor was that the custom-made curtain wall uses a sill rail instead of the “T” anchors used in the standard system. The sill rail acts as an anchor at the bottom of the curtain wall panels; each rail can receive several curtain wall panels, and the crew can install up to 24-lineal foot of sill rail in a row (Figure 23). In contrast, the “T” anchors of the standard system must be installed individually, at the top and bottom of the system, and must be installed where each vertical mullion is located (Figure 24).

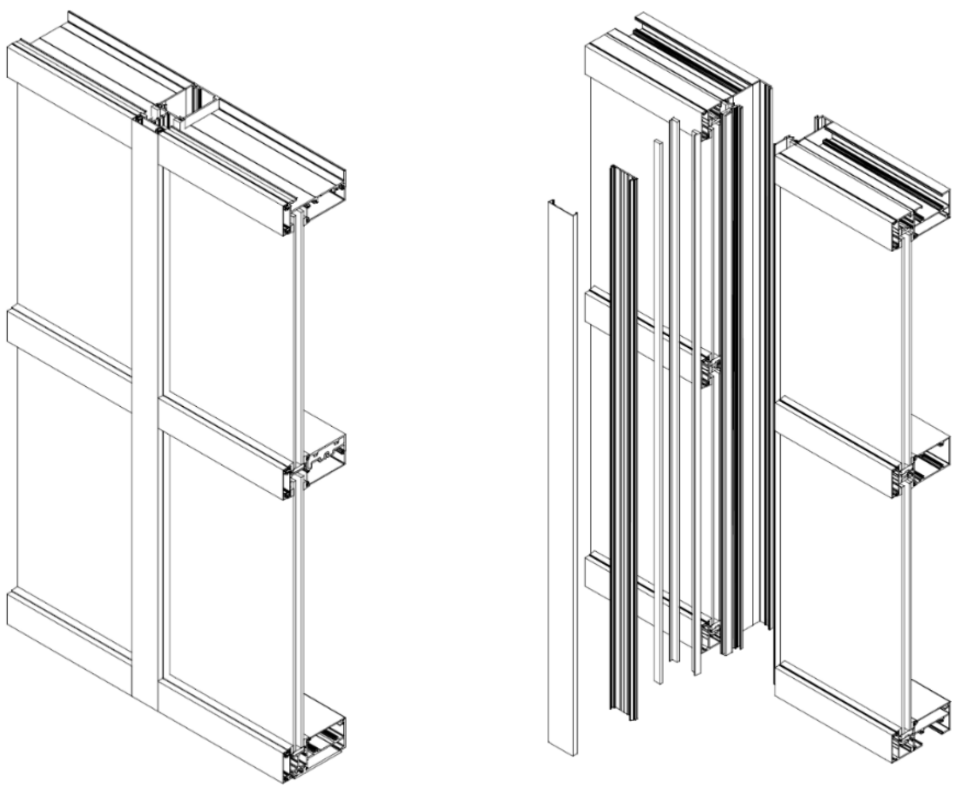

Figure 20. Kawneer 1600 Wall System 5 Type “A” Assembly (left) and Kawneer 1600 SS unitized curtain wall system (right). Adapted from “1600 System™5” Kawneer Inc. (2013), and “1600 SS Curtain Wall”, Kawneer Inc. (2014).

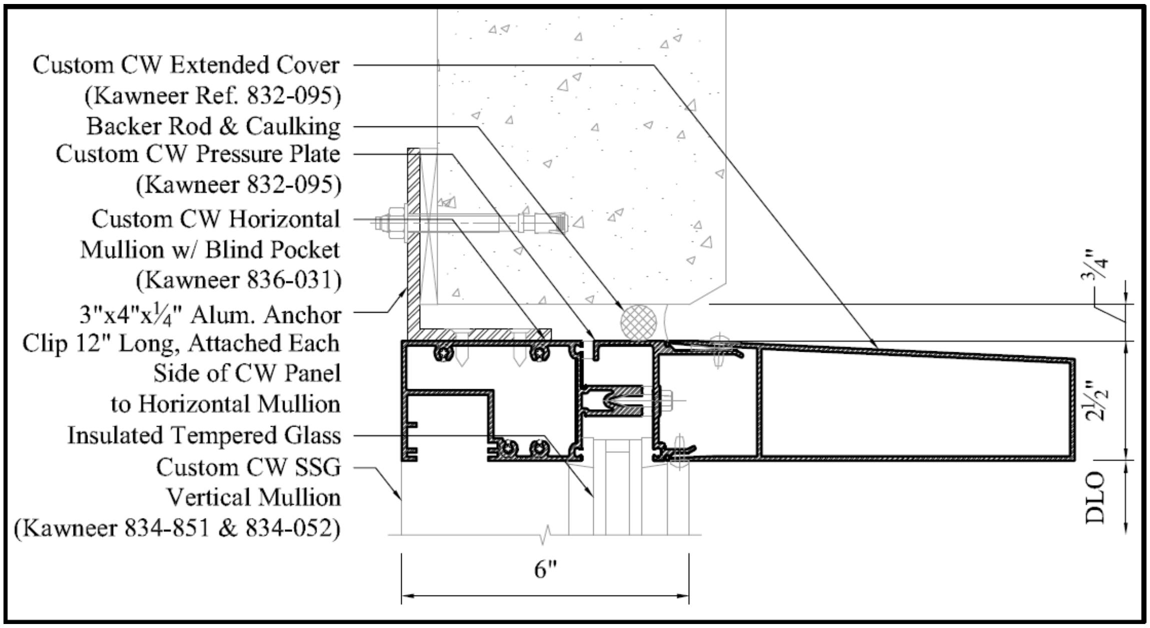

Figure 21. Custom-made head mullion detail on floors 2th to 12th. Adapted from Diaz, O. (2014).

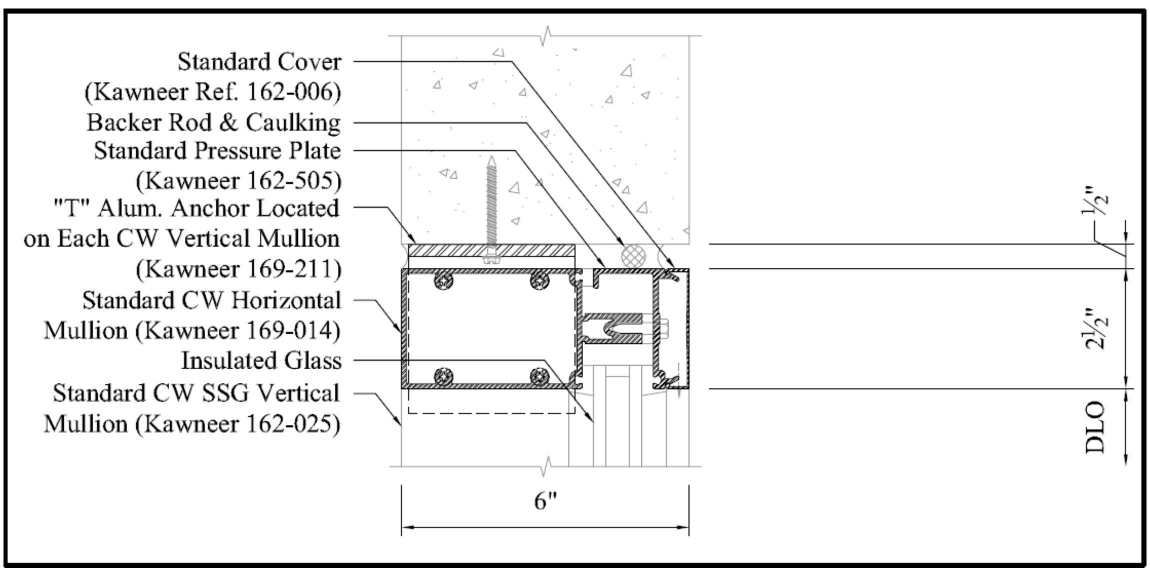

Figure 22. Standard head mullion detail, Kawneer 1600 SS curtain wall system. Adapted from Kawneer Inc. (2014).

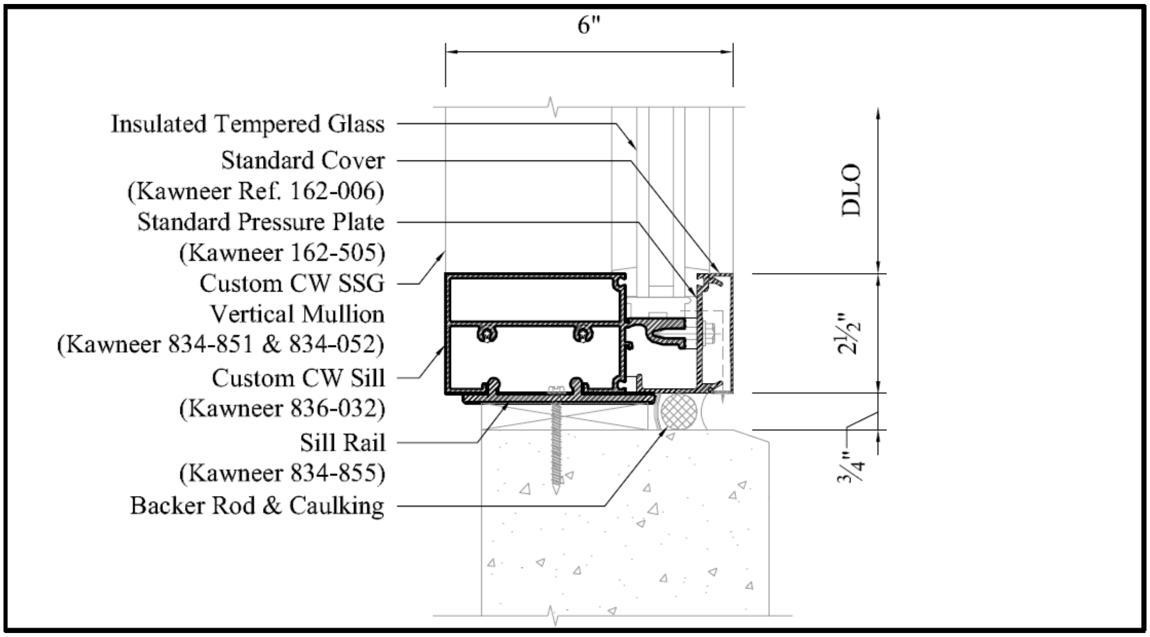

Figure 23. Typical **c**ustom-made sill mullion detail, curtain wall system on floors 1st to 12th. Adapted from Diaz, O. (2014).

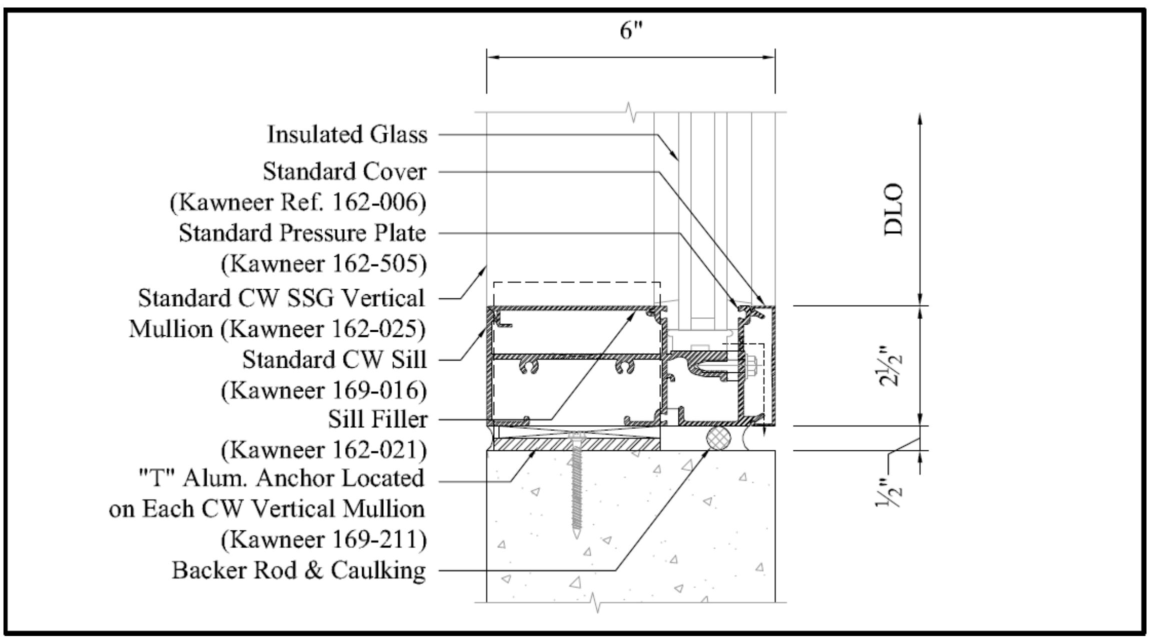

Figure 24. Standard sill mullion detail of Kawneer 1600 SS curtain wall system. Adapted from Kawneer Inc. (2014).

The vertical mullion of the custom-made system consisted of two vertical pieces (halves) joined with adjustable interlocks (Figure 25), whereas in the standard system the mullions are made of fixed interlocks that rigidly secure the entire system (Figure 26). The advantage of the adjustable interlocks was that the crew could maneuver the joint width between the two vertical pieces of the mullion and adjust the total length of the curtain wall system in a single plane. In contrast, the mullions of the standard system demand accurate opening measurements before fabricating the curtain wall frames. Finally, the custom-made system has an aluminum cap used only for aesthetic purposes; that can be moved or removed (Figure 27. Custom SSG vertical mullion detail with custom aluminum cap (above) and without aluminum cap (below). Adapted from Diaz, O. (2014).. In contrast, in the standard system the aluminum cap is fixed, and it cannot be modified in the field.

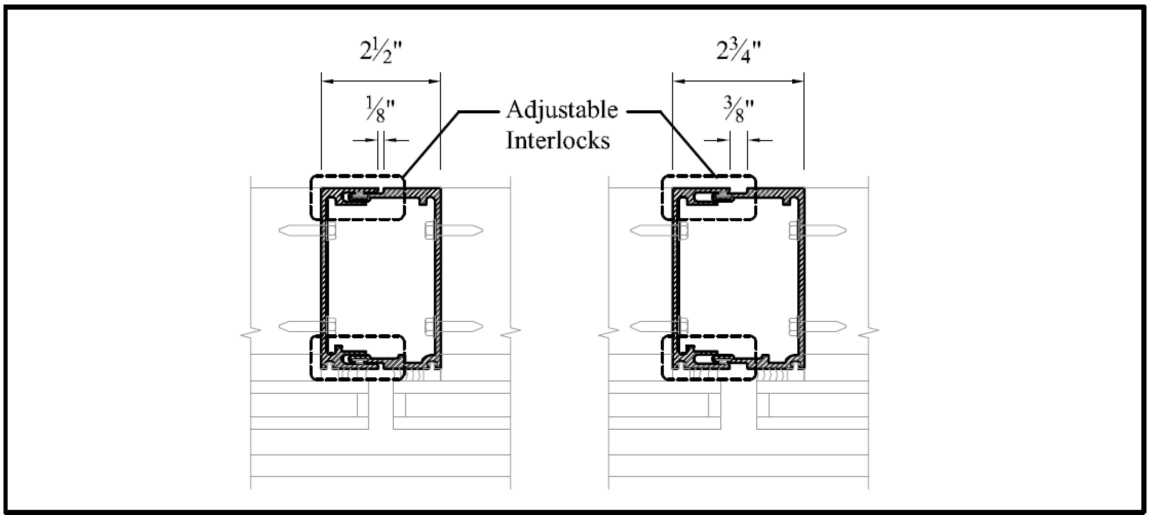

Figure 25. Custom-made SSG vertical mullion detail. Adapted from Diaz, O. (2014).

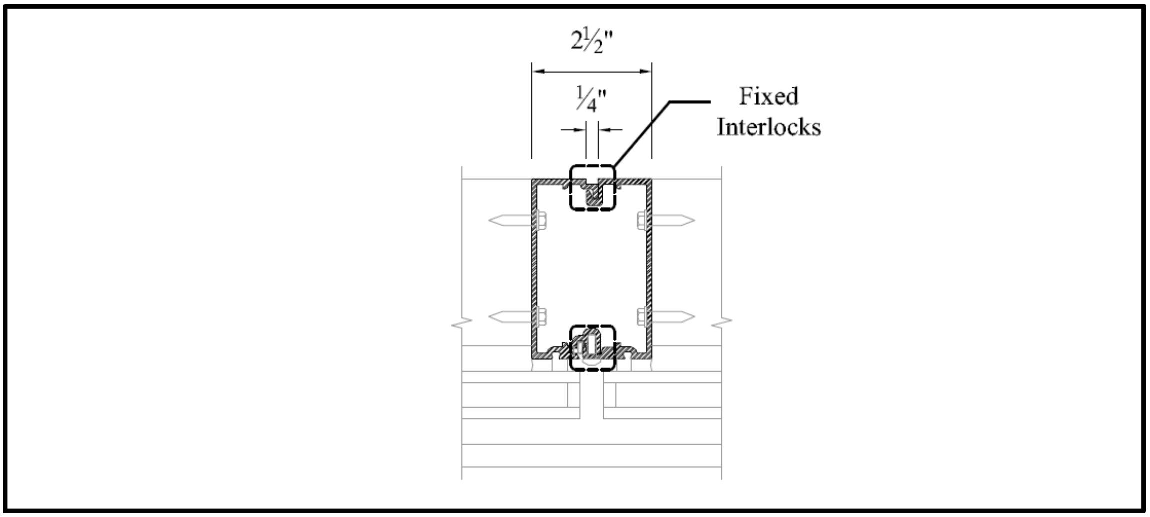

Figure 26. Standard SSG vertical mullion detail, Kawneer 1600 SS curtain wall system. Adapted from Kawneer Inc. (2014)

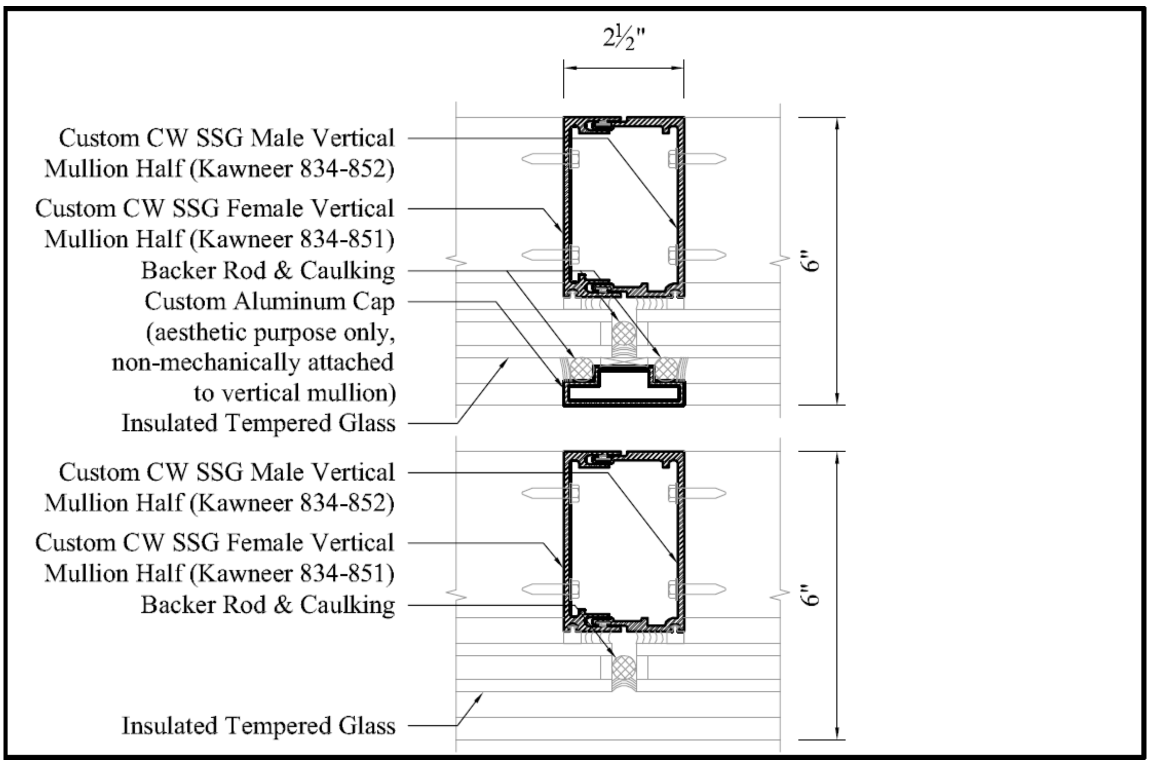

Figure 27. Custom SSG vertical mullion detail with custom aluminum cap (above) and without aluminum cap (below). Adapted from Diaz, O. (2014).

4.2. Analysis of the Processes Observed in the Construction Site

This study monitored the curtain wall installation process of a project in The Woodlands (Texas) and collected observations in a project diary. The curtain wall crew had already installed 215 out of 1418 curtain wall panels and their corresponding sill rails by the time this research started (Table 7). The diary described activities and recorded the amount of time and number of workers involved in the activities (Appendix B).

Table 7 Detailed work done by the curtain wall crew before this research started.

Dates	Total # of working hours	# of CW panels installed*	# of workers	Avg. amount of CW panels installed per worker in one hour
7/28/14 to 8/4/14 before 9:23 am	42.5 h.	2nd floor: 96 3rd floor: 68 4th floor: 51 **Total: 215**	7	0.72

*Refer to APPENDIX B for a detailed description of the activity.

4.2.1. Analysis of the curtain wall sill rail installation

The sill rail installation was an independent activity executed by two workers before the curtain wall panels were positioned. The purpose of the sill rail was to facilitate the curtain wall installation process, by providing a leveled and aligned surface on top of the precast. The process involves two phases: installation and leveling.

During the first phase, the sill rail was placed on top of the precast panels. Then the distance from the control lines was adjusted, and then the sill rail was fastened to the precast panels (Figure 28). In the second phase, the sill rail height was leveled along the precast panel, and the opening height was verified for compliance with the curtain wall panel size. This procedure was performed by the curtain wall field supervisor with the assistance of one worker. The field supervisor was responsible for this process due to his experience and decision-making abilities. Table 8 and Table 9 summarize the observations related to the sill rail and leveling respectively.

Figure 28. Sill rail installation process. Image: Andres Martinez.

Table 8 Observations about the installation of the curtain wall sill rails

Dates	Total # of working hours	Length of CW sill rail installed*	# of workers	Avg. lenght of CW sill rail installed per worker in one hour (in lf.)
8/9/14	0.21 h. (12.76 min)	One (1) piece of 24 lf.	2	57
8/11/14	0.27 h. (16.25 min)	Two (2) pieces of 12 lf.	2	44.5
8/11/14	0.18 h. (11 min)	One (1) piece of 24 lf.	2	66
Average amount of sill rails installed per worker in one hour				55.83

*Refer to APPENDIX B for a detailed description of the activities.

Table 9 Observation about the leveling of the curtain wall sill rail

Date	Total # of working hours	Length of CW sill rail leveled*	# of workers	Avg. lenght of CW sill rail leveled per worker in one hour (in lf.)
8/18/14	1.5 h. (90 min)	713 lf.	4	118.8

*Refer to APPENDIX B for a detailed description of the activities.

The results showed that on average one worker can install 44.5 lf. to 66 lf. CW curtain wall sill rails in one hour (Table 8) shows a fluctuation between 44.5 lf. and 66 lf. of curtain wall sill rail installed per worker in one hour. The difference between the lowest and the highest performance was explained in terms of the number of sill rail pieces to be installed. The data shows that connecting a single 24-foot piece of sill rail required more time than installing two 12-foot pieces of sill rail in a corner. A cause for these results was the worker's need to walk a longer distance to align, drill and fasten the sill rail.

4.2.2. Analysis of the curtain wall panel installation

Once the sill rail was installed, the curtain wall panels were mounted on top and fastened to the precast above the panel. The custom-made system used in this project allowed the installation of consecutive curtain wall panels. This study recorded the time spent to mobilize the panels from dolly carts to their final location and fasten the panels to the adjacent cladding system. The data collected in this research included the date of the observations, the time used performing the installation, the number of curtain wall panels installed, the number of workers involved in the activity, and the average amount of curtain wall panels installed per worker in one hour (Table 10 and Figure 29).

Table 10 Record of curtain wall panels installed in a lapse of time.

Observation #	**Date / Time**	**Total # of working hours**	**# of CW panels installed***	**# of workers**	**Avg. amount of CW panels installed per worker in one hour**
1	8/4/14 from 9:23 am to 11:30 am	1.62 h. (97 min)	2nd floor:10	4	1.54
2	8/4/14 from 9:23 am to 12:58 pm	3.58 h. (215 min)	3rd floor: 12	3	1.11

*Refer to APPENDIX B for a detailed description of the activities.

Table 10 Continued

Observation #	Date / Time	Total # of working hours	# of CW panels installed*	# of workers	Avg. amount of CW panels installed per worker in one hour
3	8/4/14 from 12:58 am to 1:54 pm	0.93 h. (56 min)	3rd floor: 4	3	1.43
4	8/5/14 from 7:00 am to 8:41 am	1.18 h. (71 min)	3rd floor: 18	7	2.17
5	8/6/14 from 9:00 am to 2:30 pm	5.5 h. (330 min)	4th floor: 22	4	1.0
6	8/7/14 from 6:30 am to 10:10 am	2.67 h. (160 min)	4th floor: 16	4	1.49
7	8/13/14 from 7:30 am to 10:17 am	2.78 h. (167 min)	2nd floor: 15	4	1.34
8	8/13/14 from 10:17 am to 11:30 am	1.22 h. (73 min)	2nd floor: 4	4	0.81
9	8/13/14 from 12:30 am to 3:00 pm	2.5 h. (150 min)	2nd floor: 10	3	1.33
10	8/13/14 from 7:00 am to 11:00 am	3.5 h. (210 min)	5th floor: 9	2	1.28
11	8/13/14 from 12:30 am to 3:30 pm	3.0 h. (180 min)	2nd floor: 10	3	1.11
12	8/14/14 from 7:30 am to 9:15 am	1.75 h. (105 min)	5th floor: 7	4	1.0

*Refer to APPENDIX B for a detailed description of the activities.

Table 10 Continued

Observation #	Date /Time	Total # of working hours	# of CW panels installed*	# of workers	Avg. amount of CW panels installed per worker in one hour
13	8/14/14 from 9:30 am to 10:15 am	0.75 h. (45 min)	5th floor: 5	4	1.66
14	8/15/14 from 7:30 am to 3:00 pm	7 h. (420 min)	5th floor: 43	4	1.53
15	8/18/14 from 8:42 am to 10:44 am	2.0 h. (122 min)	3rd floor: 10	4	1.25
16	8/18/14 from 10:44 am to 3:00 pm	3.76 h. (226 min)	3rd floor: 18	4	1.19
17	8/20/14 from 7:00 am to 3:00 pm	7.5 h. (450 min)	7th floor: 23	4	0.76
18	8/20/14 from 7:00 am to 3:00 pm	7.5 h. (450 min)	7th floor: 28	4	0.93
19	8/21/14 from 7:00 am to 3:00 pm	7.5 h. (450 min)	7th floor: 23	4	0.76
20	8/25/14 from 8:30 am to 5:00 pm	7.5 h. (450 min)	7th floor: 42	4	1.4
21	8/28/14 from 6:00 am to 2:30 pm	7.5 h. (450 min)	6th floor: 60	8	1.0
Average amount of CW panels installed per worker in one hour					**1.24**

*Refer to APPENDIX B for a detailed description of the activities.

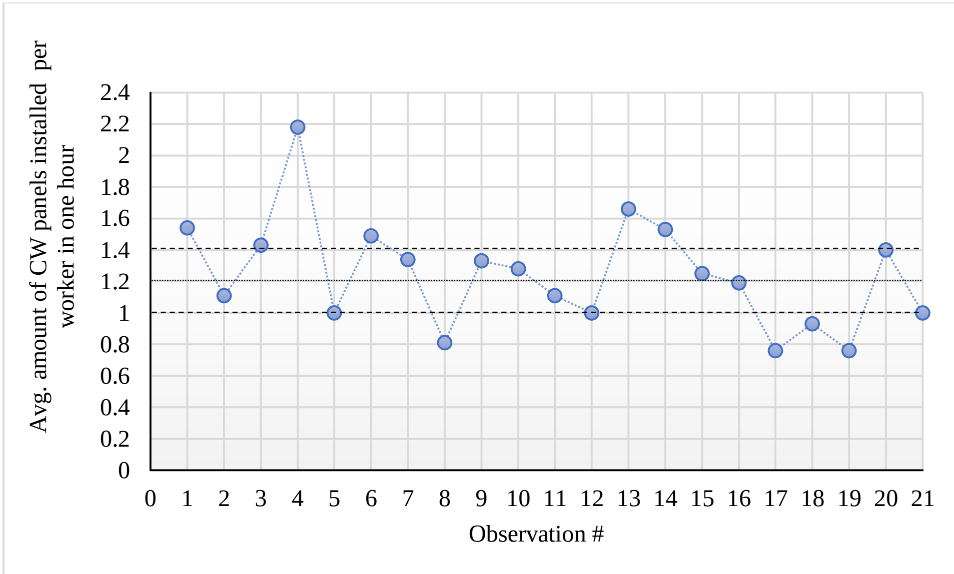

Figure 29. Worker's performance installing curtain wall panels.

The data indicated that one worker installed a minimum of 0.76 curtain wall panels, and a maximum of 2.17 curtain wall panels per hour; most likely (52% of the time) the worker installed between 1.0 and 1.4 curtain wall panels per hour. On average, the worker installed 1.24 panels per hour. The worker reached the minimum performance expectations when the curtain wall subcontractor could not fix clashes with the precast panels, and the curtain wall subcontractor mobilized the crew to a different floor. The worker reached the maximum performance expectations when the clashes did not occur, and the sequencing established by the general contractor did not interfere with the curtain wall subcontractor schedule. And the worker reached the average performance when the curtain wall subcontractor found and addressed immediately the clashes with the precast panels, and the general contractor's sequencing did not interfere with the curtain wall subcontractor schedule.

Figure 30 shows the 2nd, 3rd and 4th floors of the North façade. The curtain wall crew had already installed 147 panels. Figure 31 was taken 16 working days later, and the crew had installed 338 additional panels. Extrapolating the data obtained from Table 8, the crew may install 338 curtain wall panels in 8.5 workdays. However, they spent 16 workdays installing the same number of panels, which represents an 88% increase in time. The sequence installing the curtain wall panels presented in Figure 30 and Figure 31 shows interruptions in the workflow. Clashes between the curtain wall system with the precast panels forced the precast subcontractor to fix the problem. The sequence established by the general contractor interfered with the curtain wall subcontractor schedule. As a result, the curtain wall subcontractor mobilized the crew to other floors while the precast subcontractor corrected the problems.

Figure 30. The progress of the curtain wall installation at the North façade. Image: Andres Martinez, dated July 28, 2014.

Figure 31. The progress of the curtain wall installation at the South façade. Image: Andres Martinez, dated August 18, 2014.

4.2.3. Analysis of issues observed in the construction site

Several pictures recorded the tolerance issues between the curtain wall and other building components. Figure 32 shows a typical section during the process of the curtain wall installation over the sill rail. The curtain walls must be properly leveled to achieve their maximum performance and structural response to the environmental factors. The accuracy needed during the sill rail leveling process revealed tolerance issues between cladding systems. Figure 33 and Figure 34 show the tolerance problems between the precast and the curtain wall panels at the bottom of the curtain wall system. Figure 33 shows two sets of shims leveling the rail. Shim set 1 contained four 1/4-inch shims (black), which adds up to 1-inch total. However, the adjacent shim set 2 was made with three 1/4-

inch shims (black) and one 1/8-inch shim (red). The shim height decreased 1/8-inch in 8-inch length between sets. Figure 34 shows the sill rail detail where the last curtain wall panel installed lies. In this location, the curtain wall installers used two 1/4-inch shims (black) below the same rail (shim set 3). Therefore, the height between shim set 1 and shim set 3 decreased 1/2-inch on a 20-foot length between sets.

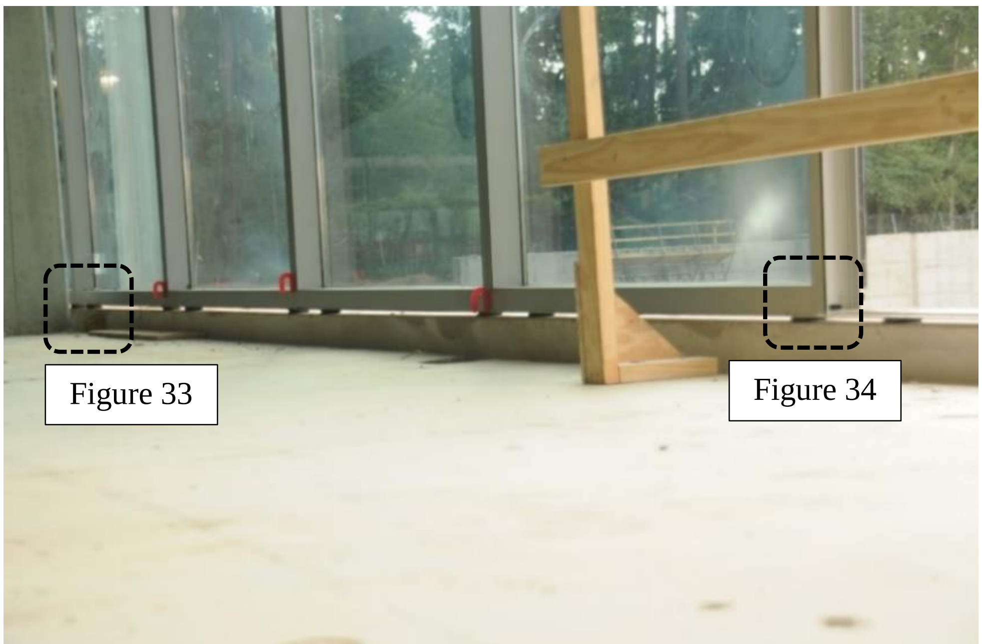

Figure 32. Curtain wall panels mounted over sill rail. Image: Andres Martinez.

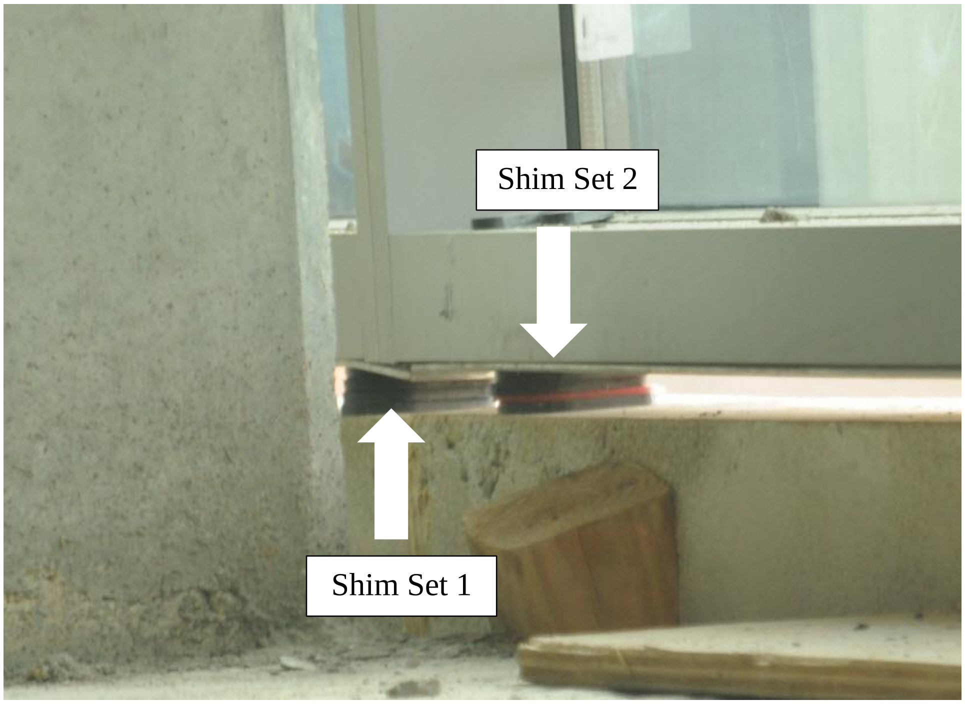

Figure 33. Detail of sill rail leveled with shim sets 1 and 2. Image: Andres Martinez.

Figure 34. Detail of sill rail leveled with shim set 3. Image: Andres Martinez.

The interface between cladding components at the top of the curtain wall panels revealed different tolerance issues. The challenges faced by the curtain wall installers range from variable join sizes to clashes between components. Figure 35 shows variable join sizes along the cladding interface on a 15-foot span. This tolerance issue did not constitute a problem during the curtain wall installation. However, the caulking process affected the efficiency of the crew. They invested more time and materials sealing the joints properly to prevent water leaks. Wide joins required thicker backer rods to fill the gap and additional silicone to caulk the joints. Narrow gaps did not allow the use of backer rods to isolate the interior from the exterior, and the caulking might not have reached the required depth to prevent future leaks.

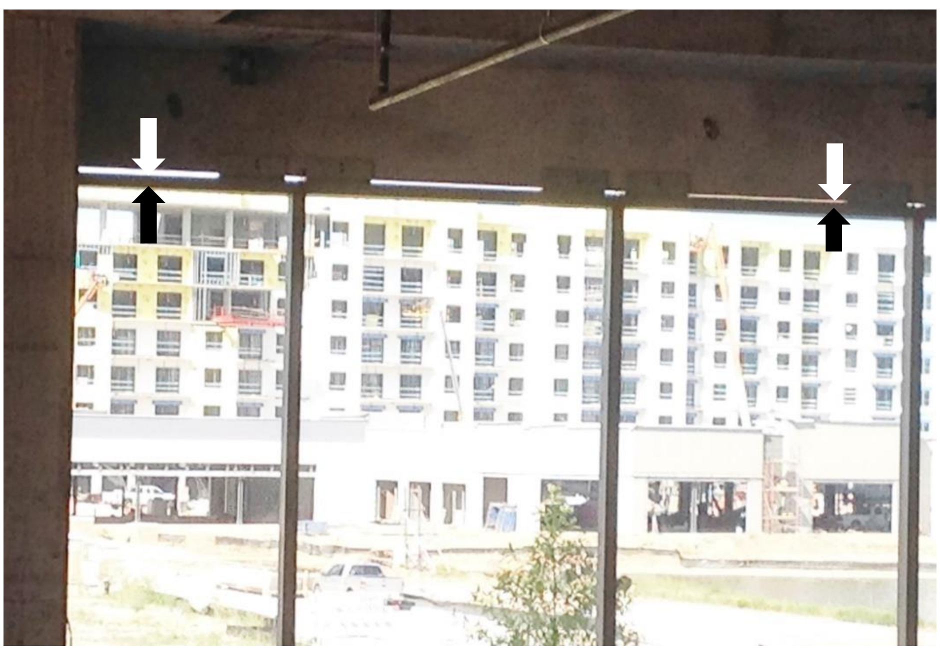

Figure 35. Tolerance issues at the top of the curtain wall panels. East façade, interior view. Image: Andres Martinez.

Figure 36 shows an inadequate leveling of the precast panel (P1) that collided with the curtain wall panel, and the join height between the curtain wall and precast panel (P2) was higher that the adjacent panel. The join between the precast panel (P1) and the curtain wall panel, decreased enough to impede the proper installation of the curtain wall panel. To avoid schedule delays, the curtain wall subcontractor removed one anchor clip to fit the panel into the opening. Then, the panel was screwed through the blind pocket as showed in Figure 37. The curtain wall supervisor stated that the structural integrity of the curtain wall the system was not compromised, because the panel was interlocked along the vertical sides with the adjacent panels (refer to Figure 26). Only one anchor was removed, and it was replaced in the same location with a screw. However, the caulking was difficult at this location because the silicone might not have filled the gap between cladding systems properly.

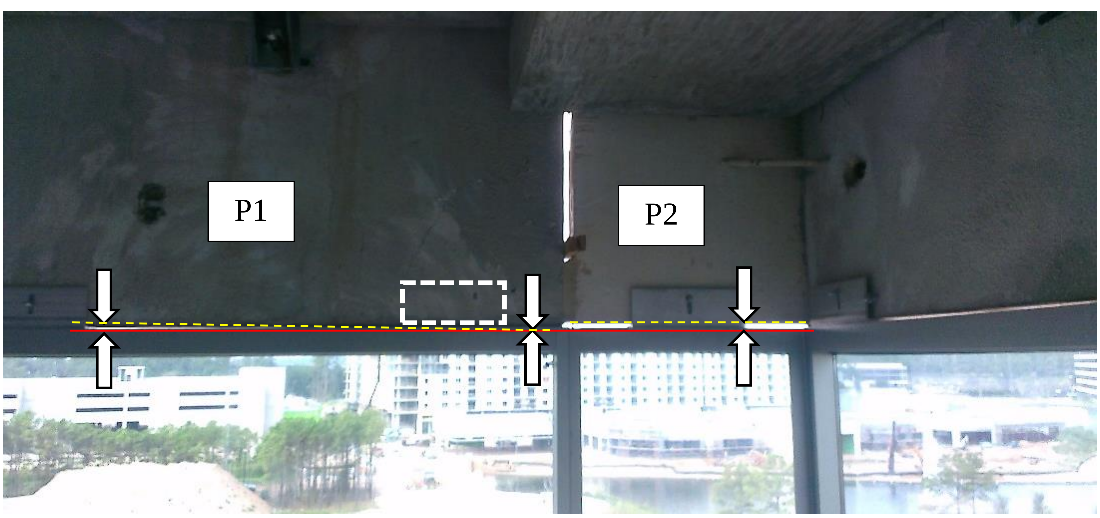

Figure 36. Collision between a precast panel (P1) and curtain wall panel. Anchor clip removed. Image: Andres Martinez.

Figure 37. Detail of curtain wall panel screwed through the blind pocket. Image: Andres Martinez.

This study also found a displacement between the center lines of the curtain wall vertical mullions and the center lines of the precast panel joins across the building (Figure 38). The general contractor setup control lines over each concrete slab to provide a guide for all trades to execute their work. The general contractor also drew the center line of the concrete slab in each direction on every floor. The precast and curtain wall subcontractors had to use this reference to align the centerlines of their cladding systems with the center line of the concrete slabs (Figure 39).

Figure 38. Misalignment of the curtain wall and precast panel joins. Exterior view of at the North façade (left), interior view at West façade (right). Image: Andres Martinez.

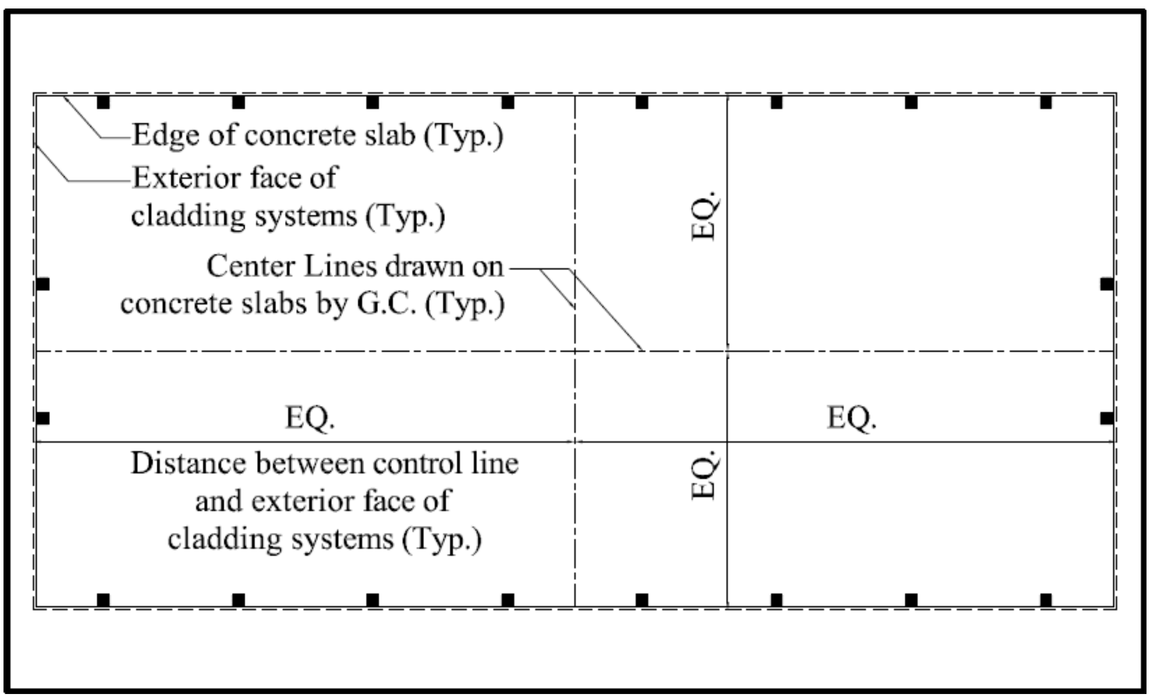

Figure 39. Adequate alignment of the cladding system with centerlines of concrete slabs. Adapted from Adapted from Dietzmann, J. M., Jr. (2014).

Field observations and measurements indicated a displacement between the center line of the concrete slabs and the center line of the precast panels in both directions (Figure 40). Similarly, this study found that the installation of the precast panels always began in the corners of the building, following the schedule of the towel cable car crane. The installation sequence followed by the precast subcontractor resulted in misalignments with the concrete slab center lines. As a result, the curtain wall subcontractor had to displace the curtain wall aluminum caps (Figure 41) to correct the alignment with the precast panel joins. The displacement of some aluminum caps can be observed from the interior of the building (Figure 42).

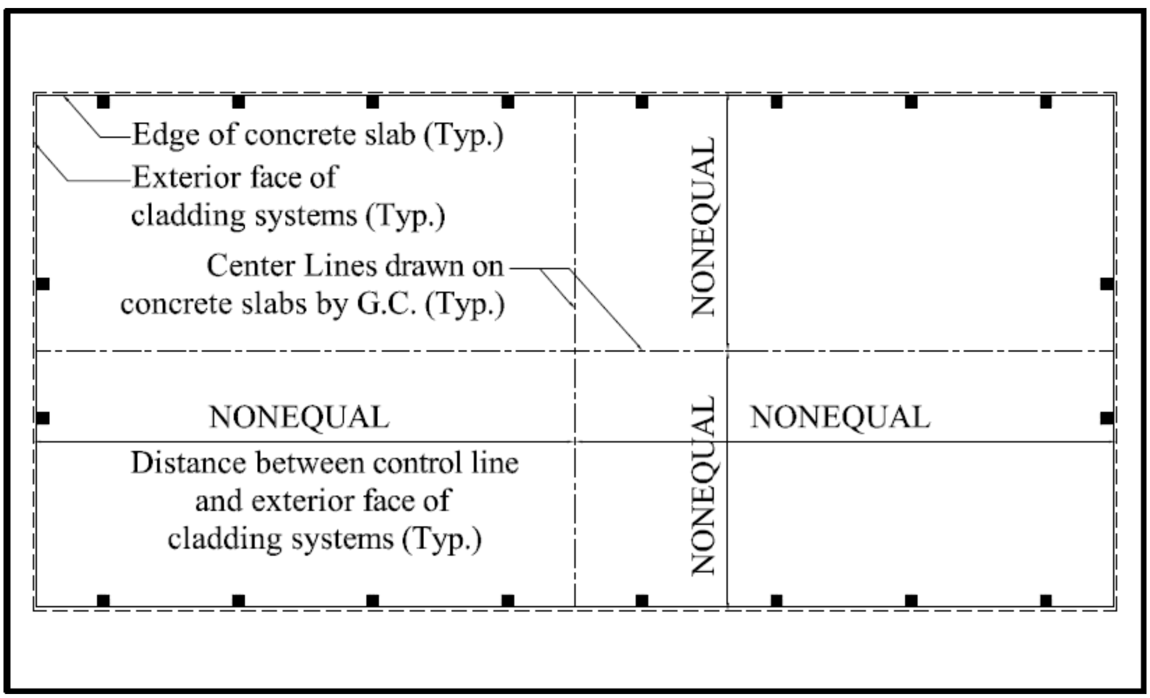

Figure 40. Alignment of the cladding system as per field observations and measurements. Adapted from Dietzmann, J. M., Jr. (2014).

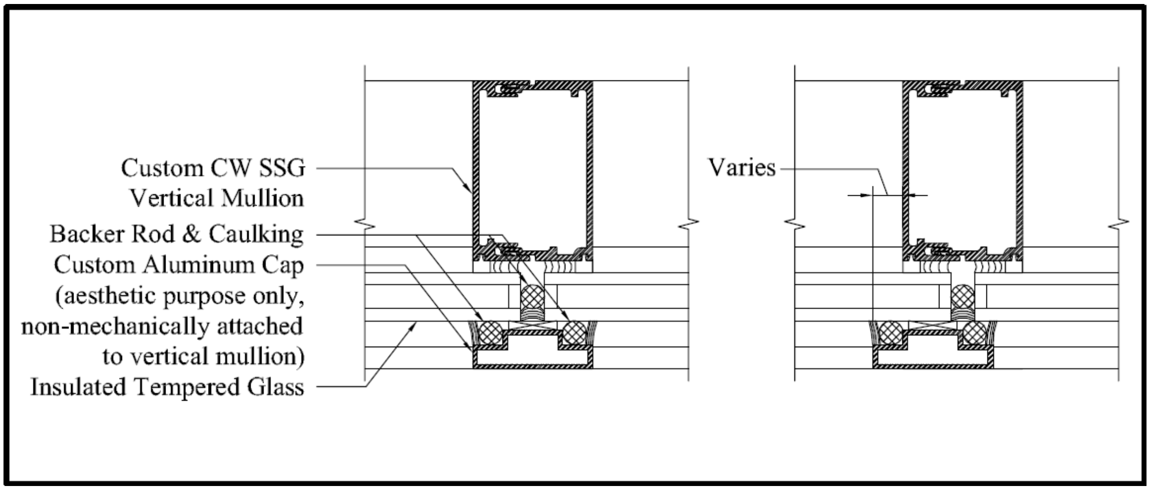

Figure 41. Custom vertical mullion detail with custom aluminum cap aligned (left) and misaligned (right). Adapted from Diaz, O. (2014).

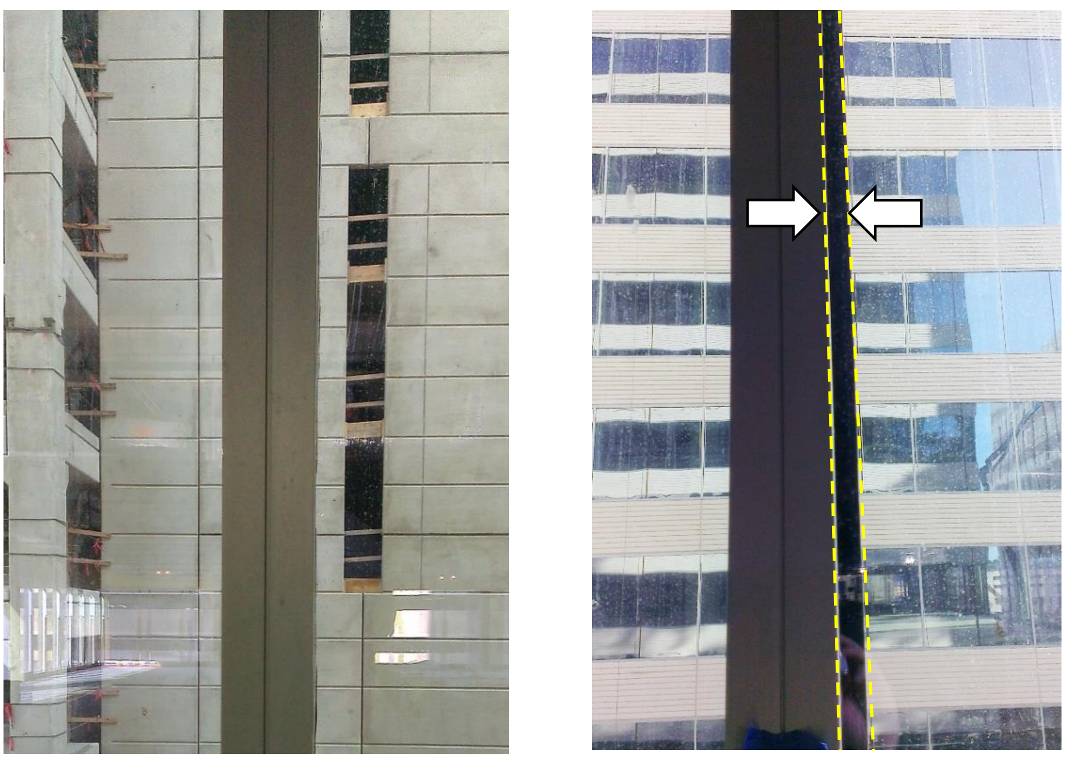

Figure 42. Interior view of vertical mullion with aluminum cap aligned at the South façade (left), and misaligned aluminum cap at East façade (right). Image: Andres Martinez.

4.3. Analysis of the Measurements Collected in the Construction Site

This study analyzed the data resulting from the measurements collected from different locations in the building, including:

A) Locations where the curtain wall panels had been installed.

The measurements were collected from the bottom and top of curtain wall panel, from the control line to the precast panels, from the control line to the curtain wall panel, and from the curtain wall anchor to the precast panels.

B) Locations ready for curtain wall installation (clean openings).

The measurements were collected from the bottom and top of the opening and from the control line to the precast panels.

Range plots generated with a MATLAB script were used to analyze the measurements of the tolerances (see Appendix C and following sections). The level of tolerance accuracy that subcontractors should achieve when installing the cladding components ranges between -1/8 inch to 1/8″ inch (see Section 3.4.3). That range was represented by red dashed lines in the sample index plots. The data was also represented as column charts, where the "y" axis shows the percentage of data that lie below, within and above the accepted range.

4.3.1. Tolerance results at the bottom of curtain wall panel

The results showed in Figure 43 show the tolerance measurements and percentages between cladding components at the lower part of the curtain wall panel from 2nd to the 7th floor. The plot shows that approximately 55 % of the data lie within the acceptable tolerances. However, nearly 20% lie below the accepted range and 25% above it. This represented additional work and therefore time for the crew, as they have to level the sill rail with plastic shims.

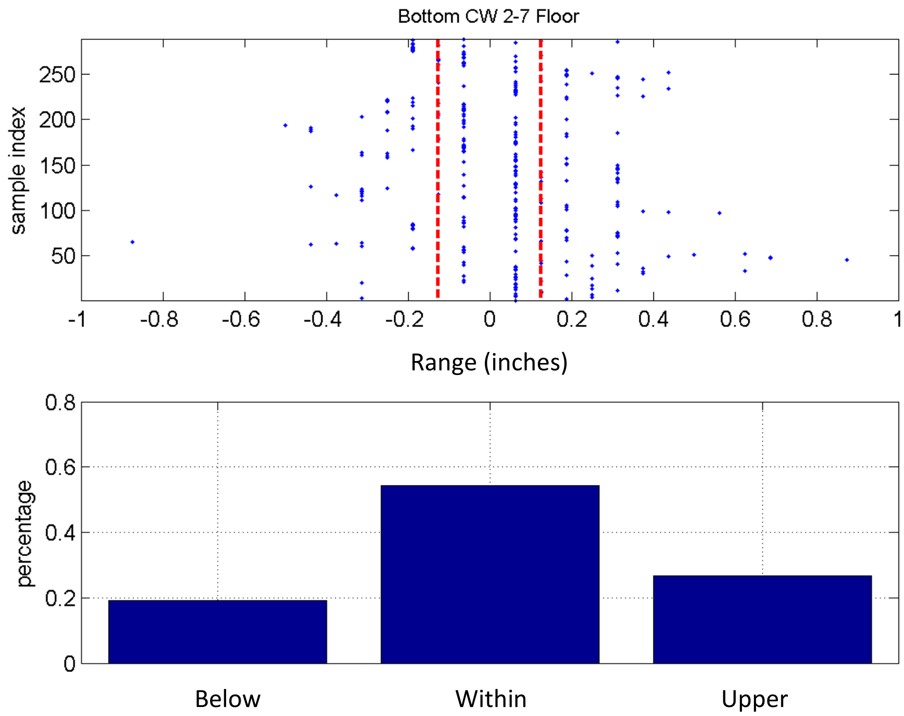

Figure 43. Plot of tolerance results at the bottom of the curtain wall panel, from 2nd to 7th floor.

4.3.2. Tolerance results at top of curtain wall panel

Figure 44 shows that for the 2nd to 7th floor 57% of the data lies above the accepted range. 35% of the data lies below and 8% above the acceptable tolerances. This represented additional work and therefore time for the crew, as they have to adjust the curtain wall panels to fit them into the openings.

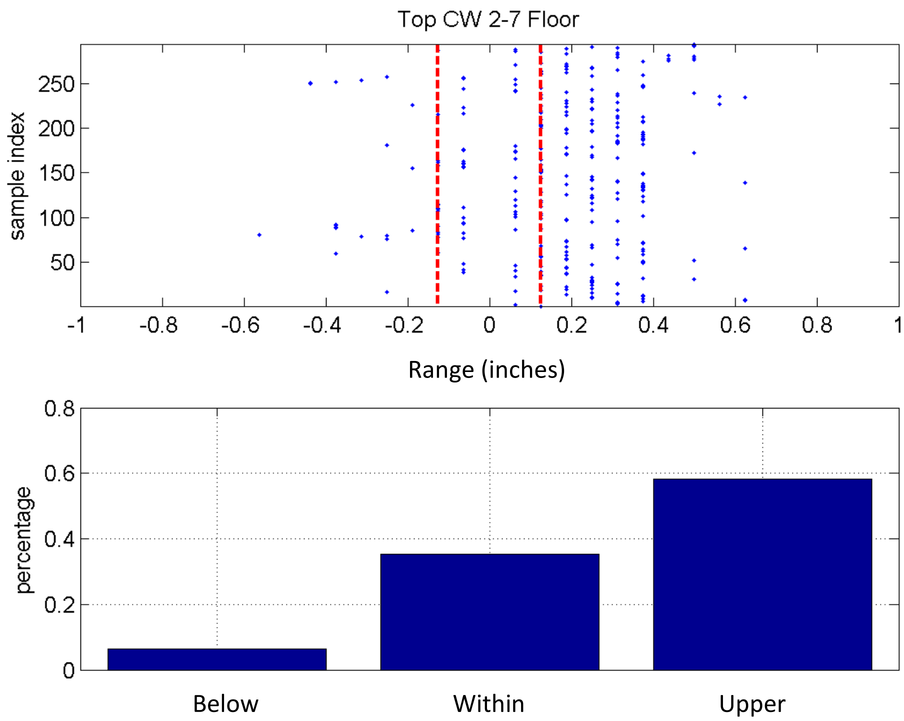

Figure 44. Plot of tolerance results at the bottom of the curtain wall panel, from 2nd to 7th floor.

4.3.3. Tolerance results from control line to the concrete (precast) panel.

Figure 45 shows the accuracy reached by the precast subcontractor installing the panels, using the control lines parallel to the edges of the concrete slabs. The plot shows that approximately 50%of the precast panels were installed farther from the control line and the concrete slab. Nearly 35% of the precast panels were installed within the acceptable range and 15% below it. This resulted in additional work for the crew locating the sill rails on top of the precast panels properly

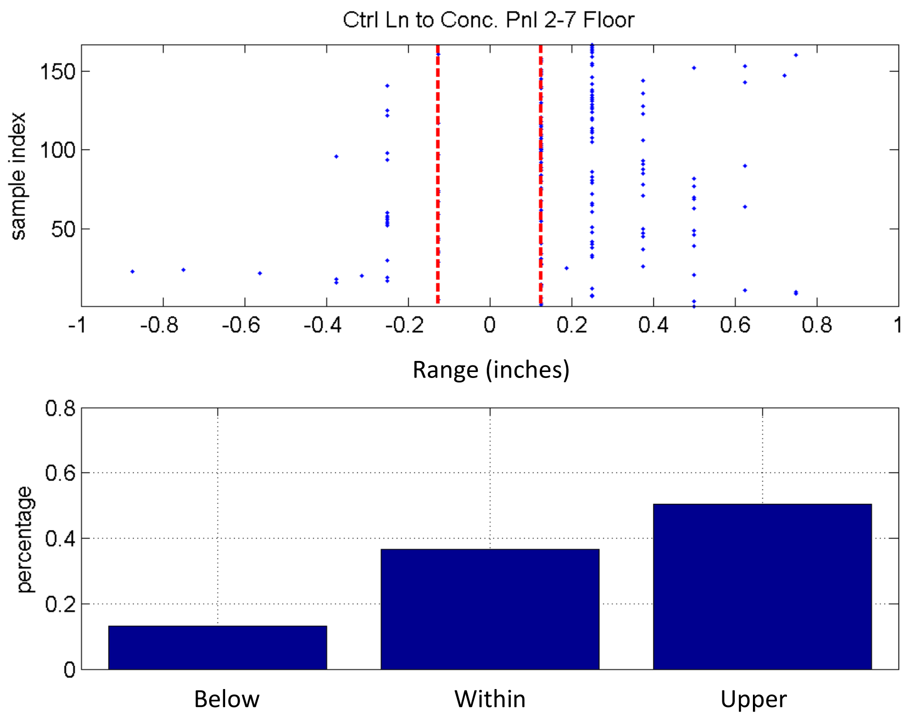

Figure 45. Plot of tolerance results from control line to precast panels, from 2nd to 7th floor.

4.3.4. Tolerance results from control line to the curtain wall panel

Figure 46 reveals the level of accuracy reached by the curtain wall subcontractor installing the curtain wall panels using the control lines parallel to the edges of the concrete slabs. The plot shows that 50% of the panels were within the acceptable tolerance range (most data lies in the upper boundary of the range). Approximately 47% of the panels were installed below the range, and 3% were installed above the range. Those percentages contrast with the results shown on Figure 45, where the highest percentage lies above the acceptable tolerance range. These results showed that the location of the precast panels from the control line was farther than the curtain wall panels required, and the crew adjusted the distance of the curtain wall panels to the control line to correct the problem.

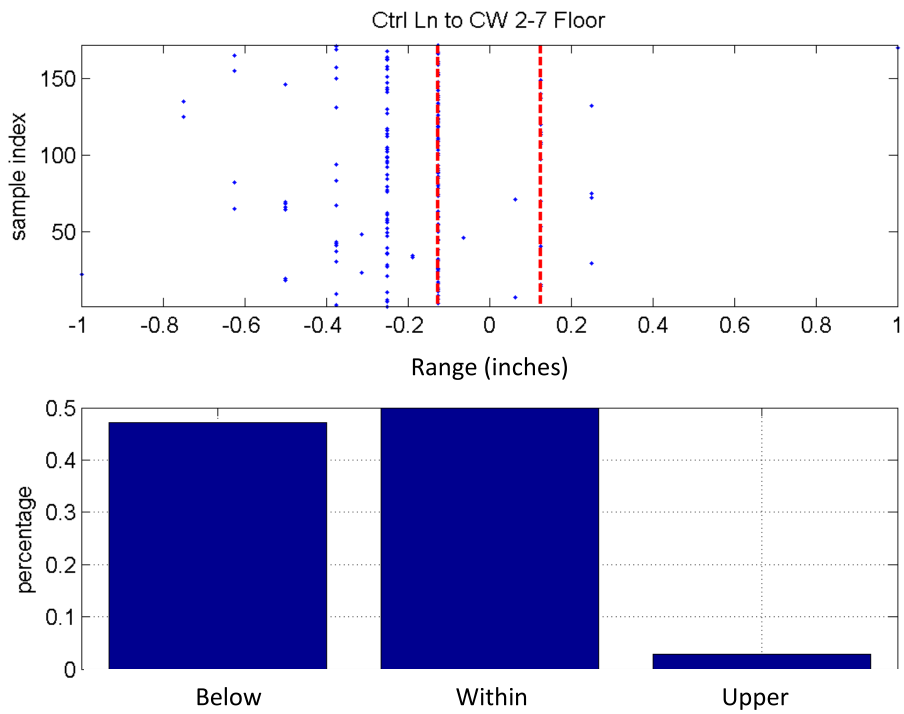

Figure 46. Plot of tolerance results from control line to curtain wall panels, from 2nd to 7th floor.

4.3.5. Tolerance results from the curtain wall anchor to the concrete panel.

Figure 47 shows the accuracy reached by the precast subcontractor installing the precast panels utilizing the control lines, prior to the curtain wall system installation. Approximately 50% of the curtain wall anchor clips were fastened farther from the precast panels. This resulted in over shimmed anchors to fasten the curtain wall panel properly. Approximately 47% of the anchor clips reached the acceptable tolerance range. Nearly 3% were below the range. This resulted in modifications to the curtain wall panel. The anchor clips were removed, and the curtain wall panel was fastened through the blind pocket.

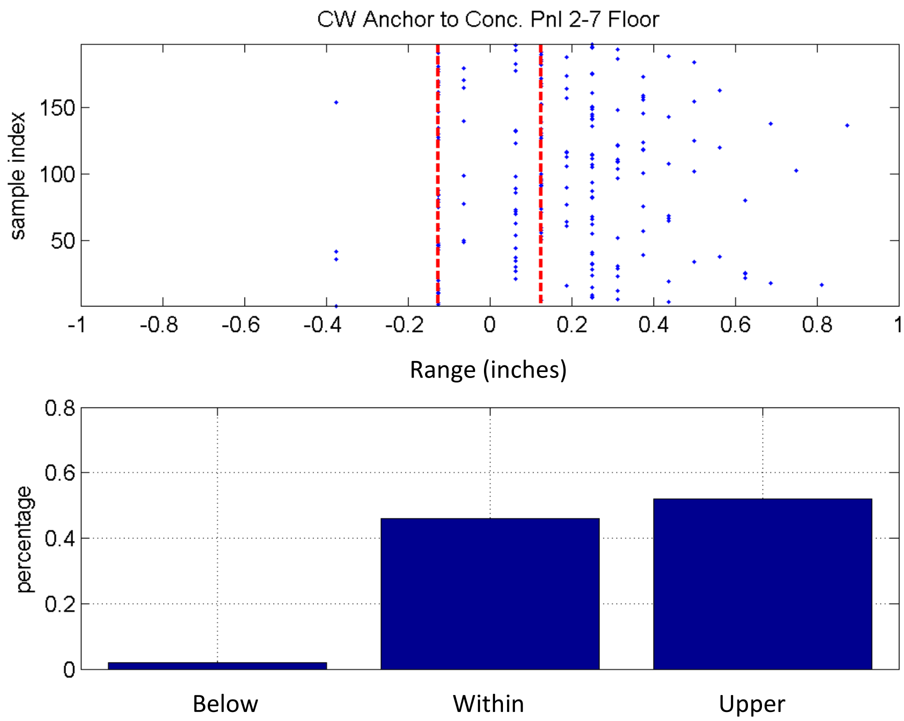

Figure 47. Plot of tolerance results from curtain wall anchor to precast panels, from 2nd to 7th floor.

4.3.6. Tolerance results at bottom of the clean openings

The results showed in Figure 48 indicate the accuracy reached by the precast subcontractor at the top of the precast panels where the curtain wall panels rested. Approximately 50% of the data lie between the acceptable tolerance ranges. 32% of the data lie above the range. This resulted in clashes between the sill rail and the precast panels. 28% of the data lie below the acceptable tolerances. This represented additional work and therefore time for the crew as they have to seal bigger gaps between cladding components.

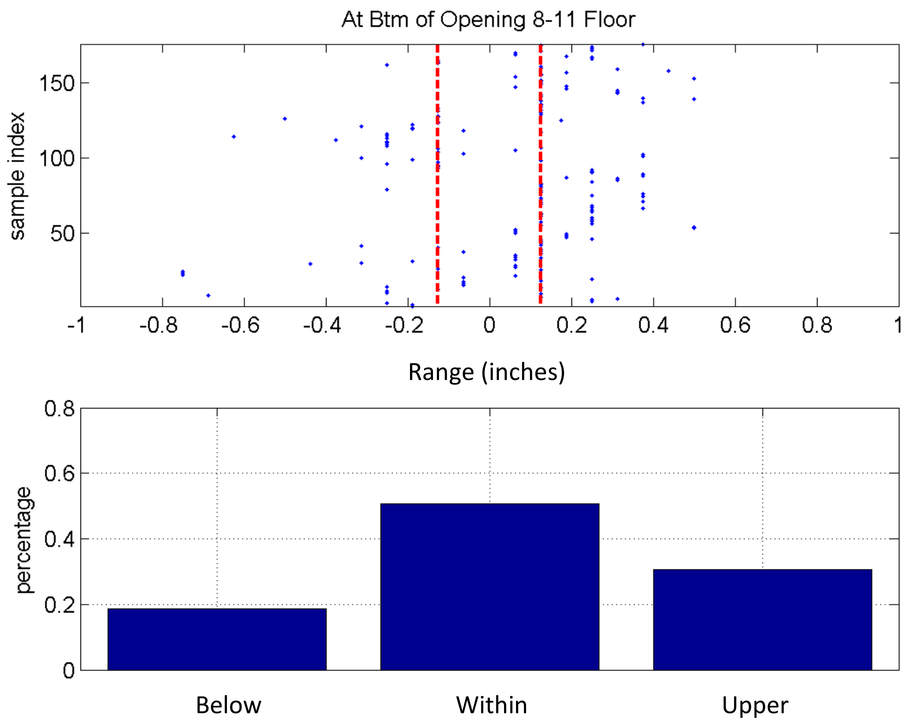

Figure 48. Plot of tolerance results at the bottom of the openings, from 8th to 11th floors.

4.3.7. Tolerance results at the top of the clean openings

Figure 49 shows the accuracy reached by the precast subcontractor where the curtain wall panels were fastened. Approximately 48% of the data lie within the acceptable tolerance range, 3% lie below, and 19% lie above. In the cases where the measurements were above the acceptable range, the curtain wall subcontractor removed the anchor clip to fit the curtain wall panel into the opening or, in some circumstances, the precast subcontractor adjusted the precast panel to reach the height needed by the curtain wall subcontractor. In the cases where the measurements were below the acceptable range, the gap between cladding components was bigger, resulting in additional labor to seal it properly.

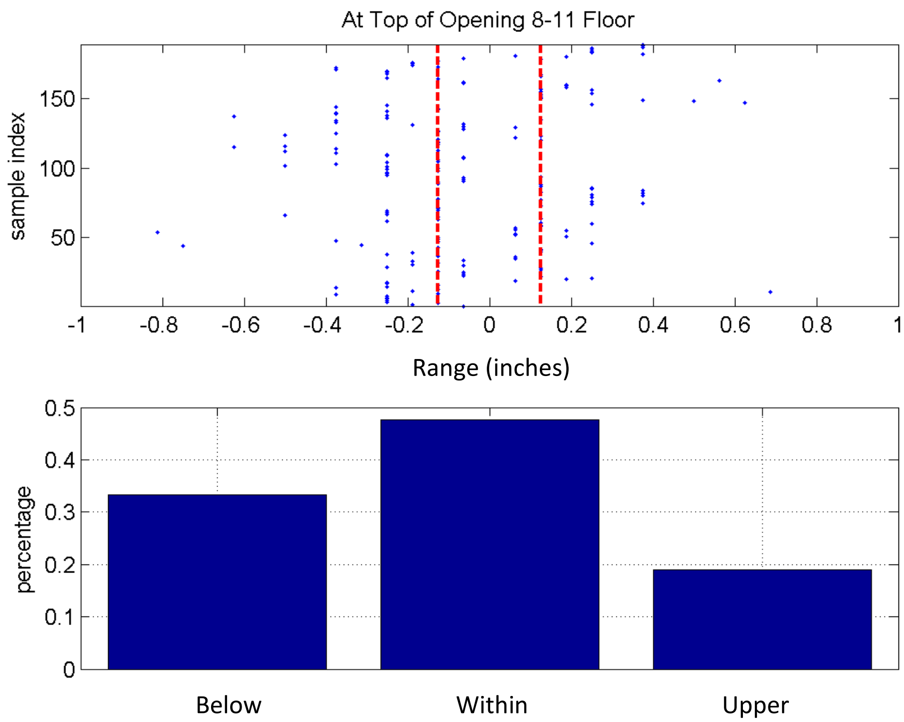

Figure 49. Plot of tolerance results at the top of the openings, from 8th to 11th floors.

4.3.8. Tolerance results from control line to the precast panel on clean openings

Figure 50 shows the accuracy reached by the precast subcontractor installing the precast panels using the control lines prepared by the general contractor. Approximately 70% of the data lie above the acceptable tolerances. This resulted in precast panels installed farther that require for the curtain wall panels installation, and the crew had to move the sill rail to correct the problem. The sill rail must be located and secured properly to receive the load of the curtain wall panels. Approximately 28% of the data lie within the acceptable tolerances. Nearly 2% of the data lie below the acceptable tolerances. Resulted in precast panels installed closer to the control line.

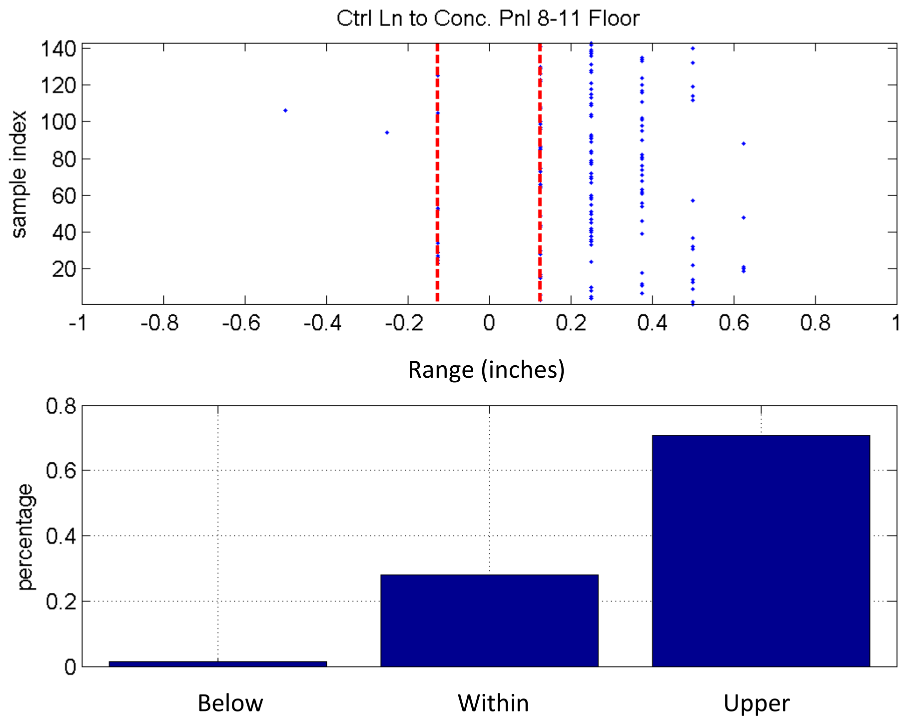

Figure 50. Plot of tolerance results from control line to precast panel, from 8^{th} to 11^{th} floor.

4.4 Interviews

Key people involved in the coordination and/or installation of the curtain wall system provided their knowledge and opinions through semi-structured interviews: the general contractor, the curtain wall subcontractor and the curtain wall field supervisor. They are professionals with experience in construction management and/or curtain wall systems, and they were directly involved in the project target of this study. The general contractor was responsible for the entire project; the subcontractor had to fabricate and deliver the curtain wall system, and the field supervisor was in charge of the installation process. During the interviews, the participants discussed the communication, coordination and decision-making process before and during the curtain wall installation process. The analysis of the data followed the steps mentioned in Section 3 and Appendix A includes the transcription of the interviews.

4.4.1. The general contractor interview

The delivery process of the curtain wall system began with a preconstruction sit down meeting between the general contractor, the curtain wall subcontractor, and other trades. They revised the shop drawings and ensured the constructability of the system. The general contractor's primary concern, regarding the cladding system, was the prevention of water leaks in the building. The architecture model was not accurate in terms of size and details of the systems, and, therefore, the general contractor had to review the subcontractors' shop drawings and ask them directly about those issues.

The architect used BIM software (ArchiCAD) to create a model of the project and to produce its blueprints. During the preconstruction phase, the general contractor ran clash detection for MEP systems using a different BIM software (Autodesk Revit™ and Navisworks™), but he did not use any BIM software for the cladding components. The general contractor argued that he sees no need of using BIM with the cladding systems because:

- The building façade was made of only two cladding systems: the curtain wall and the precast panels.
- The general contractor thought that the interface between cladding systems was not as complex as other building components such as the MEP systems.

- The general contractor knew that the cladding subcontractors did not have the expertise using the BIM software. They would have to rely on a third party to use BIM, and that would have implied an extra cost for the client.
- The general contractor is not convinced that using BIM for the cladding components can improve the efficiency of the crews in the field because most problems on the field result from human errors.

During the construction phase, the general contractor established a sequence for the installation of the cladding components, but that sequence did not consider the schedule of the curtain wall subcontractor. The precast crew installed the panels clockwise, façade by façade, and the curtain wall panels floor by floor. That way the metals crew assembled the structural decks on the upper floors using the crane, while the precast team mobilized and installed the panels to the lower levels with the same equipment. The general contractor considers that the executed schedule and sequence was the most efficient in terms of use of resources (the crane), and time (teams were working simultaneously). However, the general contractor agreed that the installation sequence of the precast panel's did not match the needs of the curtain wall subcontractor.

Finally, the general contractor stated that the project superintendent did not keep records of the problems found during the installation of the cladding systems. These issues were addressed verbally. They recorded the problems only when the project schedule or the budget were compromised.

4.4.2. The curtain wall subcontractor interview

During the preconstruction phase, the curtain wall subcontractor reviewed the construction documents and blueprints. This process helped to identify possible discrepancies or conflicts between the proposed curtain wall system and other building components. It was necessary to begin the curtain wall panel fabrication, since that demands dimensional accuracy and prompt release of purchase orders to different providers. The purchase order to the glass procurement was particularly critical because their lead time to produce and deliver the product to the curtain wall subcontractor shop could compromise the schedule of the curtain wall assembly process. It could also delay the installation of the curtain wall system at the job site. Similarly, the architect reviewed the shop drawings to verify the adequate performance of the system and its compliance with the project's layout and specifications. The shop drawings also were reviewed by the general contractor to ensure the constructability of the system. However, neither the architect nor the general contractor overlaid the shop drawings with the cladding subcontractor's drawings, to identify clashes between building components. In addition, the sequence established by the general contractor to install the cladding components hindered the installation of the curtain wall system, since the precast panels were installed clockwise façade by façade, and the curtain wall panels should be installed floor by floor.

The nature of the curtain wall system entails accurate measurements and proper tolerance management with other building components to achieve its expected performance. Due to the schedule constraints, the system was preordered, and its production began before the building was built. The fabrication of the system relied only on the shop drawings approved by the architect. However, the challenges came when the final product was sent to the construction site for installation. The tolerances found in the field, resulting from the precast subcontractor work, were different than the tolerances expected to install the curtain wall system. The issue was discovered only when then personnel in the field started the installation of the panels.

The communication and coordination between trades and the architect were always managed through the general contractor. There was not direct communication between subcontractors. As a result, there were numerous dimensional conflicts that caused alignment issues between the precast joints, the curtain wall joints, and other components.

The efficiency of curtain wall crew was compromised due to the challenges faced in the construction site. When a clash with the precast panels was detected, the curtain wall installation team had to stop the job. They had to find and explain the problem to the superintendent and the precast supervisor. And then they had to remove and reinstall the curtain wall panels to allow the precast subcontractor to either adjust the panel or to do something different to fix the problem. In terms of time, a problem could require hours or days to be corrected. That meant the crew had to be relocated to a different floor to be able to continue to work. Moving machinery and tools from one floor to another could take up to a day. The curtain wall subcontractor absorbed the additional cost caused by that non-productive time. Based on his experience and knowledge, the curtain wall subcontractor assumed an average loss between US$1,000 to US$2,000 per occurrence depending on the number of workers in the area where the issue happened. Similarly, he estimated an average cost of personnel in the field to the company, which is around US$4,000 per day, considering eighteen workers in an eight-hour work day.

The curtain wall system needed adjustments after the installation of the curtain wall panels. The system employed had a two-piece split mullion that required small horizontal adjustments for interlocks homogeneity. This process is called “tempering the opening.” Due to the tolerance issues with the precast panels, the tolerances in the curtain wall interlocks were not homogeneous. The curtain wall panels had to be slightly displaced in some areas to compensate the tolerance problems with the precast panels.

Construction documents and other information, including the ArchiCAD model of the project were accessible to all trades involved in the project. The curtain wall subcontractor produced shop drawings utilizing AutoCAD and submitted them to the architect as a Portable Document Format (PDF) for review and approval. The subcontractor did not use BIM software to produce the shop drawings. They did not have the expertise in-house and they had doubts about the impact on the field crews, since human errors in the course of the construction phase were frequent and might affect the productivity installing the curtain wall system.

4.4.3. The curtain wall field supervisor interview

The field supervisor contrasted the theoretical measurements from the blueprints and approved shop drawings against the real ones found in the job site, before installing the system. During the installation he found the following issues:

1) Misalignment between the curtain wall and the precast panel joins. The center line of the precast panels was not properly aligned with respect to the concrete slab center

lines in all façades. In addition, the spacing between precast panels was not homogeneous.

2) In some areas, anchor clips were removed from curtain wall panels and replaced with screws fastened into the blind pockets. This was done due to inadequate precast panels leveling at the top of the curtain wall, which in turn caused clashes between cladding systems.

3) Inadequate leveling of the precast panels caused over shimming on top and bottom of the curtain wall panels.

4) Inadequate tolerance management between the concrete slab and precast panels at the top of the curtain wall panels caused horizontal over shimming between the curtain wall anchor clips and the precast panels. In contrast, insufficient room for anchoring in other areas required the removal of the anchor clips and its replacement with a screw through the blind pocket.

5) The adjustment of interlocks along the curtain wall system altered the anchor clips in several locations.

The field supervisor stated that the tolerance management of other cladding components was not optimal. The issues found in the construction site were communicated verbally to the general contractor. Neither the problems nor the decisions made were recorded by either party.

5. CONCLUSIONS

This section concisely explains the research problem, motivations, and findings. It shows the study limitations, and it suggests future work and research.

5.1. Research Summary

This research addressed the reasons why curtain wall professionals are not using ICT to enhance the communication with other project participants during the curtain wall installation.

For this investigation, one project in Texas was monitored for its curtain wall installation process, and key practitioners were interviewed. Semi-structured open questions helped gain an in-depth understanding of the productivity related issues in the industry. During the preconstruction phase, the interviewees described the communication and coordination process between the project participants. During the construction phase, they described the tolerance-related problems found between the curtain wall and other building components. Finally, the participants gave their opinion about utilizing ICT to resolve clashes between the curtain wall and other building components in advance.

5.2. Findings

1) The architect created an ArchiCAD model of the building, but the general contractor stated that they did not utilize it to resolve clashes between the curtain wall and other building components in advance. The contractor thought that the interface between cladding systems was not as complex as other building components such as the mechanical, electrical and plumbing systems.

2) The general contractor centralized the communication and coordination of all construction activities. However, the following problems indicated that the communication and coordination between cladding subcontractors were not optima1. Tolerance-related problems between cladding components happened in 60% of the locations measured in this study. Crews spent 88% more time than expected to finish certain curtain wall installation activities. This percentage was based on the times measured in this study.

3) The ArchiCAD model of the building was available to all project participants. However, the cladding subcontractors produced shop drawings utilizing AutoCAD and submitted them to the architect as a Portable Document Format (PDF) for review and approval. The interviewees stated that the curtain wall subcontractor does not have the expertise in-house and that they would have to pay a third party for that system. Also, the client may not be willing to pay the over cost of its implementation.

4) Neither the general contractor nor the curtain wall subcontractor recorded the problems faced in the field. They stated that those issues did not impact the project schedule or its budget, because the curtain wall subcontractor had already made a contingency to address those uncertainties during the estimate stage. As a consequence, it is not possible to quantify their cost and their overall impact on the project, and the cost-benefit of utilizing ICT cannot be determined.

5) The interviewees stated that human errors in the course of the construction phase might cause inefficiencies during the curtain wall installation. As a consequence, they

were not sure if the use of ICT would guarantee the productivity improvement in the field.

In conclusion, this study found the existence of several problems during the curtain wall installation. Specifically, both the general contractor and the curtain wall subcontractor did not see the immediate need for using ICT to solve clashes between cladding systems. Neither the general contractor nor the architect overlaid the shop drawings provided by the cladding subcontractors. The parties did not record curtain wall related issues and, therefore, their cost cannot be determined. And finally, the interviewees in this study recognized that the use of ICT may improve interface management issues in cladding installation. However, the need of front-end investment and their doubts about the impact on the field crews hindered them from trying to use ICT in the course of the cladding installation process.

5.3. Future Work

This investigation was implemented with many questions unanswered. So, for future study, one may consider asking the following questions:

- Do all cladding subcontractors face the same challenges as the one in this case study?
- How costly are the inefficiencies of the curtain wall subcontractors on the job site and what is the overall impact in the construction industry?
- What is the cost-benefit of implementing emerging technologies in the cladding industry?

- How can cladding subcontractors implement BIM to produce shop drawings within a team collaboration environment?
- How can emerging information technologies improve the quality control process of the installation of the building cladding components?

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APPENDIX A

INTERVIEW TRANSCRIPTS

Transcript 1: Interview with the Project Manager of the Building Complex

Author: Prior to the construction phase, how the coordination and communication between trades were planned to avoid clashes during the installation process?

Interviewee: As far as coordination goes prior to the construction phase in regards to the curtain wall system, the only formality that we went through is simple sit down meeting in the trailer where we study the details, their shop drawings and make sure they are constructible, that they reviewed correctly. In no point, we run any clash detection in the 3D model that we used from the design team as part of the curtain wall system on this project. We solely used Navisworks and Revit software to run clash detection among the MEP systems in the building, nut not the actual curtain wall system. The curtain wall system was showed in the architecture model but was not accurate to the size and details that the curtain wall subcontractor ended up installing in the job. That's only came through the shop drawings process, and that's where all of our review and coordination was done, and that review and coordination was simply done through a sit down meeting.

Author: Was always the communication between subcontractors through the General Contractor? Or do the precast and curtain wall subcontractors have a (direct) communication between them?

Interviewee: It is correct. Our curtain wall subcontractor communicate directly through us. I guess you could say that where the General Contractor service the middle men between the other trades on the job that would be affected by the glass, for example precast, and also to the design team which is the architect that actually reviews the shop drawings that the curtain wall subcontractor produced.

Author: Was the architect's review mainly about the constructability of the product, beside the coordination among the traders?

Interviewee: Correct.

Author: About the (sit down) coordination meeting, did you keep any records of those meetings?

Interviewee: Yes, we did. In those meetings when we sit down as a general contractor, one of our biggest fears is something we want to prevent is leaks in the building. Obviously this curtain wall system is forming the envelope of the building, it is our barrier, so that's one thing that we pay special attention to, but that's our main concern with the shop drawings and this interviews and these meetings is to make sure these details are going to hold tight and not let the water in. That's why we sit down and talk, that's mainly what we look at it, is the flashing, caulk joints, make sure there are in the proper location to keep the water off of the building.

Author: You mentioned that you used software for clash detection, for MEP. Why do you think the software was never used for other systems, besides the MEP?

Interviewee: Obviously MEP is the most complex. All the piping in the building, all the conduits, all the rise ways, all the duct work. That's the busiest part, or our job is about ceiling and that's where clashes would be most prevalent. As far as the curtain wall system and the envelope go people had never coordinated that because is an almost stand-alone system. Yes, it is a genuine match up with the precast in our case with our ribbon window system, but that's all is going to touch its two pieces of precast above and below. So there are not too many other systems to coordinate with. I think another reason that people don't model it is because the contractor who install this glass is unknowledgeable with the software and maybe they don't see the cost-benefit investing in such software, they truly not going to have to coordinate with too many other systems in the building, so they may have not the expertise in-house, and they don't feel they are going to pay to a third party in such as system.

Author: The scheduling installing the precast (panels) and the installation the installation of the curtain wall panels were different. Also the cranes were working on one side of the building (installing the precast) and the way that the glazing subcontractor was installing the curtain wall was floor by floor, but the precast was façade by façade.

Interviewee: It is correct.

Author: So, who was in charge coordinating the crane?

Interviewee: The reason we end installing in that manner, I guess that the input came from us, the General Contractor. We establish the schedule and then we also enforce the schedule, but obviously we take subcontractor input in the crane schedule. The reason to do it in that manner was we had got out of here and start hanging precast as fast as possible knowing that glass can't go in until we have precast panels above and below. The problem is with the crane that we had, in the boom of the crane we will still forming structural decks above. So we can only hang up six (6) floors before the boom would hit our framing deck upon level –said- ten, eleven and twelve. So we can only hang the first six floors and then we have to jump into other elevation, hang those six, we do that, you know, I think, in a clockwise rotation around the building, and then the framing deck was finally clear above or our concrete decks on the higher floors, and that boom had freedom to take all the way up and hang on the higher floors. So, that's the reason that we hang the precast, no matter we did, was the subcontractor start something in place. But you are right, the curtain wall subcontractor will do it by floor.

Author: Looking part of the process and the way that was installed the precast (panels) and the curtain wall, I found several clashes, sometimes big gaps between the precast and the curtain wall, and talking with the subcontractor sometimes there is a risk for leaks because this kind of issues. Also, based on their experience, the general contractor, and the subcontractor have to deal with this kind of problems in the future, once the client moves to the building. From your point of view, your experience, how can be improved this process -since you mentioned that the use of new tools and software is not worth it right now (for the subcontractors), or they don't have the knowledge to implement it. How do you think can be improved this process -because at the end the leaks could be a big problem for the General Contractor-?

Interviewee: Absolutely, in our line of work that's the last thing we want to have is a leak in our building because can be costly for us and that will be costly for the owner. I really thing that you can see the benefit in modeling the curtain wall, that mean, we develop all kinds of different skins and envelopes, but in this case you have precast, and you have ribbon window (curtain wall panels), so in order for this to be beneficial in the process you have to have modeling capabilities for both subcontractors, but it definitely help the shop drawings process, where you can visually see on the computer screen all the joints line up, all the reveals are aligning up, but then you have to understand that we don't build in a perfect world, so the structure that we cast out in the field has to be perfect, in order for that, those drawings and models to work, so there is a variable in it because is cannot be perfect, and never is. That's kind of risk your take and maybe why some people don't do it knowing that, where we are going to be attaching the precast and glass too is not going to be perfect out there, it is can be close, It should be within their tolerance, but is not going to be perfect.

Author: Also you mention the challenges that every subcontractor face installing their products, is different installing a small panel (curtain wall) from inside that a big panel (precast) from outside using a crane…

Interviewee: Correct.

Author: So, how is the quality control process installing those products? For example, the precast, who took care of the quality control?

Interviewee: Quality control on this job kind of fall on the individual subcontractors that are installing it. We have our field engineers as a part of the general contractor team that would go and if see an issue that we know something wrong we will start shutting out elevations, but at first glance we get those guys the opportunity to correct their work, and we trust that it is going to be installed correctly, because if it is not, is going to be evidence to us. So until we really identify the problem, we don't really bring our quality control and then start shutting elevations and every precast panel, because the contractors already do that, we have the confidence that the contractors are capable of maintaining the elevations and fixing issues, so as far as the general contractor quality control on the curtain wall install and precast install we don't necessarily start shutting elevations right away unless we see an issue, because our contractors the we hire do that, and there are responsible for their panels fitting.

Author: The General Contractor has to set up the control lines…

Interviewee: Correct.

Author: Did you have any issues with those control lines? Or any kind of complaints from the subcontractors?

Interviewee: To my knowledge, when we put a deck, we would go their pop offsets, we put control on there, and that's our responsibility as a general contractor. From there subcontractors come off our control in order to do their layouts. To my knowledge, there was not issue with our control lines, outside I look at it, our building out there right now, you can see glass and precast sit on top of each other, and by the looks I think everything fit, which I am always confident, but to my knowledge there were not any issues with control lines on our part, as a general contractor we will lay down the floor where these guys can pull from.

Author: Did you experience any delay in your schedule due to any issues related to the façade of the building?

Interviewee: No, as far as the actual installer of the (curtain wall) panels and precast, no. We really didn't have any significant delays as far as the put it all the face cap and do all the caulk work to dry really the building in, yes, we have been very cold and wet winter and this caulk and seal was to set up –I don't know the threshold of the temperature –

maybe thirty-five (35) or so, but we had issue gets the building caulk and the face cap put on, but as far the actual install all the glass no, we are very pleased with the way that the glass went in, and the precast went in.

Author: So, the job was finished on time.

Interviewee: Yes.

Author: Did you receive change orders from the (precast or curtain wall) subcontractors, related to any conflicts or problems during the installation process?

Interviewee: We did not, which is always our goal, we don't like to see extra money hit the job that we didn't budget in the first place. Fortunately, in this case, we never received change order proposals from our either precast erector or curtain wall subcontractor. Usually, those change orders come from downtime and due to fault on us from no pouring the structure the way we said we will pour it. Fortunately, we have a good claim plum structure; embed place was good. Therefore, we didn't have to go back.

Author: The superintendent, since he is the person who is the whole day coordinating the processes. Did he keep any record about the daily issues faced by the subcontractors?

Interviewee: Our superintendent has a large task, here is the juggle, and he has thirty-five subcontractors, so to say that he gets into the very little details of the curtain wall installation. Obviously if there were something monumental, that would have big dollars in cost, absolutely he will note that in his daily reports, something he will communicate to us as project managers and then we will then go to the separate contractors and address. But in this particular job, considering were small issues, but not to the magnitude that dollars will be spend, and that we will need to track to cover ourselves in future cases should issues arise. So simply our general superintendent do his job, yes, he makes daily reports on a daily basis for all activities on the site. That's overlaid lay document. But as far as the curtain wall system on this job there was not anything of urgent magnitude that we are concerned with. For instance, he had an issues logger, something that he would go to physical evidence that he would write down to protect ourselves.

Transcript 2: Interview with the Project Manager of the Curtain Wall Subcontractor

Author: Did you place a request for information to the designers due to discrepancies conflicts found on construction documents during the construction phase?

Interviewee: Yes, there were numerous conflicts.

Author: Could you explain to me what kind of conflicts did you find?

Interviewee: Mainly dimensional conflicts, where our sizing doesn't match up with what other trades we will be going up.

Author: Did you find those issues in the construction documents or the field?

Interviewee: The way we do things as far as the shop drawings in the submittal phase is we take our stuff as it relates off of the construction documents, architect issues, we generate that we call shop drawings, then we submit those via the general contractor, and the architect looks them over reviews it, make changes and releases us for fabrication. As then we fabricate everything and by the time it gets sent to the field, we find that the tolerances were having here, are far different than the tolerances such as the precast concrete people. Therefore, our joints are not in alignment, because we are holding to a different tolerance than they are, and then on this project, they were off a different benchmark that was incorrect than we did, so their panels were set in the wrong places. This is not discovered until we started our installation.

Author: As I understand, you need to proceed in that way because the lead times for glass and fabrication of the whole system. So, who coordinates the process between what you did here in the shop and the other trades? Usually is the general contractor, right?

Interviewee: Correct.

Author: And since you found this kind of issues, where do you thing was the problem between the communication and coordination among the trades?

Interviewee: The only communication I am aware of was –of course, is always behind schedule, if things are not quite right, but close enough for someone's blessing, they tell them just to proceed, we'll fix later. And fixing it later is usually not the way to handle the problem because it creates issues, compounds of issues for other trades.

Author: Always your communication was direct to the architect and general contractor. Did you have the opportunity to talk with the precast subcontractor before (you start) the fabrication?

Interviewee: No, there is no communication between us and other subs (subcontractors) typically. None. We are given our drawings, approved by the architect, and we are told to proceed based upon those. Will be nice if they take our drawings and coordinate with such as the precast contractor and steel erector contractor to make sure that we are all building the same thing at the same size. That seldom happens.

Author: Due these issues, how your productivity was affected? In terms of time, schedule costs of personnel.

Interviewee: Well, obviously we will see that are what we are supposed to be aligning with the precast –joins in the precast- and they are not doing it, stop us for a period of time to go track down the superintendent for the general contractor, to show him the problem, for him to take about -the corrections- or have corrected the problem and then we either told to pull it back out, redo it or proceed in some other way of fixing the problem will be done. So we lose productivity in the field.

Author: In terms of quantity of that productivity –e.g. in quantity of time-

Interviewee: Could be several hours o could be several days.

Author: But at this point –talking about only one project, the west building that is almost done -, where I identified several clashes between the curtain wall and the precast. I spoke with the field supervisor, he told me that sometimes they had to wait for the precast subcontractor to adjust the panel; sometimes they had to move the personnel to a different floor in order to keep doing something and obviously, moving the stuff (tools and machinery) from one floor to another floor can take like a day.

Interviewee: Yes.

Author: And this is something that is out of your budget.

Interviewee: And what we did not allow for, in the budget.

Author: As a project manager, there is a way that you can track all of these additional expenses. There is a way that you can measure how much money did you invest on top of the original budget?

Interviewee: Not accurately, we can only put hypothetical guesses to it. I would say we probably each instance we are losing it at least anywhere between a thousand to two thousand (dollars) depends upon how many men were at that area that now has to re-shift and re-setback up.

Author: Taking into account the number of workers in the field (an average daily), how much is the cost for the company to have those workers one day there (in the job site)?

Interviewee: Based upon eighteen men on the job site on any given day for an eight-hour work day, the company is paying (around) four-thousand per day cost.

Author: After the curtain wall installation, did you make any adjustment to the curtain wall in any way due to conflicts with other components of the building? In other words, did you have to adjust the size of the frame? Did you have to change or modify in some way the frame?

Interviewee: Practically every wall had to be adjusted it in some way, but he (the field supervisor) sets them all into place before he does the anchoring, the finish anchoring. He will it call tempering the opening, hanging in the opening and then he will go through and make the whole drilling into the concrete for our edge anchors. So yes, our system further has a little slide adjustment, but then we will have to adjust because it is a two (2) piece split mullion. The tolerances are not uniform throughout everyone and then the architect picks us to death, showed us upon a punch list that they are not uniform. Well, is not our fault that the precast is not the size is supposed to be in, we have to make adjustments, that happens all the time.

Author: Doing those adjustments, how much time did your workers spend in the field?

Interviewee: It is part of the installation process. It is not a whole lot of time that you will be spending otherwise doing a normal installation. Very minimal, as long as he sees that ahead of time and laser out ahead of time. He did not do his layout first, and then he start staking and has to adjust later, it could be very expensive.

Author: Also, how did you schedule the installation of all frames? (I know) that the initial idea was floor by floor, from second to the top.

Interviewee: Correct, but that's not how it went. The precast was installed in one elevation at a time all the way up, and they let the precast erect two elevations, West and North of the West Tower before and move on the other two sides before he allowed us to start. So we only gave one-half of the building, half of floor instead of the whole floor at a time.

Author: So, is also coordination about the installation…

Interviewee: Yes.

Author: It was not planned at the beginning?

Interviewee: If it did not go according to the plan, no I did not.

Author: Did you take into account information provided by the General Contractor, another subcontractor to fabricate and install the curtain wall system? In other words, did the General Contractor provide additional information from other subcontractors to adjust your drawings previously to begin the fabrication or installation?

Interviewee: We were not given any other documents but do you took everything being posted to the project site (FTP server) now, sometimes you do have access to the other subs drawings. But as construction goes right now with the General Contractor and all the volume, you just genuinely don't have time to go and coordinate and verify, and what I can overlay our staff with theirs to make sure that is all correct, where at this point having to rely solely that the architect did his job correctly. And we find nine times of ten that is a failure right there.

Author: In your opinion, how can improve this issue?

Interviewee: Well, with the new technology right now and as I understand it, -I'm going to be honest, anyone here (in the project) in this has to understands, I have been in this business for thirty-seven years, I started back in 1978, prior to computers and all of that have being of our day work. But with the technology as is understand it now, it should be able to be tasked, should be able to be done where you can take our shop drawings, overlay them with the subs drawings that we are fitting in between such as precast and see that all of our vertical mullions align with the joints in the precast as what architect has detailed that you got your proper tolerances and clearances for caulk joints in our system's fit. So that overlay process could be easily done –I think- that will prevent a lot of problems in the field as long as the installers in the field are hearing to installing as per those drawings also. Still all comes down to human error or human quality control.

Author: You refer to (the use of) new technologies and as a project manager, if you have the opportunity to adapt one of those new technologies, what kind of challenges the company will face in order to increase the productivity and use properly those technologies?

Interviewee: Well, probably we will need to hire another person with the expertise, and that know what we do in the company. They would take this technology, incorporated for use in our projects and I think, as our company operates, I've already got more that I'm – they will either have to take responsibility away from me, for me to have that time, or they will hire someone that is very familiar with this, and that's what the job title or description will be.

Author: About the issues in the field, did you have to submit any change order (because of the problems mentioned above)? And if you had, what was the nature of the change order?

Interviewee: If it is just minor we absorb the cost, we did not pass it along. But if the architect is making a drastic change, yes I will make a change order.

Author: But in this project?

Interviewee: In this project we did not have change orders for that.

Author: So, adjustments in the field…

Interviewee: We absorb that cost, we did not pass along the general contractor.

Author: So, is still in the budget?

Interviewee: Yes, if not we have to make it up somewhere, we can't eat all, we have to pass along somewhere down the line, but we generally are not that you call a company that lives of change orders, when you bid the job cheap, and you hope to make your money on change orders. We don't do business in that way.

Author: Did you document all of the issues, or conversations, or meeting with the General Contractor about the challenges you faced installing the curtain wall system?

Interviewee: Probably not.

Author: Why not?

Interviewee: Due to just, it that was the only project that I was overseen I will have a lot of time available to do that. But, I got too many new numerous projects I am handling and overseeing all at the same time, and time just does not allow for minor issues. If it is a major issue that is going to present someone a large expense, that's is going to cost a bunch of money down the road, and then yes, I have to. But most of the minor stuff that we can overcome without it being a "big cut" as we call them. They just don't allow to document every little thing.

Author: In general, how do you think the productivity can be improved during the fabrication and installation process of the curtain wall system?

Interviewee: The biggest item I see is if the trade that in the project happens to be the precast contractor. If he wouldn't be working off the same benchmark that we worked, that it was supposed to be instead of an incorrect one and had his panels within the proper tolerances, then having these panels each floor done instead of us having to skip from floor to floor, we could probably have everything install in at least one-third (1/3) less amount of time, if not half.

Author: (As you mentioned above) you have to work only based on drawings, you don't have the chance to measure the openings.

Interviewee: Yes, because our stuff has to be preordered, most in advance and be fabricated as you could say where we fabricating all projects out here, and pre-glazing and installing the glass in the units, before the building is even build.

Author: in this project, how much was the lead time for the glass panels?

Interviewee: The lead time at the time we ordered, from the day we ordered was only about eight (8) weeks. The (project) glass provider got to be where they were about thirty-six (36) to forty (40) weeks lead time out. They (the glass provider) since got another plant re-open backup that was closed for maintenance, and they are now about sixteen to 20 weeks lead time. Obviously, you don't have an opportunity to field measure, fabricate your frames and stand an order of glass for a building of that nature.

Author: What about the frames (material lead time)?

Interviewee: We get the material from the supplier in roughly around four (4) weeks, at the most. But then it comes in long sticks, and we have to cut it in size and fabricated, assemble it.

Author: So, having ready those panels, how much time your people spend producing the panels here in the shop?

Interviewee: Making it ready to have the glass go in them?

Author: Including the glazing.

Interviewee: Including the glazing from the day I ordered, roughly about eight (8) weeks.

Author: In other words, having the material available, cutting the material, assembling the frames and glazing the frames, in your shop. Is going to take around eight (8) weeks?

Interviewee: Well, for the whole project?

Author: Yes, but obviously you are delivering as is needed in the project.

Interviewee: The best way to answer that is, our fabrication crew can cut, punch and assemble probably 50 to 60 panels a day –averaged, they can glaze only 42 to 45 (panels) a day. So, there is an offset period where we start cutting, we start punching, assembling as these guys are pre-glazing and installing the glass in the shop, they are working on the stuff that is a week or so away from getting to them (at the pre-glazing area). So, if your average is allow, we can do on an average of forty-five (45) panels a day. There was approximately around numbers about thirty-five hundred (3500) panels for the whole project.

Author: The day you started working in the project (or your people installing the frames). How many panels you had to be ready, to deliver the first day?

Interviewee: To the job site?

Author: Yes.

Interviewee: We tried to have at least several floors ready. On that particular job, there are a hundred and forty-four panels per floor. We tried to have at least two (2) to three (3) floors ready before we start shipping.

Author: And the average daily performance you calculated in your budget of your personnel in the field, how many panels they should install daily, according with your numbers in your budget.

Interviewee: Roughly about twenty (20) per crew.

Author: Is this a conservative number?

Interviewee: Is fairly conservative, yeah.

Author: Do you have any other comments or issues in the project with the General Contractor, with other trades besides the communication and coordination?

Interviewee: If they can just get the subs trades such as precast in the right location the first time, and have someone as we call it bird dogging overseeing it, verifying that it is correct before they turned over to us, it will make our job so much easier, and them could finish faster and on schedule or on schedule instead of being behind schedule as we always said we are.

Author: Quality control?

Interviewee: Quality control is a must and is probably one area that they lack most on.

Transcript 3: Interview with the Field Supervisor of the Curtain Wall Subcontractor

Author: Did you find the measurements provided on the Construction Documents accurate with the measurements found in the job site?

Interviewee: No, they were off on control lines. Overall measurement looks good but as you work in the building, the control lines are different from floor to floor.

Author: Besides the control lines, what other discrepancies did you find?

Interviewee: Precast (panels) was off. I think pretty much that's it, the precast had the all, almost all corners had to be move out one inch.

Author: When you spoke with the superintendent, and obviously you coordinate this process the other subcontractor, the precast subcontractor, what was the cause of the problems installing the precast?

Interviewee: Pretty much the guy who was doing it using measurements in all that for precast, because did not do it right. Once they had to build seven/eight floor, they switch the guy, and they had no problems after that. The first guy that was doing it wasn't going off the measurement that were supposed to be.

Author: Did you use the exact measurements provided on the approved shop drawings to fabricate the curtain wall system?

Interviewee: Maybe this (question) is more for them (curtain wall subcontractor Project Manager). But as far as measurements are installing (the curtain wall system), we did.

Author: Did you take any measurements before start the fabrication of the curtain wall system o everything was based on drawings?

Interviewee: Based on drawings which is pretty much set to where those drawings and measurements are set to where our frames can be fabricated beforehand to get them installed as soon as possible.

Author: Did you take into account information provided by the General Contractor, and another cladding subcontractors to prepare the frames and install the curtain wall system?

Interviewee: I guess so. That has nothing to do with me but they would had to, because you have to get measurements from precast, measurements from main contractor as far the size of the building and how far the precast can stick out to loss of the size of other precast to the chamfer where our frame sits.

Author: Did you use any measurements or shop drawings provided by other subcontractors -for example, the precast subcontractor-, to design the curtain wall system or fabricate the frames?

Interviewee: No, they (the curtain wall fabricators) shouldn't follow the precast, because the precast have a certain size that we have to sit in a certain way on the precast. So, yes, we (the installers) have to go on someone else's -or part of someone else's- drawings.

Author: After the curtain wall fabrication, did you modify the curtain wall frame or its anchors in any way during the installation process and why?

Interviewee: Not the frame, but the seal check we did. We did modify that. I am not sure why that came longer, but we took roughly three-quarters of an inch of a check on a long side. I don't know why, I think maybe there is first ahead in a joint in the middle and never did or something, I’m not too sure, but we modified the seal. That’s about it. Frames are good.

Author: I found that some curtain wall panels did not use their anchors because I think there was a conflict with the precast (panels). It is that right?

Interviewee: Yes, there are some precast (panels) that were put in, not to the measurements, to where the opening was one-o-nine (109 inches), our frame was one-o-eight and three-quarter (108 3/4 inches) with a quarter (1/4) inch clip (anchor) at the top, with a quarter (1/4) inch clip on the frame when at going in. So we have to take the clip off, put our frame clip into the blind pocket, and that would be the only way get into work and lasting into the precast.

Author: When you had to remove the anchor, was compromised the safety of the curtain wall panel?

Interviewee: No, it (the panel) is safe enough because its anchor cross, it is anchored to the frames next to it. So, shouldn’t be any problem as far as safety any other reason that can be of the way of doing.

Author: Taking into account these challenges that you faced during the installation, how much time was invested in labor and overhead due to those conflicts?

Author: Taking into account these challenges that you faced during the installation, how much time was invested in labor and overhead due to those conflicts?

Interviewee: Overall probably a week, as far as money was I cannot tell you.

Author: What are the challenges in the field that affect your productivity during the installation of the curtain wall?

Interviewee: Opening not been in the right size being too tight, where we had to stop, take the clips off, drill another hole, and fit the frame in, either fudge the sill track down low enough that we could get our framing. Put it something in and have to take it back, so they can move precast, checking another's people work. That's pretty much it.

Author: Also I remember –in the sense of productivity- that sometimes you try to start (the installation of) the curtain wall on one floor (finish it) and then you have to move to the next one, right?

Interviewee: Yes

Author: However, when I was collecting some data, I found that some panels were installed on one floor and then you had to move to the next one…

Interviewee: That's because they start the precast on five floors on two sides of the building and by the time we finish that, we had job back down and do the other side when I get the precast done. So they will put in so much precast in so many areas, not all at one time.

Author: So, when you had to move your people, and maybe to start the work in another place that you did not schedule, how much time did you spend moving your people and your stuff from one floor to other floor? How was affected your productivity?

Interviewee: It is about a day of moving stuff, just because we have a lift that couldn't fit into the elevator. So, we had that. She had to operate from outside, to move from floor to the floor moving all materials, no materials but mostly our tools and everything up. Give setback up to work once we are done there we have to do the same thing again to go the next floor than we have to come back do all again. So, we are for at least a day because no have the precast the whole way around.

Author: From your point of view, how can be improved your productivity during the installation process?

Interviewee: Make sure that the machines we use can fit in the elevator. Have most of the precast in.

Author: Who was coordinating the trades? Was (a coordination) between subcontractors? Was the General Contractor involved?

Interviewee: It is a time limit, so they haven't so much time to get the stuff done, so they have to get enough up, so another contractor can come in. I don't know put in all precast set at one time is going to help but to they help us as far as our job. That's probably the way we are going to do it. It is just put enough (precast), so another contractor can come in, get done. His work started… but, I mean, all the big good that the only thing that they can do it is to have half building, move to the other side and do the other half.

Author: Now, I will show some pictures that I took during the process (of the curtain wall installation). This is the picture number 1a (Figure A-1). I remember that you explained me something (a problem) between the (joins of) precast panels and the (joins of) curtain wall panels. What was the cause of the problem?

Figure A-1. Alignment of precast and curtain wall panels at North façade. Picture 1a. Image: Andres Martinez.

Interviewee: On several precast panels, if you start on one side of the building, you work while the other in. They start following off out of alignment with our frame and the control lines. In one (precast) panel was two and a half (2 ½) inches short or offset, so they pretty much cut it, patched it and made it look like it was right. Most of these panels have the wrong size. They are off half (1/2) inch to one (1) inch that after a while there are gross. The alignment issue is the fabrication of the precast panels.

Author: This is the (picture) 1b (Figure A-2), one of the details of the problem. How many issues did you find in the whole building?

Interviewee: A couple of issues. This is not the precast; some are actually control lines because if you shift the control lines all way up of the building the line is up. So if you go up to the centerline, everything should line up. But as far as control lines on the building and the precast, nothing is going to line up unless you have one line start up from both people, and the lines that they gave us were not right, were not aligned each other.

Author: Who set up the control lines?

Interviewee: The engineer layout all the lines.

Author: How did you find that the control lines were the problem?

Interviewee: Pretty much if you measure my frame to the control line, go to the next floor and do the same thing and you look out from the outside of the building, and look up, and is wavy, on those two, to me that means the lines are off. There is not good way of actually finding out since the precast, and the frames are in, but to me just go floor to floor and measure from the control lines to my frame and all are the same but nothing aligns up right, that's the control lines are not right.

Figure A-2. Misalignment between precast and curtain wall panels joins at East façade. Picture 1b. Image: Andres Martinez.

Author: This is the picture number 3a (Figure A-3). Here you see the (curtain wall) clips (or anchors), and there are different distances between the clips and the (precast) panels. Sometime is very tight to the panel; sometimes you have to use a lot of shims. So, what was the cause of the problem?

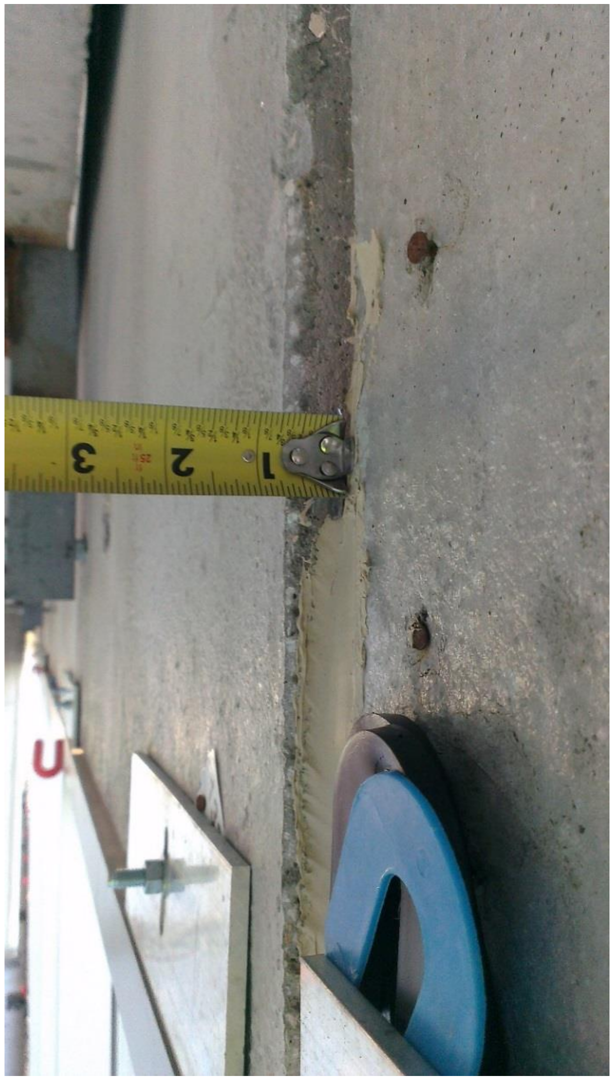


Figure A-3. Tolerance discrepancies between curtain wall anchor clips and precast panels. Picture 3a. Image: Andres Martinez.

Interviewee: Precast, it is either bowed, or the thickness is different. We actually have a tolerance of three-eighths (3/8) or three-quarters (3/4) of an inch that we actually put it in that are made for the shims. If fits perfect, we put three-eighths (3/8) and then we should be done, but the panels are bowed, these are bowed up to two (2) inches, and they put it in. So, it's concrete, you can't get it straight.

Author: This is the picture 3b (Figure A-4).

Interviewee: That's where the precast was too tight, so in one area we had to take the clips off, push the screws into the blind pocket, so right there, the precast, they shouldn't went off the tighter spot than going off the spot they have been going off instead of just doing whether the anchor point are.

Figure A-4. Evidence of removed curtain wall anchor clips at 3rd floor, West façade. Picture 3b. Image: Andres Martinez.

Author: Also the picture 4a (Figure A-5). This is similar (to the picture 3b), and this is in the corners.

Interviewee: Yeah, you can actually see right here in the corner to the next piece of precast, the corner has a gap, next piece of precast way too low, you can see it. That's a big problem right there.

Figure A-5. Evidence of removed curtain wall anchor clips at 4th floor, Southeast corner. Picture 4a. Image: Andres Martinez.

Author: In any moment, did the precast subcontractor has to move or adjust the panels in order to allow you to install the curtain wall panels?

Interviewee: They should, it is faster if I can make it work (install the curtain wall panels) without the clip or moving them from the top down. If I can adjust mine to make it going, and I keep going, I rather do that then taking the day and haven't he move his precast or waiting a week because he has to back over there. So, whatever I can do to make it work, I will do it. If I can make it work, they (precast subcontractors) don't have to move it (precast panels).

Author: During the (curtain wall installation) process, did the precast subcontractor move or adjust the panels because you cannot do anything?

Interviewee: Correct, I could I have him move everything that was not in the tolerance that I was supposed to have, but to make to process faster I did it to where makes it faster. But to flee he should move all the precast and put it in the right spot, to where it says on the prints.

Author: When the precast subcontractor moved or adjusted some of those panels because you cannot do anything, how much time did you wait to have the tolerance required?

Interviewee: It all depended on where the crane is if is in the area, sometimes could be within an hour, and sometimes takes a day or two. All depends on his schedule.

Author: Picture 4b (Figure A-6), at the bottom (of the curtain wall panels), looks pretty leveled, but at the top no (why?)

Interviewee: If you notice, here (refer to Figure A-7, top of curtain wall panels) is very tight and it has actually a bow. It is tight at the corner, middle of the two frames you see daylight and then goes back down so that precast has a bow in it. That's something might I'm not bear to fix, but I mean, they are supposed to give me an inch and a half (1 ½) bigger than my frame which they could raise it up.

Figure A-6. Uneven precast panels at top of curtain wall panel. Picture 4b. Image: Andres Martinez.

Author: Under these circumstances, do you think that the problem is during the fabrication of the precast panel?

Interviewee: Both, fabrication and installation, because take you more time to find the high spot or low spot on the precast, then they could go off that spot and sat it just going off two places. If they find the high spot or low spot, whichever they want to work with, then they could find out they need to go off that measurement because is the tighter spot.

Author: This is the picture number five (Figure A-7). Here the gap between the precast panels and the (curtain wall mullion) vertical are not aligned, (why?).

Interviewee: This one kind out looks like the one that the panel was short, and this one looks a bad fabrication of the precast panels. They should measure their stuff and line it up, but they didn't.

Figure A-7. Interior view of Joint misalignment between cladding systems**.** Picture 5. Image: Andres Martinez.

Author: Picture number 8b and 8c (Figure A-8 and Figure A-9). I found that the clips were modified or altered. Why did you cut the clip (or anchor)?

Interviewee: Because on this one (picture 8c), we had the anchor already in there and instead of put the anchor out, we made a hole in the clip itself so we can slide the frame and close it up, instead of destroy the anchor and cut it out or it was because we cut the anchor, and we move the frame, and then we put another anchor in, I am not sure about this one. But, that's from actually, either cutting the anchor out or cutting the clip to move it over the metal. But I think that one was cutting the anchor out. Because we anchored, temper it and then we are going to move it and adjust the corner, because we may have to move these frames this way to get the gaps, or we have to tight it up, so we anchor one, we have to take the anchor out to move them (the curtain wall panels).

Figure A-8. Interior view of joint misalignment between cladding systems at building corner. Picture 8b. Image: Andres Martinez.

Figure A-9. Alteration of curtain wall anchor clip caused by horizontal displacement of the panel. Picture 8c. Image: Andres Martinez.

Author: (In the) picture 9 (Figure A-10), there is a gap at the top of the (curtain wall) panel. This kind of issues during the installation, how can be a problem in the future?

Interviewee: (The problem) is mostly installation of precast, getting the measurements right. Haven't some who cares that "hey, there is other people that go in after you". This one looks like two different sizes of precast, if they can heighten the low spot, they shouldn't go off that instead of just where they anchor it.

Figure A-10. Tolerance discrepancies between cladding systems and top of the curtain wall panels. Picture 9. Image: Andres Martinez.

Author: Having the gaps (between the curtain wall and precast panels), could be a problem in the future, such as (water) leaks or something like that?

Interviewee: If there is no gap, yes. If is too big the gap, it could be. It can't be over a certain distance, I want to say is an (1) inch, after an (1) inch you are taking the chance of not holding, and if is anywhere less than a quarter (1/4) of inch we don't get enough caulk on there for filling the hole, for wind expansion, it open and close and we don't want that rip off.

Author: How are you dealing with this kind of gaps (bigger than one inch)? How are you filling them?

Interviewee: Backer rod and caulking. So far, no leaks, nothing. The guys are good guys with caulking, so they know how to do that. As far as you prepare everything right, it should be good.

Author: Picture 6a (Figure A-11). If you see, there is a difference of levels (alignment) between the frames. What was the cause of the difference of the level between the panels?

Interviewee: The problem with the alignment on that frame –if you look at the precast-, the frame on your right-hand side most likely needs came up, but you can’t because already max out. So, we do our best to align it, because if you look that clips max out on there. So, we probably had to beat that one in.

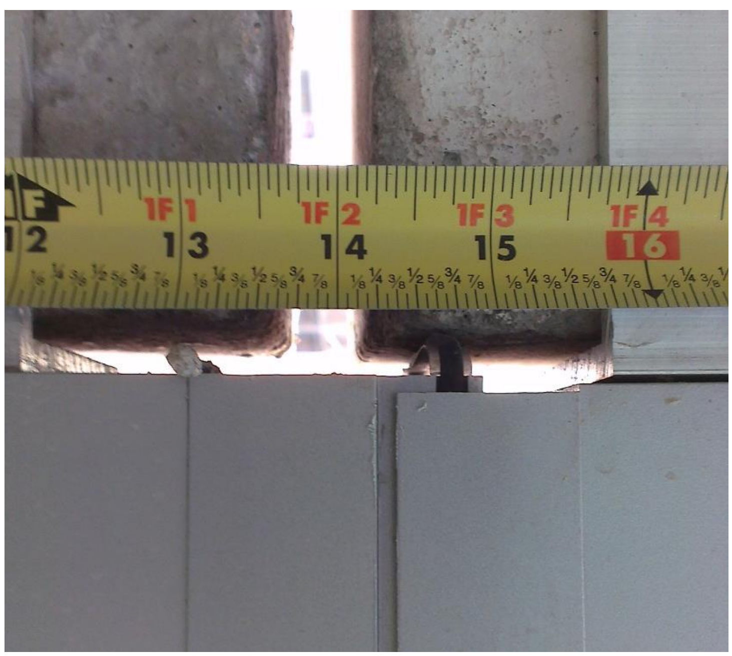


Figure A-11. Detail of horizontal misalignment between curtain wall panels. Picture 6a. Image: Andres Martinez.

Author: So, the idea was to keep the clips and fits the clips very tight, and that's why you modified the panels.

Interviewee: Yes, because you want to have a ceiling that is cover up that, but if you look at your horizontal (on the picture), looks like aligns up, it wasn't that big of a deal.

Author: Picture 6b (Figure A-12) is the same circumstance (than picture 6a) right?

Interviewee: Yes, same circumstance. Probably the clip over here (see figure) kinda looks like it's not even on. So, that might be the same problem, if you look at the precast, there is a difference in the height. That's the reason, we couldn't do so much, first to stop and fix the precast and just to do that is not going to happen.

Figure A-12. Detail of horizontal misalignment between curtain wall and precast panels. Picture 6b. Image: Andres Martinez.

Author: In the picture 8a (Figure A-13), also the clips (anchors) were modified. What was the cause of this (modification)?

Interviewee: We cut the anchor out, I guess to move it –because looks like we took the grinder to do it-, so we redo the location. So, the anchors itself we cut out and redid it.

Figure A-13. Alteration of curtain wall anchor clips. Picture 8a. Image: Andres Martinez.

Author: After the installation of the panels, what other issues did you find? (Before the interview started) you were telling me about the (curtain wall) beauty cups (or covers).

Interviewee: The alignment of fake mullions, when we are aligning up with each other from floor to floor. Alignment of the mullions with the precast (joins) was not aligning up. And for all of that should work. Should have one line that both subcontractors went off instead of just going off control lines, and the control lines were off, everybody is off. That's the biggest issue, the control lines.

Author: I took a picture today (picture 10) (Figure A-14) in the second floor. The cover of the mullion (is displaced). (Why?)

Interviewee: Third floor is the worst floor, it is off pretty bad. If you check the control lines to the frame, you can see fine but everything seems to be shifted in one way.

Figure A-14. Interior view of custom aluminum cover displaced at the exterior of the building. Picture 10. Image: Andres Martinez.

Author: The beauty cap (in Figure A-14) seems displaced maybe one-quarter (1/4) inch…

Interviewee: That one was about a quarter (1/4) inch or three-eighths (3/8) of an inch on that one. That's actually not too bad in comparison with one on the other side.

Author: (Was) the purpose of moving the alignment to fit with the precast (joins)? Or what was the purpose?

Interviewee: The alignment should align with the precast and frame to frame. The only way to make right is actually giving online that go up to the whole way up and down. There is no way to fix it right now but on next jobs they need just drop a straight line or laser and give a starting point for both companies.

Author: Based on this comment, do you think that the coordination between trades should be improved? Who will be is responsible for that?

Interviewee: The General Contractor is responsible for (control) lines. As far as going off, we can only go only for control lines, we don't go off for precast or anything. All we have to do is to make sure that our frames are fitting the area, and the precast is cannot stick out or inside the area. Coordinating with the other people, is good to be on the same page but if the lines are off on the floor, and that's way we went off, you can't coordinate to make that line right. Until we find out that the line has a problem, we consider that line to be a correct line until we find out different.

Author: In some point, maybe before the installation process, do the (curtain wall) company contact the precast, subcontractor? Or only you established communication with them during the installation process? Or everything was through the general contractor?

Interviewee: Everything is pretty much through the general contractor, we really don't talk to anybody else except for the main contractor about any problems we found. We shouldn't have to deal we the precast guys telling them that there is something wrong because is not our job. If there is something wrong, they actually mess up to everybody. Everybody who has the job knows what they have to do, so as far as I step in and find out their problems, it shouldn't be like that. The main contractor should be long behind them making sure their stuff is right.

Author: Every time that you discussed any concerns about the installation process, where those issues documented by the general contractor? Or was only a conversation and a verbal agreement?

Interviewee: I don't know who is documenting, we have –I guess – a verbal agreement that only got as far as the superintendent, no project managers, no architects, just superintendent. As far as us, we have documents, my project manager knows, my super knows, everybody I can tell knows. In this way they documented, and it cover us if makes wrong, if we have a problem.

Author: Based on your knowledge, do you know if the company had to submit a change order due to those issues?

Interviewee: No, I don't know.

Author: Do you have any other comments related to the issues found here, beside the problems that we discussed already?

Interviewee: As far as this job, the shouldn't put fake mullions, just for the fact that to do it right, you do have to have all the frames in on one side first, so everything will align up.

It is a fake mullion, it is after the fact that you put it in. To do something like this, you have to -everyone is in a loop that this has to align up no matter what- but, I thing, -you know architecture-, kind of look in advance see what the problems will be doing something like that. Will be better if you have a frame that has the mullion in already, so in this way go from floor to floor and make sure that everything aligns up, looking good and you don't have a problem with an offset, would be the right way to do this instead of putting something fake on.

APPENDIX B

DIARY NOTES

Date:	**Time**			**# of workers:**
8/4/2014	**Start:** 7/28/14	**End:** 8/4/14 9:23 am	**Total:** 10 work/days	7

Actions performed:

Glass and glazing subcontractor began curtain wall installation process on July 28, 2014 (8 daily working hours).

The number of curtain wall units (frame + glass, without full pressure plate and cover) installed to date and end time are described as follow:

2nd Floor: North façade - 48 units (complete); West façade - 9 units (incomplete); East façade - 24 units (complete); South façade - 15 units (in-progress).

3rd Floor: North façade - 48 units (complete); West façade - 9 units (incomplete); East façade - 11 units (in-progress); South façade - None.

4th Floor: North façade - 42 units (incomplete); West façade - 9 units (incomplete); East façade - None; South façade - None.

5th to 12th Floors: None.

Note: Curtain wall sill rail has been installed, from 2nd to 4th floor on top of precast concrete as per construction documents and curtain wall subcontractor's shop drawings.

Date:	Time						# of workers:
8/4/2014	Start:	9:23 am	End:	11:30 am	Total:	97 min.	4
Actions performed: **2nd Floor:** South façade - installation of 10 units							

Date:	Time						# of workers:
8/4/2014	Start:	9:23 am	End:	12:58 am	Total:	215 min.	3
Actions performed: **3rd Floor:** East façade - installation of 12 units.							

Date:	Time						# of workers:
8/4/2014	Start:	12:58 am	End:	1:54 pm	Total:	56 min.	3
Actions performed: **3rd Floor:** East façade - installation of 1 unit (corner); South façade - installation of 3 units (1 corner unit included).							

Date:	Time						# of workers:
8/4/2014	Start:	N.A.	End:	N.A.	Total:	N.A.	N.A.
General Comments: Curtain wall subcontractor supervisor describe the following issues with pre-cast concrete during the installation process of the curtain wall system: 1. Prior to beginning the installation of the precast concrete panels, a control line was setup to use as a reference for installation purposes. The distance between the control line and the interior face of the precast concrete fluctuate between 1/4" and 3/8". Horizontally, the fluctuation is not allowing the proper alignment between the exterior face of the precast and the exterior face of the curtain wall system.							

Date: 8/4/2014	Time			# of workers: N.A.
	Start: N.A.	End: N.A.	Total: N.A.	

General Comments (Cont.):

Taking into account that each curtain wall panel is supported by the precast at the bottom and anchored at the top to the precast located on the upper floor, sometimes the vertical alignment of the panel is not allowing the use of the designed anchor and the curtain wall unit must be anchored directly from the frame to the precast concrete.

2. Due the issues described above, the precast subcontractor has been adjusting some concrete panels where the problem makes impossible the curtain wall installation. During the precast adjustment, some curtain wall panels (glass and frame) already installed have been stained with concrete. The glass can be cleaned from outside only (as soon as possible). Otherwise, the stain cannot be removed without affecting the glass. The current site conditions are not allowing the access from the outside to clean the glass and is highly probable that the glass panels must be replaced at owner's cost (+/- 20 glass panels are compromised).

3. The precast issue is not allowing the installation of the curtain wall system consecutively in every floor.

4. The installation process of the curtain wall panel located at the Southeast corner of the building and some panels situated in the South façade have been video recorded in order to measure the time required.

Date: 8/5/2014	Time			# of workers: 7
	Start: 7:00 am	End: 8:41 am	Total: 71 min.	

Actions performed:

3rd Floor: South façade - installation of 18 units.

Date: 8/5/2014	Time			# of workers: N.A.
	Start: N.A.	End: N.A.	Total: N.A..	

General Comments:

The researcher measured the distance of precast panels from control lines on 2nd, 3rd, and 4th floors.

Date: 8/6/2014	Time			# of workers: 2
	Start: 9:11 am	End: 10:06 am	Total: 55 min.	

Actions performed:

Two workers are installing the sill rail on the 4th floor, south façade, between columns 3 and 4.

Procedure:

1. Sill rail is partially screwed to the precast.
2. The sill is leveled using a laser level; shims are installed bellow the sill to reach the required height.
3. Two sets of shims are installed per curtain wall panel.
2. Sill rail installed length: 24 foot.

Date: 8/6/2014	Time			# of workers: 4
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of 4 curtain wall panels, two panels are located behind a concrete column.

Procedure:

1. Mobilization of first (1^{st}) curtain wall panel from dolly panel cart to a final location utilizing a lift truck with a fork truck boom and a power vacuum cup lifting frame attached to it.

   Time required: 00h: 01m: 55s.

2. Installation of first (1^{st}) curtains wall panel over sill rail.

   Time required: 00h: 02m: 50s.

3. Mobilization of second (2^{nd}) curtain wall panel from dolly panel cart to the final location. Time required: 00h: 03m: 46s.

4. Installation of second (2^{nd}) curtain wall panel over sill rail with sealant and interlocking with side panel.

   Time required: 00h: 01m: 30s.

5. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (2^{nd} panel).

   Timer required: 00h: 04m: 25s.

6. Interlocking of the first (1^{st}) panel with a side (2^{nd}) panel.

   Time required: 00h: 01m: 10s.

Date: 8/6/2014	Time			# of workers: 4
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of 4 curtain wall panels, two panels are located behind a concrete column.

Procedure (Cont.):

7. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (1st panel).

   Timer required: 00h: 04m: 37s.

   Note: Due to lack of workable area between the column and the curtain wall panel, there is not access to install the second anchor on first (1st panel). Therefore, the curtain wall panel is screwed at the bottom of the blind pocket.

8. Mobilization of 3rd curtain wall panel from dolly panel cart to the final location.

   Time required: 00h: 03m: 00s.

9. Installation of second (3rd) curtain wall panel over sill rail with sealant and interlocking with side panel.

   Time required: 00h: 01m: 15s.

10. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (3rd panel).

    Timer required: 00h: 04m: 50s.

11. Mobilization of forth (4th) curtain wall panel from dolly panel cart to the final location.

    Time required: 00h: 03m: 25s.

Date: 8/6/2014	Time						# of workers: 4
	Start:	N.A.	End:	N.A.	Total:	N.A.	

Actions performed:

Installation of 4 curtain wall panels, two panels are located behind a concrete column.
Procedure (Cont.):

12. Installation of second (4th) curtain wall panel over sill rail with sealant and interlocking with side panel.

Time required: 00h: 02m: 10s.

13. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (4th panel).

Timer required: 00h: 04m: 43s.

Results: 4 curtain wall panels were installed in 00h: 37m: 41s.

Average time per panel: 00h: 09m: 25s.

Date: 8/6/2014	Time						# of workers: 4
	Start:	9:00 am	End:	2:30 pm	Total:	330 min.	

Actions performed:

22 curtain wall panels installed at 4th Floor

Other comments:

Low workers' performance, lack of motivation (as per field supervisor comments).

Arguments between workers and field supervisor at the end of the day.

Date:	Time			# of workers:
8/7/2014	Start: 6:30 am	End: 10:10 am	Total: 160 min	4

Actions performed:

16 curtain wall panels installed at 4th Floor

Note:

Due to tolerance issues with precast panels at the Southwest corner, curtain wall installation stopped until precast subcontractor fix the problem. Curtain wall crew moved to other floors to continue panel's installation.

Date:	Time			# of workers:
8/7/2014	Start: N.A.	End: N.A.	Total: N.A.	4

Actions performed:

Installation of 4 curtain wall panels, one panel is located behind a concrete column.

Procedure:

Mobilization of first (1st) curtain wall panel from dolly panel cart to a final location utilizing a lift truck with a fork truck boom and a power vacuum cup lifting frame attached to it.

Time required: 00h: 02m: 05s.

1. Installation of first (1st) curtain wall panel over sill rail.

Time required: 00h: 02m: 35s.

Note: Due to tolerance issues between the curtain wall and precast panels, curtain wall panel is adjusted with a rubber hammer to make it fit into the opening. Time required: 00h: 00m: 35s.

Date: 8/7/2014	Time Start: N.A.	End: N.A.	Total: N.A.	# of workers: 4

Actions performed:

Installation of 4 curtain wall panels, one panel is located behind a concrete column.

Procedure (Cont.):

1. Interlocking of the first (1^{st}) panel with existing side panel.

Time required: 00h: 02m: 12s.

2. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (1^{st} panel).

Timer required: 00h: 03m: 07s.

3. Mobilization of second (2^{nd}) curtain wall panel from dolly panel cart to a final location utilizing a lift truck with a fork truck boom and a power vacuum cup lifting frame attached to it.

Time required: 00h: 02m: 15s.

4. Installation of second (2^{nd}) curtain wall panel over sill rail.

Time required: 00h: 03m: 32s.

Note: Due to tolerance issues between the curtain wall and precast panels, the curtain wall panel is adjusted with a rubber hammer, and one (1) anchor has to be removed to make it fit into the opening.

Time required: 00h: 02m: 48s.

5. Interlocking of second (2^{nd}) panel with the first (1^{st}) panel.

Time required: 00h: 01m: 54s.

Date: 8/7/2014	Time			# of workers: 4
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of 4 curtain wall panels, one panel is located behind a concrete column.

Procedure (Cont.):

6. Curtain wall anchors screwing (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (1^{st} and 2^{nd} panels). Timer required: 00h: 03m: 15s.
7. Mobilization of the third (3^{rd}) curtain wall panel from dolly panel cart to a final location utilizing a lift truck with a fork truck boom and a power vacuum cup lifting frame attached to it.

Time required: 00h: 02m: 35s.

8. Installation of third (3^{rd}) curtain wall panel over sill rail.

Time required: 00h: 03m: 58s.

9. Interlocking of third (3^{rd}) panel with second (2^{nd}) panel.

Time required: 00h: 01m: 05s.

10. Curtain wall anchors screwing (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (3^{rd} panel).

Timer required: 00h: 03m: 32s.

Date:	Time			# of workers:
8/7/2014	Start: N.A.	End: N.A.	Total: N.A.	4

Actions performed:

Installation of 4 curtain wall panels, one panel is located behind a concrete column.

Procedure (Cont.):

11. Mobilization of the fourth (4th) curtain wall panel from dolly panel cart to a final location utilizing a lift truck with a fork truck boom and a power vacuum cup lifting frame attached to it.

Time required: 00h: 03m: 15s.

Installation of forth (4th) curtain wall panel over sill rail.

Time required: 00h: 01m: 48s.

12. Interlocking of forth (4th) panel with third (3rd) panel.

Time required: 00h: 01m: 36s.

13. Curtain wall anchors screw (holes drilling, shimming, installation of expansion bolts and screwed) worker utilized a scissor lift (3rd panel).

Timer required: 00h: 04m: 23s.

Results: 4 curtain wall panels were installed in 00h: 31m: 56s.

Average time per panel: 00h: 07m: 49s.

Date: 8/9/2014	Time			# of workers: 2
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of sill rail 24-foot length at the South façade.

Procedure:

1. Location of sill rail on top of the precast panel and alignment utilizing control lines.

Time required: 00h: 00m: 20s.

2. Drilling of the first (1) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 55s.

3. The worker moves from the first hole to the 2nd hole location.

Time required: 00h: 00m: 30s.

4. Drilling of the second (2nd) and third (3rd) holes on top of sill rail, including shimming and screwing.

Time required: 00h: 01m: 50s.

5. The worker moves from the third (3rd) hole to the fourth (4th) hole location.

Time required: 00h: 00m: 10s.

6. Drilling of the fourth (4) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 01m: 16s.

Date:	Time			# of workers:
8/9/2014	Start: N.A.	End: N.A.	Total: N.A.	2

Actions performed:

Installation of sill rail 24-foot length.

Procedure (Cont.):

1. The worker moves from the fourth (4^{th}) to the fifth (5^{th}) hole location.

Time required: 00h: 00m: 07s.

2. Drilling of the fifth (5^{th}) and sixth (6^{th}) on top of sill rail, including shimming and screwing.

Time required: 00h: 02m: 31s.

3. Worker is moving from the sixth (6^{th}) to the seventh (7^{th}) hole location.

Time required: 00h: 00m: 05s.

4. Drilling of the sixth (6^{th}) and seventh (7^{th}) on top of sill rail, including shimming and screwing.

Time required: 00h: 02m: 23s.

5. Worker moving from the seventh (7^{th}) to the eighth (8^{th}) hole location.

Time required: 00h: 00m: 06s.

6. Drilling of the eighth (8^{th}) and ninth (9^{th}) on top of sill rail, including shimming and screwing.

Time required: 00h: 02m: 35s.

Results: Installation of one (1) sill rail 24-foot length was 00h: 12m: 48s.

Date: 8/11/2014	Time			# of workers: 2
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of two (2) sill rails, 12-foot length at the Southeast building corner.

Procedure (Cont.):

1. Location of two (2) sill rails on top of precast panels and alignment utilizing control lines at the Southeast building corner.

Time required: 00h: 02m: 43s.

2. Drilling of two (2) hole on top of sill rails (one hole per sill length), including shimming and screwing at corner joint.

Time required: 00h: 03m: 10s.

3. Alignment verification at the end of sill rail located at the East façade and drilling of two (2) holes on top of sill rail, screwing without shimming.

Time required: 00h: 00m: 59s.

4. Drilling, screwing and shimming 12 holes along corner sill rails located at East and South façades.
5. Timer required: 00h: 16m: 15s.

Results: Installation of two (2) sill rails 12-foot length (each) was 00h: 23m: 07s.

Date:	Time			# of workers:
8/11/2014	Start: N.A.	End: N.A.	Total: N.A.	2

Actions performed:

Installation of 24-foot length sill rail at the East façade.

Procedure:

1. Location of sill rail on top of the precast panel and alignment utilizing control lines.

Time required: Not registered.

2. Drilling two (2) holes on top of sill rail, including shimming and screwing.

Time required: 00h: 01m: 23s.

3. Worker is moving from the fourth (4^{th}) to the fifth (5^{th}) hole location.

Time required: 00h: 00m: 19s.

4. Drilling one (1) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 45s.

5. Worker is moving from the sixth (6^{th}) to the seventh (7^{th}) hole location.

Time required: 00h: 00m: 13s.

6. Drilling one (1) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 42s.

7. Worker is moving from the seventh (7^{th}) to the eighth (8^{th}) hole location and relocation of power cord extension.

Time required: 00h: 00m: 45s.

Date:	Time						# of workers:
8/12/2014	Start:	4:30 am	End:	12:00 pm	Total:	07h 30m	8

Actions performed:

Material mobilization (curtain wall panels) from 1st to the 11th floor.

Procedure:

Mobilization of eight (8) dolly carts with curtain wall panels from first (1st) to eleventh (11th) floor utilizing a tower crane.

Results: Time required performing the action: 07h: 30m: 00s.

Date:	Time						# of workers:
8/13/2014	Start:	7:30 am	End:	10:17 am	Total:	2h 47 min.	4

Actions performed:

Installation of fifteen (15) curtain wall frames on 2nd floor, West façade

Results: Time required performing the action: 02h: 47m: 00s.

Date:	Time						# of workers:
8/13/2014	Start:	10:17 am	End:	11:30 am	Total:	1h 13 m.	4

Actions performed:

Installation of four (4) curtain wall frames on 2nd floor, South façade

Results: Time required performing the action: 01h: 13m: 00s.

Date: 8/11/2014	Time			# of workers: 2
	Start: N.A.	End: N.A.	Total: N.A.	

Actions performed:

Installation of 24-foot length sill rail at the East façade.

Procedure (Cont.):

8. Drilling of two (2) holes on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 54s.

9. Worker is moving from the seventh (7^{th}) to the eighth (8^{th}) hole location.

Time required: 00h: 00m: 05s.

10. Drilling of one (1) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 41s.

11. Worker is moving from the seventh (7^{th}) to the eighth (8^{th}) hole location.

Time required: 00h: 00m: 06s.

12. Drilling of two (2) holes on top of sill rail, including shimming and screwing.

Time required: 00h: 01m: 15s.

13. One worker began drilling the holes, and the other worker is installing shims and screwing (from step 13 to 16).

Time required: 00h: 00m: 58s.----

14. Drilling of one (1) hole on top of sill rail, including shimming and screwing.

Time required: 00h: 00m: 56s.

15. Worker is moving from the seventh (7^{th}) to the eighth (8^{th}) hole location.

Time required: 00h: 00m: 09s.

Date:	Time			# of workers:
8/11/2014	**Start:** N.A.	**End:** N.A.	**Total:** N.A.	2

Actions performed:

Installation of 24-foot length sill rail at the East façade.

Procedure (Cont.):

1. Drilling two (2) holes on top of sill rail, including shimming and screwing. Time required: 00h: 01m: 45s

Results: Installation of one (1) sill rail 24-foot length was 00h: 10m: 56s.

Date:	Time			# of workers:
8/13/2014	**Start:** 12:30 pm	**End:** 3:00 pm	**Total:** 2h 30 m.	3

Actions performed:

Installation of ten (10) curtain wall frames on 2nd floor, south façade

Results: Time required performing the action: 02h: 30m: 00s.

Date:	Time			# of workers:
8/13/2014	**Start:** 7:30 am	**End:** 11:00 am	**Total:** 3h 30 min.	2

Actions performed:

Installation of one (1) curtain wall frame at 5th floor, south façade.

Installation of eight (8) curtain wall frames at 5th floor, east façade.

Results: Time required performing the action: 03h: 30m: 00s.

Date:	Time			# of workers:
8/13/2014	Start: 12:30 pm	End: 3:30 pm	Total: 3h 00 m.	3
Actions performed: Installation of ten (10) curtain wall frames on 2nd floor, south façade **Results:** Time required performing the action: 02h: 30m: 00s.				

Date:	Time			# of workers:
8/14/2014	Start: 7:30 am	End: 9:15 am	Total: 1h 45 m.	4
Actions performed: Installation of seven (7) curtain wall frames on the 5th floor, south façade. **Note:** During the installation process, one (1) glass unit broke, causing a forty (40) minutes delay on installation (cleaning at 1st floor, safety inspection and unit replacement). **Results:** Time required performing the action: 02h: 30m: 00s.				

Date:	Time			# of workers:
8/14/2014	Start: 9:30 am	End: 10:15 am	Total: 45 m.	4
Actions performed: Installation of five (5) curtain wall frames on 5th floor, south façade **Results:** Time required performing the action: 03h: 00m: 00s.				

Date:	Time						# of workers:
8/15/2014	Start:	7:30 am	End:	3:00 pm	Total:	7 h.*	4

Actions performed:

Installation of five (5) curtain wall frames on the 5th floor, east façade.

Installation of nine (9) curtain wall frames on the 5th floor, south façade.

Installation of fifteen (15) curtain wall frames on the 5th floor, east façade.

Installation of fourteen (14) curtain wall frames on the 5th floor, south façade.

Results: Time required performing the action: 07h: 00m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date:	Time						# of workers:
8/18/2014	Start:	7:00 am	End:	8:30 am	Total:	1h 30 m.	4

Actions performed:

Verification of sill rail level at the East façade and installation of sill rail south façade (3rd floor).

Results: Time required performing the action: 01h: 30m: 00s.

Date:	Time						# of workers:
8/18/2014	Start:	8:42 am	End:	10:44 am	Total:	2h 2 m.	4

Actions performed:

Installation of ten (10) curtain wall frames on 3rd floor, east façade

Results: Time required performing the action: 02h: 02m: 00s.

Date:	Time			# of workers:
8/18/2014	**Start:** 10:44 am	**End:** 3:00 pm	**Total:** 3h 46 m.*	4

Actions performed:

Installation of five (5) curtain wall frames on 3rd floor, east façade.

Installation of thirteen (13) curtain wall frames on 3rd floor, south façade

Results: Time required performing the action: 03h: 46m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date:	Time			# of workers:
8/19/2014	**Start:** 7:00 am	**End:** 3:00 pm	**Total:** 7h 30 m.*	4

Actions performed:

Sill rail installation at 7th floor (sill rail cannot be installed yet at the 6th floor because precast panels must be adjusted first by the precast subcontractor). The track was installed at north and east façades, and partially at south-east corner.

Removal of dolly panel carts located from 2nd to 5th floors)

Results: Time required performing the action: 07h: 30m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date:	Time			# of workers:
8/20/2014	**Start:** 7:00 am	**End:** 3:00 pm	**Total:** 7h 30 m.*	4

Actions performed:

Installation of twenty-three (23) curtain wall frames on the 7th floor, east façade.

Results: Time required performing the action: 07h: 30m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date:	Time						# of workers:
8/20/2014	Start:	7:00 am	End:	3:00 pm	Total:	7h 30 m.*	4

Actions performed:

Installation of twenty-eight (28) curtain wall frames on the 7th floor, north façade.

Results: Time required performing the action: 07h: 30m: 00s.

Date:	Time						# of workers:
8/21/2014	Start:	7:00 pm	End:	3:00 pm	Total:	7h 30 m.*	4

Actions performed:

Installation of twenty (20) curtain wall frames on the 7th floor, north façade.

Installation of three (3) curtain wall frames on the 7th floor, west façade.

Finishing sill rail installation at the Southwest corner.

Results: Time required performing the action: 07h: 30m: 00s.

Date:	Time						# of workers:
8/22/2014	Start:	5:00 am	End:	1:00 pm	Total:	07h: 30m*	8

Actions performed:

Material mobilization (curtain wall panels) from 1st to the 12th floor.

Procedure:

Mobilization of eight (8) dolly carts with curtain wall panels from first (1st) to twelve (12th) floor utilizing a tower crane.

Results: Time required performing the action: 07h: 30m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date: 8/25/2014	**Time**			**# of workers:**
	Start: 8:30 am	**End:** 5:00 pm	**Total:** 7h 30 m.*	4

Actions performed:

Installation of twenty-one (21) curtain wall frames at 7th floor, west façade.

Installation of twenty-one (21) curtain wall frames at 7th floor, south façade.

Results: Time required performing the action: 07h: 30m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

Date: 8/28/2014	**Time**			**# of workers:**
	Start: 6:00 am	**End:** 2:30 pm	**Total:** 7h 30 m.*	8

Actions performed:

Installation of twenty-two (22) curtain wall frames on the 6th floor, north façade.

Installation of twenty-four (24) curtain wall frames on the 6th floor, east façade.

Installation of fourteen (14) curtain wall frames on the 6th floor, south façade.

Results: Time required performing the action: 07h: 30m: 00s.

***Note:** Thirty (30) minutes have been discounted due to lunch time.

APPENDIX C

MEASUREMENTS COLLECTED IN THE FIELD

Portions of the Building Where the Curtain Wall was Installed

The data is from the 2nd to the 5th floor and the 7th floor. Specific type of measurements are given capital letters (Table C-1 and Figures C-1, C-2 and C3) and the results include partial floor plans, tables with the measurements, and the tolerances and plots for each floor. The inventory of the results is indicated in Table C-2.

Table C-1 Nomenclature utilized to collect the information in the field

Nomenclature	Location	Figure #
A	Distance from existing horizontal control line to the bottom of curtain wall panel.	C-1
B	Distance from top of precast panel to bottom of curtain wall panel.	C-3
C	Distance from top of curtain wall panel to bottom of precast panel.	C-2
D	Distance from control line to precast panel.	C-1
E	Distance from control line to curtain wall panel.	C-1
F	Distance from curtain wall anchor to precast panel.	C-2

Table C-2 Inventory of the data collected and its results

Floor	Partial Floor Plan (Figure #)	Table #	Plots (Figure #)
2nd	C-5	C-5	C-6, C-7, C-8
3rd	C-9	C-6	C-10, C-11, C-12
4th	C-13	C-7	C-14, C-15, C-16
5th	C-17	C-8	C-18, C-19, C-20
7th	C-21	C-9	C-22, C-23, C-24

Clean Openings Ready for Curtain Wall Installation

The data is from the 8th to the 11th floor. Specific type of measurements are given again capital letters (Table C-3 and Figure C-4) and the results also include partial floor plans, tables with the measurements, and the tolerances and plots for each floor (see Table C-4).

Table C-3 Nomenclature utilized to collect the information in the field

Nomenclature	Location	Figure #
A	Distance from existing horizontal control line to the laser line.	C-4
B	Distance from top of precast panel to the laser line.	
C	Distance from bottom of precast panel to laser line.	
D	Distance from control line to precast panel.	

Table C-4 Inventory of the results

Floor	Partial Floor Plan (Figure #)	Tables	Plots (Figure #)
8th	C-25	C-10	C-26, C-27
9th	C-28	C-11	C-29, C-30
10th	C-31	C-12	C-32, C-33
11th	C-34	C-13	C-35, C-36

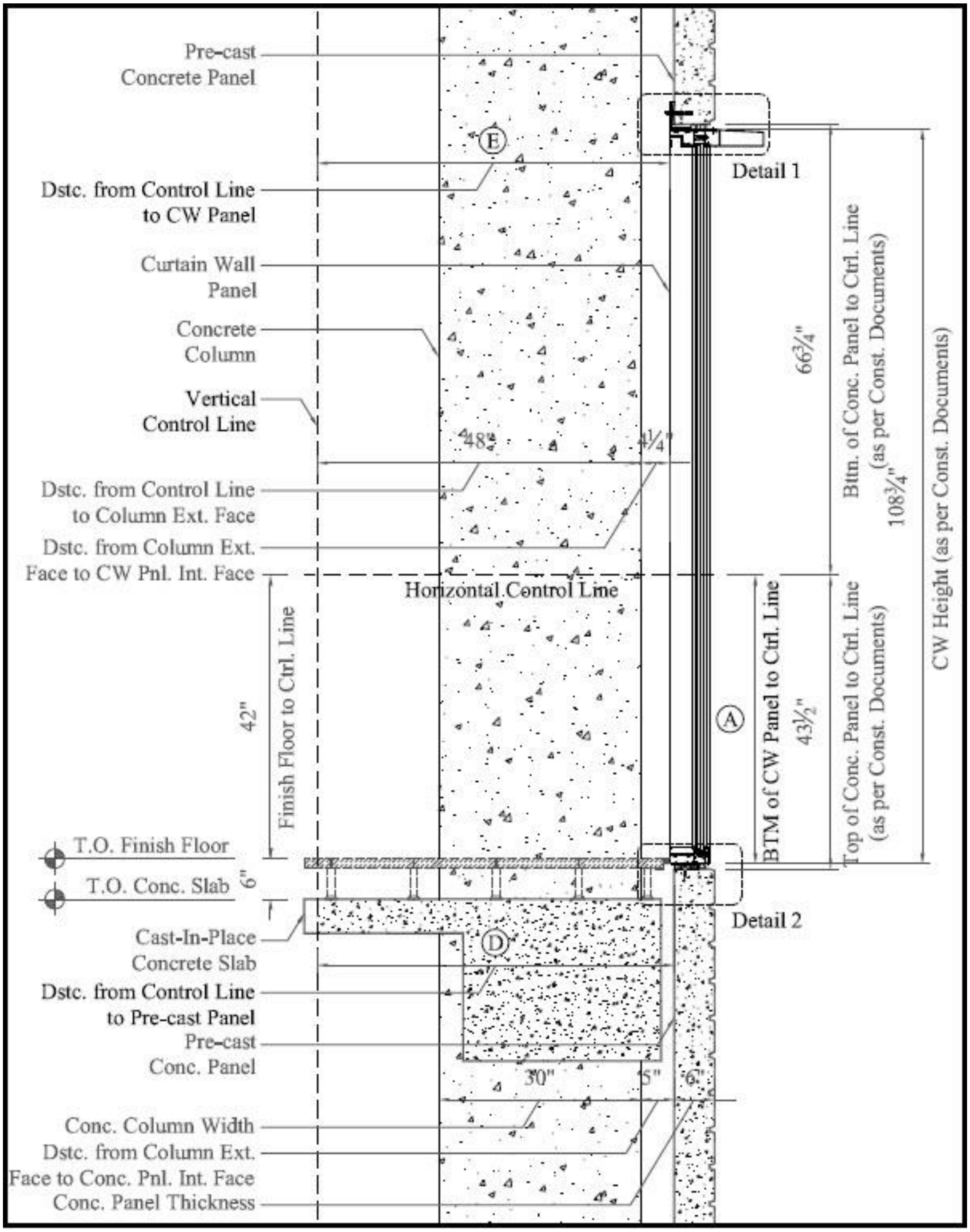


Figure C-1. Location of measurements from 2nd to 7th floor as per field condition. Letters A, D, and E denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

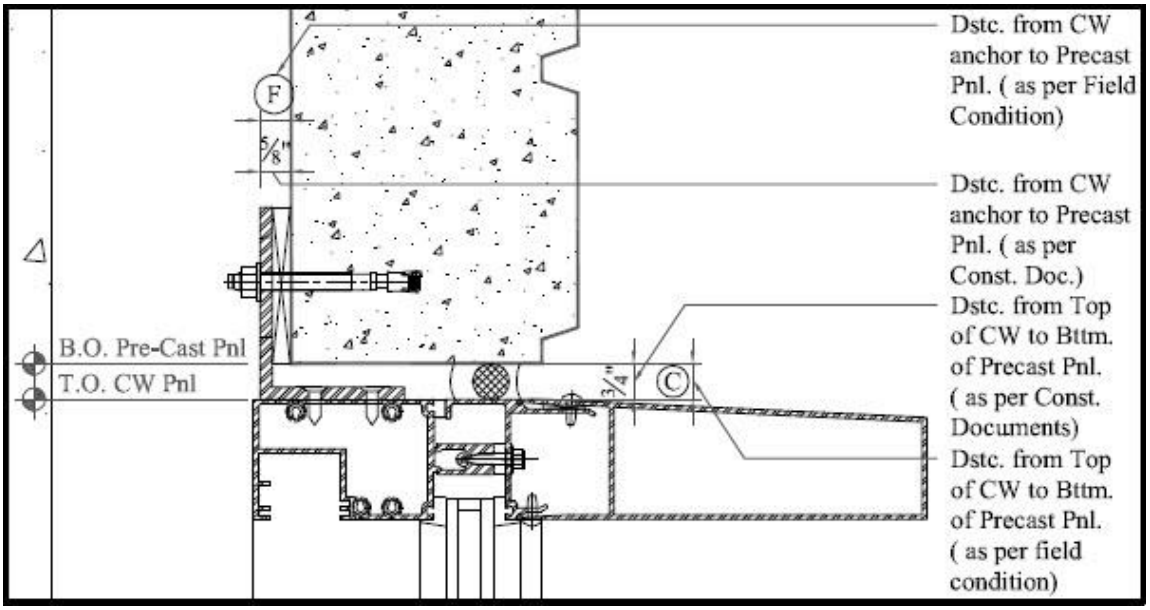


Figure C-2. Location of measurements at the head of the curtain wall panel as per field condition. See detail 1 on Figure C-1. Letter F indicates the distance between the anchor clip and the precast panel, and letter C the distance between the top of the curtain wall and the bottom of the precast panel. Adapted from Diaz, O. (2014).

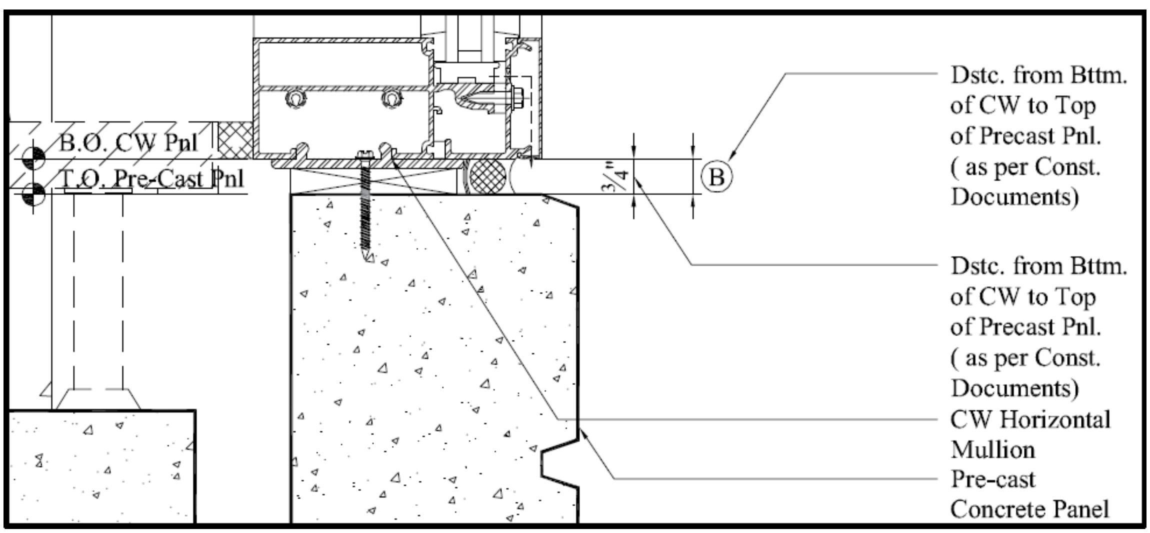


Figure C-3. Location of measurements at the sill of the curtain wall panel as per field condition. See detail 2 on Figure C-1. Letter B indicates the distance between the top of the precast panel and the bottom curtain wall system. Adapted from Diaz, O. (2014).

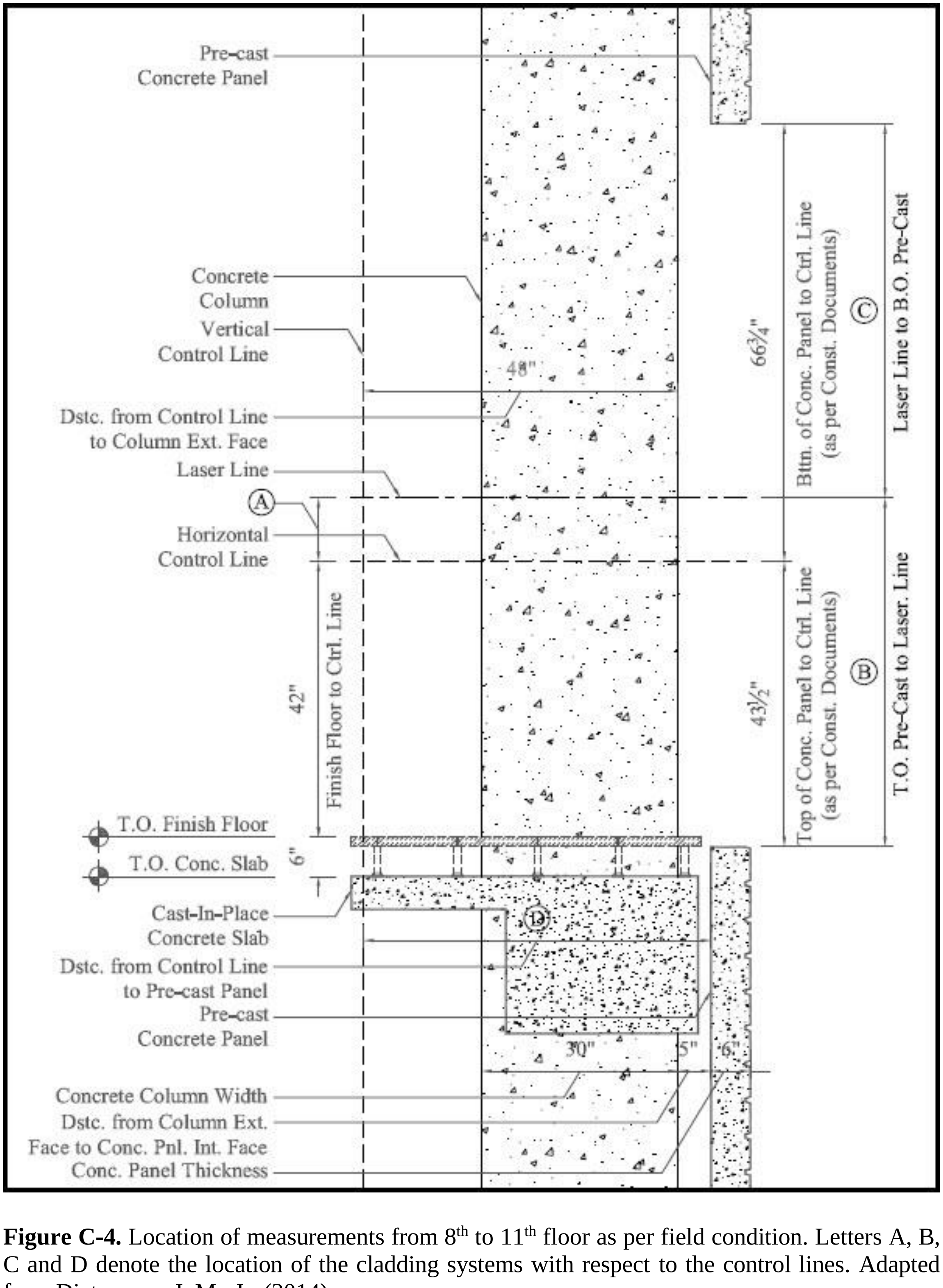


Figure C-4. Location of measurements from 8th to 11th floor as per field condition. Letters A, B, C and D denote the location of the cladding systems with respect to the control lines. Adapted from Dietzmann, J. M., Jr. (2014).

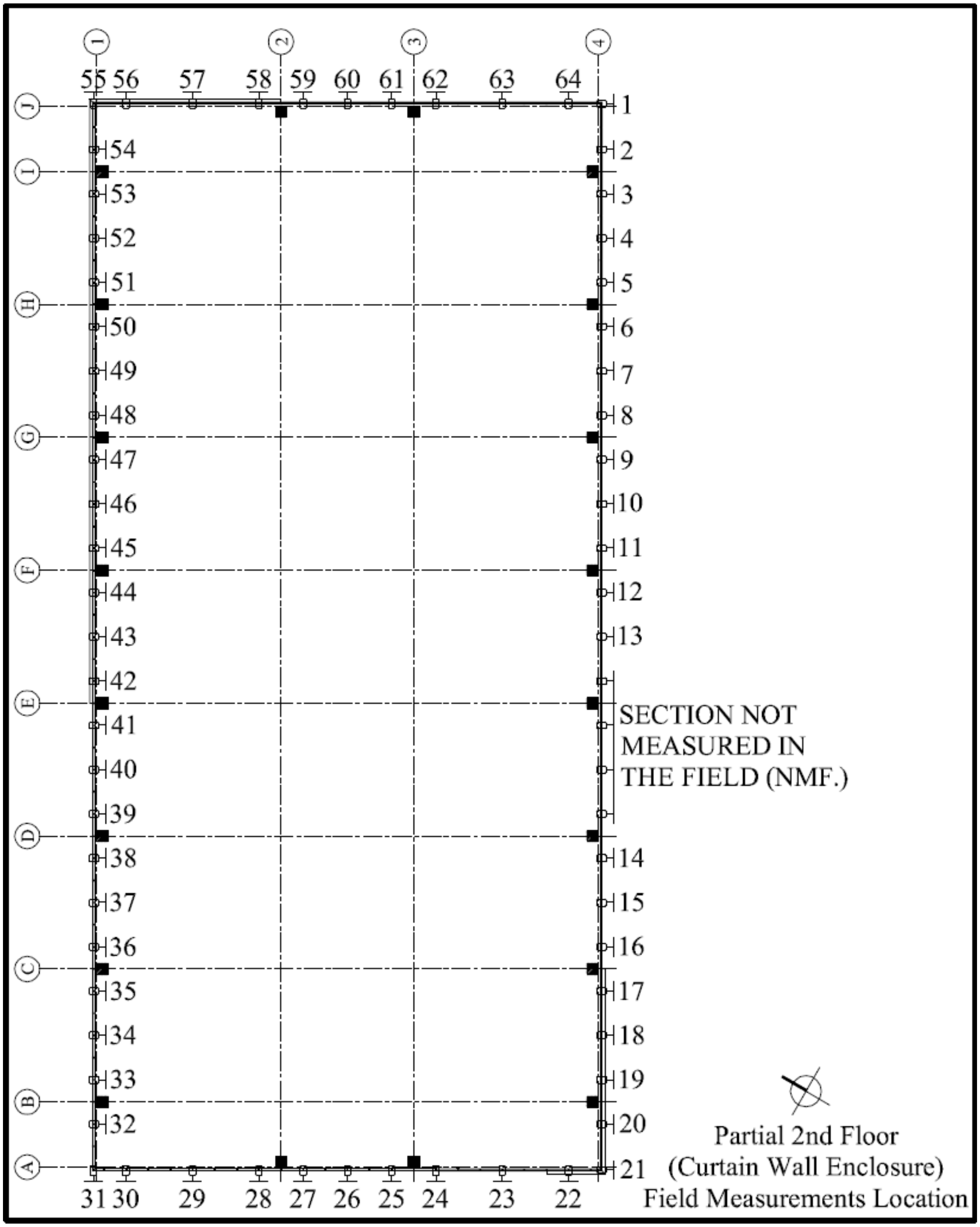


Figure C-5. Location of field measurements at 2nd floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-5 Field measurements at 2nd floor and tolerance calculations.

2nd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
1	42 5/8	13/16	1/2	52 1/2	52 1/2	0	1/16	1/8	1/2	- 1/4	- 3/8
2	42 5/8	11/16	9/16	52 7/8	52 5/8	1/4	3/16	1/16	1/8	- 3/8	- 1/8
3	42 5/8	1 3/16	5/16	52 7/8	52 3/8	1/4	- 5/16	5/16	1/8	- 1/8	- 1/8
4	42 5/8	5/8	5/16	N.A.	N.A.	N.A.	1/4	5/16	N.A.	N.A.	N.A.
5	42 5/8	13/16	5/16	52 1/2	52 1/4	13/16	1/16	5/16	1/2	0	7/16
6	42 5/8	13/16	1/4	53 1/8	52 1/2	1/2	1/16	3/8	- 1/8	- 1/4	1/8
7	42 5/8	5/8	0	N.A.	N.A.	N.A.	1/4	5/8	N.A.	N.A.	N.A.
8	42 5/8	13/16	0	52 7/8	52 1/4	11/16	1/16	5/8	1/8	0	5/16
9	42 5/8	7/8	1/4	52 3/4	52 1/4	3/8	0	3/8	1/4	0	0
10	42 5/8	3/4	3/8	N.A.	N.A.	N.A.	1/8	1/4	N.A.	N.A.	N.A.
11	42 5/8	3/4	3/8	52 3/4	52 1/4	5/8	1/8	1/4	1/4	0	1/4
12	42 5/8	3/4	1/4	53	52 1/2	5/8	1/8	3/8	0	- 1/4	1/4
13	42 5/8	9/16	1/4	N.A.	N.A.	N.A.	5/16	3/8	N.A.	N.A.	N.A.
14	42 5/8	13/16	7/16	53	52 3/8	5/8	1/16	3/16	0	- 1/8	1/4
15	42 5/8	5/8	5/16	N.A.	N.A.	N.A.	1/4	5/16	N.A.	N.A.	N.A.
16	42 5/8	13/16	3/8	52 1/4	52 3/16	1/4	1/16	1/4	3/4	1/16	- 1/8
17	42 5/8	13/16	5/8	52 1/4	52 1/4	1/4	1/16	0	3/4	0	- 1/8
18	42 5/8	5/8	5/8	N.A.	N.A.	N.A.	1/4	0	N.A.	N.A.	N.A.
19	42 5/8	13/16	7/8	52 3/8	52 3/8	11/16	1/16	- 1/4	5/8	- 1/8	5/16
20	42 5/8	13/16	9/16	52 3/4	52 5/8	1/4	1/16	1/16	1/4	- 3/8	- 1/8

*Refer to Figure C-5 for the location of the measurements taken in the field.

Table C-5 Continued

2nd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	**A**	**B**	**C**	**D**	**E**	**F**	**At Btm of CW**	**At Top of CW**	**Ctrl Ln to Conc. Pnl**	**Ctrl Ln to CW**	**CW Anchor to Conc. Pnl.**
21	42 5/8	1 3/16	1/2	52 7/8	52 1/2	1/4	- 5/16	1/8	1/8	- 1/4	- 1/8
22	42 5/8	15/16	7/16	52 7/8	52 1/4	5/8	- 1/16	3/16	1/8	0	1/4
23	42 5/8	3/4	3/8	N.A.	N.A.	N.A.	1/8	1/4	N.A.	N.A.	N.A.
24	42 5/8	15/16	7/16	52 7/8	52 3/8	3/8	- 1/16	3/16	1/8	- 1/8	0
25	42 5/8	13/16	1/2	53	52 3/8	9/16	1/16	1/8	0	- 1/8	3/16
26	42 5/8	5/8	3/8	N.A.	N.A.	N.A.	1/4	1/4	N.A.	N.A.	N.A.
27	42 5/8	13/16	5/16	53 3/8	52 3/8	1 3/16	1/16	5/16	- 3/8	- 1/8	13/16
28	42 5/8	13/16	5/16	53 1/4	52 1/8	1 1/16	1/16	5/16	- 1/4	1/8	11/16
29	42 5/8	7/8	3/8	N.A.	N.A.	N.A.	0	1/4	N.A.	N.A.	N.A.
30	42 5/8	15/16	3/8	53 3/8	52 1/8	13/16	- 1/16	1/4	- 3/8	1/8	7/16
31	42 5/8	11/16	3/8	53	52 3/8	1/4	3/16	1/4	0	- 1/8	- 1/8
32	42 5/8	7/8	3/8	53 1/4	52 3/8	7/16	0	1/4	- 1/4	- 1/8	1/16
33	42 5/8	7/8	1/8	53 5/16	52 3/4	1	0	1/2	- 5/16	- 1/2	5/8
34	42 5/8	13/16	1/4	52 1/2	52 3/4	11/16	1/16	3/8	1/2	- 1/2	5/16
35	42 5/8	7/8	3/8	53	52 3/8	5/8	0	1/4	0	- 1/8	1/4
36	42 5/8	7/8	1/2	53	52 1/4	1	0	1/8	0	0	5/8
37	42 5/8	1/2	9/16	N.A.	N.A.	N.A.	3/8	1/16	N.A.	N.A.	N.A.
38	42 5/8	7/8	1/2	53 9/16	53 1/2	1	0	1/8	- 9/16	-1 1/4	5/8
39	42 5/8	7/8	7/16	53 7/8	52 1/2	7/16	0	3/16	- 7/8	- 1/4	1/16

*Refer to Figure C-5 for the location of the measurements taken in the field.

Table C-5 Continued

2nd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
40	42 5/8	1/2	7/16	N.A.	N.A.	N.A.	3/8	3/16	N.A.	N.A.	N.A.
41	42 5/8	7/8	11/16	53 3/4	53 1/4	5/8	0	- 1/16	- 3/4	-1	1/4
42	42 5/8	13/16	9/16	52 13/16	52 9/16	11/16	1/16	1/16	3/16	- 5/16	5/16
43	42 5/8	1/4	1/2	N.A.	N.A.	N.A.	5/8	1/8	N.A.	N.A.	N.A.
44	42 5/8	13/16	11/16	52 5/8	52 3/8	7/16	1/16	- 1/16	3/8	- 1/8	1/16
45	42 5/8	13/16	7/16	52 7/8	52 1/4	11/16	1/16	3/16	1/8	0	5/16
46	42 5/8	1/2	7/16	N.A.	N.A.	N.A.	3/8	3/16	N.A.	N.A.	N.A.
47	42 5/8	13/16	1/2	52 7/8	52 3/8	5/8	1/16	1/8	1/8	- 1/8	1/4
48	42 5/8	15/16	9/16	53 1/8	52 3/8	5/8	- 1/16	1/16	- 1/8	- 1/8	1/4
49	42 5/8	5/8	5/8	N.A.	N.A.	N.A.	1/4	0	N.A.	N.A.	N.A.
50	42 5/8	9/16	5/8	53 1/4	40 3/8	7/8	5/16	0	- 1/4	11 7/8	1/2
51	42 5/8	15/16	11/16	53	52 1/2	3/8	- 1/16	- 1/16	0	- 1/4	0
52	42 5/8	3/4	3/8	N.A.	N.A.	N.A.	1/8	1/4	N.A.	N.A.	N.A.
53	42 5/8	7/8	1/4	52 7/8	52 1/4	7/16	0	3/8	1/8	0	1/16
54	42 5/8	11/16	1/4	52 3/4	52	0	3/16	3/8	1/4	1/4	- 3/8
55	42 5/8	3/4	1/4	52 3/4	52 5/8	7/16	1/8	3/8	1/4	- 3/8	1/16
56	42 5/8	3/16	7/16	52 7/8	52 3/8	15/16	11/16	3/16	1/8	- 1/8	9/16
57	42 5/8	0	1/8	N.A.	N.A.	N.A.	7/8	1/2	N.A.	N.A.	N.A.
58	42 5/8	3/16	7/16	53 1/8	52 1/4	3/4	11/16	3/16	- 1/8	0	3/8
59	42 5/8	5/8	1/2	53 1/8	52 3/8	5/8	1/4	1/8	- 1/8	- 1/8	1/4

*Refer to Figure C-5 for the location of the measurements taken in the field.

Table C-5 Continued

2nd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	**A**	**B**	**C**	**D**	**E**	**F**	**At Btm of CW**	**At Top of CW**	**Ctrl Ln to Conc. Pnl**	**Ctrl Ln to CW**	**CW Anchor to Conc. Pnl.**
60	42 5/8	7/16	5/16	N.A.	N.A.	N.A.	7/16	5/16	N.A.	N.A.	N.A.
61	42 5/8	3/8	1/2	53	52 7/16	5/8	1/2	1/8	0	- 3/16	1/4
62	42 5/8	9/16	1/4	52 5/8	52 7/16	0	5/16	3/8	3/8	- 3/16	- 3/8
63	42 5/8	1/4	7/16	N.A.	N.A.	N.A.	5/8	3/16	N.A.	N.A.	N.A.
64	42 5/8	3/4	3/8	52 5/8	52 3/8	0	1/8	1/4	3/8	- 1/8	- 3/8

*Refer to Figure C-5 for the location of the measurements taken in the field.

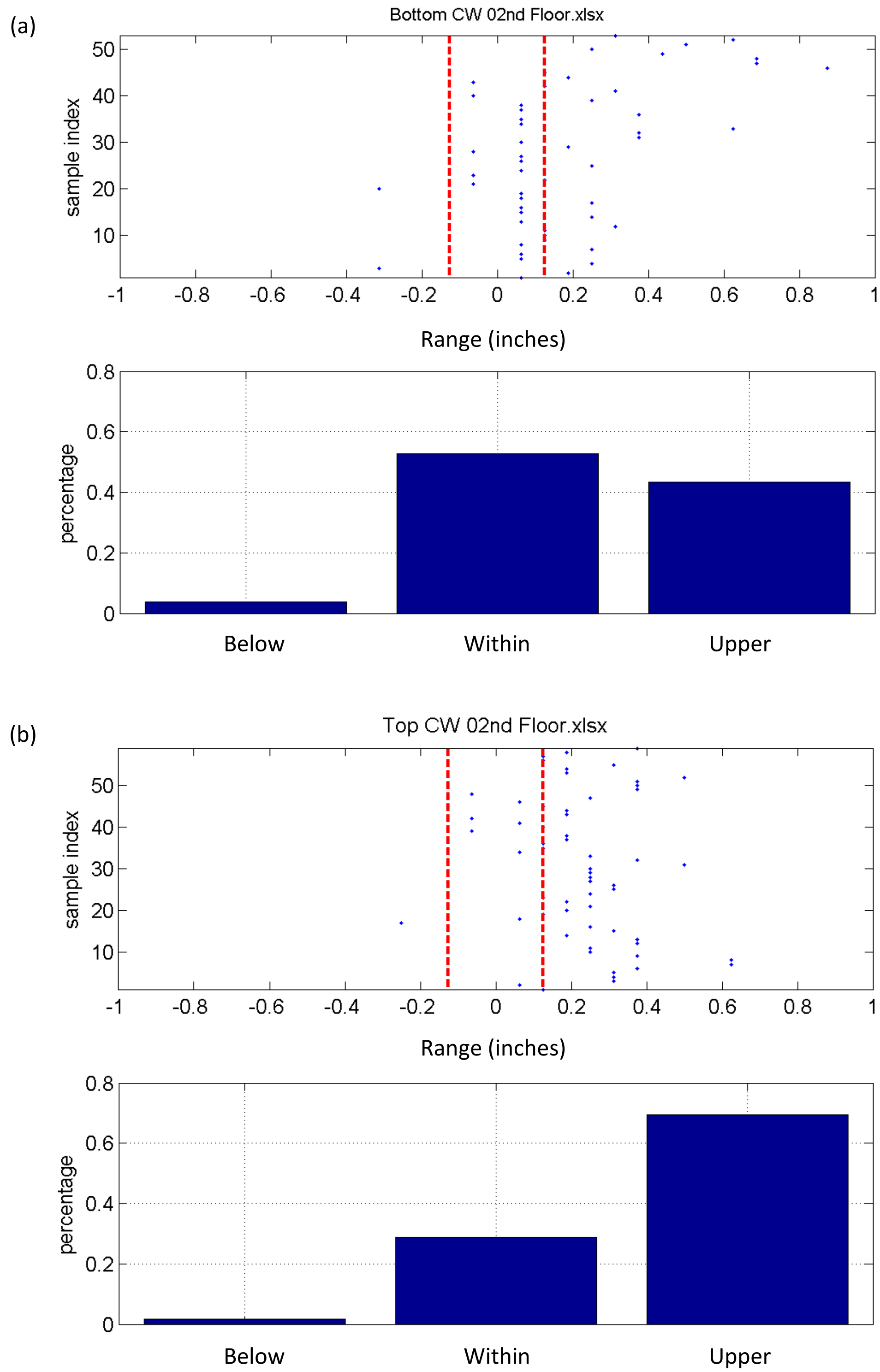
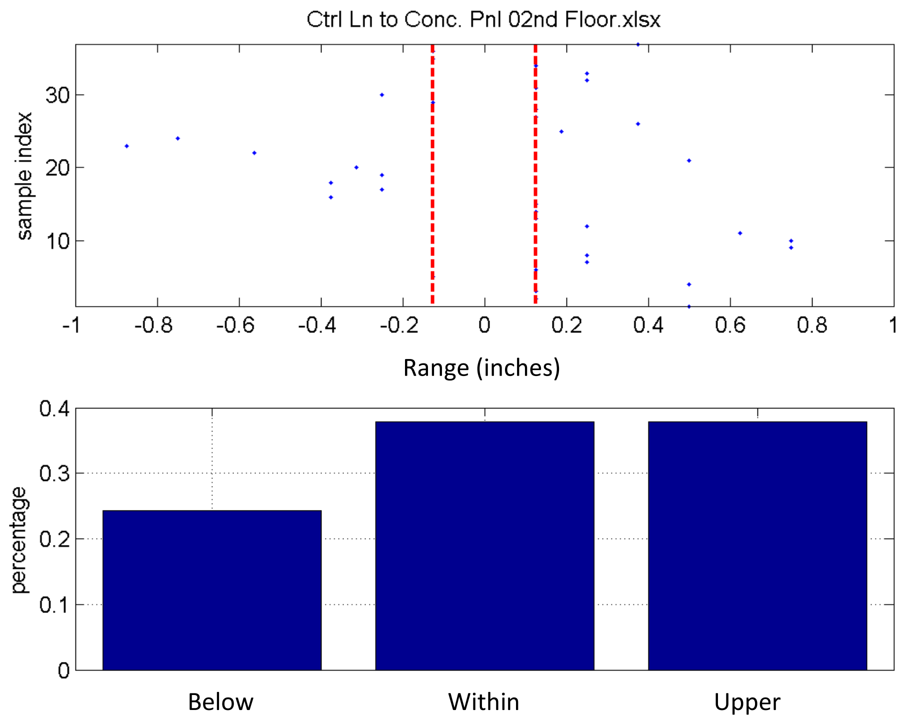


Figure C-6. Plots of tolerance results at the bottom of the curtain wall panel (a) and at the top of the curtain wall panel (b), 2nd floor.

(a)



(b)

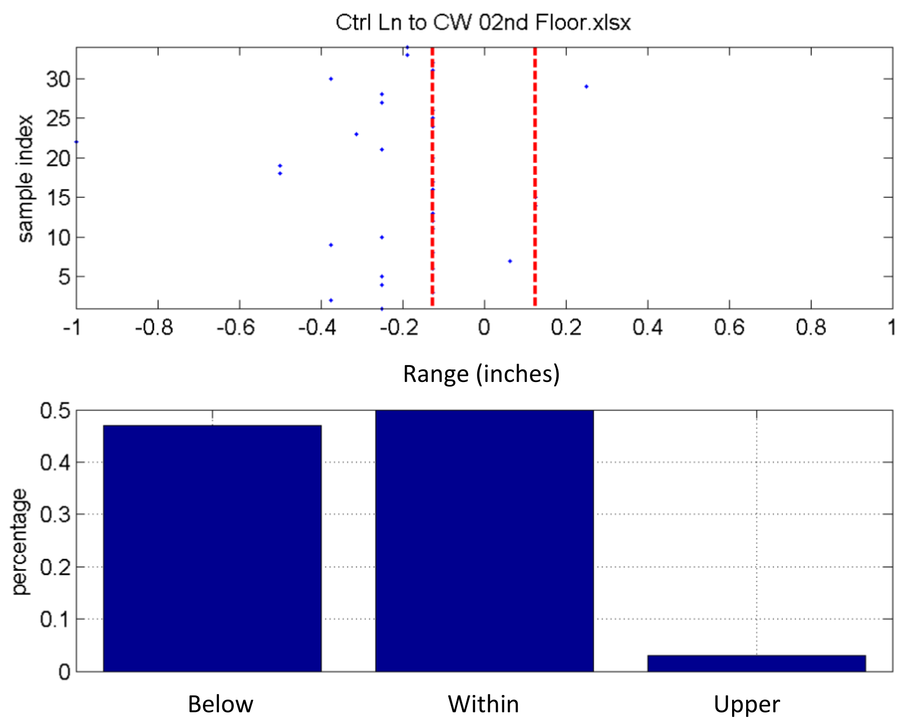


Figure C-7. Plots of tolerance results from control line to the precast panel (a) and from control line to curtain wall panel (b), 2nd floor.

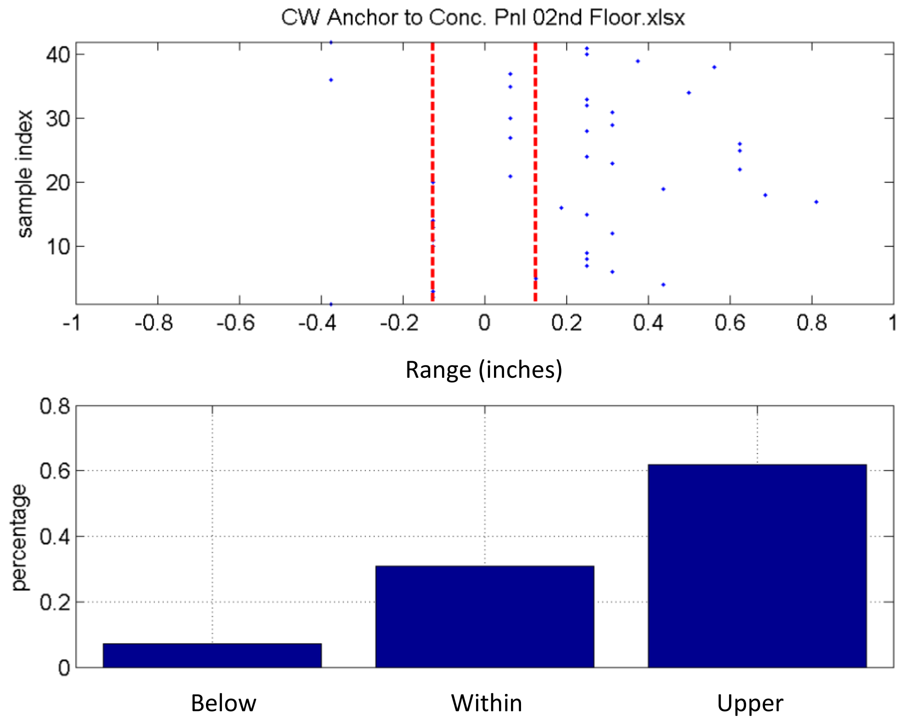


Figure C-8. Plot of tolerance results from curtain wall anchor clip to precast panel at 2nd floor.

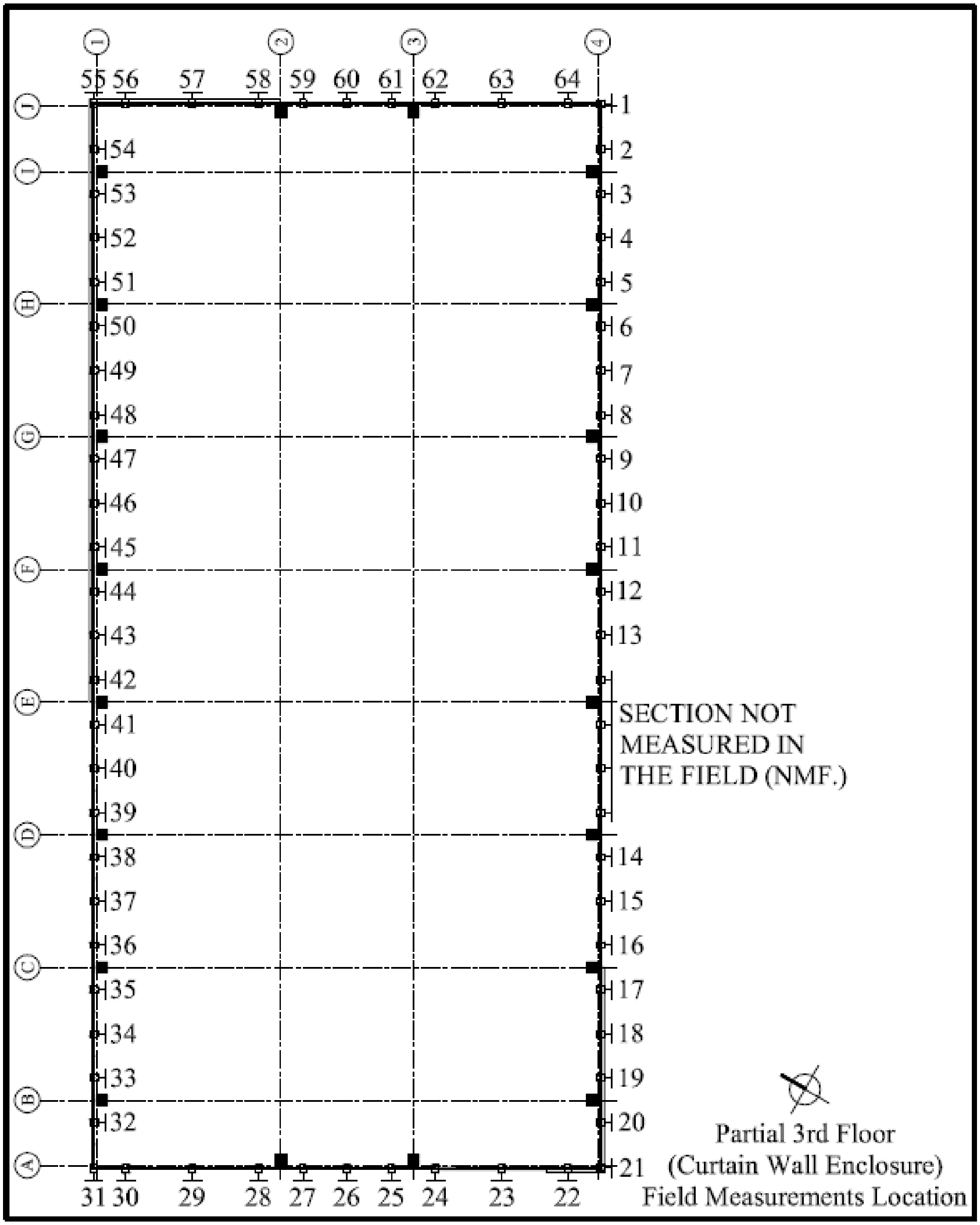


Figure C-9. Location of field measurements at 3rd floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-6 Field measurements at 3rd floor and tolerance calculations.

3rd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
1	42 5/8	15/16	1	52 3/4	52 1/2	1/4	- 1/16	- 3/8	1/4	- 1/4	- 1/8
2	42 5/8	13/16	3/4	52 1/2	52 1/2	7/16	1/16	- 1/8	1/2	- 1/4	1/16
3	42 5/8	15/16	7/16	52 3/4	52 5/8	1/4	- 1/16	3/16	1/4	- 3/8	- 1/8
4	42 5/8	7/8	1/4	N.A.	N.A.	N.A.	0	3/8	N.A.	N.A.	N.A.
5	42 5/8	15/16	1/4	52 7/8	52 3/8	1/4	- 1/16	3/8	1/8	- 1/8	- 1/8
6	42 5/8	1 1/16	0	53	52 1/2	1/4	- 3/16	5/8	0	- 1/4	- 1/8
7	42 5/8	1 1/16	3/8	N.A.	N.A.	N.A.	- 3/16	1/4	N.A.	N.A.	N.A.
8	42 5/8	15/16	7/16	52 3/4	52 1/8	1/4	- 1/16	3/16	1/4	1/8	- 1/8
9	42 5/8	1 3/16	1/2	53 1/8	52 5/8	5/16	- 5/16	1/8	- 1/8	- 3/8	- 1/16
10	42 5/8	1 5/16	3/8	N.A.	N.A.	N.A.	- 7/16	1/4	N.A.	N.A.	N.A.
11	42 5/8	1 1/4	5/16	53	52 5/8	5/16	- 3/8	5/16	0	- 3/8	- 1/16
12	42 5/8	1 3/16	1/4	53 1/8	52 5/8	1/2	- 5/16	3/8	- 1/8	- 3/8	1/8
13	42 5/8	1 3/4	1/4	N.A.	N.A.	N.A.	- 7/8	3/8	N.A.	N.A.	N.A.
14	42 5/8	3/4	7/16	53	52 3/8	11/16	1/8	3/16	0	- 1/8	5/16
15	42 5/8	11/16	7/16	N.A.	N.A.	N.A.	3/16	3/16	N.A.	N.A.	N.A.
16	42 5/8	13/16	5/16	52 5/8	52 1/4	1/2	1/16	5/16	3/8	0	1/8
17	42 5/8	13/16	5/8	52 1/2	52 3/8	7/16	1/16	0	1/2	- 1/8	1/16
18	42 5/8	11/16	5/8	N.A.	N.A.	N.A.	3/16	0	N.A.	N.A.	N.A.
19	42 5/8	9/16	7/8	53	52 5/16	5/8	5/16	- 1/4	0	- 1/16	1/4

*Refer to Figure C-9 for the location of the measurements taken in the field.

Table C-6 Continued

3rd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
20	42 5/8	9/16	11/16	52 5/8	52 1/2	1/2	5/16	- 1/16	3/8	- 1/4	1/8
21	42 5/8	9/16	3/4	52 3/4	52 9/16	3/4	5/16	- 1/8	1/4	- 5/16	3/8
22	42 5/8	13/16	15/16	52 1/2	52 1/2	1/2	1/16	- 5/16	1/2	- 1/4	1/8
23	42 5/8	9/16	7/8	N.A.	N.A.	N.A.	5/16	- 1/4	N.A.	N.A.	N.A.
24	42 5/8	9/16	1 3/16	52 5/8	52 3/8	1/4	5/16	- 9/16	3/8	- 1/8	- 1/8
25	42 5/8	11/16	3/4	52 3/4	52 3/8	1/2	3/16	- 1/8	1/4	- 1/8	1/8
26	42 5/8	11/16	11/16	N.A.	N.A.	N.A.	3/16	- 1/16	N.A.	N.A.	N.A.
27	42 5/8	7/8	3/4	53 1/4	52 1/4	9/16	0	- 1/8	- 1/4	0	3/16
28	42 5/8	1 1/16	13/16	53 1/4	52 1/4	5/8	- 3/16	- 3/16	- 1/4	0	1/4
29	42 5/8	1 1/16	9/16	N.A.	N.A.	N.A.	- 3/16	1/16	N.A.	N.A.	N.A.
30	42 5/8	7/8	1/2	53 1/4	52 1/4	7/16	0	1/8	- 1/4	0	1/16
31	42 5/8	13/16	1	52 7/8	52 1/2	9/16	1/16	- 3/8	1/8	- 1/4	3/16
32	42 5/8	15/16	1	53 1/4	52 1/4	13/16	- 1/16	- 3/8	- 1/4	0	7/16
33	42 5/8	1 1/16	3/4	53 1/4	52 1/8	5/8	- 3/16	- 1/8	- 1/4	1/8	1/4
34	42 5/8	1 1/16	1	N.A.	N.A.	N.A.	- 3/16	- 3/8	N.A.	N.A.	N.A.
35	42 5/8	1 1/16	1	53 1/4	52 1/4	13/16	- 3/16	- 3/8	- 1/4	0	7/16
36	42 5/8	15/16	5/8	53 1/8	52 3/8	5/8	- 1/16	0	- 1/8	- 1/8	1/4
37	42 5/8	15/16	11/16	N.A.	N.A.	N.A.	- 1/16	- 1/16	N.A.	N.A.	N.A.
38	42 5/8	13/16	5/8	53 1/4	52 1/4	13/16	1/16	0	- 1/4	0	7/16

*Refer to Figure C-9 for the location of the measurements taken in the field.

Table C-6 Continued

3rd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
39	42 5/8	15/16	11/16	53 1/8	52 1/4	7/16	- 1/16	- 1/16	- 1/8	0	1/16
40	42 5/8	15/16	3/8	N.A.	N.A.	N.A.	- 1/16	1/4	N.A.	N.A.	N.A.
41	42 5/8	13/16	11/16	52 3/4	52 3/8	1/2	1/16	- 1/16	1/4	- 1/8	1/8
42	42 5/8	13/16	5/16	52 7/8	52 1/4	7/16	1/16	5/16	1/8	0	1/16
43	42 5/8	15/16	7/16	N.A.	N.A.	N.A.	- 1/16	3/16	N.A.	N.A.	N.A.
44	42 5/8	13/16	7/16	52 1/2	52 1/4	7/16	1/16	3/16	1/2	0	1/16
45	42 5/8	13/16	1/2	52 5/8	52 1/2	1/2	1/16	1/8	3/8	- 1/4	1/8
46	42 5/8	13/16	9/16	N.A.	N.A.	N.A.	1/16	1/16	N.A.	N.A.	N.A.
47	42 5/8	13/16	11/16	52 3/4	52 1/2	1/4	1/16	- 1/16	1/4	- 1/4	- 1/8
48	42 5/8	13/16	1/4	53 3/4	52 1/2	3/4	1/16	3/8	- 3/4	- 1/4	3/8
49	42 5/8	7/16	9/16	N.A.	N.A.	N.A.	7/16	1/16	N.A.	N.A.	N.A.
50	42 5/8	5/16	1/2	52 1/8	52 3/8	9/16	9/16	1/8	7/8	- 1/8	3/16
51	42 5/8	11/16	3/4	N.A.	N.A.	N.A.	3/16	- 1/8	N.A.	N.A.	N.A.
52	42 5/8	13/16	9/16	52 1/2	52 1/2	5/16	1/16	1/16	1/2	- 1/4	- 1/16
53	42 5/8	13/16	9/16	52 1/2	52 1/2	1/4	1/16	1/16	1/2	- 1/4	- 1/8
54	42 5/8	13/16	3/8	52 1/2	52 1/2	1	1/16	1/4	1/2	- 1/4	5/8
55	42 5/8	13/16	3/4	52 5/8	52 5/8	1/4	1/16	- 1/8	3/8	- 3/8	- 1/8
56	42 5/8	11/16	3/4	53 3/4	52 3/4	5/8	3/16	- 1/8	- 3/4	- 1/2	1/4
57	42 5/8	11/16	1/2	N.A.	N.A.	N.A.	3/16	1/8	N.A.	N.A.	N.A.
58	42 5/8	9/16	11/16	53 1/8	52 7/8	5/8	5/16	- 1/16	- 1/8	- 5/8	1/4
59	42 5/8	9/16	9/16	53	52 3/4	1/4	5/16	1/16	0	- 1/2	- 1/8

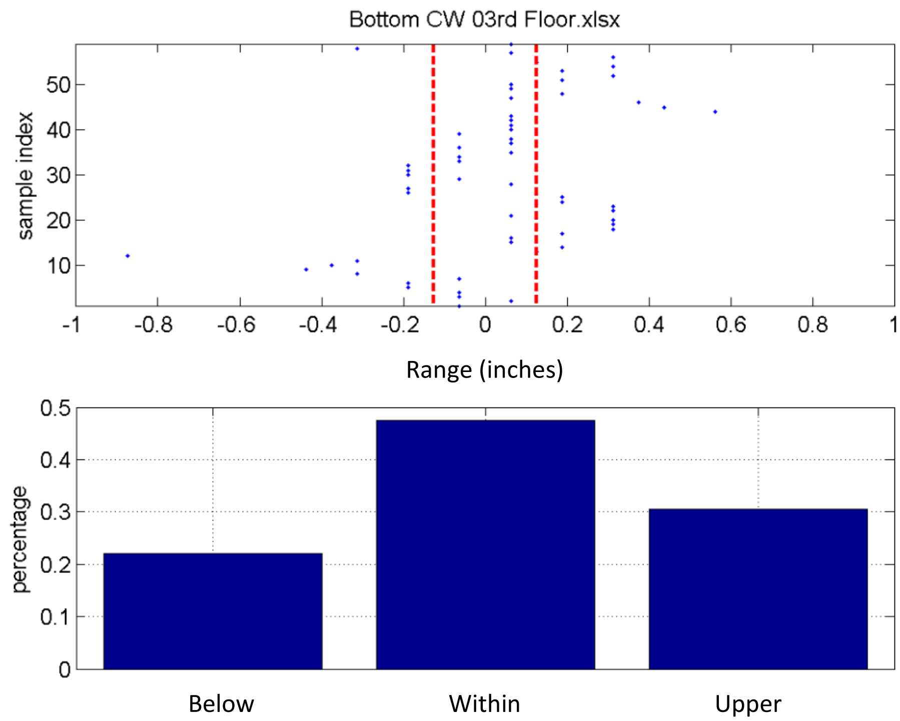
*Refer to Figure C-9 for the location of the measurements taken in the field.

Table C-6 Continued

3rd Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
60	42 5/8	9/16	3/4	N.A.	N.A.	N.A.	5/16	- 1/8	N.A.	N.A.	N.A.
61	42 5/8	3/4	3/4	53 1/8	52 5/8	1/4	1/8	- 1/8	- 1/8	- 3/8	- 1/8
62	42 5/8	13/16	3/8	53	52 3/4	7/16	1/16	1/4	0	- 1/2	1/16
63	42 5/8	13/16	1/4	N.A.	N.A.	N.A.	1/16	3/8	N.A.	N.A.	N.A.
64	42 5/8	13/16	1/2	52 7/8	52 3/4	7/16	1/16	1/8	1/8	- 1/2	1/16

*Refer to Figure C-9 for the location of the measurements taken in the field.

(a)



(b)

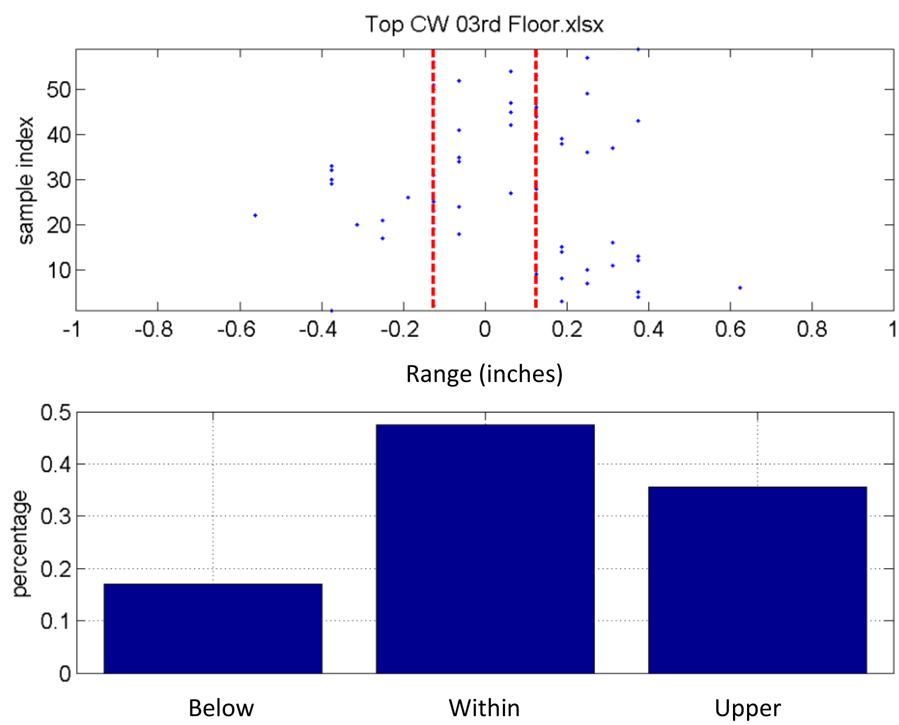


Figure C-10. Plots of tolerance results at the bottom of the curtain wall panel (a) and at the top of the curtain wall panel (b), 3rd floor.

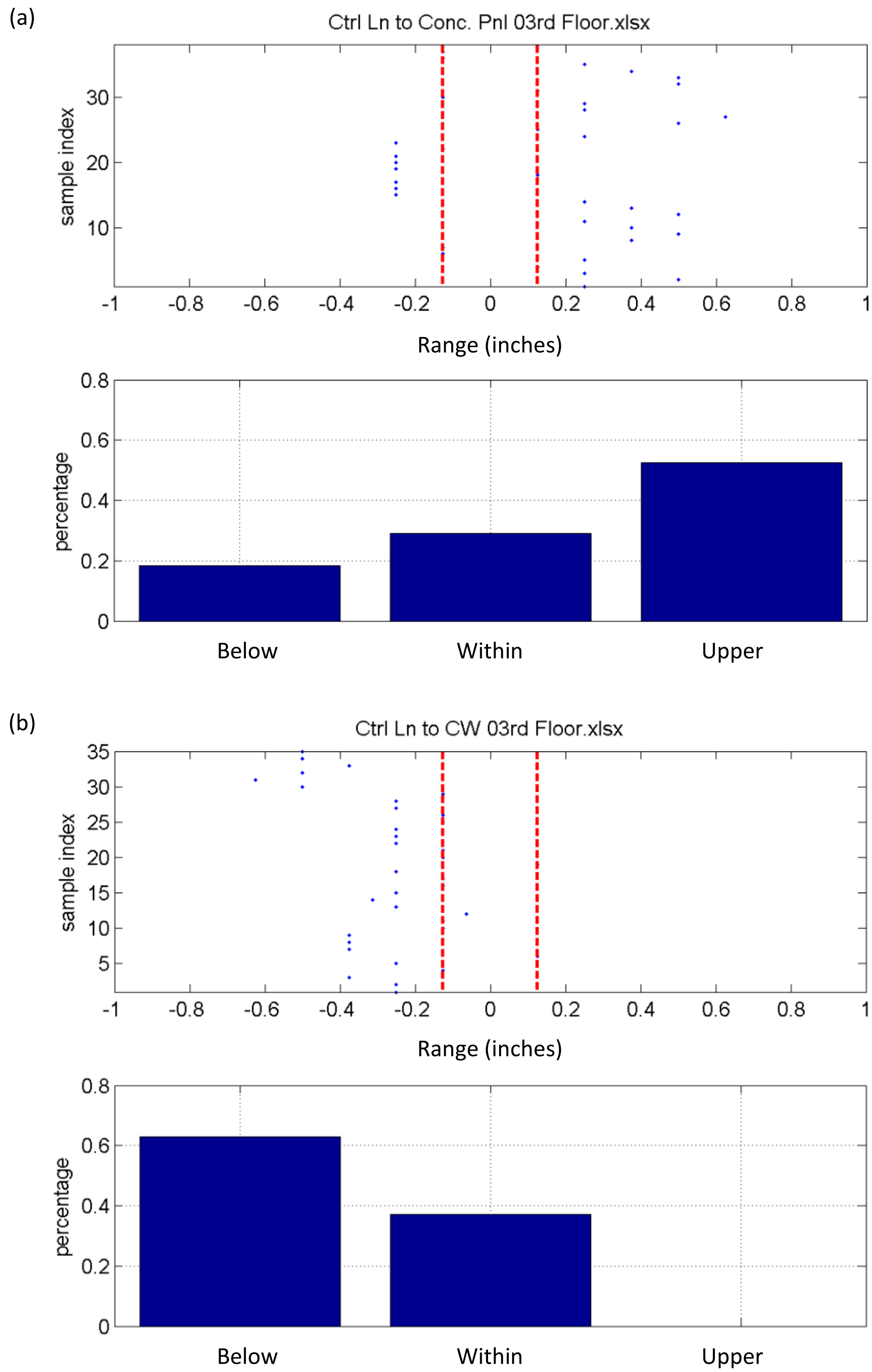


Figure C-11. Plots of tolerance results from control line to precast panel (a) and from control line to curtain wall panel (b), 3^{rd} floor.

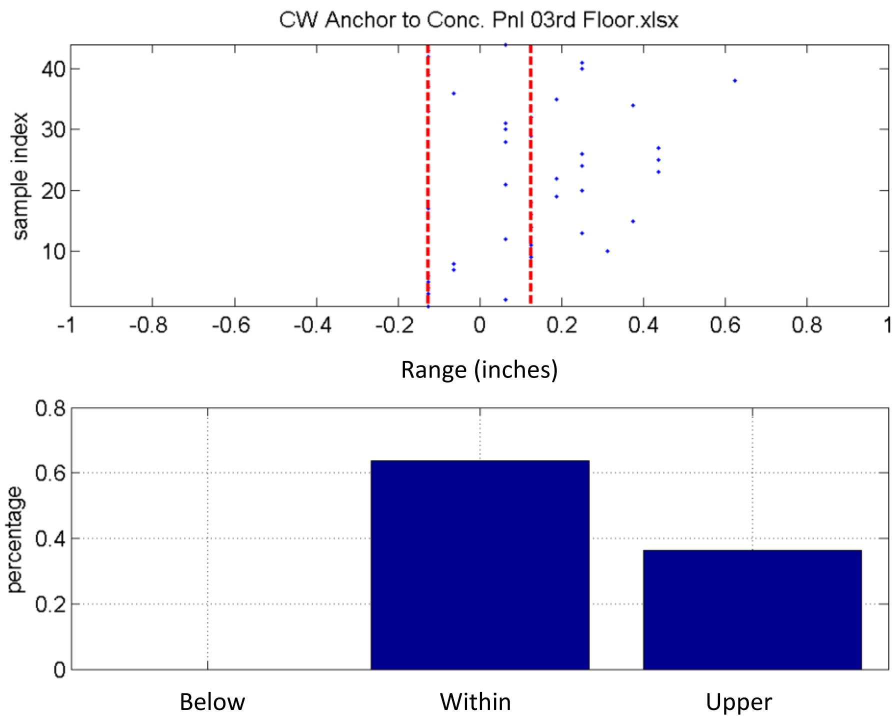


Figure C-12. Plot of tolerance results from curtain wall anchor clip to precast panel at 3rd floor.

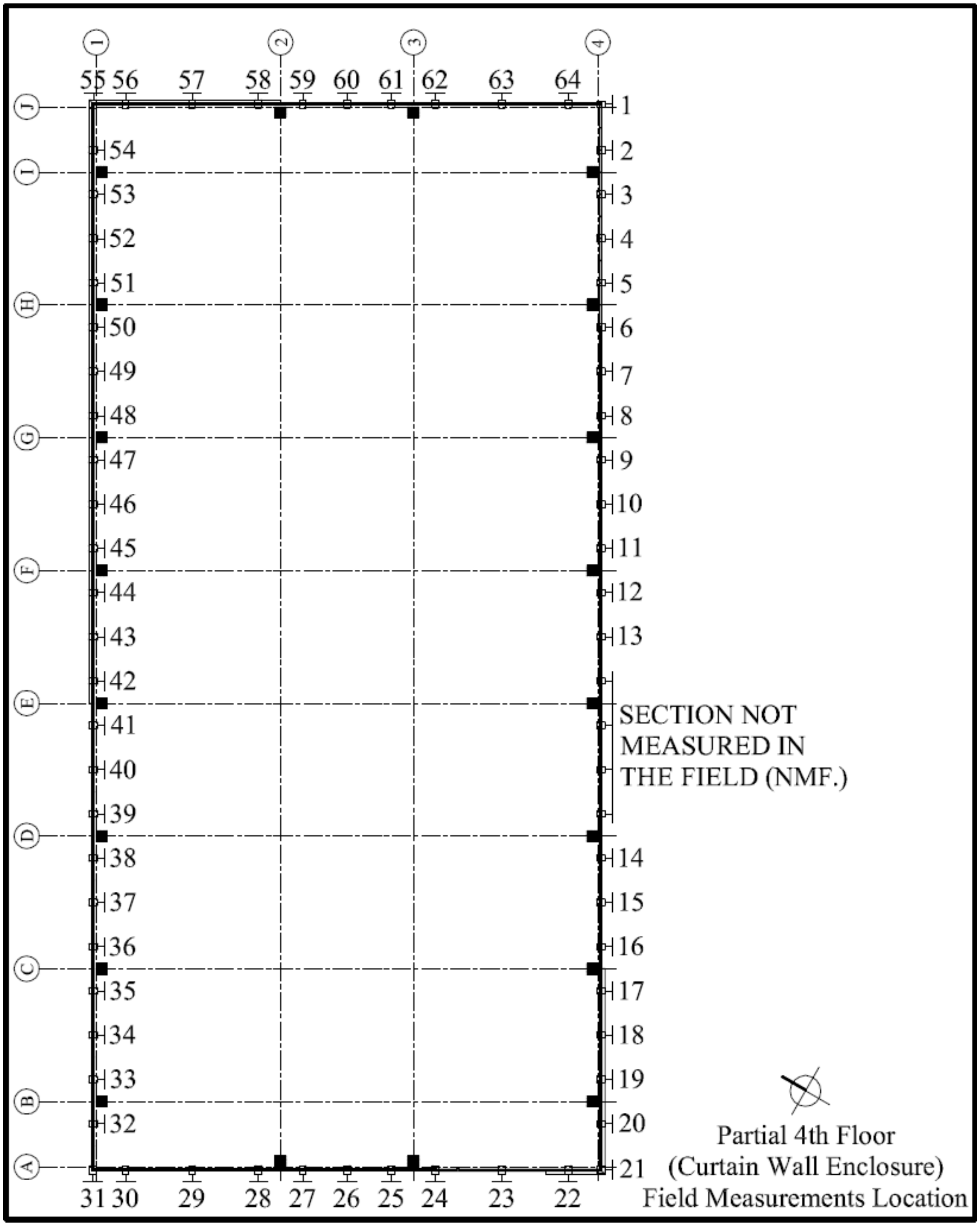


Figure C-13. Location of field measurements at 4th floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-7 Field measurements at 4th floor and tolerance calculations.

4th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
1	42 5/8	7/8	1/2	52 7/8	52 1/8	5/8	0	1/8	1/8	1/8	1/4
2	42 5/8	3/4	9/16	52 1/2	52 3/16	1/4	1/8	1/16	1/2	1/16	- 1/8
3	42 5/8	15/16	5/16	52 5/8	52	7/16	- 1/16	5/16	3/8	1/4	1/16
4	42 5/8	15/16	3/8	N.A.	N.A.	N.A.	- 1/16	1/4	N.A.	N.A.	N.A.
5	42 5/8	1 3/16	3/8	52 3/4	52 3/8	9/16	- 5/16	1/4	1/4	- 1/8	3/16
6	42 5/8	1 1/4	1/4	52 7/8	52 1/4	1/2	- 3/8	3/8	1/8	0	1/8
7	42 5/8	1	3/8	N.A.	N.A.	N.A.	- 1/8	1/4	N.A.	N.A.	N.A.
8	42 5/8	1 3/16	7/16	52 3/4	52 3/8	1/2	- 5/16	3/16	1/4	- 1/8	1/8
9	42 5/8	15/16	5/16	52 1/2	52	1/2	- 1/16	5/16	1/2	1/4	1/8
10	42 5/8	1 3/16	1/2	N.A.	N.A.	N.A.	- 5/16	1/8	N.A.	N.A.	N.A.
11	42 5/8	1 3/16	9/16	53	52 1/2	5/8	- 5/16	1/16	0	- 1/4	1/4
12	42 5/8	1 3/16	1/4	52 3/4	52 1/2	3/8	- 5/16	3/8	1/4	- 1/4	0
13	42 5/8	1 1/8	1/4	N.A.	N.A.	N.A.	- 1/4	3/8			
14	42 5/8	7/8	3/8	52 7/8	52 3/8	3/8	0	1/4	1/8	- 1/8	0
15	42 5/8	13/16	1/4	N.A.	N.A.	N.A.	1/16	3/8	N.A.	N.A.	N.A.
16	42 5/8	1 5/16	1/4	53	52 1/2	1/2	- 7/16	3/8	0	- 1/4	1/8
17	42 5/8	15/16	1/4	52 5/8	52 3/8	1/2	- 1/16	3/8	3/8	- 1/8	1/8
18	42 5/8	13/16	1/4	N.A.	N.A.	N.A.	1/16	3/8	N.A.	N.A.	N.A.
19	42 5/8	13/16	7/16	52 3/4	52 3/8	11/16	1/16	3/16	1/4	- 1/8	5/16

*Refer to Figure C-13 for the location of the measurements taken in the field.

Table C-7 Continued

4th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	**A**	**B**	**C**	**D**	**E**	**F**	**At Btm of CW**	**At Top of CW**	**Ctrl Ln to Conc. Pnl**	**Ctrl Ln to CW**	**CW Anchor to Conc. Pnl.**
20	42 5/8	13/16	1/4	52 7/8	52 3/8	7/16	1/16	3/8	1/8	- 1/8	1/16
21	42 5/8	9/16	0	52 5/8	52 5/8	5/16	5/16	5/8	3/8	- 3/8	- 1/16
22	42 5/8	3/4	5/16	52 7/8	52 1/2	1/2	1/8	5/16	1/8	- 1/4	1/8
23	42 5/8	11/16	5/16	N.A.	N.A.	N.A.	3/16	5/16	N.A.	N.A.	N.A.
24	42 5/8	9/16	3/8	52 3/8	52 3/8	3/8	5/16	1/4	5/8	- 1/8	0
25	42 5/8	9/16	3/8	52 5/8	52 3/8	3/4	5/16	1/4	3/8	- 1/8	3/8
26	42 5/8	9/16	1/2	N.A.	N.A.	N.A.	5/16	1/8	N.A.	N.A.	N.A.
27	42 5/8	3/4	9/16	52 7/8	52 1/2	7/8	1/8	1/16	1/8	- 1/4	1/2
28	42 5/8	13/16	3/8	53	52 1/4	1 1/8	1/16	1/4	0	0	3/4
29	42 5/8	15/16	7/16	N.A.	N.A.	N.A.	- 1/16	3/16	N.A.	N.A.	N.A.
30	42 5/8	13/16	1/4	53	52 3/8	11/16	1/16	3/8	0	- 1/8	5/16
31	42 5/8	9/16	1/4	52 5/8	52 3/8	5/8	5/16	3/8	3/8	- 1/8	1/4
32	42 5/8	3/4	1/2	53 1/4	52 3/8	9/16	1/8	1/8	- 1/4	- 1/8	3/16
33	42 5/8	13/16	1/2	52 7/8	52 3/8	5/8	1/16	1/8	1/8	- 1/8	1/4
34	42 5/8	13/16	1/2	N.A.	N.A.	N.A.	1/16	1/8	N.A.	N.A.	N.A.
35	42 5/8	9/16	1/2	53 3/8	52 1/2	13/16	5/16	1/8	- 3/8	- 1/4	7/16
36	42 5/8	9/16	1/2	53	52 3/8	11/16	5/16	1/8	0	- 1/8	5/16
37	42 5/8	9/16	13/16	N.A.	N.A.	N.A.	5/16	- 3/16	N.A.	N.A.	N.A.
38	42 5/8	13/16	11/16	53 1/8	52 5/8	11/16	1/16	- 1/16	- 1/8	- 3/8	5/16

*Refer to Figure C-13 for the location of the measurements taken in the field.

Table C-7 Continued

4th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	**A**	**B**	**C**	**D**	**E**	**F**	**At Btm of CW**	**At Top of CW**	**Ctrl Ln to Conc. Pnl**	**Ctrl Ln to CW**	**CW Anchor to Conc. Pnl.**
39	42 5/8	13/16	11/16	53 1/4	52 1/2	11/16	1/16	- 1/16	- 1/4	- 1/4	5/16
40	42 5/8	9/16	3/4	N.A.	N.A.	N.A.	5/16	- 1/8	N.A.	N.A.	N.A.
41	42 5/8	11/16	1/2	53	52 1/2	5/8	3/16	1/8	0	- 1/4	1/4
42	42 5/8	11/16	5/8	53	52 1/8	9/16	3/16	0	0	1/8	3/16
43	42 5/8	7/8	5/8	N.A.	N.A.	N.A.	0	0	N.A.	N.A.	N.A.
44	42 5/8	15/16	11/16	52 7/8	52 1/2	3/8	- 1/16	- 1/16	1/8	- 1/4	0
45	42 5/8	13/16	11/16	52 7/8	52 1/4	3/8	1/16	- 1/16	1/8	0	0
46	42 5/8	13/16	3/4	N.A.	N.A.	N.A.	1/16	- 1/8	N.A.	N.A.	N.A.
47	42 5/8	11/16	3/4	52 7/8	52 3/8	5/8	3/16	- 1/8	1/8	- 1/8	1/4
48	42 5/8	11/16	11/16	52 7/8	52 1/4	5/8	3/16	- 1/16	1/8	0	1/4
49	42 5/8	1 1/8	1/2	N.A.	N.A.	N.A.	- 1/4	1/8	N.A.	N.A.	N.A.
50	42 5/8	1 1/8	5/16	53	52 3/8	9/16	- 1/4	5/16	0	- 1/8	3/16
51	42 5/8	13/16	9/16	52 7/8	52 1/4	9/16	1/16	1/16	1/8	0	3/16
52	42 5/8	1 3/16	3/8	N.A.	N.A.	N.A.	- 5/16	1/4	N.A.	N.A.	N.A.
53	42 5/8	1 1/8	7/16	52 7/8	52 3/8	3/4	- 1/4	3/16	1/8	- 1/8	3/8
54	42 5/8	1 3/16	7/16	52 3/4	52 1/4	3/4	- 5/16	3/16	1/4	0	3/8
55	42 5/8	15/16	1/8	52 5/8	52 1/2	3/8	- 1/16	1/2	3/8	- 1/4	0
56	42 5/8	1 1/16	9/16	52 7/8	52 1/2	15/16	- 3/16	1/16	1/8	- 1/4	9/16
57	42 5/8	15/16	9/16	N.A.	N.A.	N.A.	- 1/16	1/16	N.A.	N.A.	N.A.
58	42 5/8	15/16	5/8	53	52 3/8	3/8	- 1/16	0	0	- 1/8	0

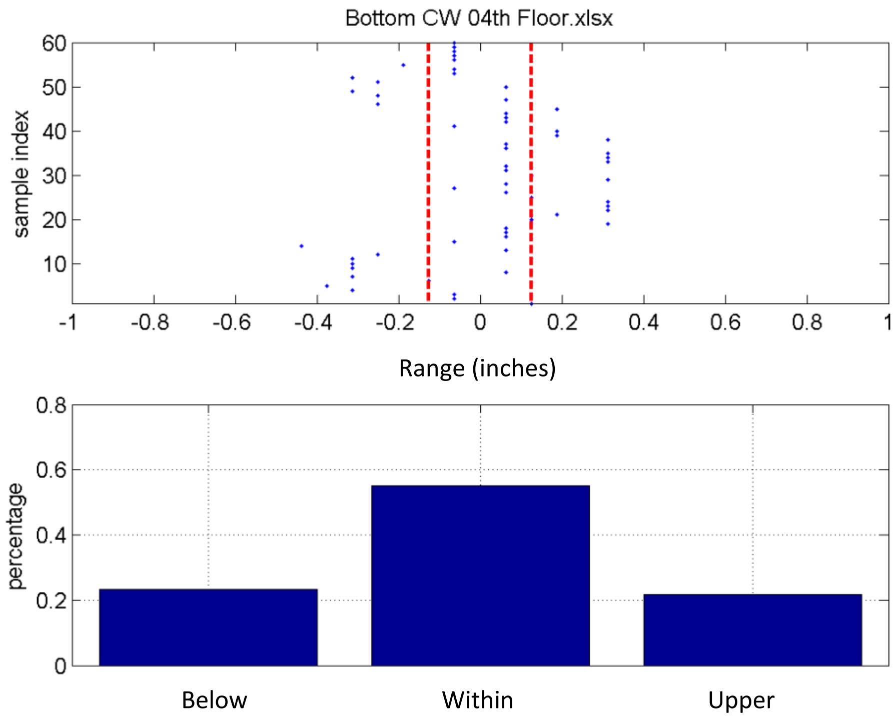
*Refer to Figure C-13 for the location of the measurements taken in the field.

Table C-7 Continued

4th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
59	42 5/8	15/16	5/8	53	52 3/8	11/16	- 1/16	0	0	- 1/8	5/16
60	42 5/8	15/16	11/16	N.A.	N.A.	N.A.	- 1/16	- 1/16	N.A.	N.A.	N.A.
61	42 5/8	15/16	11/16	52 3/4	52 1/8	11/16	- 1/16	- 1/16	1/4	1/8	5/16
62	42 5/8	7/8	1/2	52 7/8	52 1/4	7/16	0	1/8	1/8	0	1/16
63	42 5/8	15/16	5/8	N.A.	N.A.	N.A.	- 1/16	0	N.A.	N.A.	N.A.
64	42 5/8	7/8	7/16	52 7/8	52 1/8	3/4	0	3/16	1/8	1/8	3/8

*Refer to Figure C-13 for the location of the measurements taken in the field.

(a)



(b)

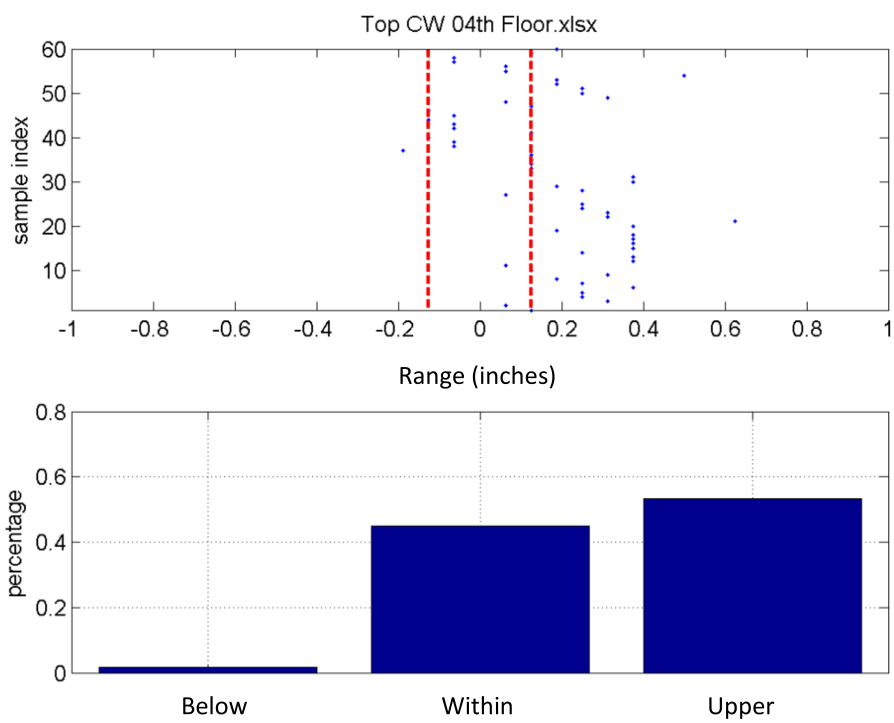


Figure C-14. Plots of tolerance results at the bottom of the curtain wall panel (a) and at the top of the curtain wall panel (b), 4th floor.

(a)

(b)

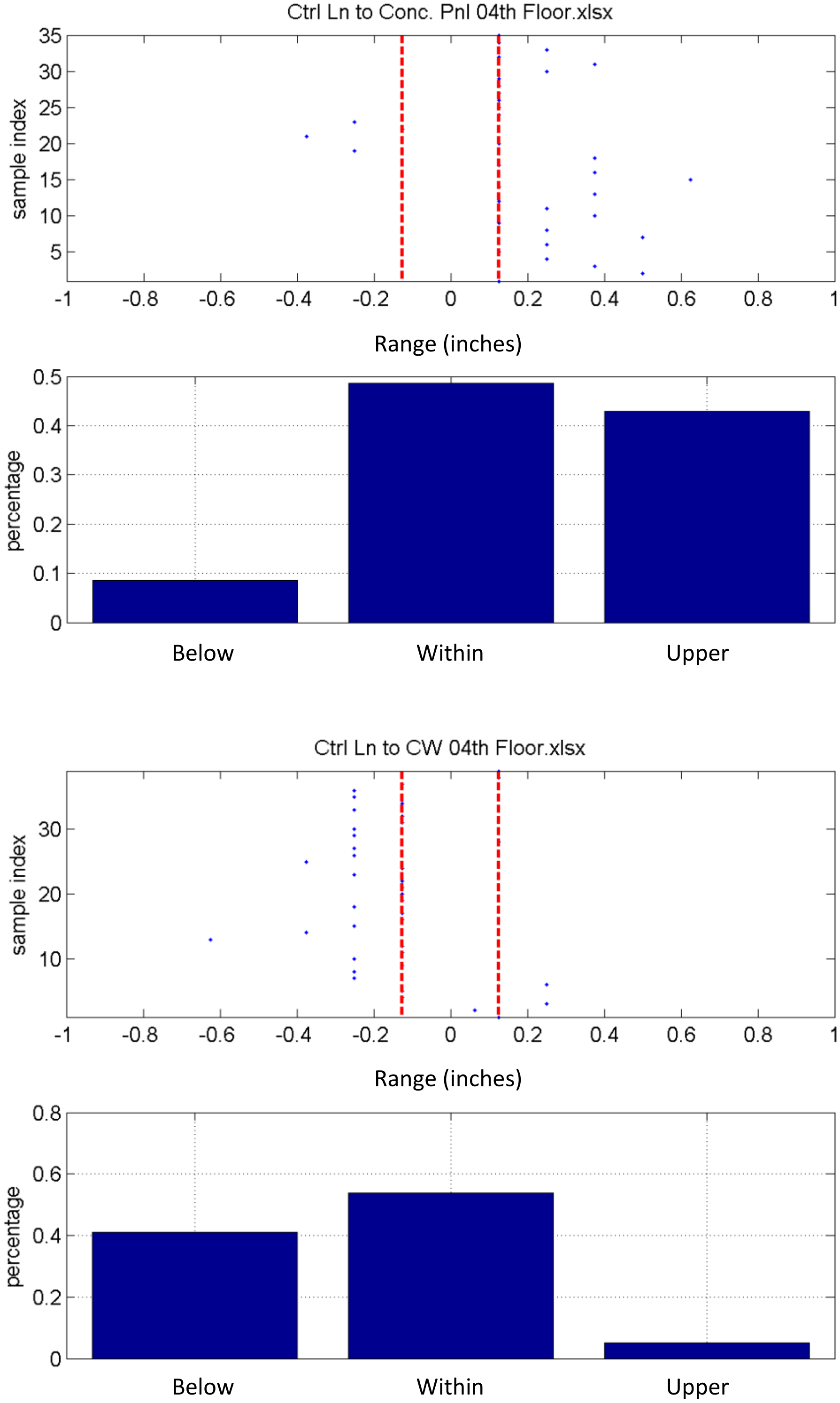


Figure C-15. Plot of tolerance results from control line to the precast panel (a) and from control line to curtain wall panel (b), 4th floor.

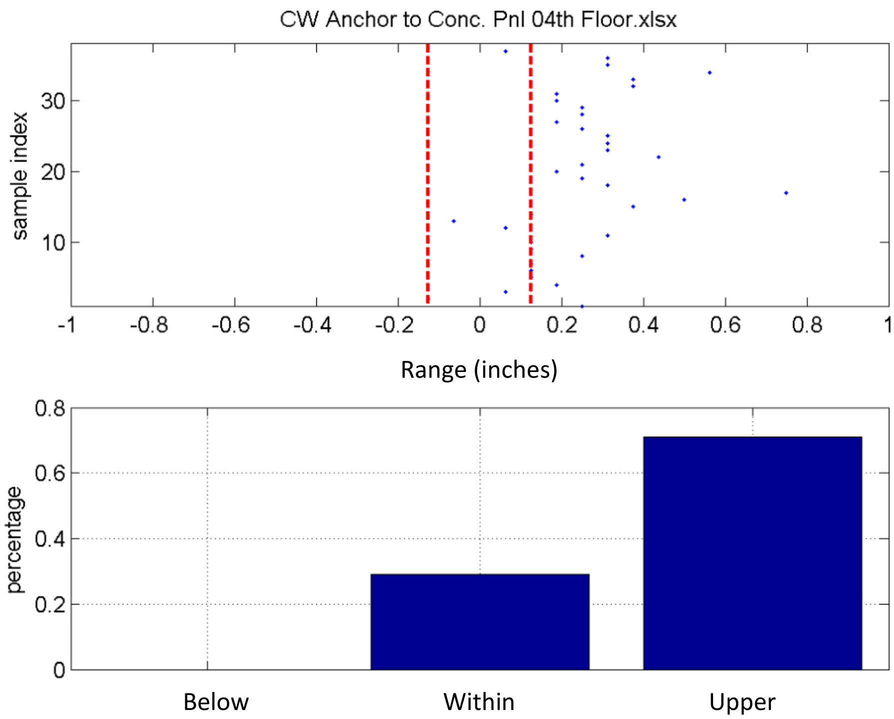


Figure C-16. Plot of tolerance results from curtain wall anchor clip to precast panel at 4th floor.

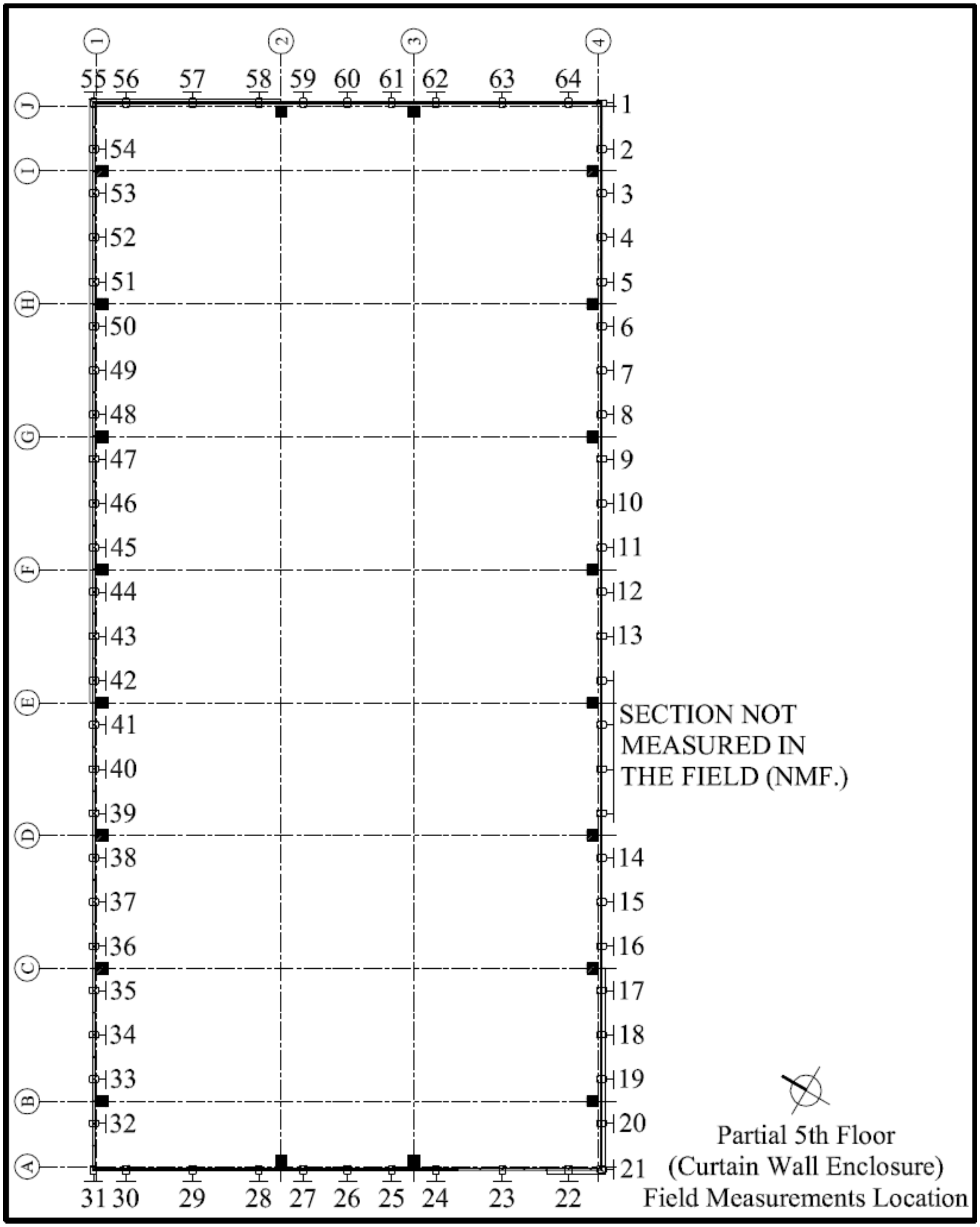


Figure C-17. Location of field measurements at 5th floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-8 Field measurements at 5th floor and tolerance calculations.

5th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
1	42 5/8	13/16	3/8	53	52 3/8	7/8	1/16	1/4	0	- 1/8	1/2
2	42 5/8	13/16	9/16	52 3/4	52 1/4	1/4	1/16	1/16	1/4	0	- 1/8
3	42 5/8	13/16	7/8	52 3/4	52 3/8	1/2	1/16	- 1/4	1/4	- 1/8	1/8
4	42 5/8	13/16	1/4	N.A.	N.A.	N.A.	1/16	3/8	N.A.	N.A.	N.A.
5	42 5/8	15/16	5/16	53	52 3/8	3/8	- 1/16	5/16	0	- 1/8	0
6	42 5/8	1	5/16	53	52 1/4	3/8	- 1/8	5/16	0	0	0
7	42 5/8	15/16	5/16	N.A.	N.A.	N.A.	- 1/16	5/16	N.A.	N.A.	N.A.
8	42 5/8	13/16	1/4	52 7/8	52 1/2	3/8	1/16	3/8	1/8	- 1/4	0
9	42 5/8	13/16	1/4	52 3/4	52 1/4	1/4	1/16	3/8	1/4	0	- 1/8
10	42 5/8	11/16	1/4	N.A.	N.A.	N.A.	3/16	3/8	N.A.	N.A.	N.A.
11	42 5/8	11/16	1/4	53 7/8	52 1/2	1/4	3/16	3/8	- 7/8	- 1/4	- 1/8
12	42 5/8	13/16	1/4	52 3/4	52 1/4	1/2	1/16	3/8	1/4	0	1/8
13	42 5/8	9/16	5/16	N.A.	N.A.	N.A.	5/16	5/16	N.A.	N.A.	N.A.
14	42 5/8	1 1/8	7/16	52 7/8	52 1/8	3/8	- 1/4	3/16	1/8	1/8	0
15	42 5/8	1 5/16	1/4	N.A.	N.A.	N.A.	- 7/16	3/8	N.A.	N.A.	N.A.
16	42 5/8	1 5/16	1/4	53 1/8	52 1/2	3/8	- 7/16	3/8	- 1/8	- 1/4	0
17	42 5/8	1 5/16	3/8	53	52 1/2	1/2	- 7/16	1/4	0	- 1/4	1/8
18	42 5/8	1 1/16	3/8	N.A.	N.A.	N.A.	- 3/16	1/4	N.A.	N.A.	N.A.

*Refer to Figure C-17 for the location of the measurements taken in the field.

Table C-8 Continued

5th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
19	42 5/8	15/16	7/16	53	52 3/8	7/16	- 1/16	3/16	0	- 1/8	1/16
20	42 5/8	1 1/16	7/16	52 7/8	52 3/8	7/16	- 3/16	3/16	1/8	- 1/8	1/16
21	42 5/8	1 3/8	1/2	53	52 1/8	3/8	- 1/2	1/8	0	1/8	0
22	42 5/8	1 3/16	1/2	52 3/4	52 3/8	1/2	- 5/16	1/8	1/4	- 1/8	1/8
23	42 5/8	13/16	5/16	N.A.	N.A.	N.A.	1/16	5/16	N.A.	N.A.	N.A.
24	42 5/8	13/16	5/8	52 3/4	52 1/4	1/4	1/16	0	1/4	0	- 1/8
25	42 5/8	15/16	1/2	52 7/8	52 3/8	5/8	- 1/16	1/8	1/8	- 1/8	1/4
26	42 5/8	15/16	1/2	N.A.	N.A.	N.A.	- 1/16	1/8	N.A.	N.A.	N.A.
27	42 5/8	11/16	5/8	53	52 3/8	1 1/16	3/16	0	0	- 1/8	11/16
28	42 5/8	13/16	5/16	53	52 3/8	1 1/4	1/16	5/16	0	- 1/8	7/8
29	42 5/8	1 1/16	3/8	N.A.	N.A.	N.A.	- 3/16	1/4	N.A.	N.A.	N.A.
30	42 5/8	1 3/16	1/4	53 1/4	53	1/2	- 5/16	3/8	- 1/4	- 3/4	1/8
31	42 5/8	15/16	1/4	52 5/8	52 3/8	5/8	- 1/16	3/8	3/8	- 1/8	1/4
32	42 5/8	1	3/8	52 3/4	52 1/4	5/8	- 1/8	1/4	1/4	0	1/4
33	42 5/8	15/16	5/8	N.A.	N.A.	N.A.	- 1/16	0	N.A.	N.A.	N.A.
34	42 5/8	1	5/8	53 1/4	52 1/2	13/16	- 1/8	0	- 1/4	- 1/4	7/16
35	42 5/8	1 1/8	1/2	53	52 3/8	5/8	- 1/4	1/8	0	- 1/8	1/4
36	42 5/8	1 1/8	5/16	N.A.	N.A.	N.A.	- 1/4	5/16	N.A.	N.A.	N.A.
37	42 5/8	15/16	1/4	53	52 1/4	5/8	- 1/16	3/8	0	0	1/4
38	42 5/8	15/16	5/16	53	52 3/8	3/4	- 1/16	5/16	0	- 1/8	3/8

*Refer to Figure C-17 for the location of the measurements taken in the field.

Table C-8 Continued

5th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
39	42 5/8	15/16	7/16	N.A.	N.A.	N.A.	- 1/16	3/16	N.A.	N.A.	N.A.
40	42 5/8	7/8	5/8	52 3/4	52 1/4	3/8	0	0	1/4	0	0
41	42 5/8	15/16	3/4	52 3/4	52 1/4	3/8	- 1/16	- 1/8	1/4	0	0
42	42 5/8	15/16	3/4	52 3/4	52 1/4	3/8	- 1/16	- 1/8	1/4	0	0
43	42 5/8	15/16	11/16	N.A.	N.A.	N.A.	- 1/16	- 1/16	N.A.	N.A.	N.A.
44	42 5/8	7/8	5/8	52 5/8	52 1/4	3/8	0	0	3/8	0	0
45	42 5/8	7/8	1/2	53	52 1/4	1/4	0	1/8	0	0	- 1/8
46	42 5/8	1 1/16	7/16	N.A.	N.A.	N.A.	- 3/16	3/16	N.A.	N.A.	N.A.
47	42 5/8	15/16	1/2	53	52 1/2	11/16	- 1/16	1/8	0	- 1/4	5/16
48	42 5/8	15/16	5/16	52 3/4	52 5/8	5/8	- 1/16	5/16	1/4	- 3/8	1/4
49	42 5/8	1	3/8	N.A.	N.A.	N.A.	- 1/8	1/4	N.A.	N.A.	N.A.
50	42 5/8	1 1/16	3/8	53	52 1/4	5/8	- 3/16	1/4	0	0	1/4
51	42 5/8	1 1/8	11/16	53	52	5/8	- 1/4	- 1/16	0	1/4	1/4
52	42 5/8	1 1/8	7/16	N.A.	N.A.	N.A.	- 1/4	3/16	N.A.	N.A.	N.A.
53	42 5/8	1 1/8	1/2	52 7/8	52 3/8	1/2	- 1/4	1/8	1/8	- 1/8	1/8
54	42 5/8	11/16	13/16	52 3/4	52 3/8	1/2	3/16	- 3/16	1/4	- 1/8	1/8
55	42 5/8	1 1/16	1/16	53	53	0	- 3/16	9/16	0	- 3/4	- 3/8
56	42 5/8	11/16	7/16	52 3/4	52 1/4	7/8	3/16	3/16	1/4	0	1/2
57	42 5/8	1/2	5/16	N.A.	N.A.	N.A.	3/8	5/16	N.A.	N.A.	N.A.
58	42 5/8	9/16	3/8	53	52 1/4	3/4	5/16	1/4	0	0	3/8

*Refer to Figure C-17 for the location of the measurements taken in the field.

Table C-8 Continued

5th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
59	42 5/8	13/16	7/16	53	52 3/8	9/16	1/16	3/16	0	- 1/8	3/16
60	42 5/8	13/16	3/8	N.A.	N.A.	N.A.	1/16	1/4	N.A.	N.A.	N.A.
61	42 5/8	13/16	1/2	52 3/4	52 1/4	3/4	1/16	1/8	1/4	0	3/8
62	42 5/8	13/16	0	53	52 1/8	3/4	1/16	5/8	0	1/8	3/8
63	42 5/8	13/16	1/16	N.A.	N.A.	N.A.	1/16	9/16	N.A.	N.A.	N.A.
64	42 5/8	13/16	5/16	52 7/8	52 3/8	1/4	1/16	5/16	1/8	- 1/8	- 1/8

*Refer to Figure C-17 for the location of the measurements taken in the field.

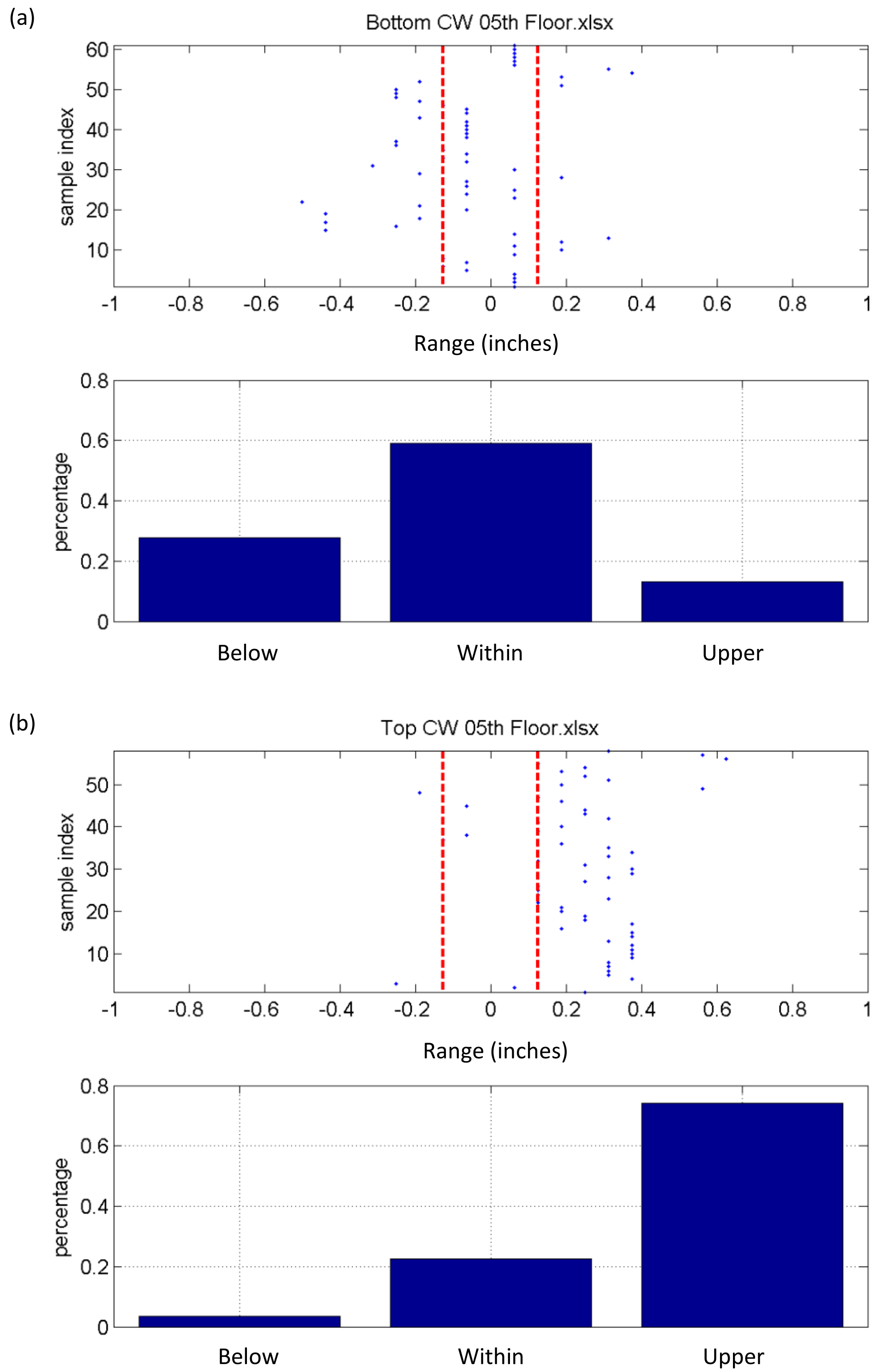


Figure C-18. Plots of tolerance results at the bottom of the curtain wall panel (a) and at the top of the curtain wall panel (b), 5th floor.

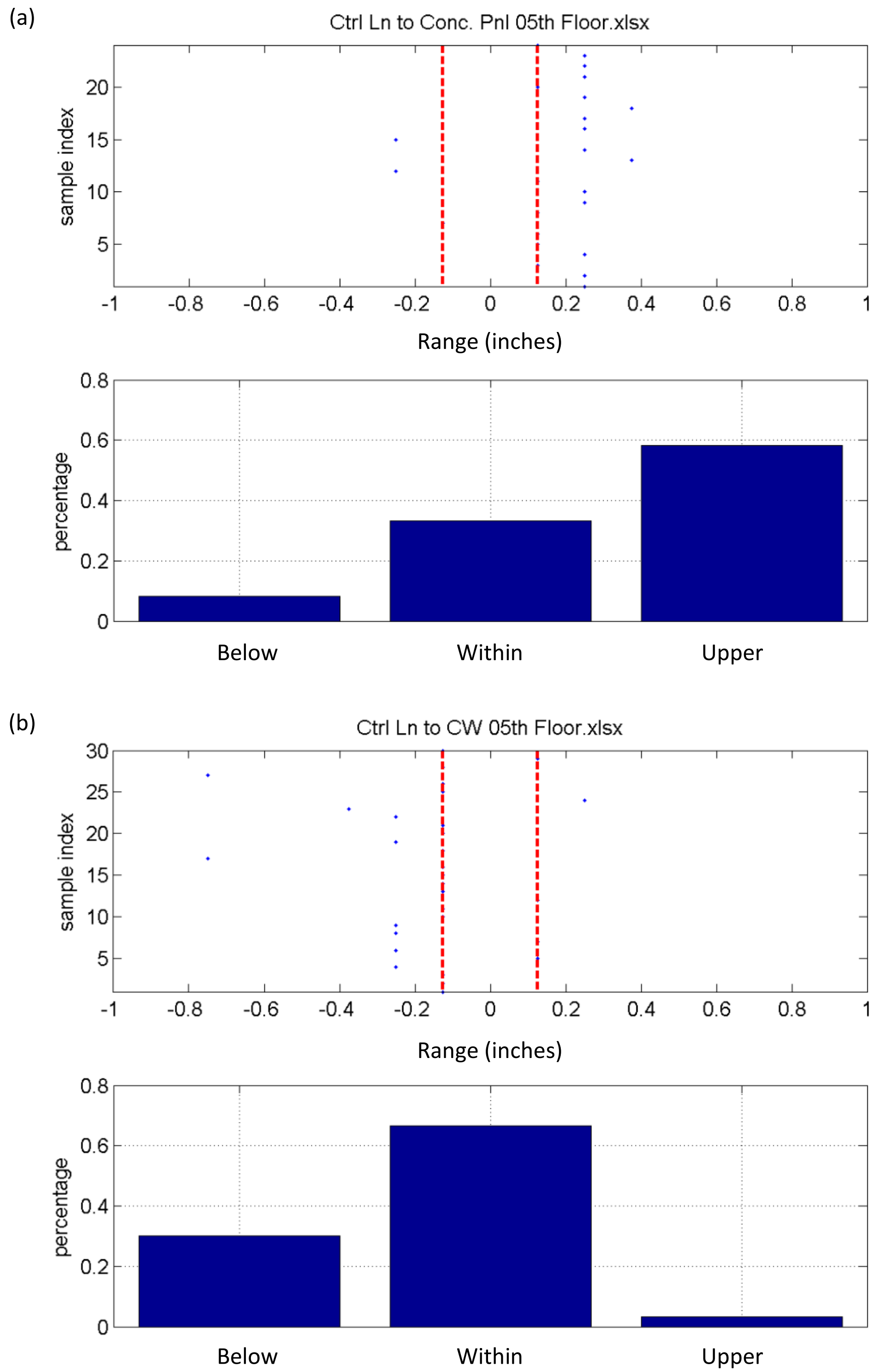


Figure C-19. Plots of tolerance results from control line to the precast panel (a) and from control line to curtain wall panel (b), 5th floor.

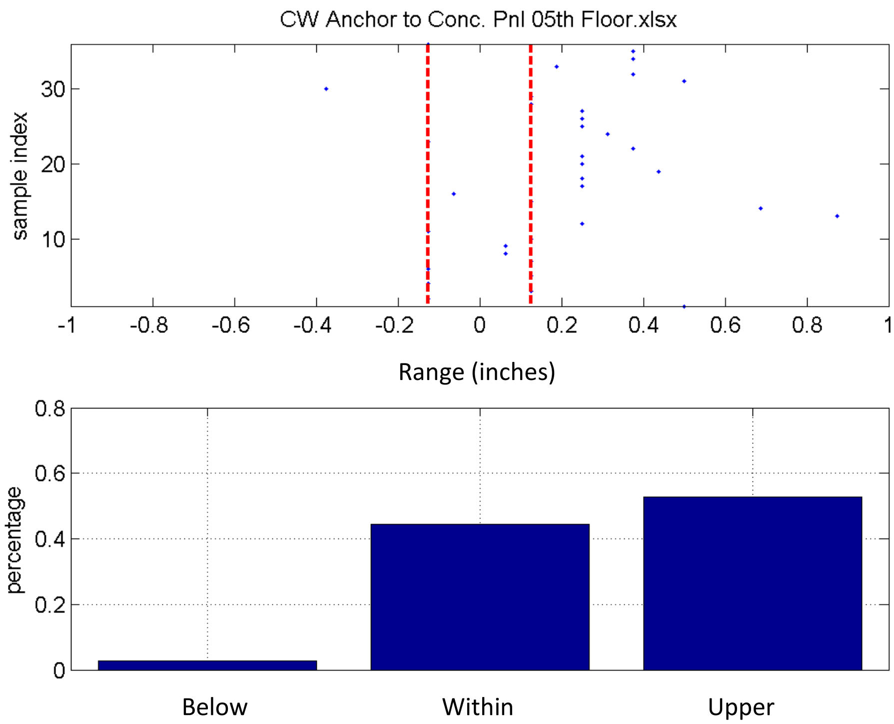


Figure C-20. Plot of tolerance results from curtain wall anchor clip to precast panel at 5th floor.

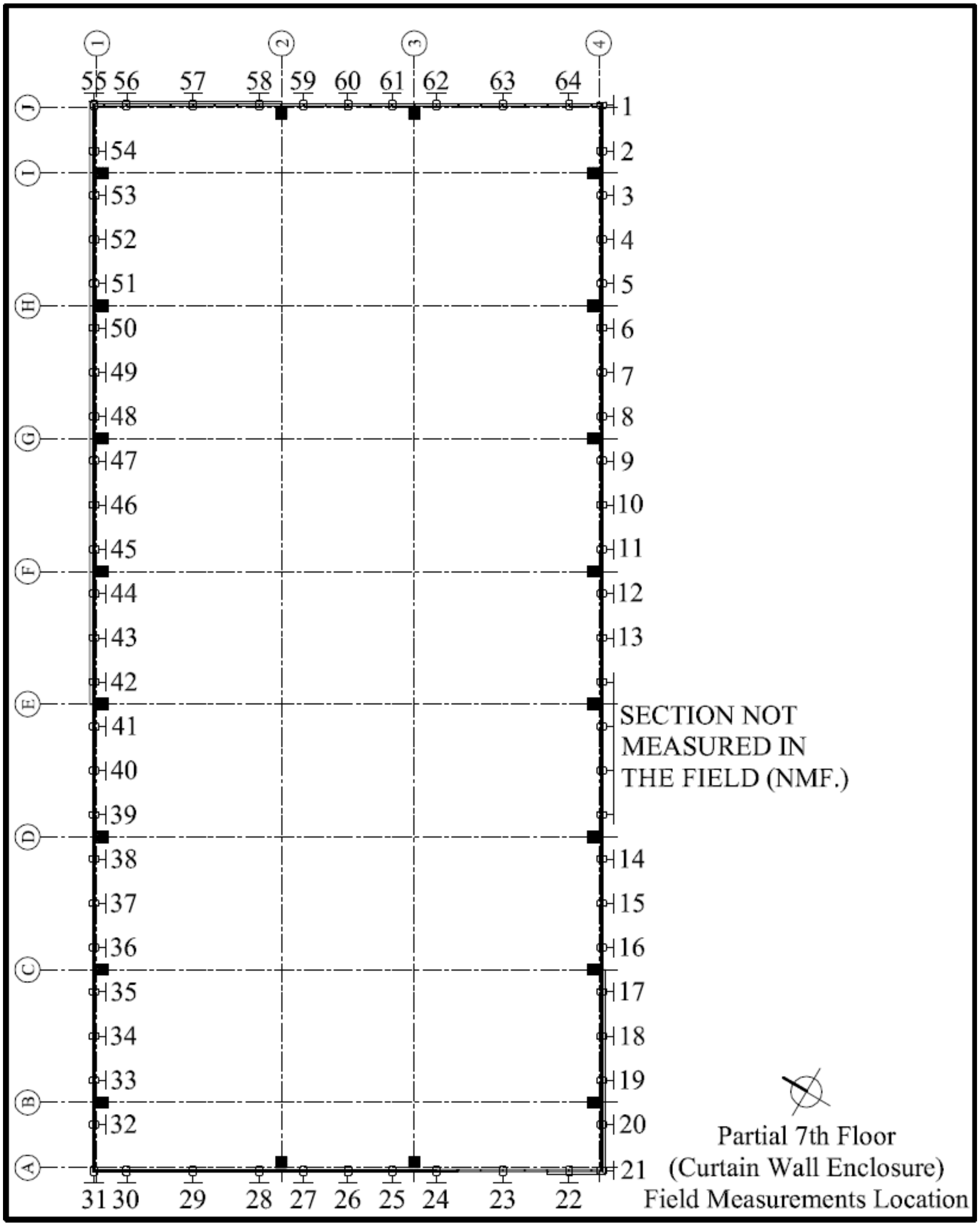


Figure C-21. Location of field measurements at 7th floor plan. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-9 Field measurements at 7th floor and tolerance calculations.

7th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
1	42 3/4	5/16	5/8	52 3/4	52 1/4	5/8	7/16	1/8	1/4	0	1/4
2	42 3/4	7/16	7/16	52 5/8	52 3/8	1/4	5/16	5/16	3/8	- 1/8	- 1/8
3	42 3/4	11/16	1/4	52 3/4	52 1/8	15/16	1/16	1/2	1/4	1/8	9/16
4	42 3/4	3/4	9/16	N.A.	N.A.	N.A.	0	3/16	N.A.	N.A.	N.A.
5	42 3/4	13/16	11/16	52 3/4	52 1/2	9/16	- 1/16	1/16	1/4	- 1/4	3/16
6	42 3/4	11/16	11/16	52 7/8	52 3/8	5/16	1/16	1/16	1/8	- 1/8	- 1/16
7	42 3/4	9/16	1/2	N.A.	N.A.	N.A.	3/16	1/4	N.A.	N.A.	N.A.
8	42 3/4	11/16	13/16	52 7/8	52 1/2	1/2	1/16	- 1/16	1/8	- 1/4	1/8
9	42 3/4	3/4	5/8	53	52 1/2	3/8	0	1/8	0	- 1/4	0
10	42 3/4	7/8	3/8	N.A.	N.A.	N.A.	- 1/8	3/8	N.A.	N.A.	N.A.
11	42 3/4	11/16	3/8	53	52 3/8	1/4	1/16	3/8	0	- 1/8	- 1/8
12	42 3/4	3/4	3/8	53 1/4	52 3/4	1/2	0	3/8	- 1/4	- 1/2	1/8
13	42 3/4	5/8	11/16	N.A.	N.A.	N.A.	1/8	1/16	N.A.	N.A.	N.A.
14	42 3/4	3/8	1 3/16	52 3/4	52 1/2	1/4	3/8	- 7/16	1/4	- 1/4	- 1/8
15	42 3/4	7/16	1 3/16	N.A.	N.A.	N.A.	5/16	- 7/16	N.A.	N.A.	N.A.
16	42 3/4	7/16	1 1/8	52 3/8	52 1/4	1/4	5/16	- 3/8	5/8	0	- 1/8
17	42 3/4	7/16	1 1/16	52 5/8	52 3/8	5/16	5/16	- 5/16	3/8	- 1/8	- 1/16
18	42 3/4	9/16	11/16	N.A.	N.A.	N.A.	3/16	1/16	N.A.	N.A.	N.A.

*Refer to Figure C-21 for the location of the measurements taken in the field.

Table C-9 Continued

7th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
19	42 3/4	9/16	13/16	52 7/8	52 1/4	3/8	3/16	- 1/16	1/8	0	0
20	42 3/4	9/16	3/4	52 3/4	52 1/8	1/2	3/16	0	1/4	1/8	1/8
21	42 3/4	1/2	13/16	52 5/18	52 5/8	3/4	1/4	- 1/16	13/18	- 3/8	3/8
22	42 3/4	5/16	1	53	52 1/2	9/16	7/16	- 1/4	0	- 1/4	3/16
23	42 3/4	11/16	3/4	N.A.	N.A.	N.A.	1/16	0	N.A.	N.A.	N.A.
24	42 3/4	9/16	3/4	53	52 3/8	5/8	3/16	0	0	- 1/8	1/4
25	42 3/4	9/16	1/2	52 7/8	52 3/8	5/8	3/16	1/4	1/8	- 1/8	1/4
26	42 3/4	5/8	3/8	N.A.	N.A.	N.A.	1/8	3/8	N.A.	N.A.	N.A.
27	42 3/4	3/4	5/8	52 7/8	52 3/8	1/4	0	1/8	1/8	- 1/8	- 1/8
28	42 3/4	11/16	5/8	52 7/8	52 1/4	7/16	1/16	1/8	1/8	0	1/16
29	42 3/4	11/16	9/16	N.A.	N.A.	N.A.	1/16	3/16	N.A.	N.A.	N.A.
30	42 3/4	13/16	5/8	52 7/8	52 7/8	1/4	- 1/16	1/8	1/8	- 5/8	- 1/8
31	42 3/4	7/8	5/8	52 1/2	52 1/2	5/16	- 1/8	1/8	1/2	- 1/4	- 1/16
32	42 3/4	13/16	7/16	52 3/8	52 5/8	1/4	- 1/16	5/16	5/8	- 3/8	- 1/8
33	42 3/4	13/16	9/16	53	52 1/2	3/8	- 1/16	3/16	0	- 1/4	0
34	42 3/4	13/16	1/2	N.A.	N.A.	N.A.	- 1/16	1/4	N.A.	N.A.	N.A.
35	42 3/4	3/4	3/4	52 3/4	52 3/8	1/2	0	0	1/4	- 1/8	1/8
36	42 3/4	11/16	1/2	52 3/4	52 3/8	7/16	1/16	1/4	1/4	- 1/8	1/16
37	42 3/4	7/8	9/16	N.A.	N.A.	N.A.	- 1/8	3/16	N.A.	N.A.	N.A.
38	42 3/4	7/8	9/16	53	52 1/4	7/8	- 1/8	3/16	0	0	1/2

*Refer to Figure C-21 for the location of the measurements taken in the field.

Table C-9 Continued

7th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	**A**	**B**	**C**	**D**	**E**	**F**	**At Btm of CW**	**At Top of CW**	**Ctrl Ln to Conc. Pnl**	**Ctrl Ln to CW**	**CW Anchor to Conc. Pnl.**
39	42 3/4	7/8	11/16	53	52 1/4	1/2	- 1/8	1/16	0	0	1/8
40	42 3/4	13/16	9/16	N.A.	N.A.	N.A.	- 1/16	3/16	N.A.	N.A.	N.A.
41	42 3/4	13/16	5/8	52 7/8	52 3/8	3/8	- 1/16	1/8	1/8	- 1/8	0
42	42 3/4	13/16	3/8	52 7/8	52 1/2	1/2	- 1/16	3/8	1/8	- 1/4	1/8
43	42 3/4	5/8	5/16	N.A.	N.A.	N.A.	1/8	7/16	N.A.	N.A.	N.A.
44	42 3/4	3/4	1/4	52 7/8	52 1/2	3/8	0	1/2	1/8	- 1/4	0
45	42 3/4	13/16	5/16	52 3/4	52 1/2	3/8	- 1/16	7/16	1/4	- 1/4	0
46	42 3/4	13/16	1/4	N.A.	N.A.	N.A.	- 1/16	1/2	N.A.	N.A.	N.A.
47	42 3/4	13/16	7/16	53	52 1/4	11/16	- 1/16	5/16	0	0	5/16
48	42 3/4	15/16	1/4	53 1/4	52 7/8	3/8	- 3/16	1/2	- 1/4	- 5/8	0
49	42 3/4	15/16	5/16	N.A.	N.A.	N.A.	- 3/16	7/16	N.A.	N.A.	N.A.
50	42 3/4	15/16	7/16	53	52 3/8	9/16	- 3/16	5/16	0	- 1/8	3/16
51	42 3/4	15/16	9/16	53 1/8	52 3/8	13/16	- 3/16	3/16	- 1/8	- 1/8	7/16
52	42 3/4	15/16	7/16	N.A.	N.A.	N.A.	- 3/16	5/16	N.A.	N.A.	N.A.
53	42 3/4	15/16	5/8	52 3/4	52 1/2	1/2	- 3/16	1/8	1/4	- 1/4	1/8
54	42 3/4	13/16	11/16	53	52 5/8	1/4	- 1/16	1/16	0	- 3/8	- 1/8
55	42 3/4	7/8	7/8	52 3/4	51 1/4	1/2	- 1/8	- 1/8	1/4	1	1/8
56	42 3/4	15/16	11/16	52 3/4	52 1/2	7/16	- 3/16	1/16	1/4	- 1/4	1/16
57	42 3/4	15/16	9/16	N.A.	N.A.	N.A.	- 3/16	3/16	N.A.	N.A.	N.A.
58	42 3/4	11/16	3/4	52 3/4	52 1/4	11/16	1/16	0	1/4	0	5/16

*Refer to Figure C-21 for the location of the measurements taken in the field.

Table C-9 Continued

7th Floor (measurements collected from openings with CW panels installed)							Tolerance Results				
Loc.*	A	B	C	D	E	F	At Btm of CW	At Top of CW	Ctrl Ln to Conc. Pnl	Ctrl Ln to CW	CW Anchor to Conc. Pnl.
59	42 3/4	7/16	3/4	53	52 5/8	5/8	5/16	0	0	- 3/8	1/4
60	42 3/4	5/8	7/16	N.A.	N.A.	N.A.	1/8	5/16	N.A.	N.A.	N.A.
61	42 3/4	3/4	1/2	52 3/4	52 1/4	5/8	0	1/4	1/4	0	1/4
62	42 3/4	15/16	1/4	52 3/4	52 1/4	7/16	- 3/16	1/2	1/4	0	1/16
63	42 3/4	13/16	1/4	N.A.	N.A.	N.A.	- 1/16	1/2	N.A.	N.A.	N.A.
64	42 3/4	3/4	1/4	53	52 3/8	5/8	0	1/2	0	- 1/8	1/4

*Refer to Figure C-21 for the location of the measurements taken in the field.

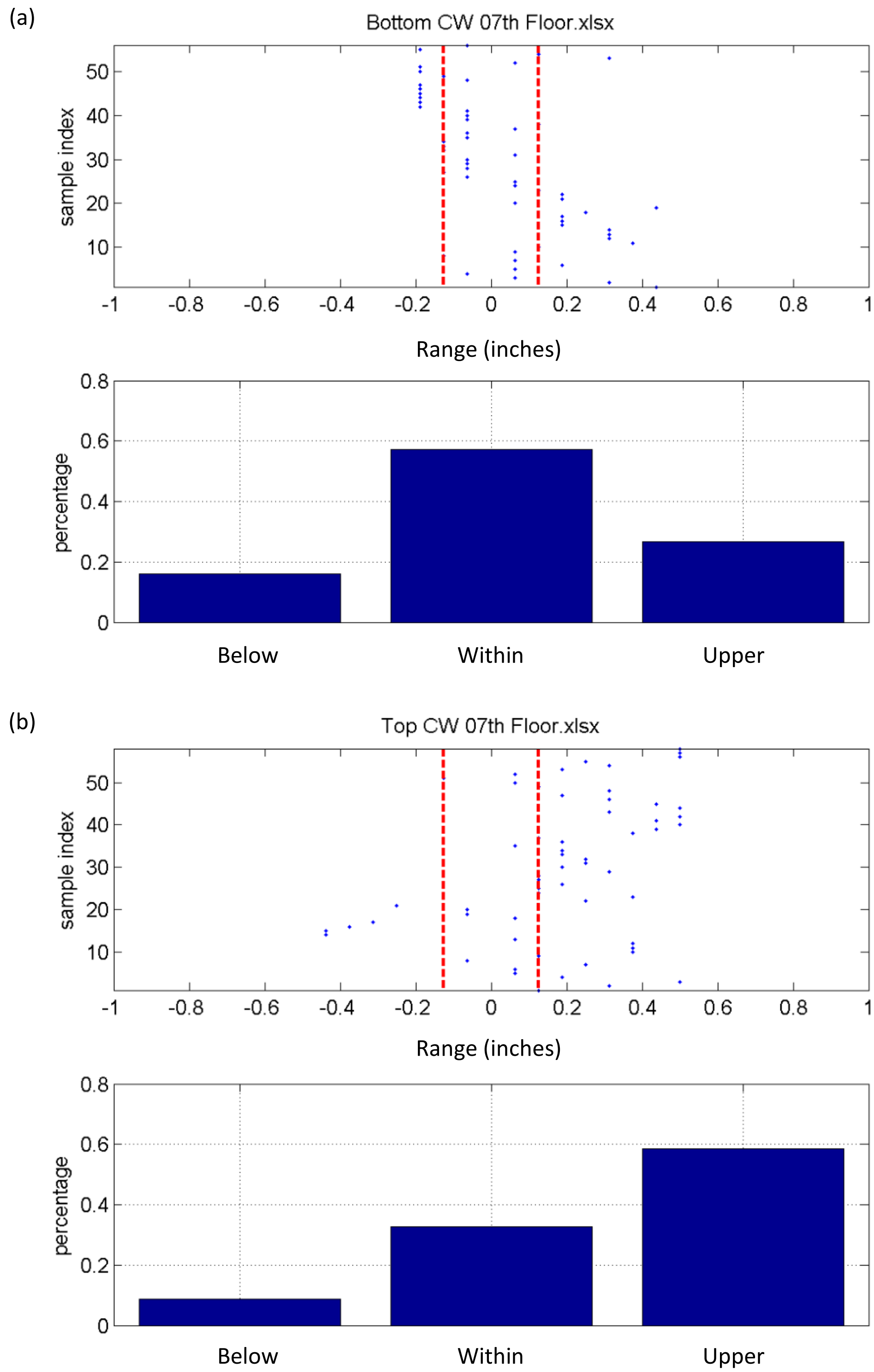


Figure C-22. Plots of tolerance results at the bottom of the curtain wall panel (a) and at the top of the curtain wall panel (b), 7th floor.

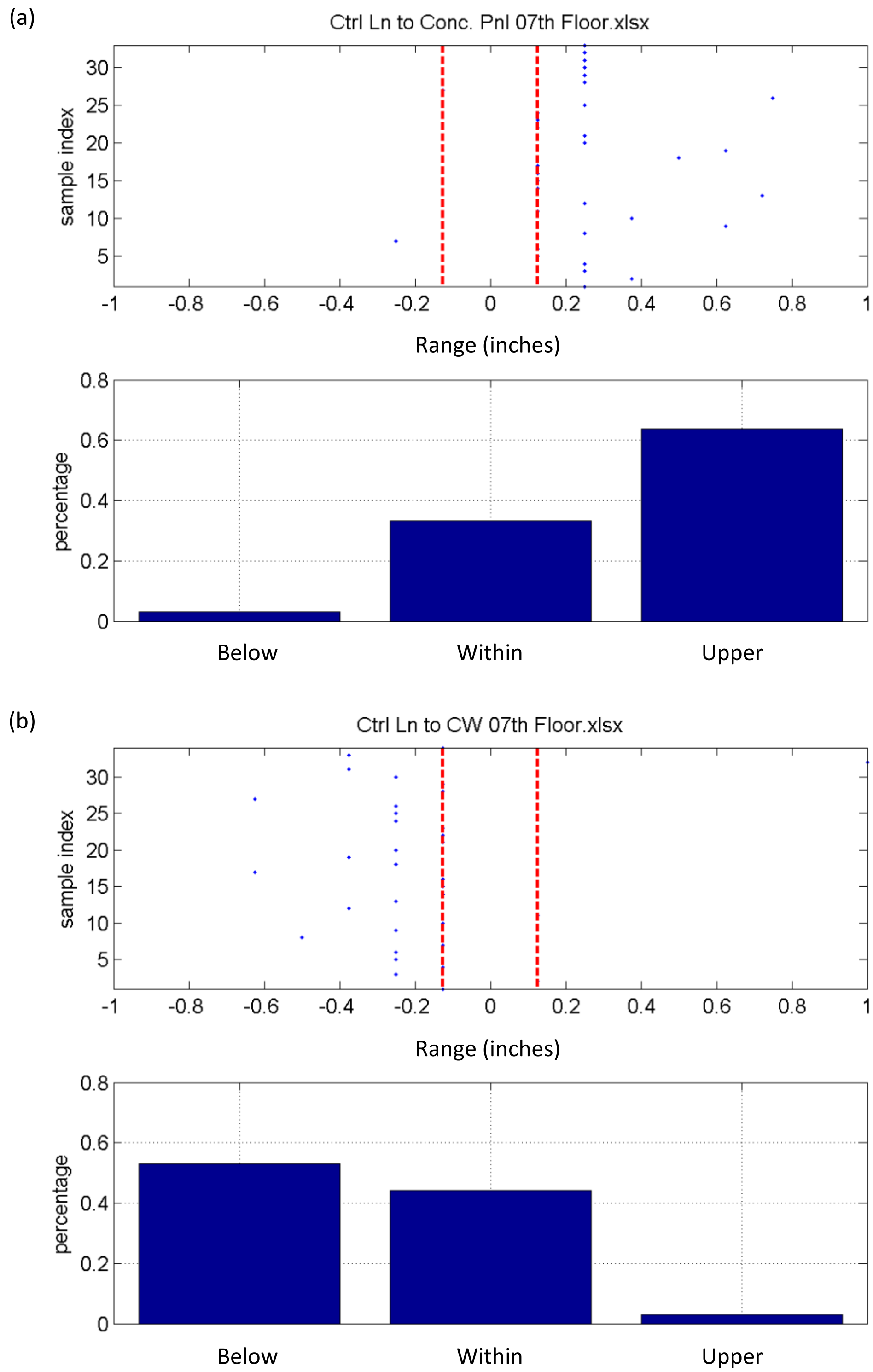


Figure C-23. Plots of tolerance results from control line to the precast panel (a) and from control line to curtain wall panel (b), 7th floor.

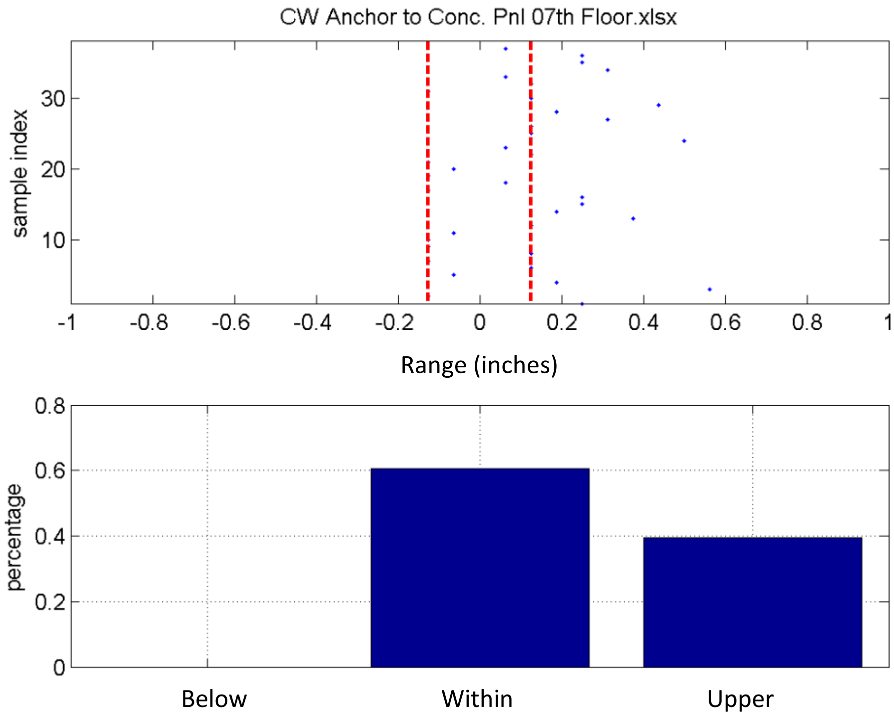


Figure C-24. Plot of tolerance results from curtain wall anchor clip to precast panel at 7th floor.

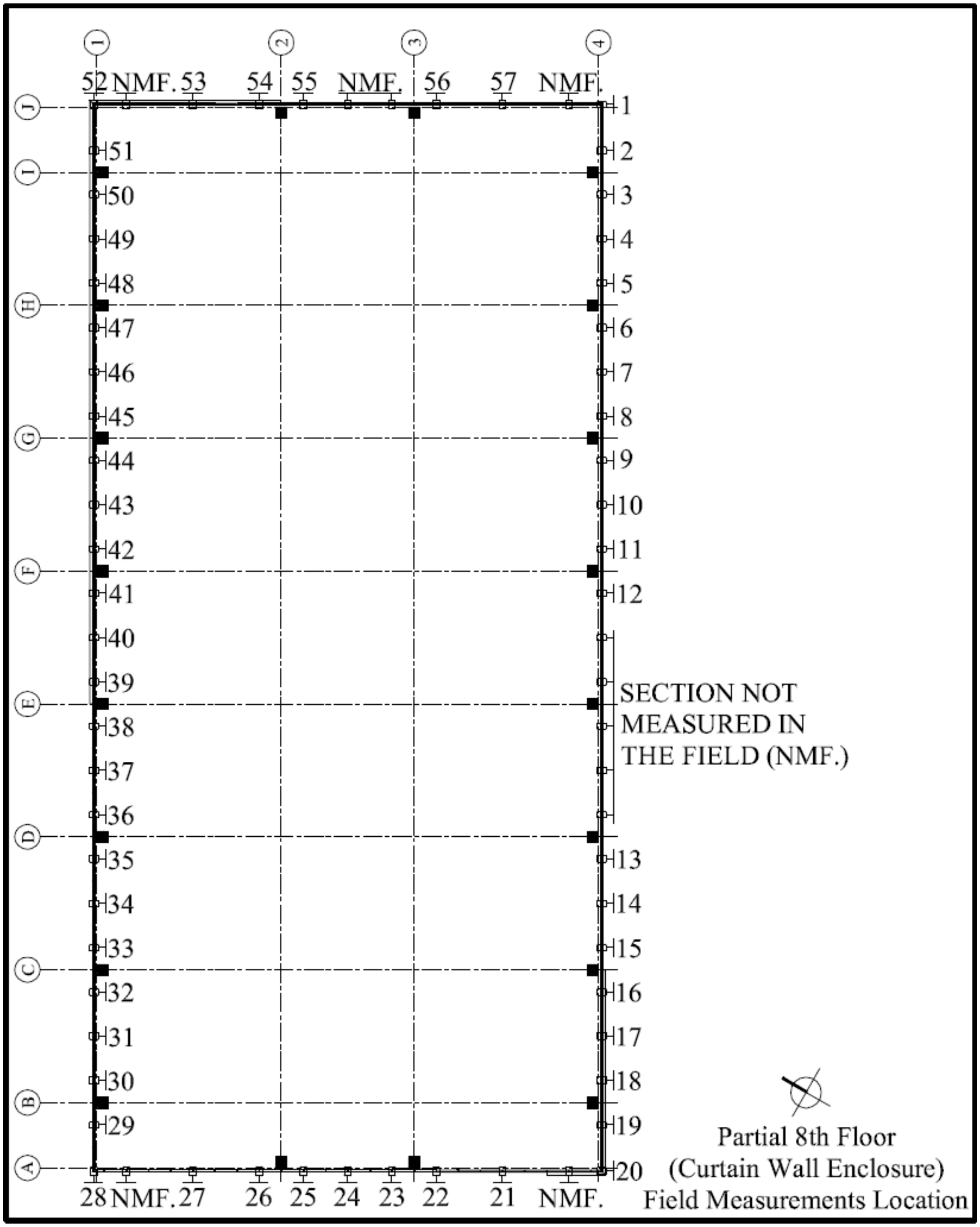


Figure C-25. Location of field measurements at 8th floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-10 Field measurements at 8th floor and tolerance calculations.

8th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	**A**	**B**	**C**	**D**	**At Btm of Opening**	**At Top of Opening**	**Ctrl Ln to Conc. Pnl**
1	16 3/16	59 7/8	50 5/8	53	- 3/16	- 1/16	0
2	16 3/16	59 7/8	50 3/4	52 1/2	- 3/16	- 3/16	1/2
3	13 3/4	57 1/2	53 1/8	52 1/2	- 1/4	- 1/8	1/2
4	13 3/4	57 1/4	53 1/4	N.A.	0	- 1/4	N.A.
5	13 3/4	57 1/4	53 1/4	52 7/8	0	- 1/4	1/8
6	1 3/4	45 1/4	65 1/4	52 3/4	0	- 1/4	1/4
7	1 3/4	45	65 1/4	N.A.	1/4	- 1/4	N.A.
8	2	45 1/4	65	52 3/4	1/4	- 1/4	1/4
9	2	45 3/16	65 1/8	52 7/8	5/16	- 3/8	1/8
10	1 3/8	44 3/4	65 3/8	N.A.	1/8	0	N.A.
11	1 3/8	44 7/8	65 1/2	52 5/8	0	- 1/8	3/8
12	1 3/16	45 3/8	64 7/8	52 3/4	- 11/16	11/16	1/4
13	1 7/8	45 1/4	65 1/16	52 1/2	1/8	- 3/16	1/2
14	1 7/8	45 3/8	65	N.A.	0	- 1/8	N.A.
15	1 7/8	43 3/8	65 1/4	52 3/4	2	- 3/8	1/4
16	1 3/4	45 1/4	65 1/4	52 5/8	0	- 1/4	3/8
17	1 3/4	45 1/2	65 1/8	N.A.	- 1/4	- 1/8	N.A.
18	1 3/4	45 1/2	65 1/4	52 5/8	- 1/4	- 1/4	3/8
19	2 1/2	46	64 1/2	52 1/2	0	- 1/4	1/2
20	2 1/2	46 1/8	64 1/2	52 1/2	- 1/8	- 1/4	1/2
21	2 1/2	45 7/8	64 3/16	52 7/8	1/8	1/16	1/8

*Refer to Figure C-25 for the location of the measurements taken in the field.

Table C-10 Continued

8th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
22	2	45 3/4	64 3/4	53	- 1/4	0	0
23	2	45 9/16	64 9/16	52 7/8	- 1/16	3/16	1/8
24	2	45 9/16	64 1/2	N.A.	- 1/16	1/4	N.A.
25	2	45 9/16	64 3/4	52 7/8	- 1/16	0	1/8
26	2 1/8	45 5/8	64 1/2	52 5/8	0	1/8	3/8
27	2 1/8	45 1/2	64 5/8	N.A.	1/8	0	N.A.
28	2 5/16	45 9/16	64 1/2	52 3/8	1/4	- 1/16	5/8
29	2 5/16	45 7/8	64 1/2	52 3/8	- 1/16	- 1/16	5/8
30	2 5/16	45 3/4	64 1/2	53	1/16	- 1/16	0
31	1 5/8	45 7/8	65 1/4	N.A.	- 3/4	- 1/8	N.A.
32	1 5/8	45 7/8	65 1/8	52 3/8	- 3/4	0	5/8
33	1 5/8	45 7/8	65	52 1/2	- 3/4	1/8	1/2
34	1 3/4	48 3/16	64 7/8	N.A.	-2 15/16	1/8	N.A.
35	1 3/4	47 5/8	65 1/4	53 1/8	-2 3/8	- 1/4	- 1/8
36	1 3/4	47 1/2	65	52 3/4	-2 1/4	0	1/4
37	1 1/2	45	65 5/16	N.A.	0	- 1/16	N.A.
38	1 1/2	44 7/8	65 7/16	53 1/8	1/8	- 3/16	- 1/8
39	1 1/2	45	65 1/4	53 1/8	0	0	- 1/8
40	1 1/2	45 1/8	65 3/8	N.A.	- 1/8	- 1/8	N.A.
41	1 1/2	45	65 1/4	53 1/8	0	0	- 1/8
42	1 11/16	45 1/8	65 1/4	52 7/8	1/16	- 3/16	1/8

*Refer to Figure C-25 for the location of the measurements taken in the field.

Table C-10 Continued

8th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
43	1 11/16	45 1/8	65 1/8	N.A.	1/16	- 1/16	N.A.
44	1 15/16	45 7/8	64 3/4	53 1/8	- 7/16	1/16	- 1/8
45	1 15/16	45 3/4	64 3/4	52 7/8	- 5/16	1/16	1/8
46	1 7/8	45 9/16	64 7/8	N.A.	- 3/16	0	N.A.
47	1 7/8	45 5/16	65	53	1/16	- 1/8	0
48	1 5/8	45	65 3/8	53	1/8	- 1/4	0
49	1 5/8	45 1/16	65 1/8	N.A.	1/16	0	N.A.
50	1 5/8	45 1/16	65 5/16	52 1/2	1/16	- 3/16	1/2
51	2 1/8	45 1/2	64 5/8	52 1/2	1/8	0	1/2
52	2 1/8	45 11/16	64 1/2	52 3/4	- 1/16	1/8	1/4
53	3 7/8	47 3/8	62 3/4	N.A.	0	1/8	N.A.
54	3 7/8	47 1/4	62 3/4	53	1/8	1/8	0
55	1 7/8	45 1/4	65	53 1/8	1/8	- 1/8	- 1/8
56	1 7/8	45 1/2	65 5/8	52 3/4	- 1/8	- 3/4	1/4
57	16 3/16	60	50 7/8	N.A.	- 5/16	- 5/16	N.A.

*Refer to Figure C-25 for the location of the measurements taken in the field.

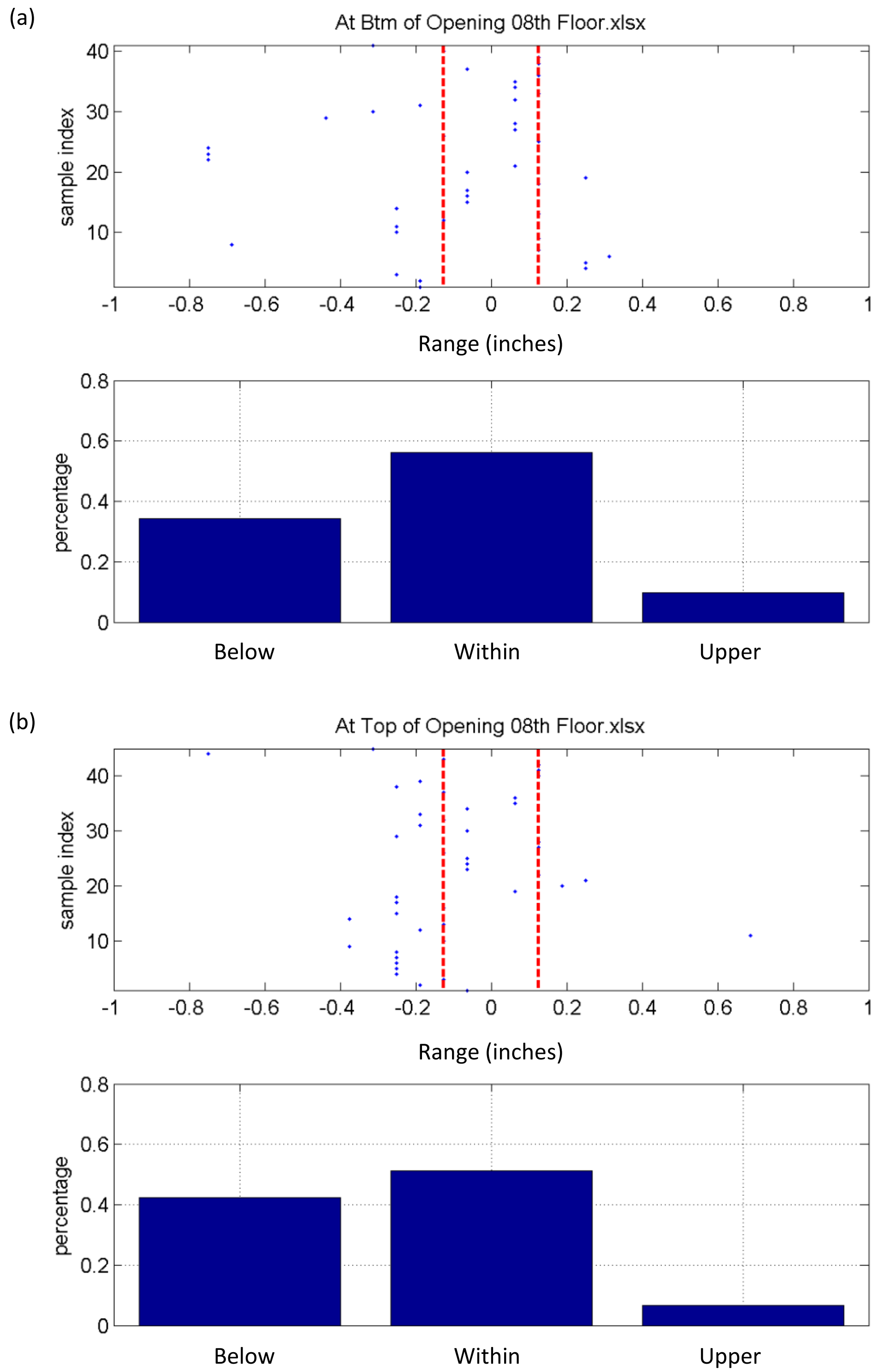


Figure C-26. Plots of tolerance results at the bottom of the opening (a) and at the top of the opening from control line (b) at 8th floor.

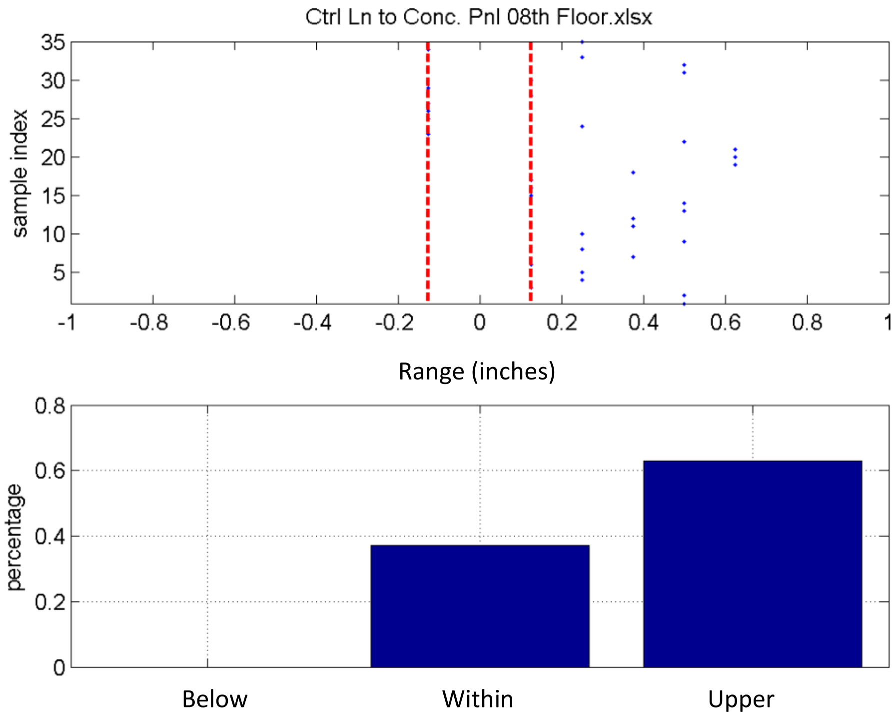


Figure C-27. Plot of tolerance results from control line to the precast panel.

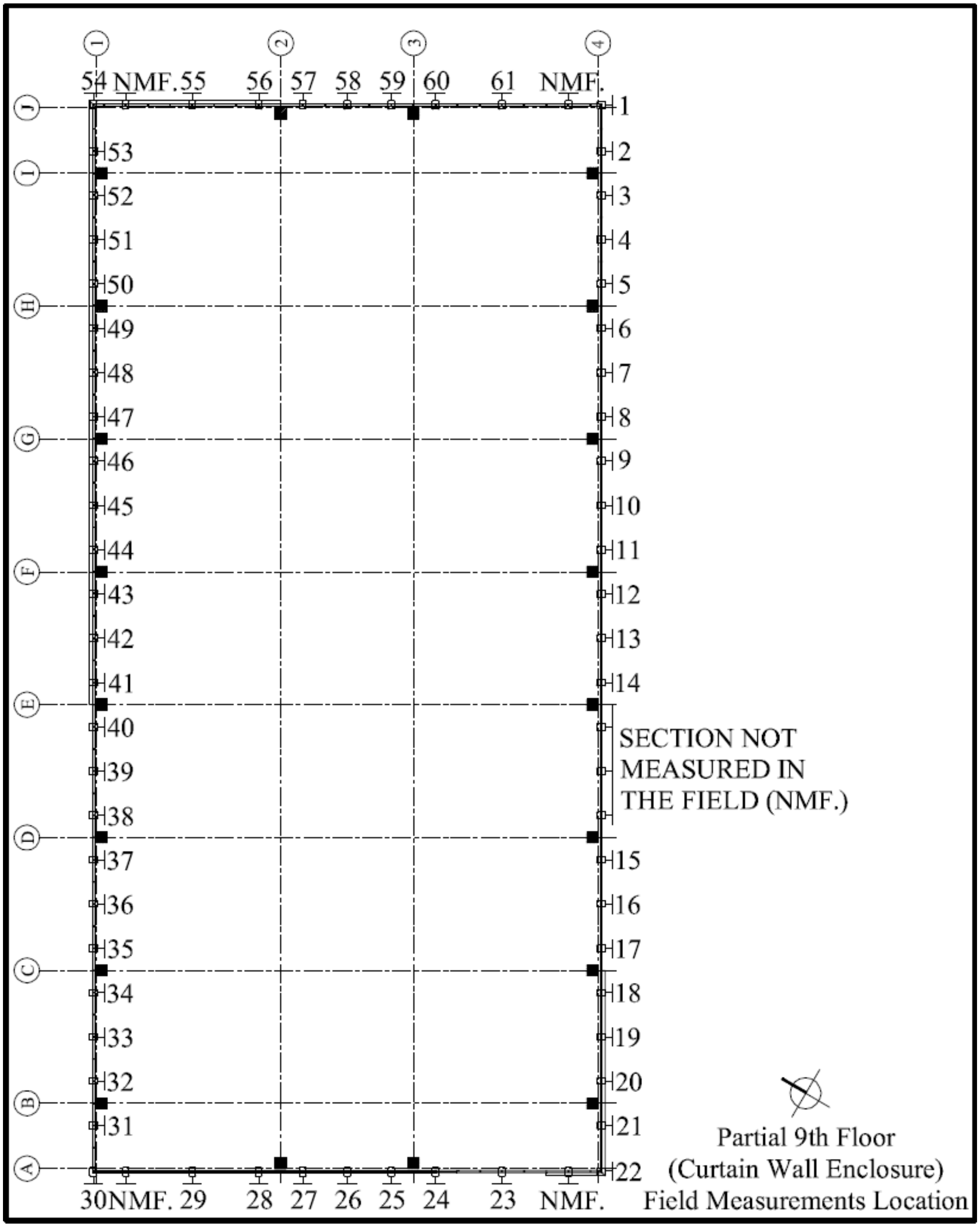


Figure C-28. Location of field measurements at 9th floor. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-11 Field measurements at 9th floor and tolerance calculations.

9th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
1	1 1/2	44 7/8	65	52 3/4	1/8	1/4	1/4
2	1 1/2	44 7/8	65 3/8	52 1/2	1/8	- 1/8	1/2
3	1 3/8	44 3/4	65 3/4	52 3/4	1/8	- 3/8	1/4
4	1 3/8	44 3/4	65 1/2	N.A.	1/8	- 1/8	N.A.
5	1 3/8	44 5/8	65 1/2	52 5/8	1/4	- 1/8	3/8
6	1 3/16	44 1/2	65 3/8	52 3/4	3/16	3/16	1/4
7	1 3/16	44 1/2	65 1/2	N.A.	3/16	1/16	N.A.
8	1 3/16	44 1/2	65 1/2	52 3/4	3/16	1/16	1/4
9	1 15/16	44 1/4	65 5/8	52 3/4	1 3/16	- 13/16	1/4
10	1 15/16	44 1/8	65 7/8	N.A.	1 5/16	-1 1/16	N.A.
11	1 15/16	44 3/8	65 7/8	52 7/8	1 1/16	-1 1/16	1/8
12	1 1/16	44 1/2	65 1/2	52 7/8	1/16	3/16	1/8
13	1 1/16	44 1/2	65 5/8	N.A.	1/16	1/16	N.A.
14	1 1/16	44 1/2	65 5/8	52 3/4	1/16	1/16	1/4
15	1 5/8	44 5/8	65	52 5/8	1/2	1/8	3/8
16	1 5/8	44 5/8	65	N.A.	1/2	1/8	N.A.
17	1 3/8	44 3/4	65 1/8	53	1/8	1/4	0
18	1 1/2	44 3/4	65 1/4	52 3/4	1/4	0	1/4
19	1 1/2	44 7/8	65 1/8	N.A.	1/8	1/8	N.A.
20	1 1/2	44 3/4	65 1/2	52 3/8	1/4	- 1/4	5/8
21	1 7/8	45 1/8	65	52 7/8	1/4	- 1/8	1/8

*Refer to Figure C-28 for the location of the measurements taken in the field.

Table C-11 Continued

9th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	**A**	**B**	**C**	**D**	**At Btm of Opening**	**At Top of Opening**	**Ctrl Ln to Conc. Pnl**
22	1 7/8	45 1/8	64 5/8	53	1/4	1/4	0
23	1 7/8	45 1/4	64 3/4	N.A.	1/8	1/8	N.A.
24	1 7/8	45 1/4	65	52 3/4	1/8	- 1/8	1/4
25	1 1/2	44 7/8	65 1/4	52 3/4	1/8	0	1/4
26	1 1/2	44 3/4	65 1/4	N.A.	1/4	0	N.A.
27	1 1/2	44 3/4	65 1/4	53 1/8	1/4	0	- 1/8
28	2	45 1/2	65 1/4	53 1/8	0	- 1/2	- 1/8
29	2	45 1/2	64 3/4	N.A.	0	0	N.A.
30	2	45 1/8	64 3/4	52 5/8	3/8	0	3/8
31	2	45 1/4	65	52 3/4	1/4	- 1/4	1/4
32	2	45 1/4	64 3/4	52 5/8	1/4	0	3/8
33	2	45 1/2	65	N.A.	0	- 1/4	N.A.
34	2	45 1/2	65	52 1/2	0	- 1/4	1/2
35	7/8	44 1/4	66	52 3/4	1/8	- 1/8	1/4
36	7/8	44 1/4	66	N.A.	1/8	- 1/8	N.A.
37	7/8	44	66	52 3/4	3/8	- 1/8	1/4
38	1 1/8	44 1/2	65 1/2	52 3/4	1/8	1/8	1/4
39	1 1/8	44 5/8	65 3/8	N.A.	0	1/4	N.A.
40	1 1/8	44 1/2	65 1/4	52 5/8	1/8	3/8	3/8
41	1 1/8	44 1/4	65 3/8	52 5/8	3/8	1/4	3/8
42	1 1/8	44 3/8	65 1/2	N.A.	1/4	1/8	N.A.

*Refer to Figure C-28 for the location of the measurements taken in the field.

Table C-11 Continued

9th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
43	1 1/8	44 1/4	65 3/4	53	3/8	- 1/8	0
44	1 1/8	44 1/2	65 3/8	52 5/8	1/8	1/4	3/8
45	1 1/8	44 5/8	65 1/4	N.A.	0	3/8	N.A.
46	1 1/8	44 1/2	65 3/8	52 7/8	1/8	1/4	1/8
47	1 1/8	44 5/8	65 1/4	52 7/8	0	3/8	1/8
48	1 1/8	44 7/8	65 1/2	N.A.	- 1/4	1/8	N.A.
49	1 1/8	44 1/2	65 1/4	55 1/8	1/8	3/8	-2 1/8
50	1	44 3/8	65 1/2	52 7/8	1/8	1/4	1/8
51	1	44 3/8	65 1/2	N.A.	1/8	1/4	N.A.
52	1	44 3/8	65 5/8	52 3/4	1/8	1/8	1/4
53	1 3/4	45 1/4	64 7/8	52 5/8	0	1/8	3/8
54	1 3/4	45 1/4	65	53	0	0	0
55	1 3/4	45 1/4	65 1/8	N.A.	0	- 1/8	N.A.
56	1 3/4	45	65 1/8	52 3/4	1/4	- 1/8	1/4
57	1 9/16	44 3/4	65 1/4	53	5/16	- 1/16	0
58	1 9/16	44 3/4	65 1/4	N.A.	5/16	- 1/16	N.A.
59	1 9/16	44 7/8	65 1/4	52 3/4	3/16	- 1/16	1/4
60	1 3/4	44 7/8	64 7/8	52 5/8	3/8	1/8	3/8
61	1 3/4	44 7/8	65	N.A.	3/8	0	N.A.

*Refer to Figure C-28 for the location of the measurements taken in the field.

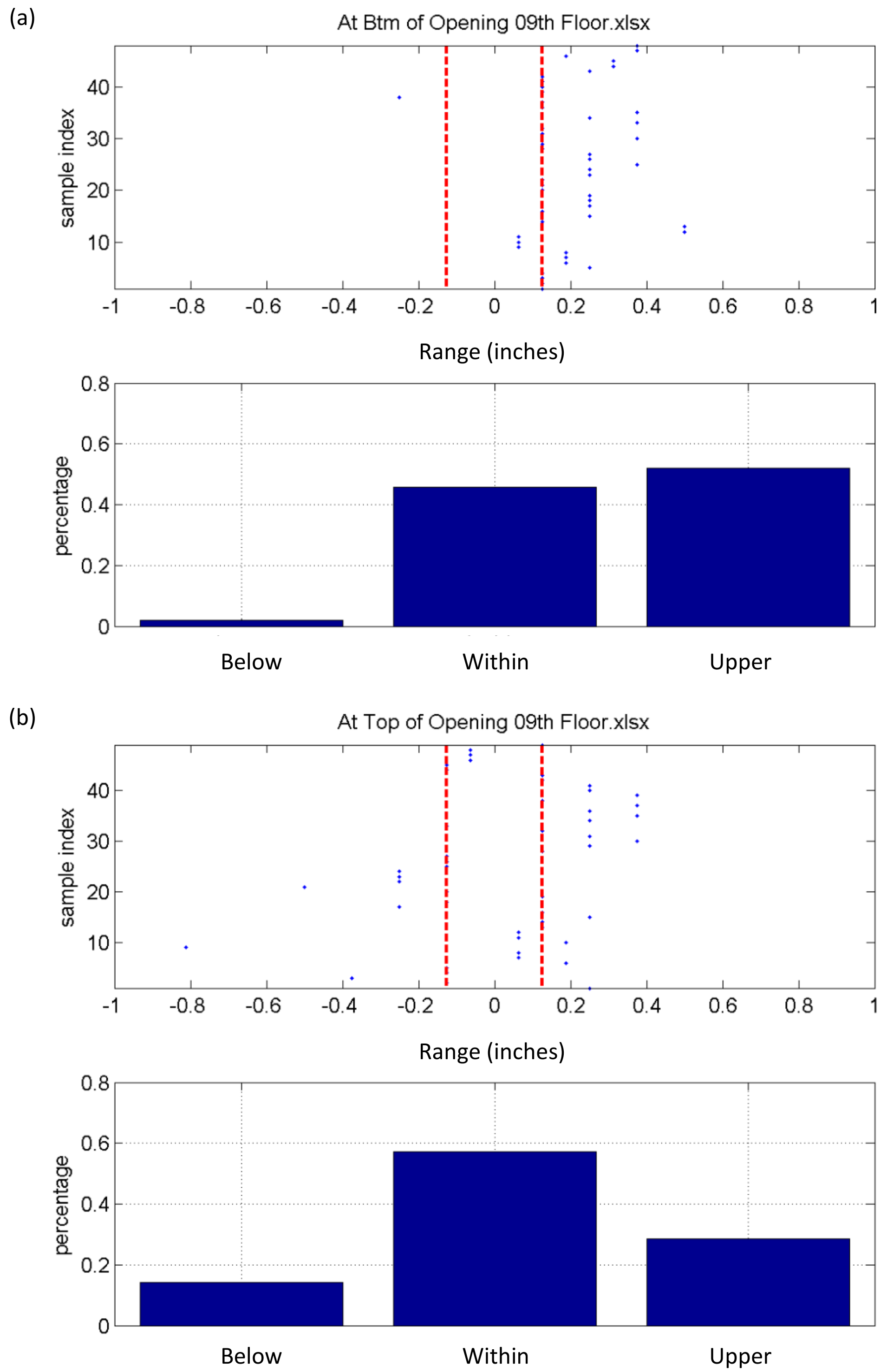


Figure C-29. Plots of tolerance results at the bottom of the opening (a) and at the top of the opening from control line (b), 9th floor.

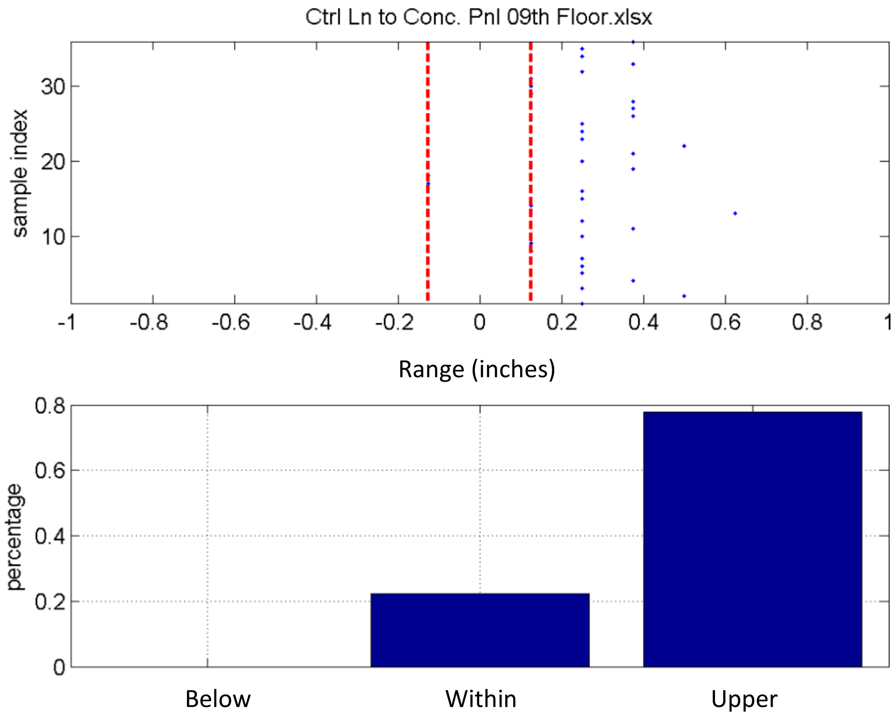


Figure C-30. Plot of tolerance results from control line to the precast panel.

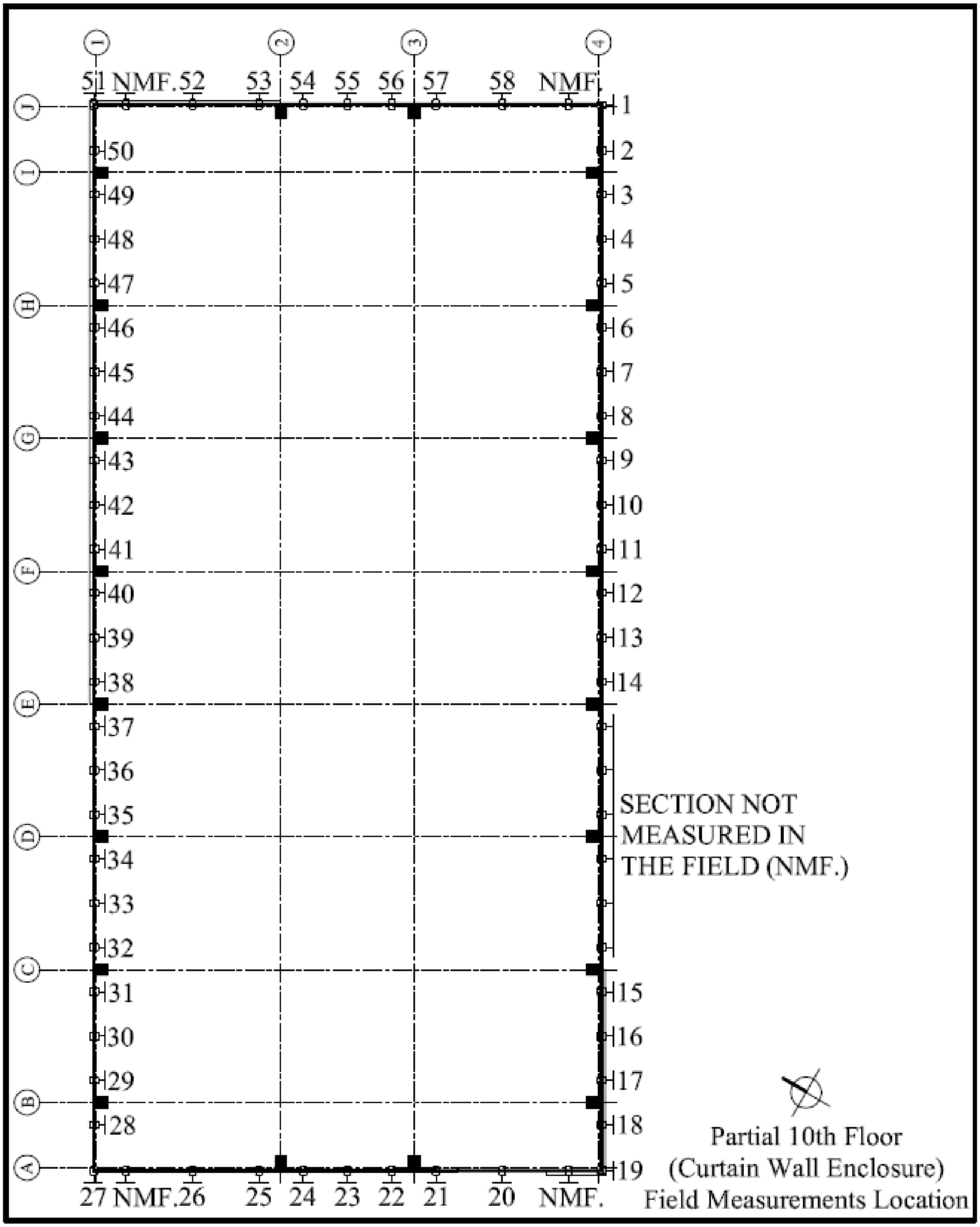


Figure C-31. Location of field measurements at 10^{th} floor plan. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014).

Table C-12 Field measurements at 10th floor and tolerance calculations.

10th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
1	2 1/8	45 5/8	64 7/8	52 3/4	0	- 1/4	1/4
2	2 1/8	45 3/8	64 7/8	53	1/4	- 1/4	0
3	2 1/8	45 3/8	64 7/8	52 7/8	1/4	- 1/4	1/8
4	2 1/8	45 3/8	64 3/4	N.A.	1/4	- 1/8	N.A.
5	2	45 1/2	65	52 5/8	0	- 1/4	3/8
6	2	45 5/8	64 7/8	52 7/8	- 1/8	- 1/8	1/8
7	2	45 5/8	65	N.A.	- 1/8	- 1/4	N.A.
8	1 3/4	45 1/4	65 1/2	52 5/8	0	- 1/2	3/8
9	1 3/4	45 3/8	65 3/8	52 3/4	- 1/8	- 3/8	1/4
10	1 3/4	45 1/4	65 1/4	N.A.	0	- 1/4	N.A.
11	1 3/4	45 1/4	65 1/8	52 3/4	0	- 1/8	1/4
12	1 3/8	45 1/8	65 3/8	52 3/4	- 1/4	0	1/4
13	1 3/8	45	65 3/8	N.A.	- 1/8	0	N.A.
14	1 3/8	44 3/4	65 1/2	52 5/8	1/8	- 1/8	3/8
15	1 9/16	45 1/4	65 1/4	52 5/8	- 3/16	- 1/16	3/8
16	1 9/16	45 3/8	65 1/4	N.A.	- 5/16	- 1/16	N.A.
17	15 3/4	58 7/8	51 1/4	52 5/8	3/8	- 1/4	3/8
18	15 3/4	58 7/8	51 1/4	N.A.	3/8	- 1/4	N.A.
19	13 3/4	57 5/16	53 3/8	N.A.	- 1/16	- 3/8	N.A.
20	13 3/4	57 1/4	53 1/2	N.A.	0	- 1/2	N.A.
21	13 3/4	57 1/4	53 1/8	52 3/4	0	- 1/8	1/4

*Refer to Figure C-31 for the location of the measurements taken in the field.

Table C-12 Continued

10th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
22	13 3/4	57 3/8	53	52 3/4	- 1/8	0	1/4
23	13 3/4	57 3/16	53 3/8	N.A.	1/16	- 3/8	N.A.
24	13 3/4	57 3/8	53 5/8	52 7/8	- 1/8	- 5/8	1/8
25	13 3/4	57 1/8	53 1/2	52 7/8	1/8	- 1/2	1/8
26	13 3/4	57 1/4	53 1/8	N.A.	0	- 1/8	N.A.
27	13 3/4	57 1/2	53 1/8	52 7/8	- 1/4	- 1/8	1/8
28	13 3/4	57 1/2	53 1/8	52 3/8	- 1/4	- 1/8	5/8
29	13 1/2	57 1/4	53 1/8	52 3/4	- 1/4	1/8	1/4
30	13 1/2	57	53 1/4	N.A.	0	0	N.A.
31	13 1/2	57	53 1/4	52 5/8	0	0	3/8
32	13 1/2	57 1/4	53 3/8	52 3/4	- 1/4	- 1/8	1/4
33	13 1/2	57	53 3/16	N.A.	0	1/16	N.A.
34	13 1/2	57	53 1/4	52 3/4	0	0	1/4
35	13 1/2	57 3/8	53 1/8	52 3/4	- 3/8	1/8	1/4
36	13 1/2	57 1/4	53 1/4	N.A.	- 1/4	0	N.A.
37	13 1/2	57 5/8	53 3/4	53 1/4	- 5/8	- 1/2	- 1/4
38	11 3/8	55 1/8	55 3/4	52 5/8	- 1/4	- 3/8	3/8
39	11 3/8	55 1/8	55 1/2	N.A.	- 1/4	- 1/8	N.A.
40	11 3/8	54 3/4	55 1/2	52 7/8	1/8	- 1/8	1/8
41	10 5/16	53 7/8	56 1/2	52 7/8	- 1/16	- 1/16	1/8
42	10 5/16	54	56 3/8	N.A.	- 3/16	1/16	N.A.

*Refer to Figure C-31 for the location of the measurements taken in the field.

Table C-12 Continued

10th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
43	10 5/16	54	56 1/2	52 5/8	- 3/16	- 1/16	3/8
44	10 5/16	54 1/8	56 5/8	52 7/8	- 5/16	- 3/16	1/8
45	10 5/16	54	56 1/2	N.A.	- 3/16	- 1/16	N.A.
46	10 5/16	54 7/8	56 13/16	52 7/8	-1 1/16	- 3/8	1/8
47	9 7/8	53 1/2	57 1/4	52 5/8	- 1/8	- 3/8	3/8
48	9 7/8	53 1/2	56 3/4	N.A.	- 1/8	1/8	N.A.
49	9 7/8	53 1/5	57 1/8	52 5/8	7/40	- 1/4	3/8
50	9 7/8	53 7/8	57 1/2	52 3/4	- 1/2	- 5/8	1/4
51	9 7/8	53 1/2	57 1/8	52 3/4	- 1/8	- 1/4	1/4
52	9 7/8	53 1/2	57 1/4	N.A.	- 1/8	- 3/8	N.A.
53	10 5/8	54	56 1/2	53 1/8	1/8	- 3/8	- 1/8
54	1 3/4	45 1/8	65 1/4	53 1/2	1/8	- 1/4	- 1/2
55	1 3/4	45 1/4	65 1/8	N.A.	0	- 1/8	N.A.
56	1 7/8	45 1/2	65	52 7/8	- 1/8	- 1/8	1/8
57	1 7/8	45 3/8	65 1/4	52 7/8	0	- 3/8	1/8
58	1 7/8	45 1/4	65 1/8	N.A.	1/8	- 1/4	N.A.

*Refer to Figure C-31 for the location of the measurements taken in the field.

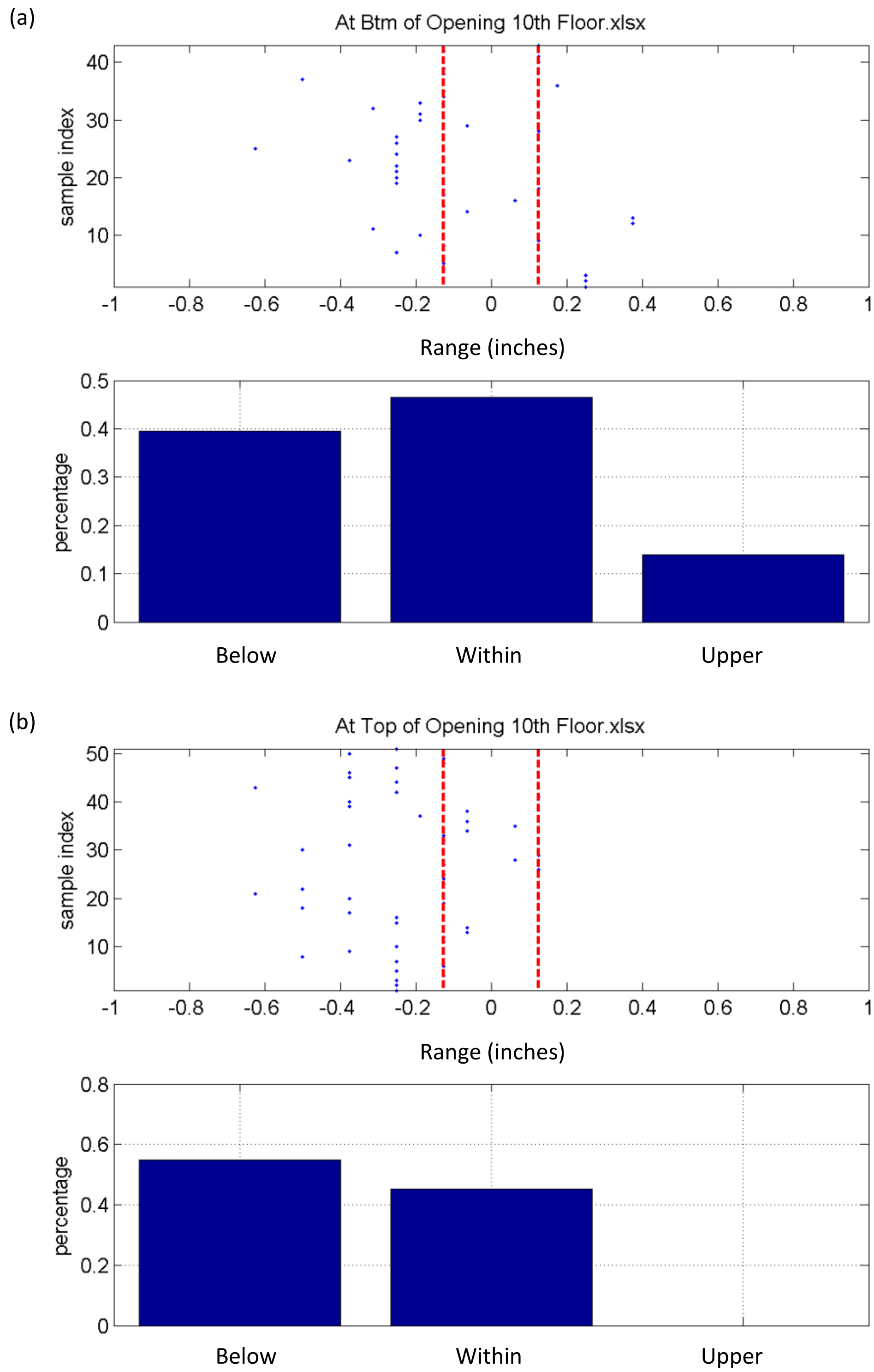


Figure C-32. Plots of tolerance results at the bottom of the opening (a) and at the top of the opening from control line (b), 10th floor.

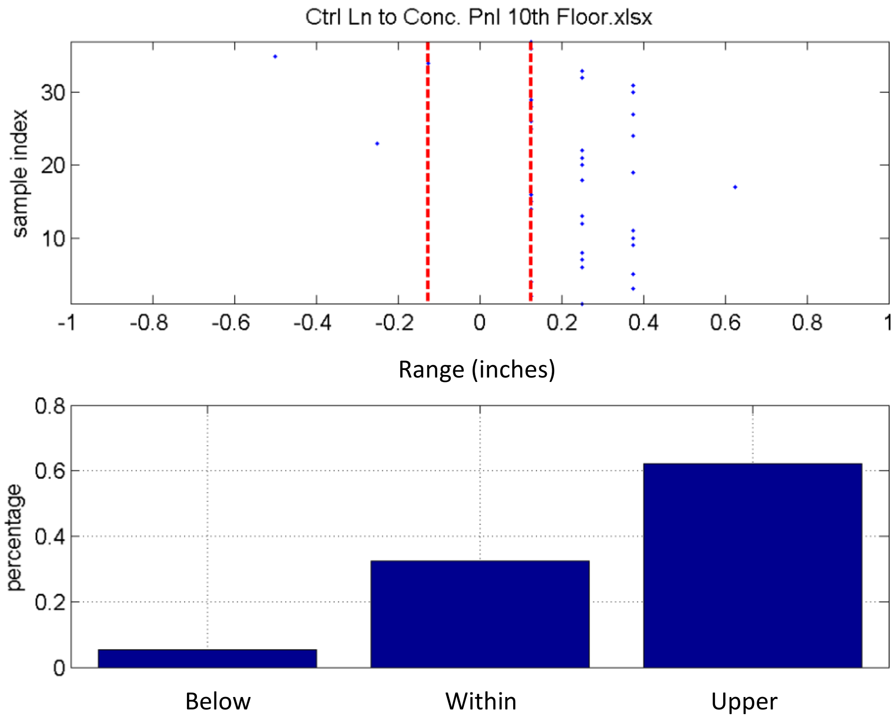


Figure C-33. Plot of tolerance results from control line to the precast panel at 10^{th} floor.

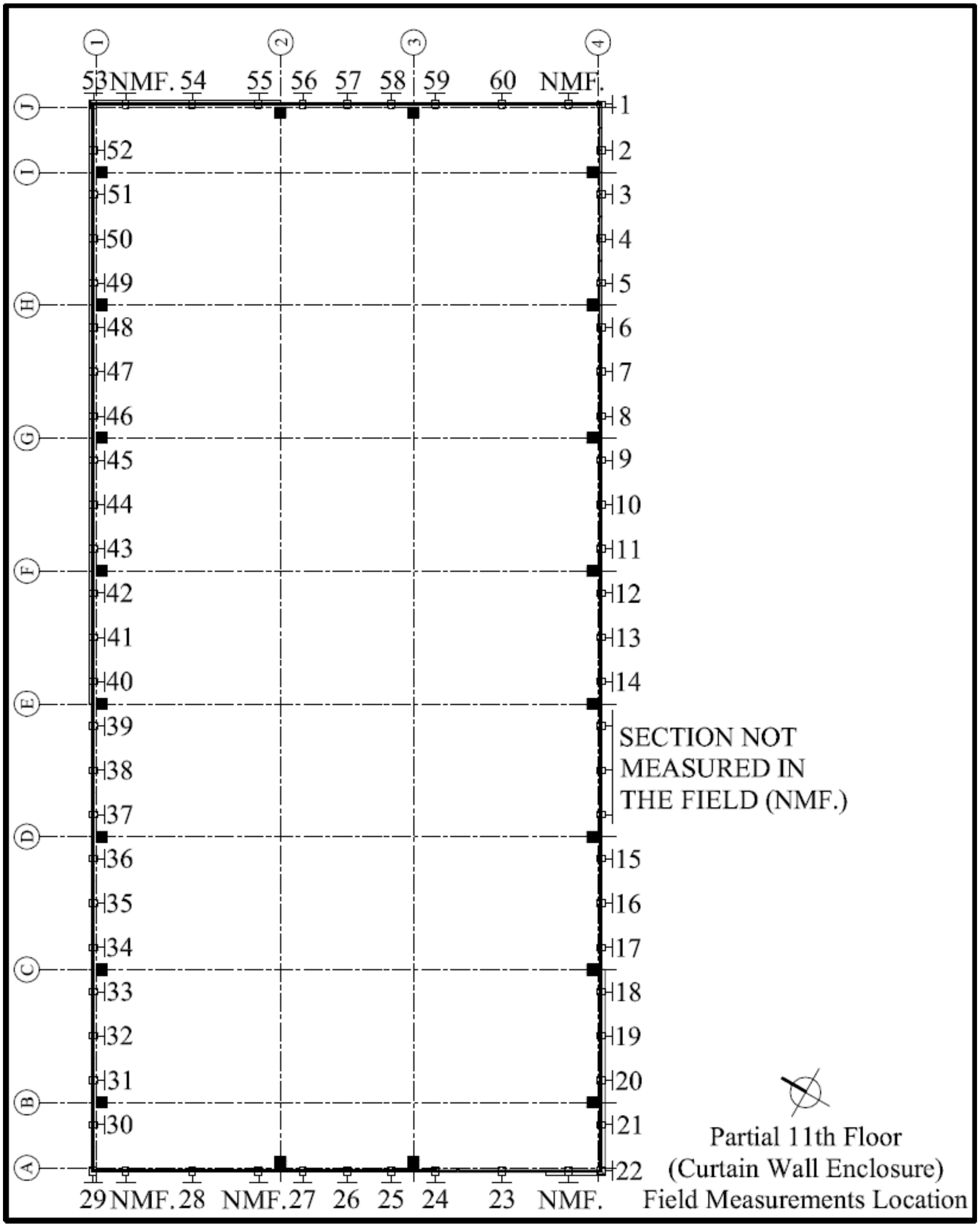


Figure C-34. Location of field measurements at 11th floor plan. Numbers denote the location of the measurements taken in the field by the researcher. Adapted from Dietzmann, J. M., Jr. (2014)

Table C-13 Field measurements at 11th floor and tolerance calculations.

11th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	**A**	**B**	**C**	**D**	**At Btm of Opening**	**At Top of Opening**	**Ctrl Ln to Conc. Pnl**
1	3 1/4	46 3/4	63 1/4	52 3/4	0	1/4	1/4
2	2 7/8	46 1/2	63 1/4	52 3/4	- 1/8	5/8	1/4
3	2 7/8	46 1/4	63 3/8	52 5/8	1/8	1/2	3/8
4	2 7/8	46 1/4	63 1/2	N.A.	1/8	3/8	N.A.
5	2 7/8	46 1/4	63 3/4	52 1/2	1/8	1/8	1/2
6	3 3/8	46 1/2	63 1/4	53	3/8	1/8	0
7	3 3/8	46 3/4	63 1/4	N.A.	1/8	1/8	N.A.
8	3 3/8	46 3/8	63 1/4	52 3/4	1/2	1/8	1/4
9	1 1/8	44 1/4	65 3/8	52 1/2	3/8	1/4	1/2
10	1 1/8	44 1/2	65 1/2	N.A.	1/8	1/8	N.A.
11	1 1/8	44 1/2	65 3/8	53	1/8	1/4	0
12	2 3/4	46 1/4	63 7/8	52 3/4	0	1/8	1/4
13	2 3/4	46 1/4	64	N.A.	0	0	N.A.
14	2 3/4	46 1/4	64	52 5/8	0	0	3/8
15	2 13/16	46	63 3/4	52 5/8	5/16	3/16	3/8
16	2 13/16	46	63 3/4	N.A.	5/16	3/16	N.A.
17	2 13/16	46	63 3/4	53	5/16	3/16	0
18	2 15/16	46 1/4	63 7/8	52 3/4	3/16	- 1/16	1/4
19	2 15/16	46 3/8	63 7/8	N.A.	1/16	- 1/16	N.A.
20	2 15/16	46 1/4	63 1/4	52 1/2	3/16	9/16	1/2
21	3 1/4	46 5/8	63 1/2	52 5/8	1/8	0	3/8

*Refer to Figure C-34 for the location of the measurements taken in the field.

Table C-13 Continued

11th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
22	3 1/4	46 5/8	63 5/8	53	1/8	- 1/8	0
23	3 1/4	46 3/4	63 1/2	N.A.	0	0	N.A.
24	3 1/4	46 3/4	63 3/4	52 3/4	0	- 1/4	1/4
25	3 3/8	46 3/4	63 1/4	53	1/8	1/8	0
26	3 3/8	46 3/4	63 1/4	N.A.	1/8	1/8	N.A.
27	3 3/8	46 3/8	63 3/8	52 7/8	1/2	0	1/8
28	3 5/8	47 1/16	63 3/8	N.A.	1/16	- 1/4	N.A.
29	3 5/8	47 1/8	63 3/8	52 7/8	0	- 1/4	1/8
30	3 1/2	46 7/8	63 1/2	52 5/8	1/8	- 1/4	3/8
31	3	46 1/2	64 1/8	53 1/8	0	- 3/8	- 1/8
32	3	46 1/2	64 1/8	N.A.	0	- 3/8	N.A.
33	3	46 3/8	63 7/8	52 7/8	1/8	- 1/8	1/8
34	2 15/16	46 1/4	64	52 3/4	3/16	- 3/16	1/4
35	2 15/16	46	64	N.A.	7/16	- 3/16	N.A.
36	2 15/16	46 1/8	64	52 3/4	5/16	- 3/16	1/4
37	2 3/4	46 1/8	64	52 7/8	1/8	0	1/8
38	2 3/4	46 1/4	64	N.A.	0	0	N.A.
39	2 3/4	46 1/8	64	52 7/8	1/8	0	1/8
40	3	46 1/2	63 3/4	52 3/4	0	0	1/4
41	3	46 3/4	63 3/4	N.A.	- 1/4	0	N.A.

*Refer to Figure C-34 for the location of the measurements taken in the field.

Table C-13 Continued

11th Floor (measurements collected from clean openings ready for CW installation)					Tolerance Results		
Location*	A	B	C	D	At Btm of Opening	At Top of Opening	Ctrl Ln to Conc. Pnl
42	3	46 1/2	63 7/8	52 1/2	0	- 1/8	1/2
43	2 5/8	46 1/4	64 1/8	52 5/8	- 1/8	0	3/8
44	2 5/8	46 1/4	64	N.A.	- 1/8	1/8	N.A.
45	2 5/8	46 1/4	64 1/8	52 5/8	- 1/8	0	3/8
46	2 3/4	46 1/4	64	52 5/8	0	0	3/8
47	2 3/4	46	64	N.A.	1/4	0	N.A.
48	2 3/4	46	64	52 3/4	1/4	0	1/4
49	2 15/16	46 1/4	63 7/8	52 3/4	3/16	- 1/16	1/4
50	2 15/16	46 3/8	63 5/8	N.A.	1/16	3/16	N.A.
51	2 15/16	46 3/8	63 3/4	52 3/4	1/16	1/16	1/4
52	3 1/2	46 7/8	62 7/8	52 3/4	1/8	3/8	1/4
53	3 1/2	47	63	52 1/2	0	1/4	1/2
54	3 1/2	47	63 1/4	N.A.	0	0	N.A.
55	3 3/8	46 5/8	63 1/8	52 7/8	1/4	1/4	1/8
56	3 1/2	46 3/4	63	53	1/4	1/4	0
57	3 1/2	46 3/4	63	N.A.	1/4	1/4	N.A.
58	3 1/2	46 7/8	62 7/8	52 3/4	1/8	3/8	1/4
59	3 1/4	46 3/4	63 1/8	52 3/4	0	3/8	1/4
60	3 1/4	46 3/8	63 1/8	N.A.	3/8	3/8	N.A.

*Refer to Figure C-34 for the location of the measurements taken in the field.

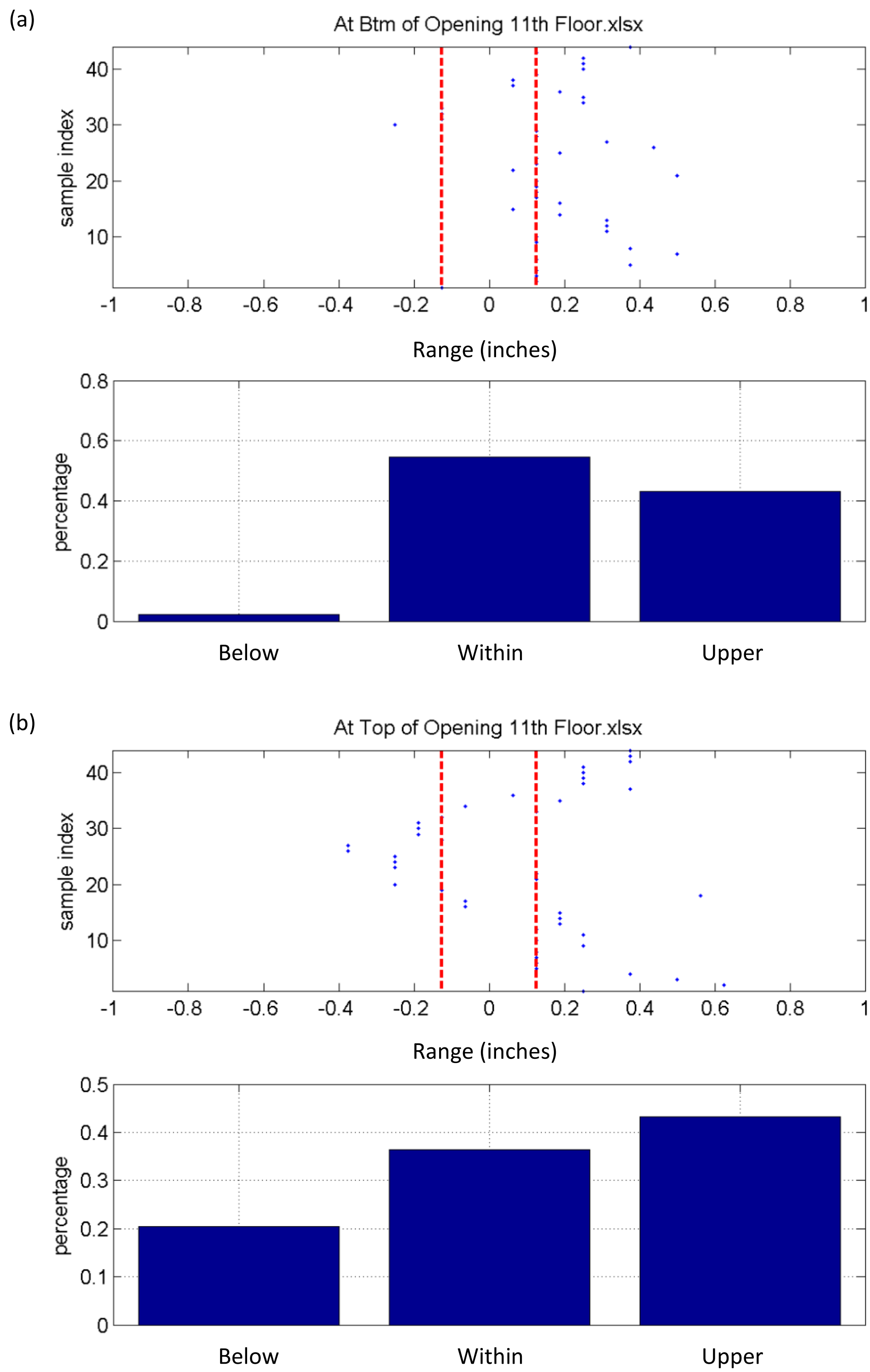


Figure C-35. Plots of tolerance results at the bottom of the opening (a) and at the top of the opening from control line (b), 11th floor.

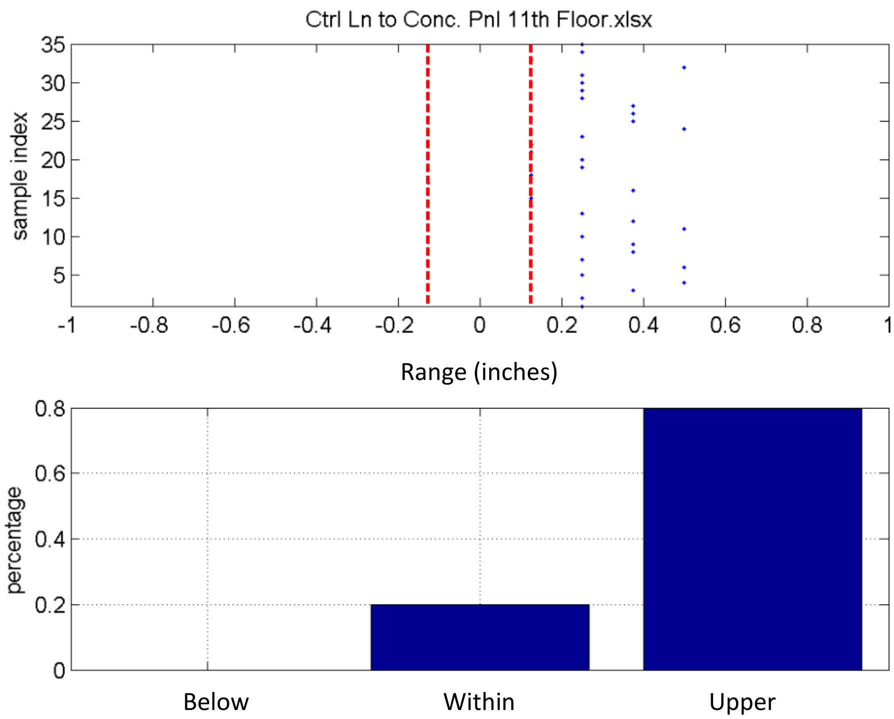


Figure C-36. Plot of tolerance results from control line to the precast panel at 11th floor.