Final Report:

Evaluation of Wind Resistance of Vinyl Siding and Soffit Systems, and Performance during the 2017 Hurricane Irma

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EXECUTIVE SUMMARY

University of Florida undertook a comprehensive assessment of the wind resistance performance of vinyl-cladding residential buildings during Hurricane Irma in 2017. The storm produced a wide distribution of wind speeds in Florida and thus enabled researchers to observe how these building envelope materials performed, using a robust dataset of building damage observations collected and publicly made available. The primary question being addressed is whether vinyl siding materials are failing at a disproportionately high rates during less than design level wind events, such as Hurricane Irma.

The report also describes prior research conducted at the University of Florida on the performance of soffit materials. Recommendations such as developing specific details for installing soffits at building corners were identified as potential means of augmenting the building code provisions, as corner soffits had disproportionately large percentage of failures in high winds.

The researchers supplemented the post-hurricane assessments with permit records provided by the Monroe County Building Department, oblique imagery of every building in the assessment provided through Pictometry Eagleview, public attributes from the county property appraiser databases, and wind speed and direction time histories at each location using a calibrated hurricane wind field model provided through the Florida Public Hurricane Loss Model. Using this information, the researchers built out a database of 125 homes (64 post-FBC and 61 pre-FBC) for which vinyl siding, vinyl soffit, and fascia performance was quantified with respect to the location of the material on the building, and the orientation relative to the highest wind speeds.

Analysis of the dataset revealed that siding failure rates were consistently lower in post-FBC homes than in pre-FBC homes. However, for post-FBC homes, failure rates were higher in Hurricane Irma, where estimated wind speeds were well below design, than in Hurricane Michael, where estimated wind speeds were close to or exceeded design. The popularity of modular homes in the Florida Keys appears to be a contributing factor and should be researched further. Analysis of the dataset also revealed a moderate positive correlation between the location of fascia damage and the locations of vinyl soffit damage. There are some indications that vinyl siding damage is more likely to occur under cornering wind angles of attack, which should therefore be modeled in the experimental approach.

Details of the study and analysis of vinyl performance are provided herein. Further, the researchers fabricated as Phase I of this study a multi-chamber pressure chamber that is feasible for evaluating the wind uplift resistance of vinyl siding. This test device which is based on the University of Florida Spatio-Temporal Pressure Loading Actuator will enable the simulation of spatially varying pressures. Of prime interest is the development in future of reasonable pressure equalization factor tests that could replicate the testing performed on full scale buildings in the IBHS wind tunnel. The fabrication is continuing and will be completed at the end of the June 2019.

TABLE OF CONTENTS

List of Tables

Table **Page**

List of Figures

1 INTRODUCTION

The University of Florida's report on the 2017 hurricane season submitted to the Florida Building Commission, observed high numbers of premature failure of vinyl siding and soffit materials on residential building structures (Prevatt et al. 2018). The report assessed damage to houses, noting 347 out of approximately 800 structures had either vinyl siding or soffits, with various levels of damage occurring to them. Many of the failures resulted in costly water leakage to the interiors of the structures that damaged the structures and ruined the contents within the buildings.

The performance of vinyl siding was reported among all residential building performance finding the damage occurred throughout a large portion of the state of Florida. However, specific causes and failure mechanisms for vinyl siding and soffits were not identified as this was outside the report scope. However, the report recommended further studies to address the performance, particularly to understand whether newly installed vinyl siding on newer (post-2001) building failed prematurely during Hurricane Irma.

1.1 Hurricane Irma

Hurricane Irma made its first landfall in the continental US at Cudjoe Key in southern Florida on September 10, 2017, with Category 4 winds reaching 58 m/s (130 mph). The National Hurricane Center (NHC) downgraded Irma to a Category 3 storm as it made its second landfall later that afternoon on Marco Island, just south of Naples on the Florida's Gulf Coast, with sustained winds near 54 m/s (120 mph). It weakened further to a Category 2 once inland.

The storm's large wind field resulted in strong winds across much of Florida. The highest reported sustained wind speed was 50 m/s (112 mph) on Marco Island, while the strongest observed wind gust was 64 m/s (142 mph), recorded near Naples, though wind gusts of 67 to 72 m/s (150 to 160 mph) likely occurred in the Middle Florida Keys. Generally, heavy amounts of rainfall were recorded to the east of the Irma's path, including a peak total of 550 mm (21.66 in) in Fort Pierce. Heavy precipitation – and storm surge, in some instances – overflowed at least 32 rivers and creeks, causing in significant flooding, particularly along the St. Johns River and its tributaries. The highest recorded storm surge was 8.31 ft NAVD88 near Everglade City. A complete synopsis of Hurricane Irma and its impacts is available through the National Hurricane Center (NOAA, 2018).

1.2 Motivation and Purpose

The motivation for this research is to shed light on the apparent premature failure of vinyl siding and soffit systems during Hurricane Irma and other hurricanes. The analysis of survey data is expected to show whether the appropriate siding and soffit systems were installed in the locations, whether they failed at or above the design wind pressures and whether there are any patterns within the construction or workmanship of the installations. Through the experimental testing, the research will advance current testing to include spatially non-uniform pressures. This test procedure if proved to be appropriate, will be a forerunner for future multi- chamber pressure testing on discontinuous siding and roofing systems.

1.3 Scope of Work

- Review the database summary and results from the 2017 Hurricane Irma and identify the structures and wind speeds related to vinyl siding and soffits failure.
- Review the previous University of Florida research report on wind resistance of soffit panel systems and report upon design requirements for evaluating wind loading on vented (perforated) soffit systems.
- Estimate the wind speed and direction at each home with vinyl siding/soffit/fascia failure, using local wind observations, and map to failure locations.
    - i. Contact other organizations involved in collecting post Hurricane Irma damage investigation on residential structures (FEMA, Vinyl Siding Institute, NIST) to augment the University of Florida damage assessment and performance data from additional surveys. Analyze damage assessment surveys to determine the extent of additional available information on the performance of vinyl siding and soffits in order to assemble a complete set of data on performance.
    - ii. Identify from the augmented database of surveyed houses, the locations of failed soffit and siding systems relative to the dominant wind direction and wind speeds causing failures. If possible, determine whether failures are caused by mean positive pressure fluctuations on the windward side or due to suction pressures on leeward location from accelerating air flows around the sides of the building.
    - iii. Conduct up to three days of field work to assess vinyl siding systems that failed, or did not fail but were in close proximity to systems that did fail with the intent of documenting in greater more detail dimensions and properties of typical vinyl siding systems, fastener schedules, etc. Work with local building officials to coordinate the deployment and gain access to target homes.

iv. Identify specific post-2001 installed vinyl siding and soffit materials and systems that were surveyed following Hurricane Irma, tracking down their manufacture and design specifications and performance.

- Convene an invited Advisory Panel to provide advice to the Principal Investigator. Invitations to participate will be extended to representatives from IBHS, FIU, Vinyl Siding Institute and UWO. Hold three conference calls during the contract period.
- Develop experimental test procedure that recreates wind loading on vinyl siding systems observed in the field. Coordinate this development with recent research findings from UWO and IBHS and Vinyl Siding Institute.
    i. Conduct testing on representative samples of the observed vinyl siding systems using the appropriate test devices (Spatio-Temporal Pressure Loading Actuator SPLA or Dynamic Flow Simulator) to simulate the failure mechanisms observed in the 2017 post-hurricane damage survey.

- Report to the Florida Building commission a summary of the performance factors for vinyl siding systems, including recommendations of the modifications of existing test specifications if appropriate.

1.4 Literature Review

The University Florida, in previous research, some of which was sponsored in part by the Florida Building Commission and conducted between 2008 and 2010, addressed some issues for performance of vinyl siding and soffits. Those studies modeled under laboratory conditions water intrusion into residential wall cladding systems (including vinyl siding) (C Lopez et al. 2011) and structural performance of vented (perforated) soffits (C. L. Alexander et al. 2013). It is not certain whether any of the recommendations from the previous studies have been included into the current building code provisions. This proposal developed by the University of Florida (The Contractor) will offer a further study for consideration by the Florida Building Commission. Chapter 2 includes details of these studies.

1.5 Pressure Equalization Factor Studies

The evaluation of wind loading on discontinuous building cladding systems such as vinyl siding, soffits and discontinuous metal roofing systems is an area of active research by several organizations at present. There is evidence that current testing procedures that utilize uniform pressure on the test specimen to produce the design value PEFs may not be appropriate. Oh and Kopp (Oh and Kopp 2014) used an experimental test setup consisting of four pressure chambers to replicate the spatial and temporal variation of wind pressures on a vinyl siding specimen. By developing a numerical model this study clearly provided an approach to explain the physical mechanisms governing air pressure equalization. Miller et al. have furthered this work to practical implications suggesting that a test method is feasible using multiple test chambers (Miller et al. 2017).

The standard specification for rigid PVC/vinyl siding is ASTM D3679 (ASTM 2017) which recommends wind load testing per ASTM D5206 (ASTM 2013). This test standard utilizes a step and hold monotonically increasing test approach starting a 5 psf uniform pressure for 30 seconds and increasing in 5psf increments each held for 30 seconds. The Wind Load Resistance Test Design Factors in Annex 1 of ASTM D3679 provide additional information regarding the provision of Pressure Equalization Factors (PEFs) for reducing the design wind load because vinyl siding systems are discontinuous, and they enable wind flow between the cavity and the exterior.

The current test methods make the simplification of applying a single uniform pressure to the siding systems, whereas realistic wind flows create spatially varying external pressures. How the vinyl siding behaves under such spatial pressures is unknown, although the assumption is that the uniform pressure test replicates the response to some extent.

In recent years, the wind loading, and testing of vinyl siding systems has been the focus of other organizations. In testing by Florida International University (Moravej et al. 2016) their report suggest that the current lower PEF value of 0.36 specified in ASTM D3679 may lead to the underestimation of loads for the design of details affected by local loads. This conclusion provided further support for the IBHS report on a full-scale building test at their wind load facility (Cope et al. 2012; Morrison and Cope 2015). In a follow-up study by the IBHS addressing fastener loads directly, the paper noted that there is a strong overall one to one correlation between the net outward loads calculated by applying the pressure load to the tributary area and the measured loads on the fasteners (Cope et al. 2014).

To the extent that some of the vinyl siding that failed during Hurricane Irma were approved based upon existing ASTM D 5206, they could be expected to have premature failure prior to attaining the actual design loads. Research utilizing the existing UF database of failures may be able to determine the extent of these conditions.

2 LITERATURE REVIEW

2.1 Soffit Panel Systems

2.1.1 Soffit Systems

Elements that enclose the underside of sloped or flat-roof overhang. Soffits are commonly made of fiber-cement panels, metal panels, stucco, vinyl panels or wood sheathing (FEMA 2008) .

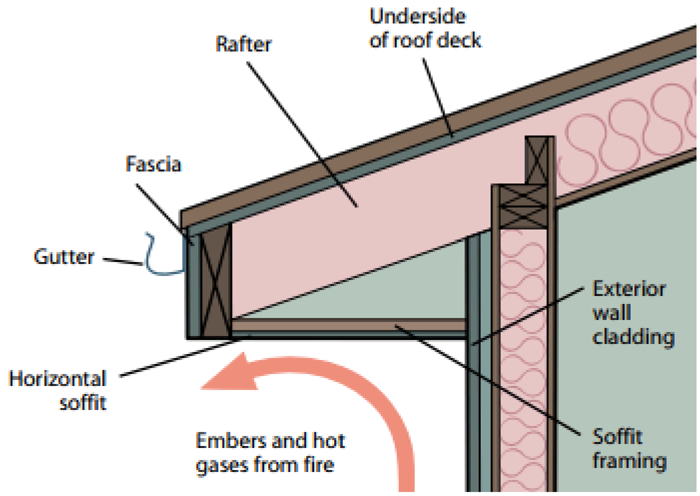


Figure 1. Enclosed Overhang with a Horizontal Soffit (FEMA 2008)

2.1.2 Design Requirements According to Florida Building Code 2017

The following steps summarize the design procedure for soffit systems according to the Florida Building Code 2017 (FEMA 2018)

Determine the location and site-specific factors

- Design wind speed
- Exposure category
- Mean roof height
- Find Zone 5 (soffit surfaces) pressures
- Modify wind pressure for specific wind zone
- Select the soffit system rated to resist Zone 5 pressures

2.1.3 Key issues

Following the building performance after hurricane Irma FEMA (2018) stated the following issues :

- Wind-damaged soffits allow wind-driven rain to enter the building envelopes
- The amount of water intrusion increases dramatically when the soffit material is missing
- Need for clarification of soffit installation criteria

2.1.4 Preliminary Investigation of Wind-Driven Rain Intrusion through Soffits

Reference

Masters, F. (2006). "PRELIMINARY INVESTIGATION OF WIND-DRIVEN RAIN INTRUSION THROUGH SOFFITS." project report to the Florida Department of Community Affairs Summer.

Experiment

Compare the performance of six soffit specimens subjected to wind-driven rain. The performance is measured as average percentage of freestream wind-driven rain that enters the soffit system (i.e. low average means better performance and viceverse) (Masters 2006).

Specimens

Specimen 1-Hidden vent soffit

Specimen 2- Perforated vinyl soffit

Specimen 3- Perforated aluminum soffit

Specimen 4-The perforated vinyl soffit in conjunction with an insect screen across the threshold of the attic and soffit space

Specimen 5- deflectors were added to the hidden vent soffits

Specimen 6-Baffled system

Figure 2. Specimens (Masters 2006)

Relevant Information

Unmodified soffit (specimen1~3)

- The perforated vinyl soffit (2.2% - 2.6% intrusion) outperformed the hidden vent and perforated aluminum soffits (4.2% - 8.3%).
- The perforated aluminum soffit (2.6% - 3.8%) outperformed the hidden vent soffit (4.2% - 8.3%).

Insect screen vinyl (specimen 4)

- Dry or wet initial condition make no difference
- Insect screen reduced intrusion 79% - 86% with values of average percentage of freestream wind-driven rain of (0.3% - 0.5%)

Deflector vent (specimen 5)

- Dry or wet initial condition didn't affect the performance of soffits.
- Deflectors reduced intrusion 69% - 79% with values of average percentage of freestream wind-driven rain of (1.3% - 1.8%)

Slot vent and Baffle system (specimen 6)

- Worst performer with 10.9% - 22.1% average percentage of freestream wind-driven rain

2.1.5 Structural and Wind-Driven Rain Resistance of Soffits

Reference

Fiscal Year 2011/2012 Scope of Work." <http://www.floridabuilding.org/fbc/commission/FBC_0812/HRAC/Task_5_Final_Report-Soffit.pdf>.

Experiment

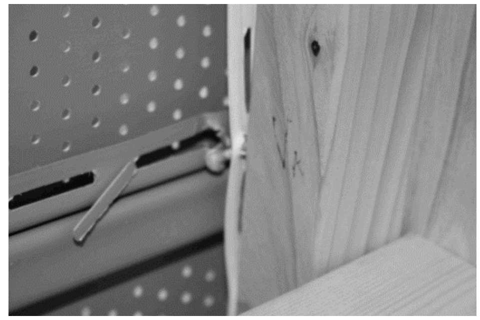
The experiment consist in the application of several quasi-static and dynamic wind loading to soffit panles. In the first stage considers vinyl and aluminum soffit while the second stage considers stucco, fiber cement board and OSB soffit.

Observed Failure Modes Vinyl and Aluminum Soffits

Panel Disengagement

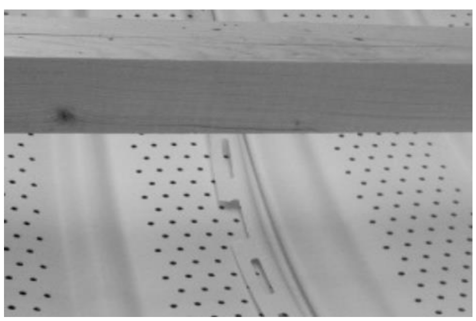
- Dominant failure mode
- The aluminum sections failed in the middle from panel disengagement.
- The vinyl sections failed in the end from panel disengagement.

Nail Pullover



- Dominant failure mode
- Nail pullover of the J-channel can cause the panels to disengage
- The sequence of nail pullover and panel unlocking could not easily be distinguished visually

Torn Nail Slot



Non-dominant failure mode

Permanent Set

Non-dominant failure mode

Figure 3. Failure Modes (Masters and Kiesling 2011)

Relevant information from Vinyl and Aluminum Soffits

- Straight 305 mm (1 ft) overhang soffit for both vinyl and aluminum soffits that have J-channels are expected to fail at pressures that exceed design requirements in hurricane prone areas.
- Straight 610 mm overhang (2 ft) for both vinyl and aluminum soffit experienced lower values of failure pressures; many of the soffit product approval documents list the same failure pressure values as the Straight 305 mm (1 ft) case

- For the straight 610 mm overhang vinyl siding soffit, there was no statistical difference for failure pressures in the quasi-static and dynamic load cases. This may be attributed to the same dominant failure mode.
- Aluminum soffits failed at larger pressures from dynamic loading than quasi-static loading.
- Panel disengagement was the dominant failure mode followed by material yielding (nail pull-over) at the fastener. Fastener withdrawal does not appear to represent a problem
- Consistency was observed between the range of observed failure pressures caused by dynamic loading and field observations in single story homes during Hurricane Charley by Gurley and Masters (2011). These homes experienced failures at 50 m/s (110 mph) winds, corresponding to ~1.5 kPa threshold in suburban terrain exposure at the height of a one-story building.
- Corner sections were more susceptible to wind loads than straight sections. There is very little guidance in the public domain for installing corner sections. Standardized product approval testing protocols should be updated to evaluate the performance of corner sections.

Observed Failure Modes Stucco, Fiber Cement Board and OSB Soffits

Figure 4. Predominant Failure Mode (Masters and Kiesling 2011)

- The most common mode of failure was pullout of the soffit around the fasteners in the intermediate nailing member (as the picture show)
- This failure was seen in each of the 610 mm (2 ft) fiber cement board soffit during both loading.
- The middle fastener should receive nominally twice the load the edge fasteners receive due to the difference in tributary area.

Relevant information from Stucco, Fiber Cement Board and OSB Soffits

In contrast to the aluminum and vinyl soffit sections OSB, stucco and fiber cement board systems performed adequately under steady and time varying wind loads. Fiber cement board was an exception because it did not fail at 150% of the unfactored design pressure.

2.1.6 Component and Cladding Wind Loads for Soffits

Reference

Vickery, P. J. (2008). "Component and cladding wind loads for soffits." *Journal of structural engineering*, 134(5), 846-853.

Relevant Information

The experiment indicate that wall and soffit pressures are highly correlated. The high correlation of the soffit-wall loads suggest that the reduction in pressures with increased area for the soffits will be consistent with that which occurs along the walls. The results indicate a simple and accurate solution to the soffit loading deficiency in ASCE 7 (i.e. no guidance as to the wind load requirements for the design of soffits) is to prescribe that the component and cladding pressures. Both negative and positive for use in the design of soffits to be identical to the component and cladding loads used for the design of wall components (Vickery 2008).

2.2 Vinyl Siding

2.2.1 Vinyl Siding Systems

Vinyl siding is a durable form of plastic exterior wrapping for a home, used both for aesthetics and weatherproofing. Engineered primarily from polyvinyl chloride (PVC) resin.

- It improves the home's energy performance.
- It can reduce wall sheathing moisture content
- It can improve the aesthetic appeal of a home
- It can withstand winds of 110 mph (most products achieve much higher ratings)

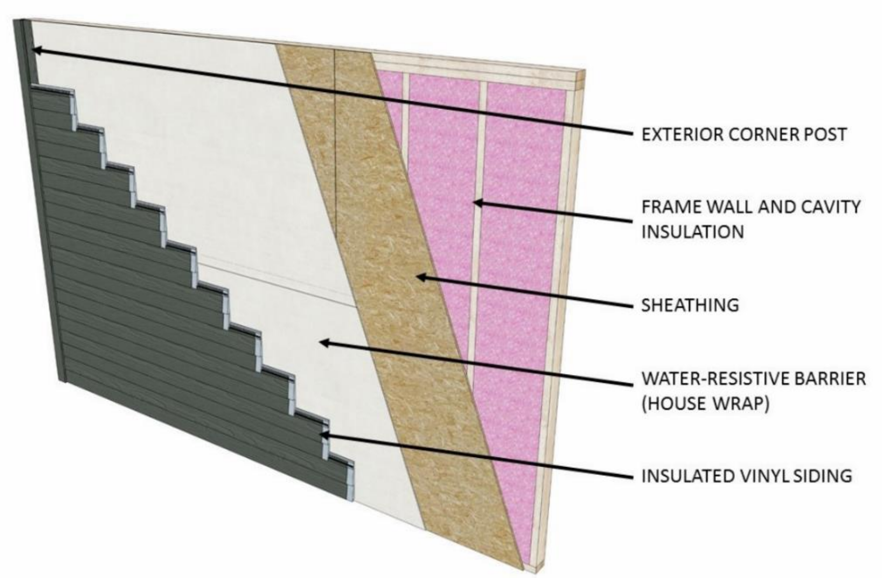


Figure 5. Multilayer wall system with vinyl siding cladding system (Building America Solution Center 2017)

2.2.2 Design Requirements According to Florida Building Code 2017

The following steps summarize the design considerations for vinyl siding according to the Florida Building Code (FBC).

FBC 2017 refers to the 2011 ASTM D 3679, Standard Specification for Rigid (Vinyl Chloride) (PVC Siding); FBC 2014 refers to the 2009 ASTM D 3679 edition

ASTM D 3679 allows for the reduction of load due to the net reduction of wind forces across cladding layers (pressure equalization)

A pressure equalization factor of 0.36 is used in design pressure rating and a safety factor of 1.5

$$P_t = D_p \times PEF \times 1.5$$

Where:

P_t = test pressure

D_p = design pressure rating of vinyl siding

PEF = Pressure Equalization Factor, 0.36

1.5 = Factor of Safety

Figure 6. Design pressure rating equation for vinyl siding (Fema 2018)

2.2.3 Key issues

Mitigation Assessment Team found that most of the observed exterior wall covering damage was to vinyl siding. (Fema 2018)

Vinyl siding failures at pressures it should have resisted based on design pressures, and design pressure rating. (Fema 2018)

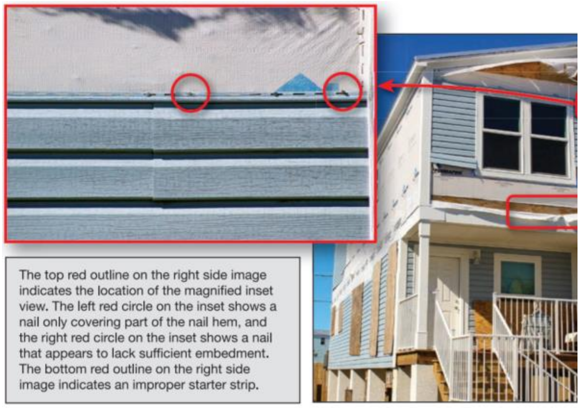
Frequently, loss of siding begins at the lowest course and proceeds up the wall. (FEMA 2010)

The rating in many products do not make it easy to determine whether the product will be adequate for the coastal environment. (FEMA 2010)

Recent full scale research performed by Cope et al. (2013), Morrison and Cope (2015) and Miller et al. (2017) recommend a PEF for vinyl siding closer to 0.8.

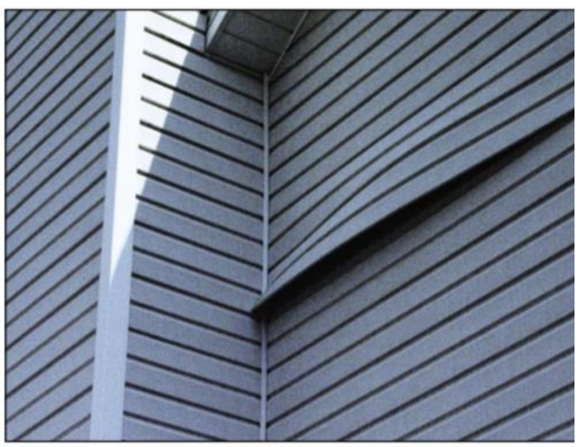
- These results deem the 0.36 PEF of ASTM D 3679 an un-conservative value.

2.2.4 Observed failures in Hurricane Events



Failure of vinyl siding failure due to nail covering only part of the nail hem, and lack of nail embedment (Fema 2018)

Vinyl siding failure because to lack utility trim under the windows (Fema 2018)



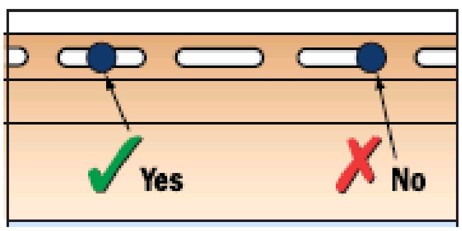
Unlatched vinyl siding panel susceptible to blow (FEMA 2005)

Extensive lost of vinyl siding and housewrap event though high wind panel was used (FEMA 2005)

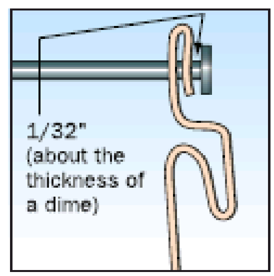
Figure 7. Failure of vinyl siding in hurricane events

2.2.5 *Relevant Information*

- Use an effective moisture barrier (i.e. housewrap or building paper) to avoid wind-driven rain penetration into wall cavities
- Stainless steel fasteners are recommended for buildings within 3,000 feet of the ocean line.
- When applying new siding over existing siding, use shims or install a solid backing to create a uniform, flat surface on which to apply the siding, and avoid creating gaps or projections that could catch the wind.
- Nails should be positioned in the center of the nailing slot (Figure 8a). To allow for thermal movement of the siding, do not drive the head of the nail tight against the nail hem (unless the hem has been specifically designed for this). Leave approximately 1/32-inch (which is about the thickness of a dime) clearance between the fastener head and the siding panel (Figure 8b).



(a)



(b)

Figure 8. Nail location

- Drive nails straight and level to avoid distortion and buckling in the panel.
- Do not caulk the panels where they meet the receiver of inside corners, outside corners, or J-trim. Do not caulk the overlap joints.
- Do not face-nail or staple through the siding.
- Use aluminum, galvanized steel, or other corrosion-resistant nails when installing vinyl siding.
- Nail heads should be 5/16 inch minimum in diameter. Shank should be 1/8 inch in diameter.
- Screw fasteners must be able to penetrate at least 1-1/4'' into studs and should be size #8, truss head or pan head; (ii) Corrosion-resistant, self-tapping sheet metal type.
- Adjacent panels shall overlap properly, about half the length of the notch at the end of the panel, or approximately 1 inch. Overlap should not be cupped or gapped, which is caused by pulling up or pushing down on the siding while nailing. Reinstall any panels that have this problem.
- Location of panel overlaps shall be staggered for following panels

- Use utility trim under windows or anywhere the top nail hem needs to be cut from siding to fit around an obstacle. Be sure to punch snap-locks into the siding to lock into the utility trim. Do not overlap siding panels directly beneath a window
- At gable end walls, it is recommended that vinyl siding be installed over approved sheathing capable of independently resisting the full design wind pressures

2.3 Experimental Research

2.3.1 Detailed Misconceptions "Three Little Pigs" Project: Hurricane Risk Mitigation by Integrated Wind Tunnel and Full-Scale Laboratory Tests

Kopp et al. (2010) developed a new testing methodology to apply realistic wind loads on homes, and other light frame structures during severe wind storms to mitigate previously observed damage. This methodology consists of utilizing pressure loading actuators (PLA) which are able to apply spatial and time varying wind loads. The PLA system was able to replicate the desired target pressure with 0.95 correlation compared to IBHS full scale results.

Reference

Kopp, G. A., Morrison Murray, J., Gavanski, E., Henderson David, J., and Hong Han, P. (2010). "“Three Little Pigs” Project: Hurricane Risk Mitigation by Integrated Wind Tunnel and Full-Scale Laboratory Tests." Natural Hazards Review, 11(4), 151-161.

Objectives

To develop a more realistic testing method considering temporal and spatial variations that allows to calibrate a simplified test to full scale. In addition, the development principles for the incorporation of material variability in computational models.

Loading conditions

- External Pressure Gradient
- Compared with uniform, time varying external pressure
- Compared with full scale loading results

Equipment (PLA System)

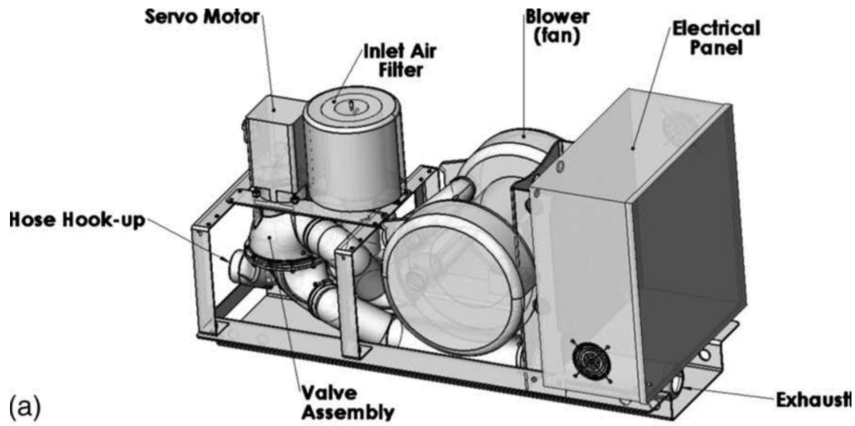


Figure 9. Pressure loading actuator system (PLA) (Kopp et al. 2010)

- Blower Fan
- Rotating Disk inside the valve
- Servomotor to regulate pressure
- Pressure transducer to monitor pressure inside bags connected to each PLA
- PLA updates 100 times/sec
- Maximum frequency 10hz
- Maximum pressure 23kPa Minimum pressure -20kPa Q=0.24 m3/sec

Relevant Information

- The relationships between the pressure and velocity is as clearly defined
- Temporal effects of real storms, with all the load cycling and duration effects, can be simulated, including changes in wind speed and direction
- The PLA approach replicates only the pressure field, so in situations where the flow field is equally important, PLA's cannot be used
- Airbags:
    - For very flexible cladding elements, like vinyl siding, the requirement of mechanical attachment means that only uniform pressures can be applied using a single air box which surrounds a relatively large test sample. Therefore, while time varying loads can be used, any spatial effects cannot be identified.
    - Maximum allowable displacements are imposed by the depth of the airbags
    - Very small elements cannot be tested, such as fascia, due to limitations on the minimum airbag size.

2.3.2 *Experimental Assessment of Wind Loads on Vinyl Wall Siding*

Moravej et al. (2016) conducted a full-scale test on a vinyl siding wall to study pressure equalization effects as a function of pressure tap location and combinations. The experiment wants to test the hypothesis that it may be under conservative to design vinyl siding cladding based on pressure equalization values from averaging net pressure coefficients over entire wall areas. This study was conducted at the WOW experimental facility in Florida International University for various wind directions. Using a 2.43 m by 2.74 m and eave height 2.34 m building model, wind pressures were measured in the exterior, interior cavity surfaces of the vinyl siding cladding. Interior pressures of the building model was also determined for pressure equalization factors. The area in which the pressure coefficients are averaged was varied in order to compare effects of pressure equalization in the entire wall system and how much equalization occurs at local connection areas.

Reference

Moravej, M., Zisis, I., Gan Chowdhury, A., Irwin, P., and Hajra, B. (2016)."Experimental Assesment of Wind Loads on Vinyl Wall Siding." Frontiers in Built Environment, 2(35).

Objectives

To prove that the area over which pressure equalization factor (PEF) is calculated affects its value. If the entire wall area is considered PEF value tends to be lower than considering localized areas (smaller areas) resulting in under-estimation of design wind loads.

Loading Condition

Wall of Wind (WOW) wind tunnel load at Florida International University

- Sampling rate of 512 s-1 using a Scanivalve ZOC 33

Experimental Setup (building model)

- The wood frame building was sheathed by a layer of plywood and was then covered by the vinyl siding.
- The vinyl siding consisted of several individual panels that were connected to the building wall sheathing using nails (using spacing of 23 cm or 9″).
- 49 pressure taps on the exterior surface of the vinyl siding.
- 49 pressure taps on the exterior surface of the plywood layer for cavity pressure.
- 4 pressure taps on the interior surface of the plywood layer.

Pressure measurements

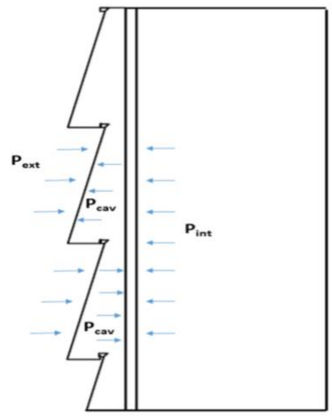


Figure 10. Schematic of the wall section and the location of pressure measurements (Moravej et al. 2016)

- Exterior taps on the vinyl siding to measure external pressures.
- Pressure taps on the exterior face of the plywood sheathing to measure pressures in the cavity.
- Internal taps inside the building model to measure building internal pressure

Results

- The study found that positive pressures produces a near zero net pressure on the vinyl siding due to the pressure equalization. The sheathing takes most of the pressure in this case. In suction, between 70° and 90°, the net pressure coefficient was in the range of approximately 0.25- 0.35 and closer to zero for the other wind directions.
- The study found that PEFs for suction zones vary from 78% to 106% for individualized pressure tap areas and from 52% to 78% for case combinations of pressure taps. In pressure zones, PEFs varied from 39% to 110% for individualized pressure taps areas and from 13% to 74% for cases of pressure taps combinations. This proves that the area considered to average pressure coefficients and calculate pressure coefficients has a definite effect on the observed reduction of load.

Relevant Information

- Net wind pressure across vinyl siding is minimal when pressures are averaged over a large area of the wall.
- The current results suggest that the net load on vinyl wall siding for 1 m^2 tributary area can be obtained by applying PEFs of 0.75 to the net design “suction” and 0.40 to the net design “pressure” loading, across the whole wall assembly.
- For smaller tributary areas (0.2 m^2), the PEF should be about 0.85 suction to help prevent local failure of connections that could lead to cascading failure.

2.3.3 Multichamber, Pressure- Based Test Methods to Determine Wind Loads on Air-Permeable, Multilayer Cladding Systems

Miller et al. (2017) studied if it was feasible to determine realistic wind loads on multi-layer vinyl siding wall systems using a multichamber airbox/pressure chamber approach. The experiment wants to test the hypothesis that by creating an external pressure gradient, sealed airbox systems pressure equalization factors (PEF) should agree with PEFs in full scale testing. The study was conducted at the University of Western Ontario. Five pressure traces were applied to a 12 ft. long by 8 ft. high multilayer wall system. External and internal cavity pressures were measured in order to calculate PEF. PEFs form multichamber test approach were compared to IBHS full scale testing on the same vinyl siding multilayer wall systems.

Reference

Miller, C. S., Kopp, G. A., Morrison, M. J., Kemp, G., and Drought, N. (2017). "A Multichamber, Pressure- Based Test Method to Determine Wind Loads on Air-Permeable, Multilayer Cladding Systems." Frontiers in Built Environment, 3, 7.

Objectives

To determine if multichamber airbox testing is feasible for assessing wind loads on air-permeable, multilayer cladding systems. If an external pressure gradient is created for the multilayer wall system by using different airbox chambers, similar pressure equalization factors (PEF) should be observed than those obtained in IBHS full scale testing.

Loading Conditions

- Pressure loading actuators in multiple chambers creating external pressure gradient at the University of Western Ontario
    - Able to capture pressure fluctuations up to 10 Hz
    - Peak pressures of 23 kPa and -20 kPa
    - Controlled by Proportional-Integral-Derivate system (PID) capable of following target pressure; system corrected in 1/10 of a second a pressure trace deviation in this experiment
- Compared with uniform, time varying external pressure
- Compared with full scale loading results

Experimental Setup

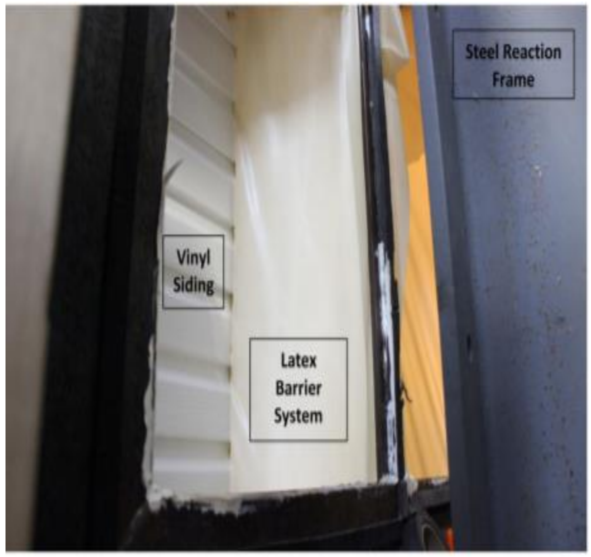


Figure 11. Latex barrier system which creates to separate airboxes (Miller et al. 2017)

- Walls of 12 foot long by 8 ft high with 2 by 4's studs
- ¾" plywood sheathing with polyurethane sheet to seal the pressure chamber
- Housewrap over plywood to replicate typical construction practice
- Pressure taps installed at same locations of IBHS walls
- 12 feet vinyl siding installed using appropriate nails at 16" intervals
- Test wall installed in rigid-sided chamber (same as used by (Gavanski and Kopp 2011(b))
- Five pressure chambers created using latex barrier system and each chamber had a different pressure trace from IBHS full scale testing creating the external gradient

Relevant Information

Concept of creating multi-chamber, pressure-based, testing apparatus to obtain accurate wind loads on air-permeable cladding worked.

Accomplished by:

- Application of multiple, discreet, time-varying loads across a test specimen
- Development of linearized five-port, flow reversing valve
- Adaptive Proportional-Integral-Derivate system (PID) as a control strategy

Multi-chamber pressure loading together with external pressure data obtained from the IBHS wind tunnel matched the cavity pressures and PEF's from the IBHS full scale test on vinyl siding. Results confirm PEF used in ASTM D3679-13 is unconservative. Static, multi-chamber test may be feasible for a test standard eliminating the complexity of using PLA system. These PEF varied by 5% from the results obtained in the multi-chamber using the pressure-time history

3 VINYL SIDING DAMAGE OBSERVATIONS IN RECENT HURRICANES

3.1 Background

Hurricane Irma made its first landfall in the continental US at Cudjoe Key in southern Florida on September 10, 2017, with Category 4 winds reaching 58 m/s (130 mph sustained). The National Hurricane Center (NHC) downgraded Irma to a Category 3 storm as it made its second landfall later that afternoon on Marco Island, just south of Naples on the Florida's Gulf Coast, with sustained winds near 54 m/s (120 mph). It weakened further to a Category 2 once inland. Following landfall, the PI assisted and coordinated with a large engineering response effort coordinated through the Structural Extreme Events Reconnaissance (StEER) network to assess damage across the state of Florida. Teams documented damage to structures, delineating the effects of wind and coastal hazards (where visible) with a standardized damage assessment instrument created and programmed using the Fulcrum mobile smartphone application (Spatial Networks 2017) for door-to-door implementation, providing an enhanced workflow compared to what the team used for Hurricane Matthew (Prevatt et al. 2017). Fulcrum supports in-line capture of geotagged photos directly from the user's mobile device, extracts all device-supplied metadata (date, time, etc.), and automatically geocodes local addresses based on GPS coordinates. The customized app then steps through major assessment categories defined by the team, beginning with classification of the structure including number of stories, occupancy and typology (roof shape, etc.). Any visible mitigation measures such as storm shutters, roof-to-wall connections, etc. are also noted. Assessment teams assign an overall damage rating, attribute damage cause (wind, surge/wave, rain damage/water penetration, freshwater flooding, tree fall) and post-event functionality, followed by component-level damage ratings to roof cover, roof sheathing, roof structure, wall cladding, wall sheathing, wall structure, doors and windows.

Similar methodologies were used by the PI and co-PI following Hurricane Michael, which made landfall in the southeastern United States near Panama City, FL as a Category 4 hurricane on the Saffir-Simpson scale, with a minimum sea level pressure of 919 hPa and sustained wind speeds of 70 m/s. Assessments were conducted within 48 hours of landfall, and again approximately one month after landfall. Focus was given to residential structures impacted by storm surge and/or high winds in regions of Panama City, Mexico Beach, and Port St. Joe. Assessments were typically conducted in clusters, capturing non-biased samples of building performance throughout the impacted regions.

While the original scope of work for this project focused on analysis of vinyl siding and soffit performance in the Hurricane Irma dataset, there were limitations to this dataset since it was not captured with the intent of assessing vinyl siding and soffit performance in detail. These limitations included a lack of clear views of soffits, and inconsistency in the number of sides of each structure that were captured in photographs. To fulfill the goals of the project, the scope was expanded to include a selection of homes assessed following Hurricane Michael, with the intention of building out a more robust and detailed building performance dataset for evaluating vinyl siding and soffit performance. The following sections describe the data and analysis in more detail.

3.2 Supplemental Data Sources

Limitations induced by time, access and other factors prevented the reconnaissance teams in Hurricanes Irma and Michael from accessing full details of all four elevations of an assessed building. For example, reconnaissance teams generally avoided entering personal properties, particularly behind the home, unless the owner was there and provided permission. This policy often prevented the back of the building from being documented as thoroughly using terrestrial cameras relative to the front and sides of most buildings. It also made it difficult to access some of the finer details important to contextualizing the vinyl siding performance, such as the siding manufacturer, fastener schedule, and nailing hem type that were not always visible from public access points. To minimize these limitations, the research team requested and obtained access to several supplemental data sources related to vinyl siding performance, described below. The team also requested and received access to output of calibrated hurricane wind field models for Hurricanes Irma and Michael that were used to relate vinyl siding and soffit performance to local hazard conditions.

3.2.1 Monroe County Permit Records

The research team requested and received building permit records from 41 buildings in Monroe County that were identified as having vinyl siding. The records were compiled by the Monroe County Building Department and graciously provided to the researchers. The permit records provided details of the building construction materials and design parameters, but unfortunately rarely provided any details of the specific product approval related to the vinyl siding installed. In the drawings and permit records that we reviewed, vinyl siding would typically be called out with instructions to “install per manufacturer’s instructions” or similar language. In only two out of the 41 buildings were a specific product approval and installation details provided for the vinyl siding, one of which was for a post-Irma vinyl siding installation. The reason for the lack of detail was that the majority of the homes in our detailed dataset were actually modular homes, which may be more common in the Florida Keys for a number of reasons. Modular homes do not typically provide details such as specific product approvals as the permitting by the county relates to installation of the home and connection of infrastructure. Cladding elements are inspected in the factory during construction for compliance to the Florida Building Code and specific products are not called out in the drawings provided to the county.

3.2.2 Bay County Permit Records

The research also reached out to the Bay County Builder Services department, specifically Mr. Rick Holmes (Building Official), regarding the potential for matching building permits with post-Michael assessment locations. Mr. Holmes was eager to assist in any future efforts, albeit staffing was still overburdened with processing Hurricane Michael permits. This data source should be pursued with any continuing studies related to vinyl siding or other topics of interest.

3.2.3 FEMA Post-Hurricane Irma MAT Photographs

The FEMA MAT provided access to a number of on-site photographs for 20 individual homes that were assessed. This set of photographs offered substantially the same exterior views of these homes as were already available in field assessment photographs and so did not contribute additional siding, soffit, or fascia damage data for analysis. The photograph set did however include high-resolution images of siding failure details, including instances of installation error, unusual substrate materials, corrosion of fasteners, and other possible contributors to failure. Although these data were not considered in the present analysis, they would be of use in a future detailed investigation of the causes and modes of vinyl siding failure in individual homes.

3.2.4 Pictometry EagleView

Pictometry EagleView maintains a database of nadir and oblique imagery post-Irma and post-Michael, access to which was purchased to supplement the research team's data. EagleView enables oblique views of the north, south, east and west of each building, albeit at varying resolutions. For Hurricane Michael, the imagery is sufficiently clear, particularly in coastal areas, to conclusively identify siding damage. For Hurricane Irma, the imagery was of a lower resolution and not suitable for precise damage quantification. For both Michael and Irma, Pictometry EagleView was not suitable for soffit damage quantification due to the vertical viewing angle, but fascia damage could often be identified, particularly for Hurricane Michael.

3.2.5 Florida Public Hurricane Loss Model Hind-cast Hurricane Wind Fields

The Florida Public Hurricane Loss Model (FPHLM) team provided wind field outputs for Hurricanes Irma and Michael consisting of wind speed and direction time histories at a regular grid within the areas of interest. The wind speeds were provided as 1-minute sustained velocities at 33 ft height in open terrain. Wind speed and direction were provided at 30 minute intervals. The wind speed and direction time history for each building assessed by the research team was associated with that of the nearest grid point in the FPHLM wind field outputs. Examples of the outputs are provided in Figure 122, here compared against surface observations from installed anemometers (data for which was obtained through the Weatherflow Datascope platform). In general, the simulated wind field time histories matched observations better for Hurricane Michael than for Hurricane Irma. The outputs were primarily used to obtain an estimate of dominant wind directions during the highest wind speeds from each hurricane for a given location, hence the accuracy of the wind direction estimates was more important than the magnitude of the wind speeds.

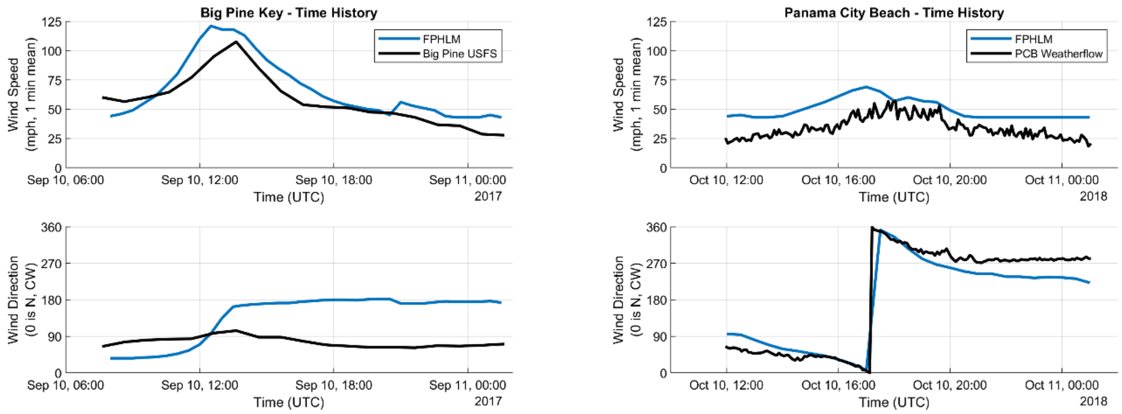


Figure 12: Example output of the FPHLM wind field models for (left) Hurricane Irma and (right) Hurricane Michael. Observed wind speeds were adjusted to 10 m height above ground level if necessary assuming a surface roughness length of 0.03 m (open terrain). The actual surface roughness upwind of the station for each wind direction was not accounted for.

3.3 Vinyl Siding Identification and Damage Quantification

Vinyl siding was identified using the following methods:

1) On-site inspections during deployment. Within the building assessment survey form was a multiple-choice field for reporting the wall cladding material. Investigators while on site often identified the wall cladding type(s). Soffits were less often classified in the field, both for Irma and Michael.

2) Photographs of the building. Photographs of the building were most often used to classify the wall cladding types. Photographs were obtained from the on-site inspections by the research team, on-site inspections by the FEMA MAT team, remote assessments using UAVs, and Pictometry Eagleview. To differentiate from similar-looking cladding systems, researchers looked for any visible joints in the cladding system, or where failures occurred, to identify whether the horizontal plank features of the cladding systems were single (8-inch width, which typically indicated wood plank or fiber cement cladding) or double (two 8-inch width sections in one plank, which indicated vinyl siding). This is illustrated in Figure 13. Other key indicators of vinyl siding were the presence of edge details and starter strips.

3) Property appraiser database. The Monroe County and Bay County property appraisers maintain public databases for each county that identify basic attributes of each building and parcel, including the wall cladding type. This resource was primarily used when the first two methods were inconclusive.

More than one method was often used for a given site to ensure accuracy, but on-site photographs were used most often, with confirmation using the property appraiser databases.

Vinyl siding was identified for each surface of the building, i.e., the front, back, left and right, and for each story of the building, i.e., understory, first, second, etc. Mixed cladding types on a given wall surface were rare, but when it occurred, the wall surface was still included in the dataset but with only damage to the vinyl siding quantified.

Figure 13. (Left) Vinyl siding indicated by “double” slats; (right) non-vinyl product indicated by “single” slats and lack of perforated nailer hem.

Damage to vinyl siding was quantified by wall elevation (i.e., front, back, left, and right) as well as wall story (i.e., understory, 1st story, 2nd story, etc). Each wall elevation and story (e.g., front 1st story) is termed a wall surface. Vinyl siding damage was quantified visually as the percentage of vinyl siding present on a given wall surface that was fully or partially detached, termed the damage ratio. An example of vinyl siding damage quantification is provided in Figure 14.

Wall Surface Damage Ratios:

Front (1st story): 0%
Front (2nd story): 0%
Left (1st story): 80%
Left (2nd story): 90%
Back (1st story) : 20%
Back (2nd story): 95%
Right (1st story): 90%
Right (2nd story): 95%

Figure 14. Illustration of damage ratios assigned to each wall surface for a home in Port St. Joe (Bay County) built in 1999.

In quantifying vinyl siding damage, the researchers primarily focused on homes for which the presence of vinyl siding could be conclusively identified and quantified for at least two of the four wall elevations.

3.4 Vinyl Soffit and Fascia Identification and Damage Quantification

Vinyl soffits were identified from on-site inspection photographs taken by the research teams, as aerial photographs are not able to capture soffits. The Hurricane Irma database was not particularly well-suited for identification of soffit systems as clear views of the soffit were generally not available for the majority of the wall surfaces in most buildings. The Hurricane Michael dataset was improved, particularly for certain subdivisions, but typically soffits on the back side of homes were not visible. Wherever soffit was visible that could be positively identified as vinyl, performance was documented as the percentage of vinyl soffit that was damaged for each wall surface. Similar methods were used for fascia.

Figure 15. (Left) Failed vinyl soffit on the second story of a 1998 home in the Gulf Aire neighborhood due to Hurricane Michael; and (right) Failed fascia on a 2015 home in the Cedar's Crossing neighborhood due to Hurricane Michael.

3.5 Summary of Data

The research team focused on homes where vinyl siding and/or vinyl soffit was present and performance quantifiable for multiple wall surfaces. Maps of the home locations relative to the estimated peak wind speeds are used. Table 1 summarizes the number of assessments by wall surface and individual building for vinyl siding, while Table 2 does the same for vinyl soffits and fascia. Note that there are four wall surfaces for a standard single-story home, eight for a two-story home, and an additional four for any home with an understory. For Hurricane Irma, the homes were clustered primarily in Little Torch Key, Big Pine Key, and Ramrod Key. In Hurricane Michael, the detailed assessments were applied to homes primarily contained within two regions – 1) Cedar's Crossing, a neighborhood of single-story, single-family homes with a mix of late 1990's and post-2005 homes; and 2) Gulf Aire / Beacon Hill, two neighborhoods in close proximity in Mexico Beach with a mix of pre- and post-2002 homes.

Table 1. Summary of vinyl siding assessments

Hurricane	**Irma (2017)**	**Michael (2018)**
Individual Wall Surfaces	203	148
Buildings	48	39

Table 2. Summary of vinyl soffit and fascia assessments

Hurricane	**Irma (2017)**	**Michael (2018)**
Individual Wall Surfaces	30	216
Buildings	15	77

Out of the 125 total buildings in the combined dataset for vinyl siding and vinyl soffit, there were 64 post-FBC homes and 61 pre-FBC homes.

For each wall surface in each of these homes, the presence and performance of vinyl siding, soffit, and fascia was quantified. The complete dataset is provided in Appendix C.

The visual layout of the vinyl siding data is provided for the Cedar's Crossing and Gulf Aire neighborhoods in Figure 16 and Figure 17. Insets provide the estimated 1-minute sustained wind speed and direction time histories from the FPHLM hindcast for Hurricane Michael.

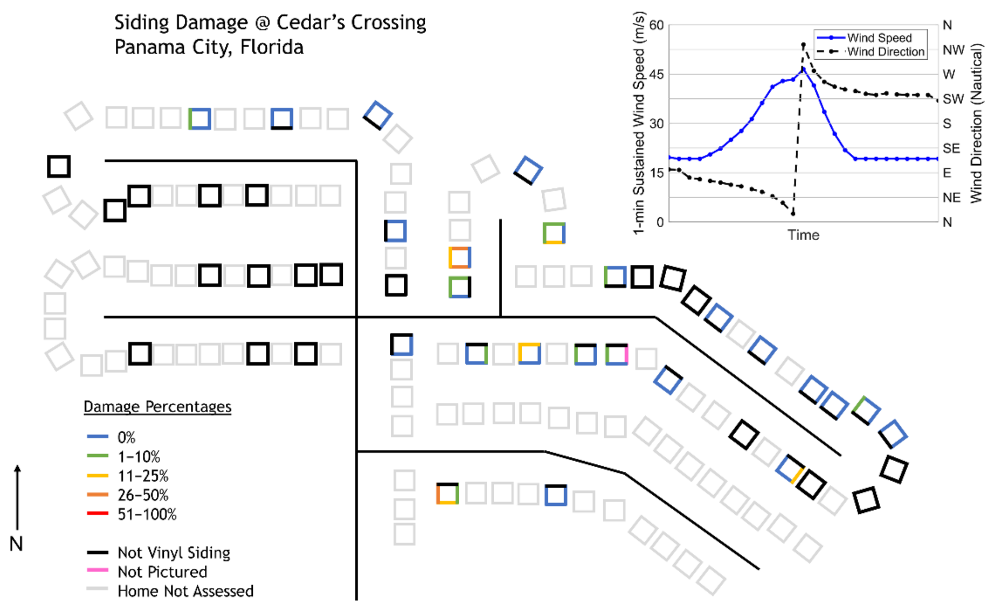


Figure 16. Summary of damage to vinyl siding in the Cedar's Crossing neighborhood. The estimated wind speed and direction time history at this location is provided in the inset. The peak 1-minute sustained wind speed at this location was approximately 45 m/s out of the NE to NW.

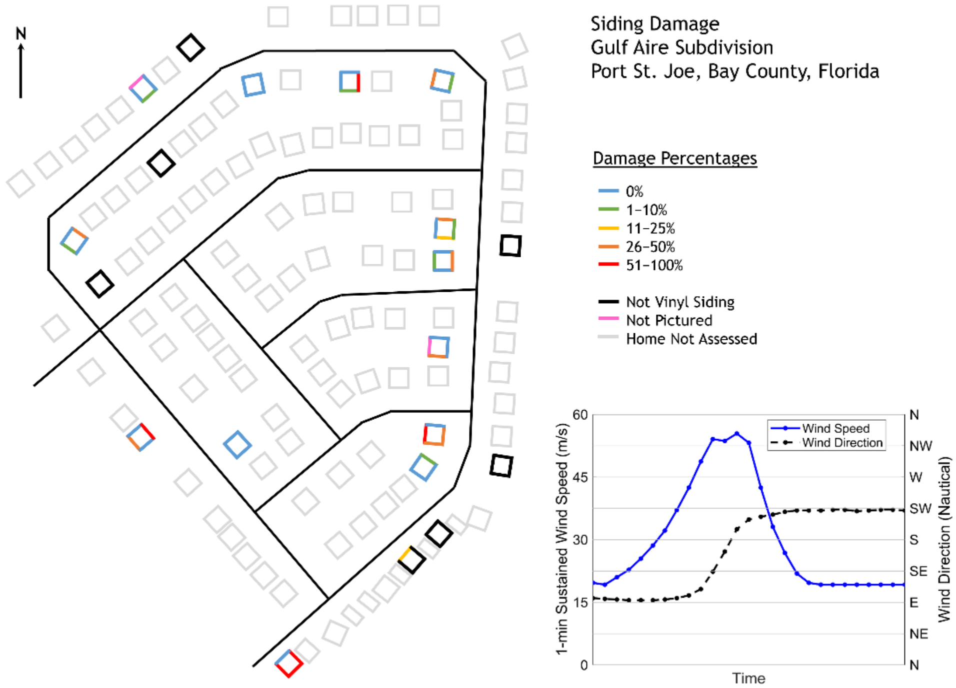


Figure 17. Vinyl siding damage classified in Gulf Aire neighborhood. The estimated wind speed and direction time history for the neighborhood is shown in the inset. The estimated peak 1-minute sustained wind speed was 56 m/s, coming out of the SE to SW.

A summary of the peak wind speeds estimated in the study areas for Hurricanes Irma and Michael are provided in Table 3 and Table 4. Estimated peak wind speeds are taken from the wind field hindcasts of the Florida Public Hurricane Loss Model, with the normal output (1-minute sustained wind speeds) converted to a 3-second gust using the Krayer-Marshall hurricane gust factor model (Krayer and Marshall 1992). All wind speeds here and elsewhere in this report correspond to 10 m height above ground level in open terrain.

Table 3. Estimated peak wind gusts (10 m height, 3 second gust averaging time, open terrain) produced by Hurricane Irma over homes in the Florida Keys relative to ASCE 7-10 design values.

	Minimum	Maximum
Estimated Peak 1-min Wind Speed (m/s)	44	58
Estimated Peak Gust Wind Speed, $\hat{V}_{est}$ (m/s)	55	73
Ultimate Design Wind Speed, $\hat{V}_{ASCE7-10}$ (m/s)	80	80
Wind Load Ratio, $\left(\frac{\hat{V}_{est}}{\hat{V}_{ASCE7-10}}\right)^2$	0.47	0.83

Table 4. Estimated peak wind gusts (10 m height, 3 second gust averaging time, open terrain) produced by Hurricane Michael in the Cedar's Crossing and Gulf Aire neighborhoods relative to ASCE 7-10 design values.

Neighborhood	Cedar's Crossing	Gulf Aire and Beacon Hill
Estimated Peak 1-min Wind Speed (m/s)	40	56
Estimated Peak Gust Wind Speed, $\hat{V}_{est}$ (m/s)	50	70
Ultimate Design Wind Speed, $\hat{V}_{ASCE7-10}$ (m/s)	60	60
Wind Load Ratio, $\left(\frac{\hat{V}_{est}}{\hat{V}_{ASCE7-10}}\right)^2$	0.7	1.36

3.6 Analysis and Discussion

The following provides an overview of siding, soffit and fascia performance for homes affected by Hurricanes Irma and Michael. Analysis is based on the data described in the preceding section.

3.6.1 Overall Performance of Vinyl Siding on Pre- and Post-FBC Homes

Overall performance of vinyl siding performance was mixed in both Hurricanes Irma and Michael. Figure 18 and Figure 19 provide the percentage of vinyl siding on each home that was damaged, stratified by wind speed. The extent of damage to post-FBC homes observed in Hurricane Irma is concerning given the below design level wind speeds. Failure rates were higher in the Florida Keys for post-FBC homes than in the Gulf Aire neighborhood for pre-FBC homes following Hurricane Michael, despite the design wind speed being exceeded there. The contrast in damage suggests there are other underlying factors beyond the vinyl siding material itself that may be contributing to enhanced probabilities of failures, one potentially being the elevation of homes above the flood plain in the Florida Keys. For example, based on discussions with local building officials in Monroe County, it is unclear whether modular homes (which comprised a significant proportion of the homes in our Irma vinyl siding dataset) take into account the enhanced wind loads that occur on elevated homes as compared to those installed at ground level. Modular homes may be being designed for the correct design wind speed, but not taking into account wind loads which may be as much as 12% higher (per ASCE 7-10 velocity exposure factor) when elevated above the flood plain. Further exploration is needed in this area.

In Cedar's Crossing, vinyl siding was only present on post-FBC homes, making it a good case study for performance. Average siding loss was less than 40% for all homes, and averaged approximately 5%. Nonetheless, significant sections of vinyl siding were lost for multiple wall surfaces at wind loads 30% below design. Failures for individual wall surfaces is discussed more fully in later sections of this report.

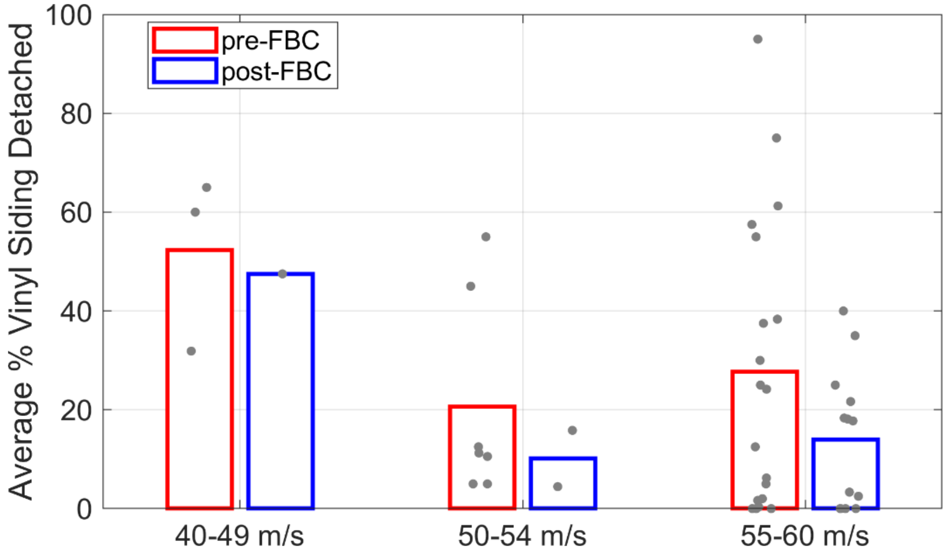


Figure 18. Sample performance of pre- and post-FBC vinyl siding in Hurricane Irma stratified by estimated 1-minute sustained wind speeds. Boxes designate the average % vinyl siding detached over all homes within each bin and code classification. Each grey dot represents an individual home.

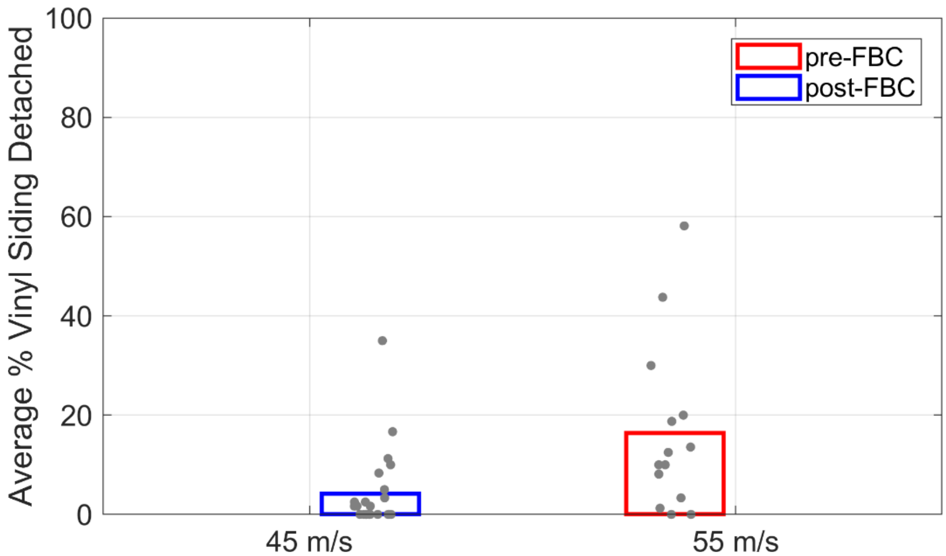


Figure 19. Sample performance of pre- and post-FBC vinyl siding in Hurricane Michael stratified by estimated 1-minute sustained wind speeds (45 m/s = Cedar's Crossing, 55 m/s = Gulf Aire). Boxes designate the average % vinyl siding detached over all homes within each bin and code classification. Each grey dot represents an individual home.

Product approvals were obtained for a couple siding systems that experienced failures, presented as case studies here. Case Study #1 is a 2006 home in Cedar's Crossing that experienced approximately 5% siding loss. The manufacturer and model number was traced to the Miami-Dade Notice of Acceptance (NOA), which provided more details. This specific system consisted of double 100 mm (4 inch) slats with a thickness of 1 mm (0.042 inches) and design pressure rating of -2.2 kPa (-46.6 psf). Assuming Exposure B and a peak gust wind speed of 50 m/s (10 m height, Exposure C), the peak component and cladding pressure is estimated as:

$$\hat{p}_{est} = 0.613 * K_z K_{zt} * \hat{V}_{est}^2 * C_{p,ext}^-$$

where $K_z = 0.57, K_{zt} = 1, \hat{V}_{est} = 50$ m/s, and $C_{p,ext}^- = -1.4$, resulting in $\hat{p}_{est} = -1.22$ kPa. The estimated wind loads were therefore nominally 55% of design, not accounting for any pressure equalization factors that are likely present with permeable cladding systems. The observed failure in this case was minor, and the reconnaissance team was unable to determine whether any deficiencies in installation were present. Given the similar layout and products used elsewhere in this subdivision, it is likely the same manufacturer and material that was used in all 2006/2007 homes in this same neighborhood, some of which had more significant vinyl siding failures.

Figure 20. Case Study #1: Minor failure of a vinyl siding system on a 2006 home in the Cedar's Crossing neighborhood for which the siding manufacturer and Miami-Dade Notice of Approval were able to be traced.

Case Study #2 is a single story, elevated, site-built home originally constructed in 1958. The original wall cladding system was replaced in 2004 with PVC vinyl siding (different manufacturer than that of Case Study #1). Per the Notice of Acceptance included in the permit file, the siding had a thickness of approximately 1 mm (0.04 inches), a single nailing hem, and a rated design pressure of +/-1.91 kPa (40 psf). The vinyl siding looks to have been installed directly atop the original exterior wood paneling. Approximately 40% of the siding was detached on the entire home. The failure of the vinyl siding in this home may have been exacerbated by the installation over existing cladding surface. The Structural Extreme Events Reconnaissance (StEER) Early Access Reconnaissance Report following Hurricane Florence also noted frequent vinyl siding failures when installed over existing cladding systems (Kijewski-Correa et al. 2018).

Figure 21. Case Study #2: Failure of a vinyl siding system on a 1958 home on Sugarloaf Key. The vinyl siding was installed in 2004 per the county permit records.

More case studies like this would be beneficial, but unfortunately are not possible with Hurricane Irma due to the lack of product approvals on file for many of the homes assessed. Many of the newer homes are modular and do not have product approvals on file, while pre-2002 homes of any kind did not have product approvals in the permit files. Similar analysis for Hurricane Michael assessments is possible with the assistance of the Bay and Gulf County Building Services departments, but was not able to be conducted during the timeline of this project.

3.6.2 Overall Performance of Vinyl Soffits on Pre- and Post-FBC Homes

Soffit and fascia damage was observed in the post-Hurricane Irma reconnaissance, but overall the damage database collected by the research team did not contain many homes with clear views of soffits on multiple wall surfaces necessary for accurate quantification. More attention was given to soffits and fascia in the post-Michael reconnaissance efforts, particularly in the detailed assessments conducted in the Cedar's Crossing, Beacon Hill, and Gulf Aire neighborhoods.

Figure 22 and Figure 23 illustrate the performance of vinyl soffits and fascia systems in pre- and post-FBC homes in the Cedar's Crossing neighborhood and in the Gulf Aire / Beacon Hill neighborhoods. Vinyl soffit damage was more pronounced in pre-FBC homes in Gulf Aire as compared to the post-FBC homes in Gulf Aire and Beacon Hill that experienced approximately the same wind speeds. In Cedar's Crossing, vinyl soffit damage was similar in both pre- and post-FBC homes, while fascia damage was actually higher on average in post-FBC homes.

Figure 24 demonstrates the positive correlation between soffit damage and fascia damage on a given wall surface. Soffit damage did occur without corresponding fascia damage, with this failure typically occurring when the soffit separated from the starter strip at the exterior wall. Fascia damage was more common however, often corresponding to soffit failures on the same wall. The correlation coefficient between soffit and fascia failures was 0.67, indicating a moderate positive correlation between the two failures. On average, when soffit failure occurred, 21% of the failures corresponded to fascia failures at the same locations. Anecdotally, the presence of gutters prevented fascia loss, which in turn mitigated soffit loss.

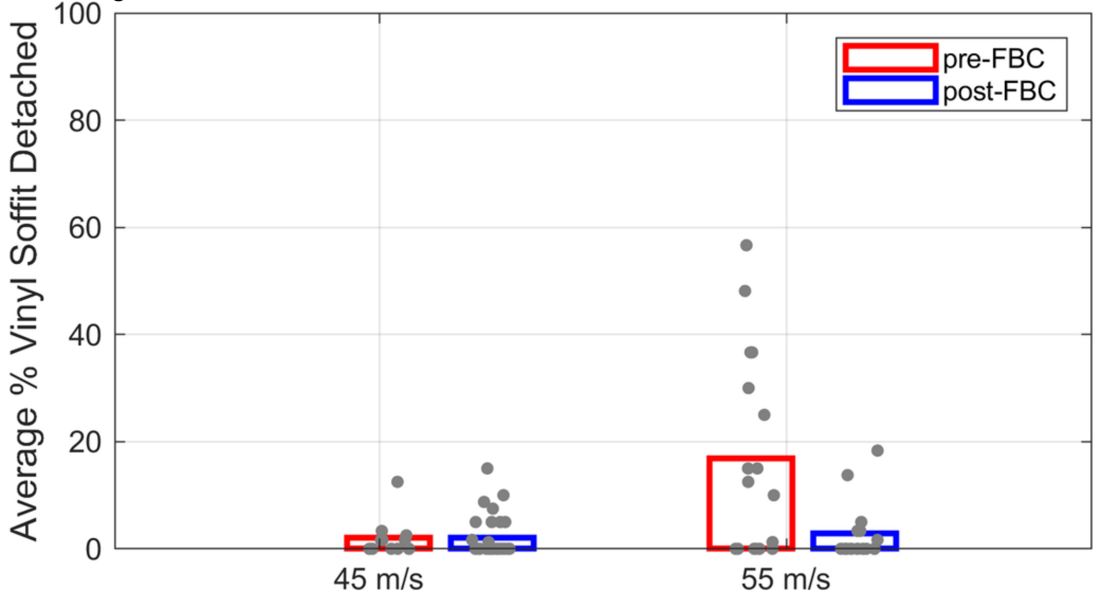


Figure 22. Sample performance of pre- and post-FBC vinyl soffit in Hurricane Michael stratified by estimated 1-minute sustained wind speeds (45 m/s = Cedar's Crossing, 55 m/s = Gulf Aire). Boxes designate the average % vinyl siding detached over all homes within each wind speed and code classification. Each grey dot represents an individual home.

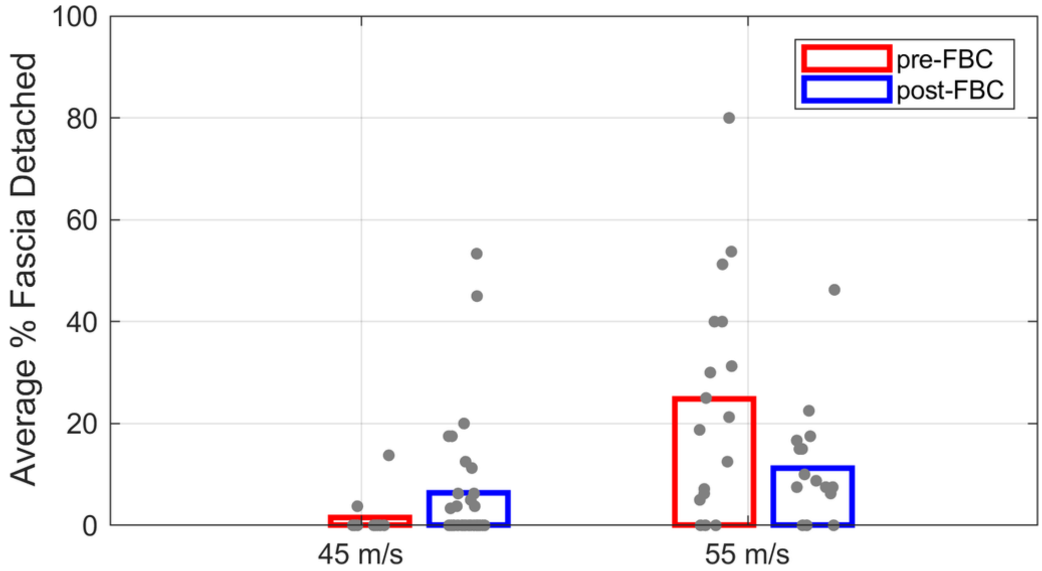


Figure 23. Sample performance of pre- and post-FBC fascia in Hurricane Michael stratified by estimated 1-minute sustained wind speeds (45 m/s = Cedar's Crossing, 55 m/s = Gulf Aire). Boxes designate the average % vinyl siding detached over all homes within each wind speed and code classification. Each grey dot represents an individual home.

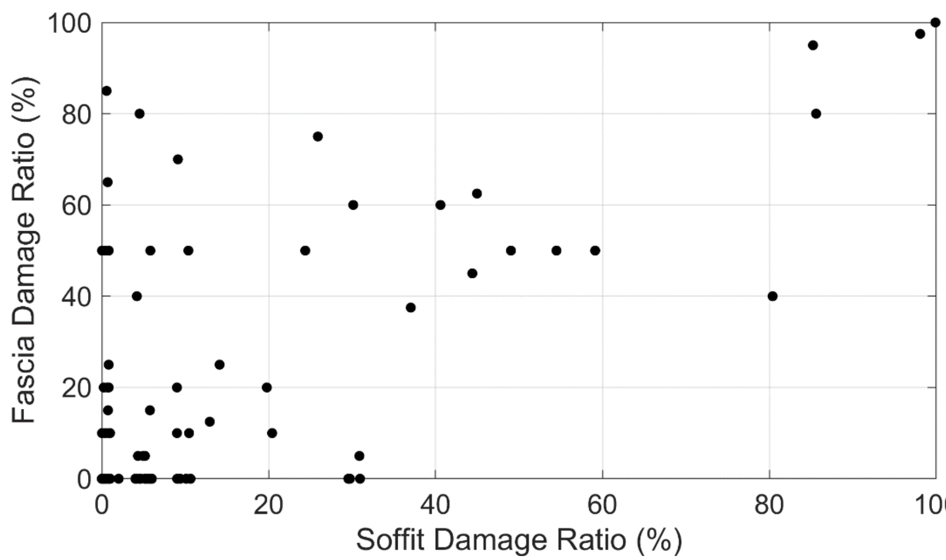


Figure 24. Relationship between soffit damage ratio and fascia damage ratio for each wall surface. Each marker represents a single wall surface for which both soffit and fascia performance could be assessed.

Figure 25. Soffit and fascia damage. (A) a 2017 home in Beacon Hill subdivision; (B) soffit damage without corresponding fascia damage to a 2015 home in Cedar's Crossing neighborhood; (C) extensive soffit and fascia damage to a 2016 home in Cedar's Crossing neighborhood; (D) extensive soffit and fascia damage to a 2012 home seaward of the Coastal Construction Control line in Mexico Beach, FL. Note the lack of fascia failure where the gutter is installed.

3.6.3 Building Aerodynamics Perspective on Vinyl Siding and Soffit Performance

A key effort of the research team was to relate the observed performance of vinyl siding and soffit systems to the aerodynamics of the building, with the objective of evaluating whether specific flow regimes (e.g., cornering flows, separation zones, wake regions) were correlated with observed failures. Correlations, if present, would inform the experimental approach for evaluating design wind pressures for vinyl siding and soffit systems.

Detailed assessments of vinyl siding, soffit and fascia performance were conducted by relating the performance of vinyl siding, soffit and fascia systems observed on each visible wall surface to the orientation of the wall with respect to the dominant wind direction acting on the building. This analysis required the wind speed and direction time series from the FPHLM hindcasts described previously in order to estimate the dominant wind direction when the peak wind speeds occurred at each assessment location. The convention for relating the wall surfaces to the dominant wind direction is shown in Figure 26. In this example, the front and left walls would both have angles of attack of 135°, while the back and right walls would have angles of attack of 45°.

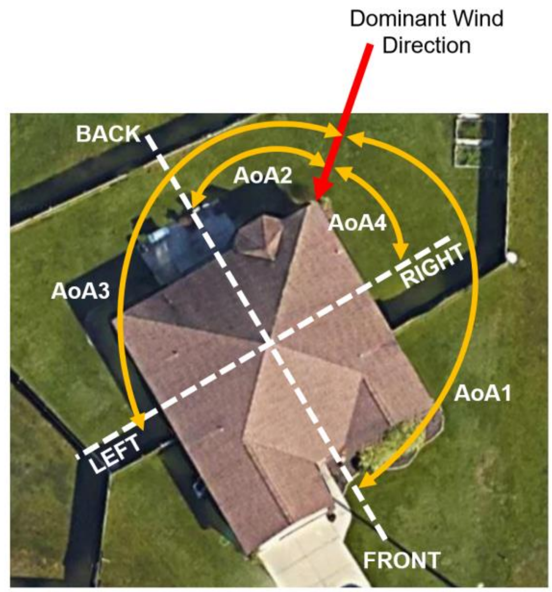


Figure 26. Convention for determining the wind angle of attack (AoA) for each wall surface. In the example above, $\mathrm{AoA1} \cong 135°$, $\mathrm{AoA2} \cong 45°$, $\mathrm{AoA3} \cong 135°$, $\mathrm{AoA4} \cong 45°$.

The following set of figures provides the relationship between siding damage, averaged for each wall elevation (1st and 2nd stories for front, back, left and right elevations), and the wind angle of attack relative to the wall surface. Figure 27 presents the results for vinyl siding in the Cedar's Crossing and Gulf Aire neighborhoods impacted by Hurricane Michael. A distinct bi-modal relationship is evident in the Cedar's Crossing neighborhood, but the trend is much nosier, if present at all, in the Gulf Aire homes. Evaluated within the context of the entire wind speed time history for Cedar's Crossing, where the highest winds shifted from NE to NW, the data suggests that vinyl siding failure is most likely to occur in the separation regions associated with cornering flows. More data is needed in neighborhoods with similar homes in order to confirm the trend more strongly.

Figure 28 and Figure 29 provide the relationship between soffit and fascia damage and the wind angle of attack relative to each wall surface, with added data from the Beacon Hill neighborhood (which had vinyl soffit but no vinyl siding). The same trend between cornering winds and failures may be present in the Cedar's Crossing neighborhoods, where soffit and fascia failures appear to be more common under cornering flows, but overall the trends are noisy and inconclusive, particularly for fascia damage.

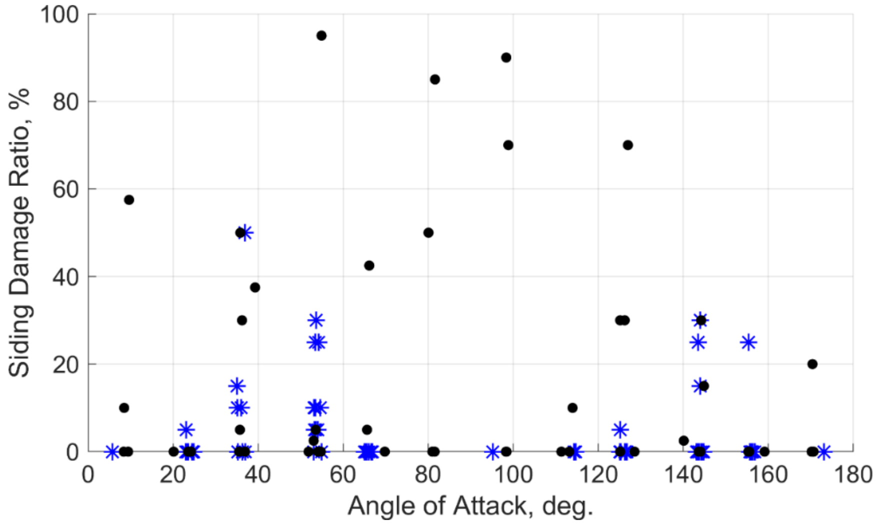


Figure 27. Relationship between siding damage ratio and wind angle of attack for vinyl siding in Cedar's Crossing (blue asterisks) and Gulf Aire (black dots). Each marker represents a single wall elevation in the dataset.

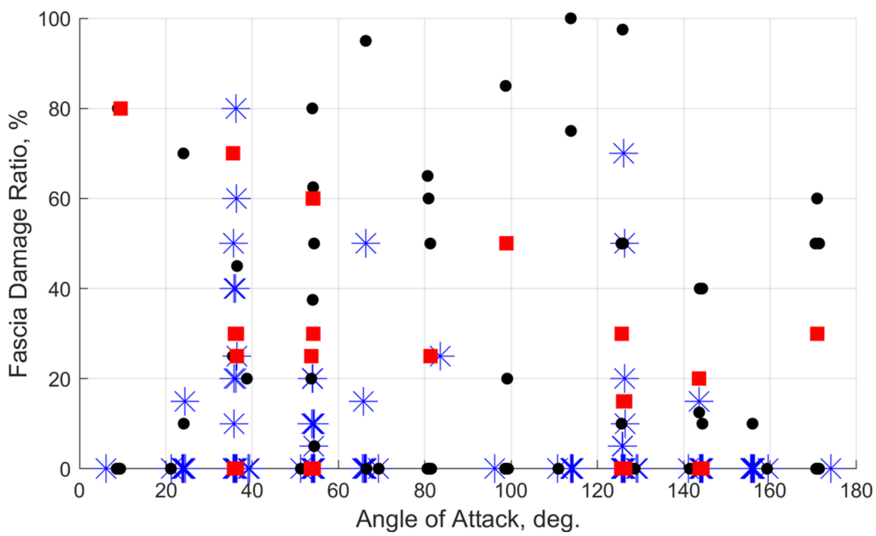


Figure 28. Relationship between soffit damage ratio and wind angle of attack for vinyl soffit in Cedar's Crossing (blue asterisks), Gulf Aire (black dots), and Beacon Hill (red squares). Each marker represents a single wall elevation in the dataset.

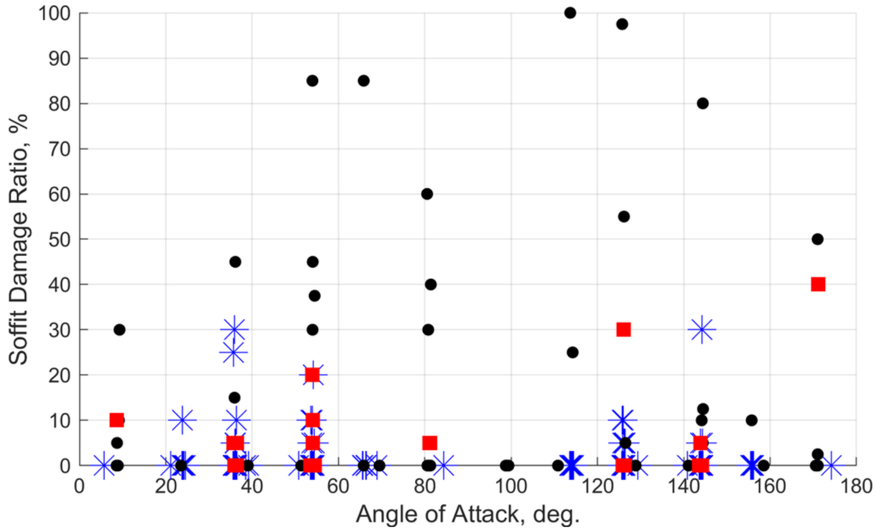


Figure 29. Relationship between fascia damage ratio and wind angle of attack for fascia in Cedar's Crossing (blue asterisks) and Gulf Aire (black dots). Each marker represents a single wall elevation in the dataset.

3.7 Conclusions

The following conclusions can be drawn from the data presented above:

- Vinyl siding failures frequently occurred in both pre- and post-FBC homes in both Hurricane Irma and Hurricane Michael, although damage was typically more extensive in pre-FBC homes.
- Fascia and vinyl soffit damage was also common in both pre- and post-FBC homes. The extent of damage to vinyl soffit systems was typically similar to the extent of damage observed in vinyl wall cladding systems, but fascia damage was more extensive than either siding or soffit damage.
- A moderate correlation exists between soffit damage and fascia damage. Improving fascia fastening requirements should improve soffit performance, but in isolation would not prevent all failures.
- In the dataset with the most similar housing and terrain conditions (Cedar's Crossing, impacted by Hurricane Michael), there appears to be a moderate trend of increasing vinyl siding and soffit damage occurring when subjected to cornering wind angles of attack. In the other neighborhoods however, no such trend is apparent, perhaps due to the increase in other influencing factors such as a variety of construction years, presence of trees within the neighborhoods, mix of single- and multi-story homes, etc.

4 DEVELOPMENT OF MUTI-CHAMBER TEST FOR VINYL SIDING

4.1 Project Hypothesis

Full scale testing as well as multichamber testing performed when vinyl siding is used as cladding has shown different pressure distributions in walls. Our hypothesis is that if the cavities of the vinyl siding specimen allow airflow interaction between adjacent pressure chambers, the observed pressures across the vinyl siding wall will be different from a static uniform pressure test.

The interaction of pressures between the pressure chambers create a gradient which affects the direction of airflow through the vinyl siding mechanical attachments. During a static uniform pressure test this gradient does not affect airflow, thus the airflow through the vinyl siding mechanical attachment by the is only affected by size of the gaps. It is expected that the net pressure felt by the vinyl siding specimen will be less due to equalization than in tests where this gradient exists.

To test this hypothesis a procedure was developed consisting in three different pressure applications to the wall specimen. The first is a Uniform- Static Pressure test following ASTM D 5206- Standard Test Method for Wind Load Resistance of Rigid Plastic (ASTM 2013). For the second pressure application approach different static uniform pressures will be applied in each pressure chamber. The third pressure application approach will incorporate dynamic pressure in each pressure chamber.

4.1.1 Uniform- Static Pressure Test

To compare the differences in the different type of loading application, the first loading protocol applies the same static pressure loading to the four pressure chambers. Loading is performed according to ASTM D5206. Figure 30 shows the ASTM D5206 test assembly and figure 31 shows an example of how the pressure is incremented in a step-hold approach. ASTM D5206 loading follows the following procedure:

- Apply 5 psf as a preload and hold it for 30 seconds; release pressure difference across the specimen and recover for 1 minute.
- Apply pressure difference in 5 psf increments, holding for 30 s before each increment, continue until failure occurs.
- Record the pressure when the specimen fails, which is the ultimate pressure, and the record the failure mode.
- Record the highest pressure that was sustained for 30s without failure, which is the maximum sustained static test pressure.

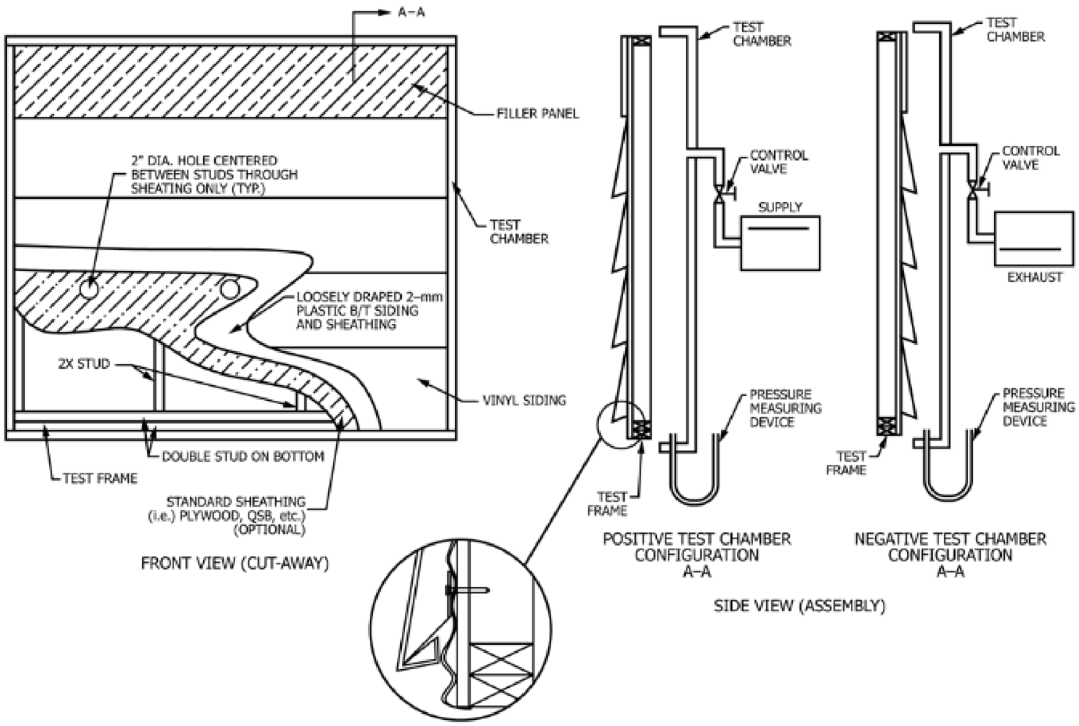


Figure 30. Test Chamber assembly for ASTM D5206-13

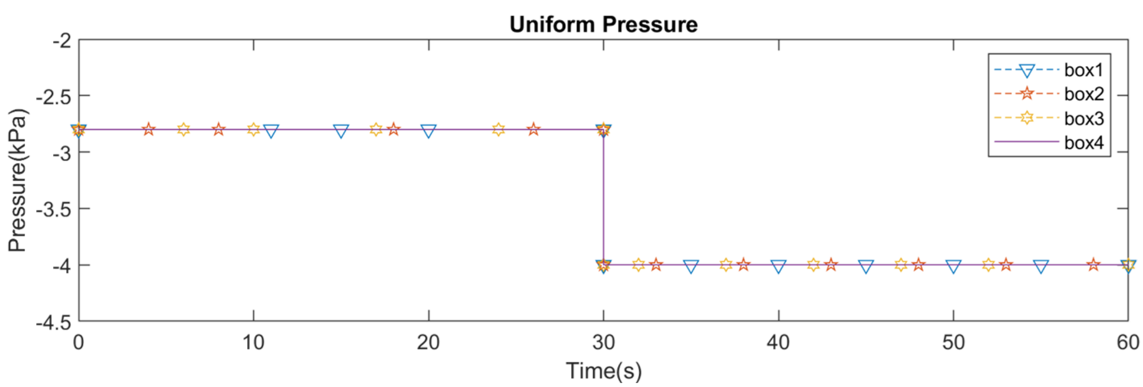


Figure 31. Static uniform pressure increased every 30 seconds until failure

4.1.2 Individual- Static Pressure Test

For the second loading protocol, different uniform static pressure is applied to each pressure chamber. Pressure is either held constant at some of the pressure chambers while it is increased/ decreased in other chambers, or different uniform static pressure are applied to each pressure chamber at the same time. This approach is a simpler approach to create the spatio-temporal variation of wind and is compared with the dynamic loading approach. Figure 32 shows an example of the different uniform static pressures applied to each pressure chamber.

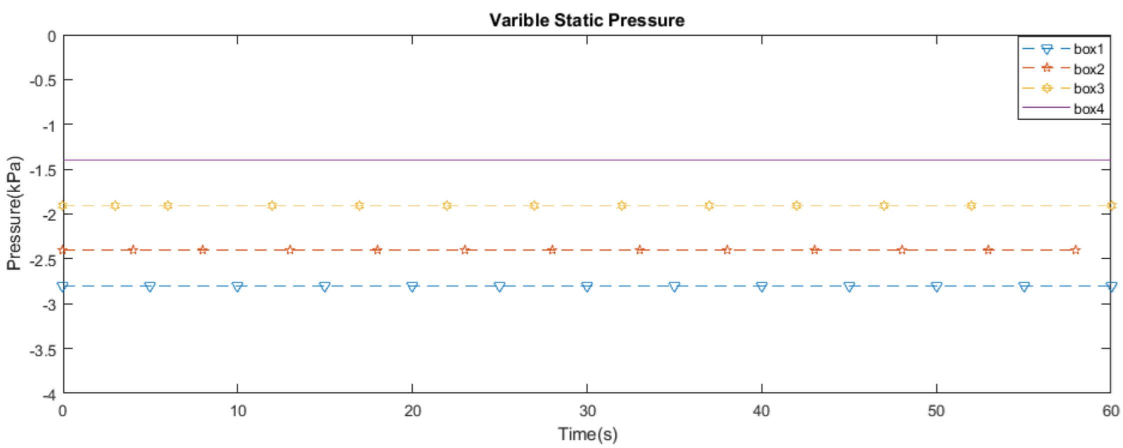


Figure 32. Example of different magnitude of static pressure in the four pressure chambers

4.1.3 Dynamic Pressure Test

The third loading approach applies different dynamic pressure traces to each pressure chamber (figure 33). The spatio-temporal loading actuator (SPLA) is used to create the dynamic pressure variations and is controlled by a Proportional-Integral- Derivative (PID) controller. Results obtained from this approach are expected to match IBHS full scale pressure distributions across vinyl siding as well as multi-chamber testing shown in section 2.3.3.

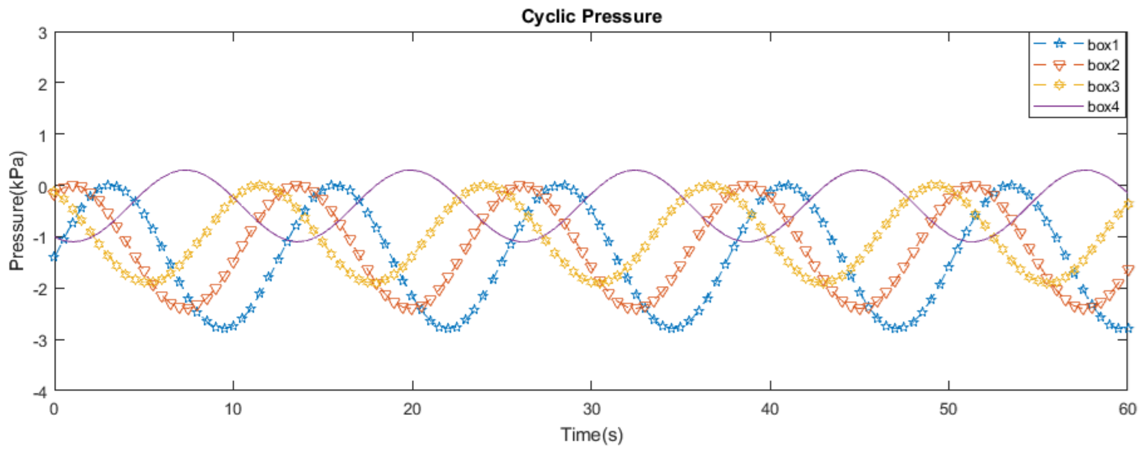


Figure 33. Example of different dynamic pressure traces in the four pressure chambers

4.2 Vinyl Siding Specimen

4.2.1 Product information

One common vinyl siding cladding is Georgia Pacific Double Latch 5” Vision Pro and was the selected vinyl siding for testing. This type of vinyl siding was last approved by the Miami Dade County Product Section in September 20, 2018. Uniform Static Air Pressure Loading per Florida Building Code TAS 202-94 and Cyclic Wind Pressure Loading per Florida Building Code TAS 203-94 were applied during the approval tests. The specified design pressure in this product approval is 40 psf. Figure 34 shows an isometric of this type of vinyl siding and dimensions.

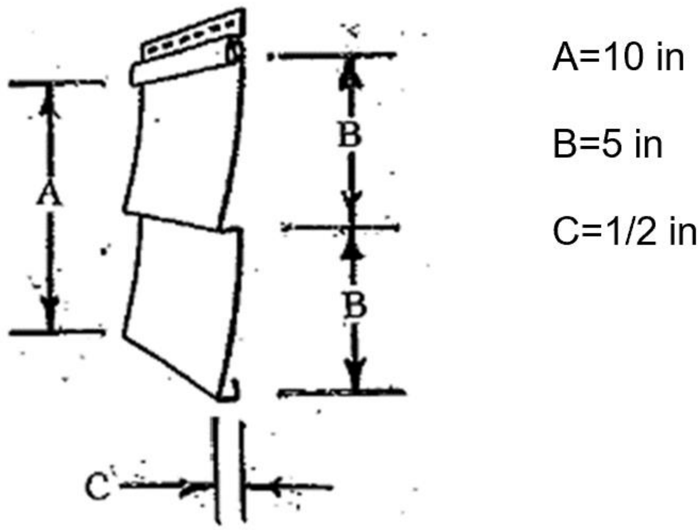


Figure 34. Georgia Pacific Vision Pro Vinyl Siding dimensions

4.3 Installation Method

4.3.1 Wood Wall Frame

Vinyl siding is normally installed into wood frame walls as cladding. For this reason, a 160.75 in x 112 in with 2 in x 4 in stud members wood frame was constructed following APA's Engineered Construction Guide. Wood studs 2 in x 4 in are used as wall plates for the wood frame. Wood studs are spliced with a Simpson Strong Tie TP37 G90, 3 in x 7 in tie plate and wood blocking is added to provide support where a new wood sheathing panel starts as shown in figure 35. Wood sheathing of ½ in thickness is used as the wall substrate fastened to wood studs using 8d nails at 6 in spacing. Table 5 shows the dimensions for the wood sheathing panels. Figure 36 shows the wood sheathing panel arrangement in the wall. Vinyl siding is installed on the wall frame using appropriate nails at 16" intervals along the length of the wall and pertinent requirements listed in section 2.2.5. Figure 37 shows a plan view of how the vinyl siding is installed to the wall.

Figure 35. Wood Wall Frame with stud splicing and wood blocking

Table 5. Plywood sheathing panel dimensions

Panel Number	Dimension (in x in)
1	96 x 48
2	96 x 48
3	96 x 48
4	96 x 16.75
5	96 x 16
6	64.75 x 16

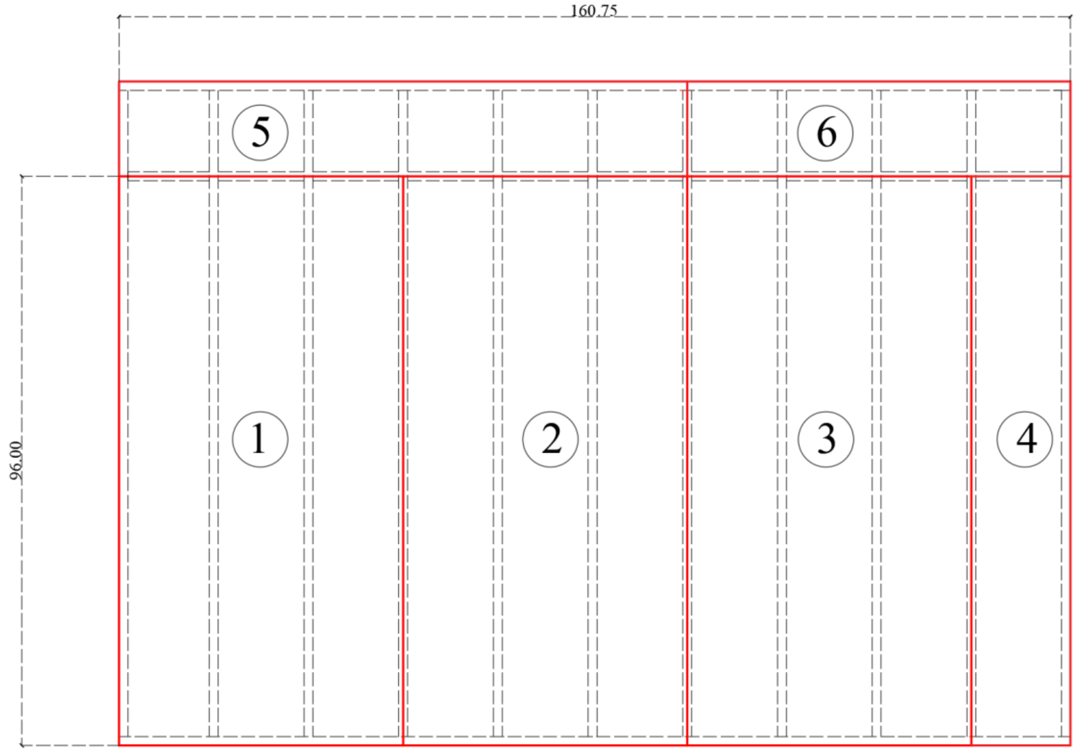


Figure 36. Plywood sheathing arrangment (sheathing shown in red)

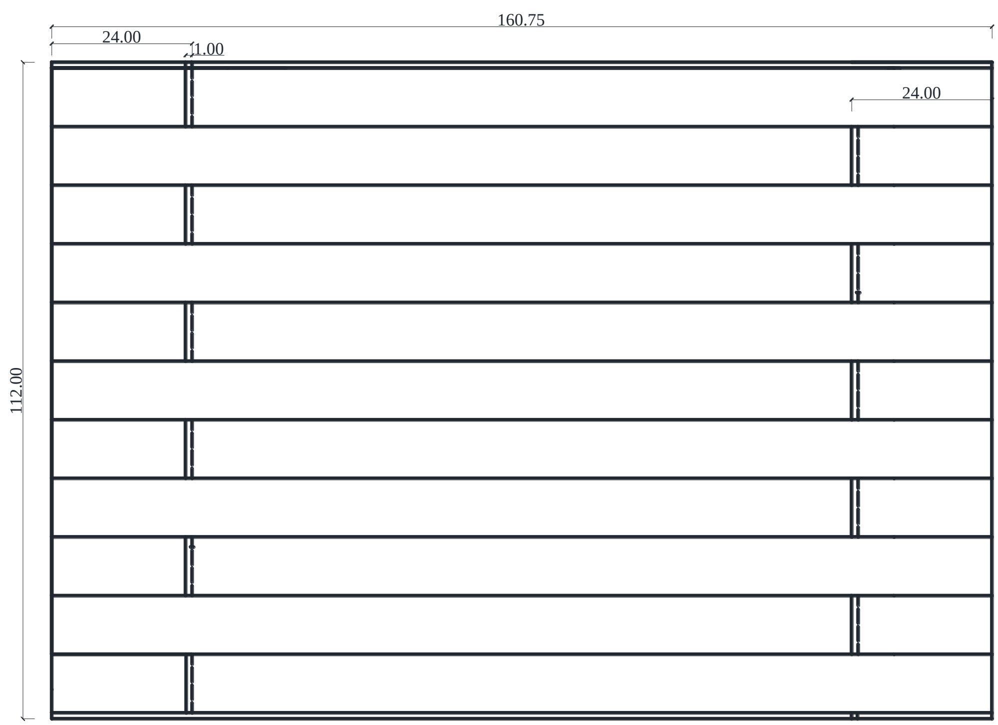


Figure 37. Vinyl siding layout on the wall specimen

4.3.2 *Attachment to Murphy Bed.*

The vinyl siding wall is placed horizontally in a steel test bed (Murphy bed) which along with aluminum HSS sections, shown in section 5.4, act as a reaction frame for the pressure loading. The wood frame is placed on top of diagonal steel beams of the test bed. Wood members of 2 in x 4 in are placed in the bottom of the test bed diagonal beams. A 12-Gauge galvanized steel heavy strip tie is used to connect the wood frame to the bottom wood members; the wall is now fixed to the test bed preventing displacement due to the applied pressures. Figures 38 shows the wood wall frame placed on the test bed.

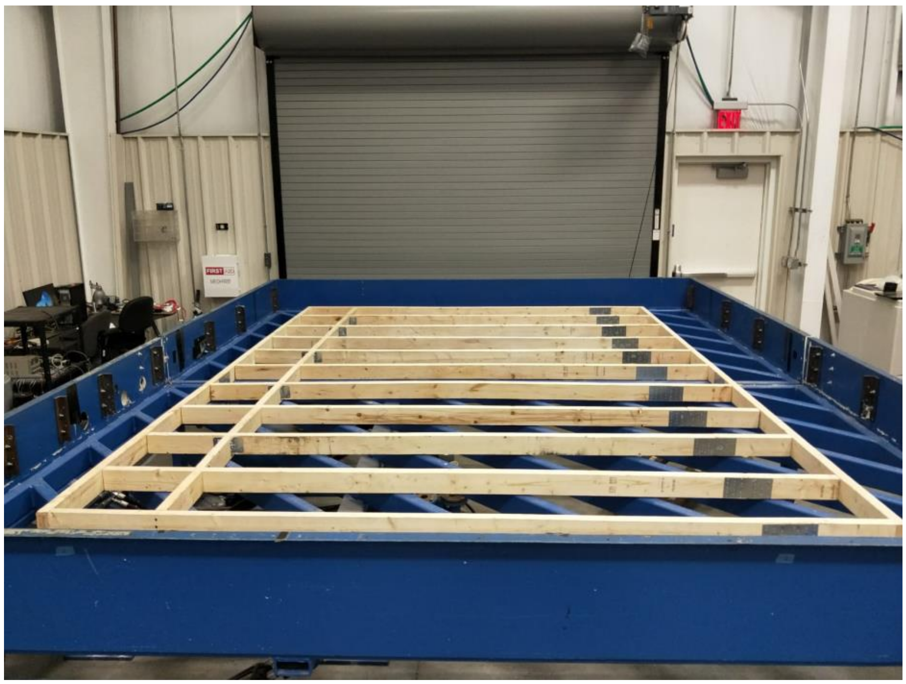


Figure 38. Wood Wall frame placed on top of the test bed

4.4 Test Chamber

Four pressure chambers are created across the wall to create spatio-temporal wind pressure variation. Two of the chambers are 24 in x 96 in and simulate the corner of the wall (zone 5). The other two pressure chambers are 48 in x 96 in and simulate areas located more to the center of the wall (zone 4). The chambers are divided by five 4 in x 4 in aluminum HSS frames which provide reaction support to the pressure loading. The latex is glued from the HSS frames into the vinyl siding creating the individual pressure chambers. Figure 39 shows a complete assembly of the vinyl siding wall and its connection to the blower fan.

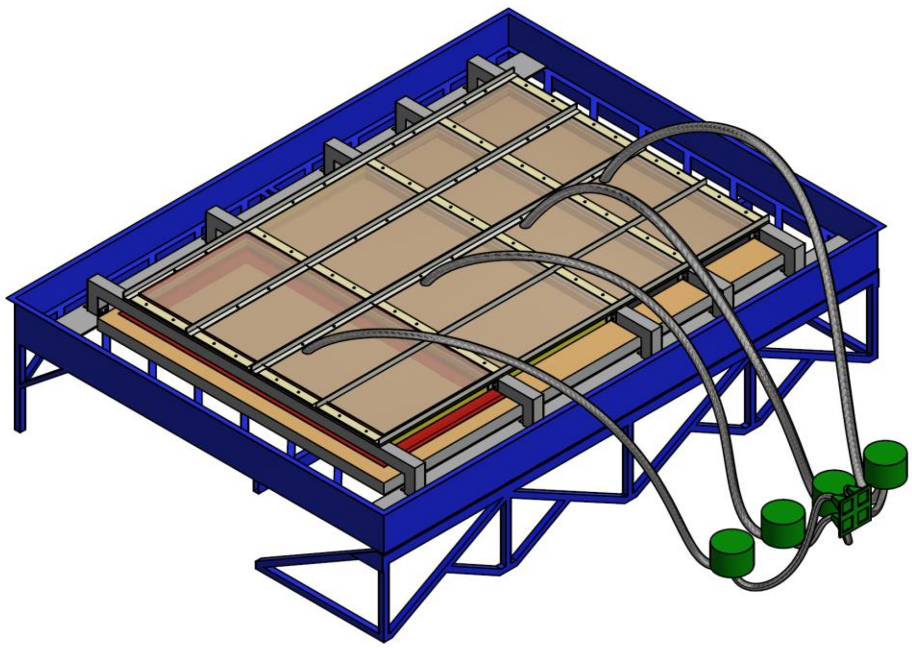


Figure 39. SPLA connection to the pressure chambers; latex attachment can be observed in red in the first pressure chamber

4.5 Test Devices

4.5.1 Spatio Temporal Loading Actuator (SPLA)

The Spatiotemporal Pressure Loading Actuator uses four individual pressure loading actuators (PLA). The PLAs are powered by a 40 Horse Power centrifugal blower. SPLA can simulate a more realistic wind pressure on wall systems. Overall capacity of the fan blower is 3000 CFM. The SPLA (shown in figure 40) is able to create a severely non-uniform wind pressure distribution, with extreme suction pressures at the building corners and the distribution itself changes rapidly with time.

The key features of SPLA is:

- Can produce wind loads up to a Category 5 Hurricane (i.e. +5 kPa to -10 kPa range)
- Can follow a pressure trace with high accuracy for a range of surface area
- Multiple PLAs can be simultaneously controlled to apply independent pressure traces.

Figure 40. Connection of three PLAs to the exterior centrifugal fan; suction is applied from the top ducts while pressure is applied from the bottom

4.6 Instrumentation

4.6.1 Differential Pressure Transmitter Dwyer MS2-W103-LCD

Twenty-six Dwyer differential pressure transmitters are used for this test with a pressure limit of 1 psi and a 1% accuracy. Twenty-two MS2-W103-LCD are used to acquire the net pressure felt on the vinyl siding by measuring differential pressure between top of the vinyl siding and directly above the substrate (sheathing) of the wall. Four MS2-W103-LCD are used to measure pressure inside the boxes relative to static pressure outside of the chambers. Location of the differential pressure transmitters are shown in figure 41 and 42.

4.6.2 Barometric Pressure Sensor

Atmospheric pressure is measured from underneath the test bed to detect if there are any significant changes that may affect pressure readings within the test pressure chambers. A barometric pressure sensor is placed on the wood frame wall as shown in figure 42.

4.6.3 String Potentiometer

Four string potentiometer sensors are placed at the center of each pressure chamber to measure vinyl siding displacement as pressure is applied. The string potentiometer measure up to 2 two inches of vertical displacement. Monitoring displacement allows to determine if a change in the vinyl siding mechanical interlocks affect the pressure distributions. Displacement spring potentiometers are shown in figure 42.

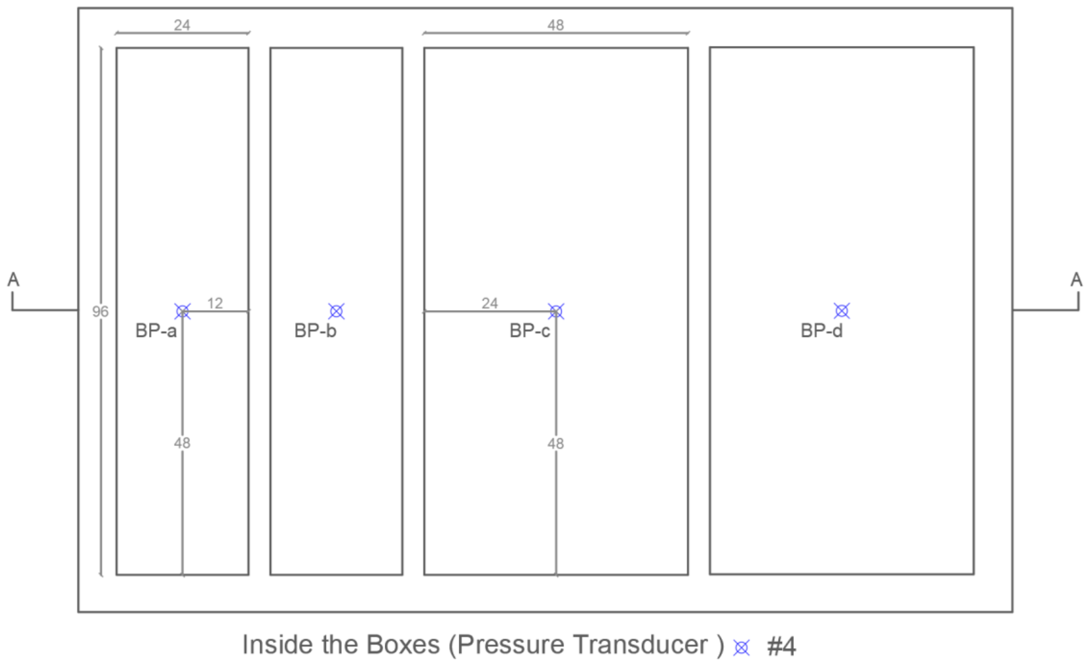


Figure 41. Box pressure tranducers sensor location

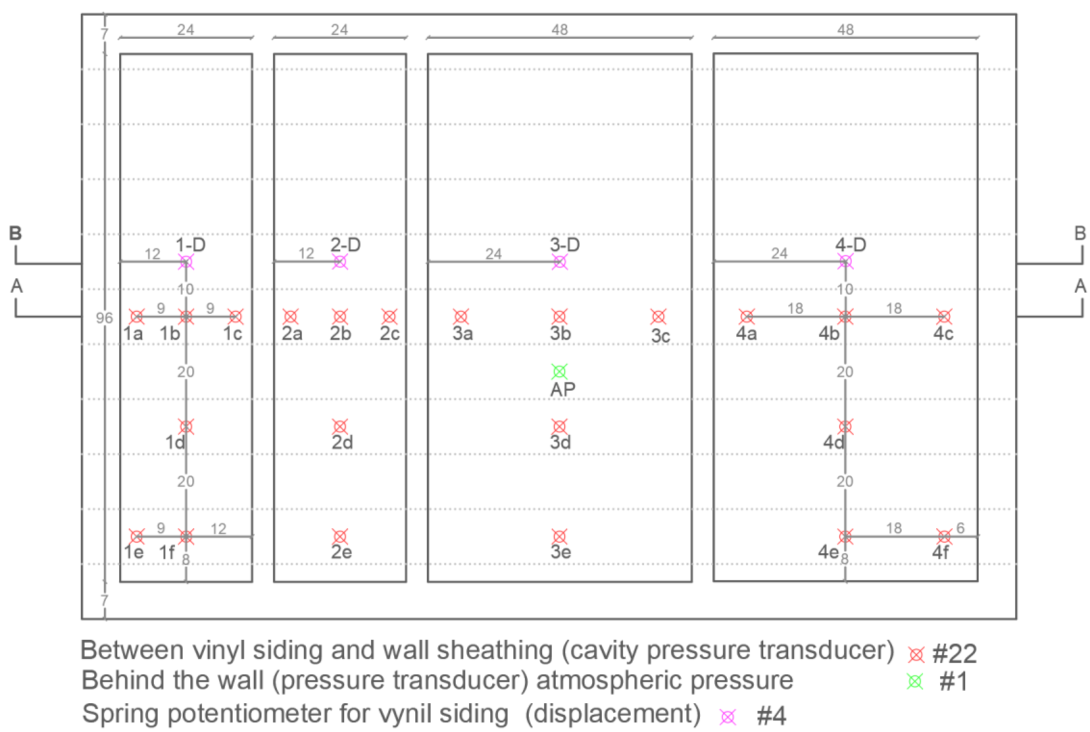


Figure 42. Pressure transducers, displacement and atmospheric sensors

Table 6. Sensors Description

	IDs	Description	Location	Sensor Type
		Atmospheric Pressure Sensor		
1	AP	Atmospheric Pressure	Chamber 3	Barometric Pressure
		Box Differential Pressure Sensors		
2	BP-a	Pressure in Chamber A	Inside Box 1	Dwyer MS2-W103-LCD
3	BP-b	Pressure in Chamber B	Inside Box 2	Dwyer MS2-W103-LCD
4	BP-c	Pressure in Chamber C	Inside Box 3	Dwyer MS2-W103-LCD
5	BP-d	Pressure in Chamber D	Inside Box 4	Dwyer MS2-W103-LCD
		Differential Pressure Sensors in the cavity between Vinyl siding and Plywood		
6	1a	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
7	1b	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
8	1c	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
9	1d	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
10	1e	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
11	1f	Cavity Differential Pressure	Cavity Chamber 1	Dwyer MS2-W103-LCD
12	2a	Cavity Differential Pressure	Cavity Chamber 2	Dwyer MS2-W103-LCD
13	2b	Cavity Differential Pressure	Cavity Chamber 2	Dwyer MS2-W103-LCD
14	2c	Cavity Differential Pressure	Cavity Chamber 2	Dwyer MS2-W103-LCD
15	2d	Cavity Differential Pressure	Cavity Chamber 2	Dwyer MS2-W103-LCD
16	2e	Cavity Differential Pressure	Cavity Chamber 2	Dwyer MS2-W103-LCD
17	3a	Cavity Differential Pressure	Cavity Chamber 3	Dwyer MS2-W103-LCD
18	3b	Cavity Differential Pressure	Cavity Chamber 3	Dwyer MS2-W103-LCD
19	3c	Cavity Differential Pressure	Cavity Chamber 3	Dwyer MS2-W103-LCD
20	3d	Cavity Differential Pressure	Cavity Chamber 3	Dwyer MS2-W103-LCD
21	3e	Cavity Differential Pressure	Cavity Chamber 3	Dwyer MS2-W103-LCD
22	4a	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
23	4b	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
24	4c	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
25	4d	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
26	4e	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
27	4f	Cavity Differential Pressure	Cavity Chamber 4	Dwyer MS2-W103-LCD
		Vinyl Siding Displacement Sensors		
28	1-D	Vinyl Siding Displacement	Siding Chamber 1	String Potentiometer
29	2-D	Vinyl Siding Displacement	Siding Chamber 2	String Potentiometer
30	3-D	Vinyl Siding Displacement	Siding Chamber 3	String Potentiometer
31	4-D	Vinyl Siding Displacement	Siding Chamber 4	String Potentiometer

4.7 Data Acquisition

4.7.1 Pressure Data

The differential pressure sensors Dwyer MS2-103 LCD utilizes piezo sensing technology in which an electrical charge is generated after mechanical stress is applied to a piezoelectric material. This electrical charge is proportional to the applied mechanical stress and is used to determine the applied pressures through time. Piezoelectric materials have a high modulus of elasticity which allows the sensors to have a high natural frequency and good linearity through a wide pressure range. Pressure data is collected at a sampling rate of 100 Hz.

4.7.2 Displacement Data

String potentiometers are composed of a measuring cable, spool, spring and a rotational sensor. The measuring cable is connected to the vinyl siding and will extend when the vinyl siding specimen displaces due to pressure loading. As the cable moves, the spool and the rotational sensor shaft rotate creating an electrical signal proportional to the cable’s linear extension which is used to obtain the specimen displacement. Displacement data is collected at a sampling rate of 100 Hz.

4.7.3 CompactDAQ

Both the pressure and displacement data produce an electrical signal output. This data is gathered by a portable data acquisition platform which allows to collect, process and analyze sensor data. This CDAQ can acquire and synchronize different type of measurements such as voltage, temperature, vibration, etc. in one system.

4.7.4 LabVIEW

LabVIEW is a software used for instrumentation control, data acquisition and process automation. LabVIEW allows to control the proposed test by manipulation of the applied pressures in each pressure chamber and the duration of the loading. LabView collects the pressure and displacement data from each test and stores this data in a file which can be used for statistical analysis.

4.8 Adhesive Test

Four pressure chambers are created across the vinyl siding as shown in section 5.4. A latex sheet is used for creating these pressure chambers without affecting the stiffness of the vinyl siding when subjected to the pressure loads. A smaller scale test was conducted to determine the adherence capacity of Masterweld 948 for attaching the latex sheet to the vinyl siding and aluminum plates.

4.8.1 Adhesive Test Details

Masterweld 948 is used as the adhesive to attach the latex sheets to the vinyl siding and aluminum HSS frames. A 68 in x 39 in and 28 in thick wood box pressure chamber was used. A 39 in x 26 in vinyl siding specimen was fastened into a 68 in x 39 in and ½ in thick Oriented Strand Board (OSB) sheathing. The OSB sheathing had aluminum plates in the perimeter of the vinyl siding specimen. Rubber latex was glued 4” to the vinyl siding and to the aluminum plates. The test assembly is shown in figure 43. Suction pressures were applied from within the pressure chamber. Table 7 shows the results of the adhesive test.

Figure 43. Latex sheet adhered over the vinyl siding and to the aluminum plates

Table 7. Results of specimen resistance to pressure differentials

Differential Pressure (Pa)	Test 1 (Specimen 1)	Test 2 (Specimen 2)	Test 3 (Specimen 3)	Test 4 (Specimen 3)	Test 5 (Specimen 4)
500	*	*	*	*	*
1000	*	*	*	*	*
1500	**A**	*	*	*	*
2000		*	*	*	*
2300		**B**	*	*	*
2500			*	*	*
2700			*	**C**	*
2800			**B**		*
3000					**D**
3300					**B**

A Vinyl siding trim failure at 1450 Pa

B Latex detachment from the vinyl siding

C Latex sheet capacity failure

D Leakage started to be observed

***** No failure or noticeable leakage observations were determined

4.8.2 Selected Installation

The observed failures modes during the adhesive test led to the use of a thicker latex (0.14 in) due to the latex capacity failure during test 4. A wood batten is used to provide a compression plate/ seal along the top edge of the latex sheet to hold it in place against the aluminum plate based on test 3. Additional latex sheet in the exterior of the pressure chamber to provide resistance to the peeling failure based on test 2 and test 5.

5 CURRENT OBSERVATIONS

At this time, no experimental conclusions can be assessed before performing the tests. From the adhesive test, we have observed that peeling of the latex is the predominant failure mode. A batten is necessary to prevent latex sheet peeling from the aluminum and a thicker latex is also required (0.14 in). The distance the latex sheet is glued to the vinyl siding and the aluminum was increased from 3 inches to 4 inches to provide more peeling resistance. The current experimental set-up utilizes the same HSS aluminum section for two pressure chambers. By using the same HSS section, space between the pressure chamber is limited and it eliminates the option of using the latex to the exterior of the pressure chamber which would provide more resistance to the peeling. Nevertheless, we opted to add another layer of latex bent to the exterior in the corner zones of the chamber. The performance of the latex will dictate if any change is required in the set-up for future testing.

The purpose of this test is to obtain the pressure distributions across vinyl siding through time as it displaces. Three pressure application methods controlled via LabVIEW using the SPLA are executed. Pressure transducers are used to monitor how these pressure distributions across the vinyl siding behave in each of these application methods. Dwyer MS2-103-LCD is capable to take pressure differentials on top the vinyl siding and within the sheathing cavity; this is the net pressure felt by the siding in each pressure application method. The uniform static pressure application is the benchmark for how tests are currently performed, and the dynamic application is the more realistic application according to current literature. The application of individual static- uniform pressures for each pressure chamber will be compared with the dynamic pressure application to determine if they are similar or if there is a noticeable pattern. If there is, applying individual uniform static pressures in each pressure chamber can be far more useful for test standard purposes since it eliminates the complexity of using the SPLA.

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APPENDIX A: CONSTRUCTION DRAWINGS

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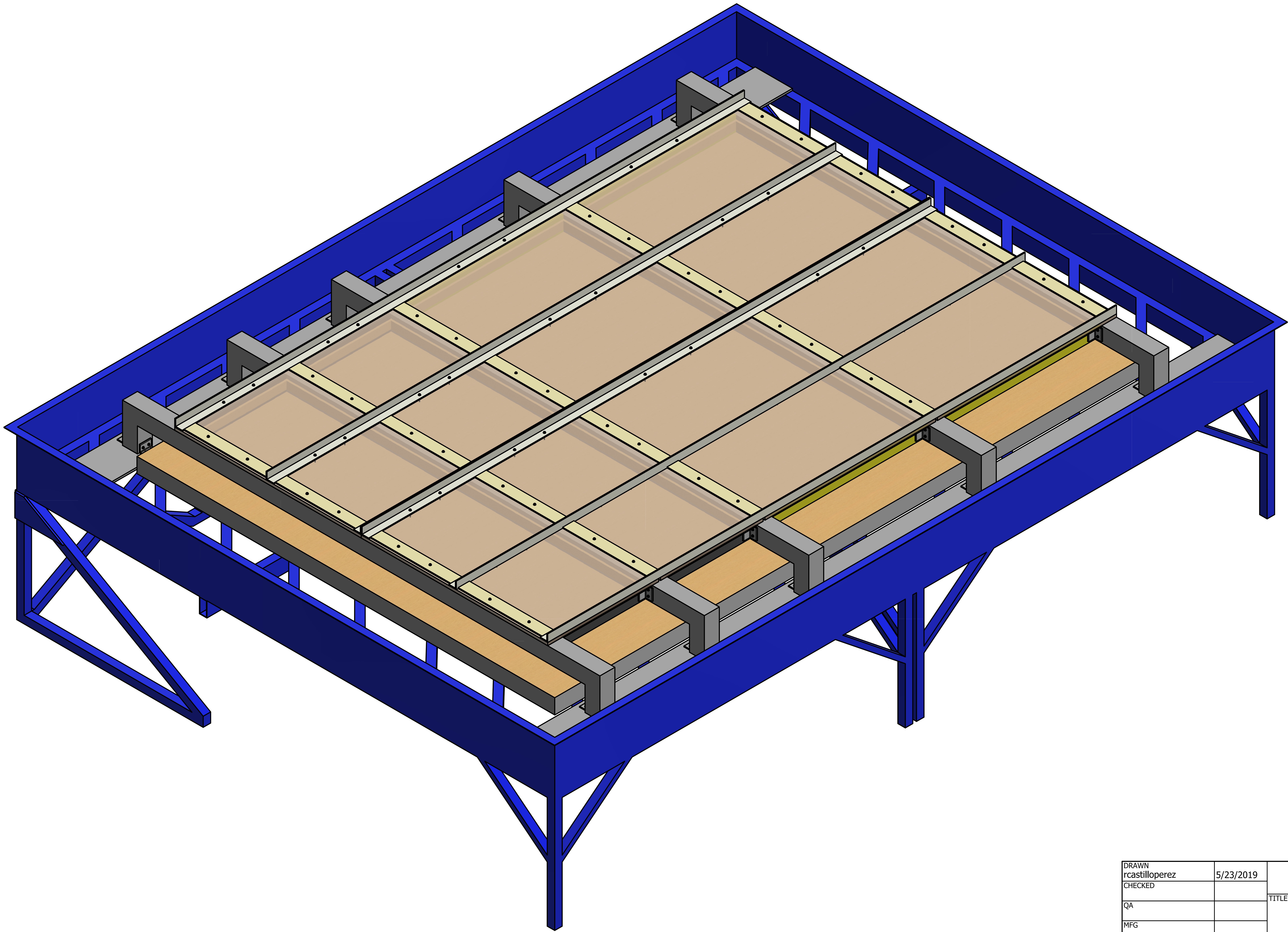

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QA				
MFG				
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		SCALE 1:10	SHEET 1 OF 4	

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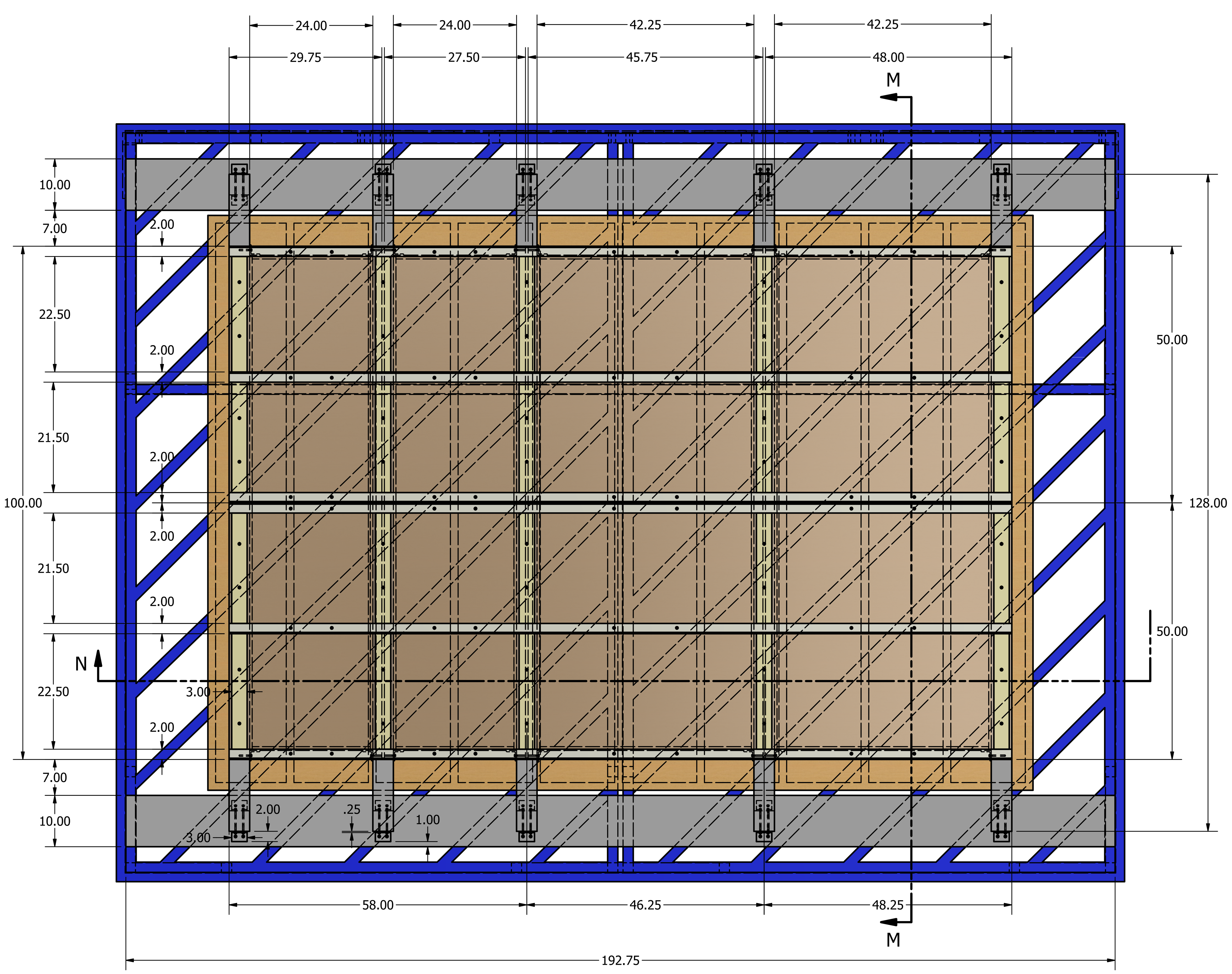

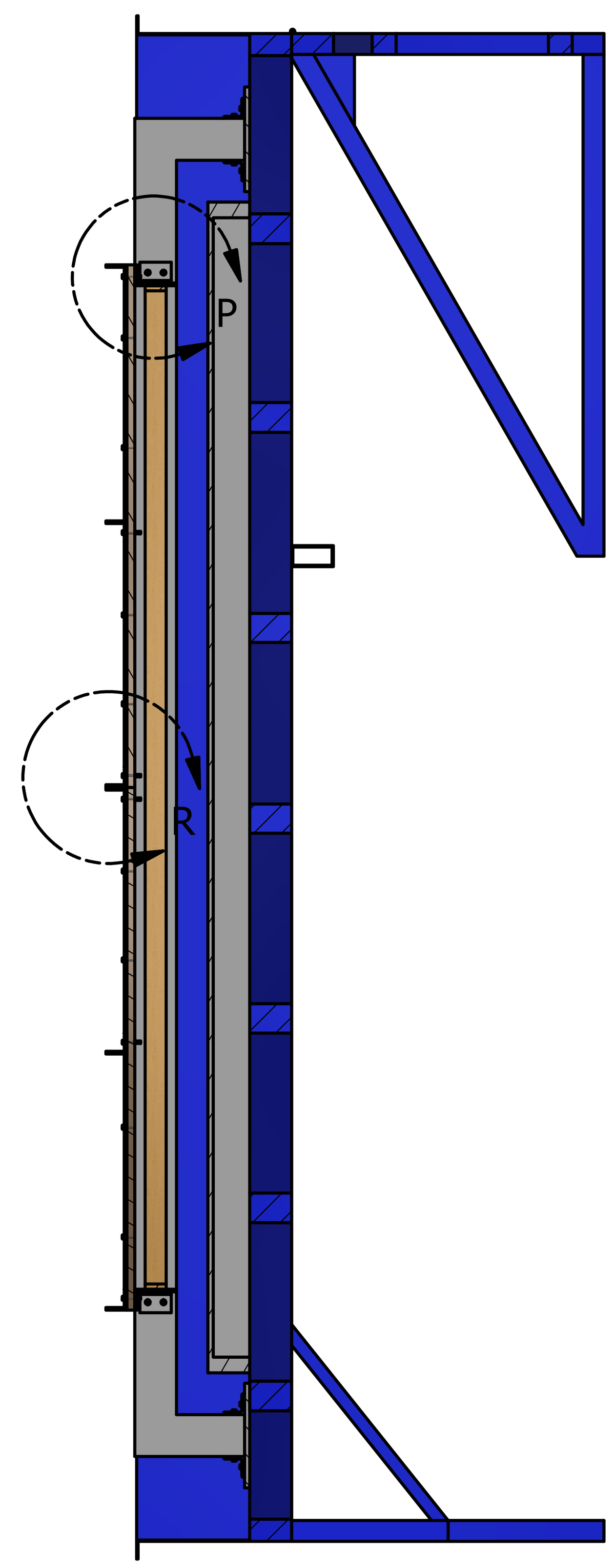

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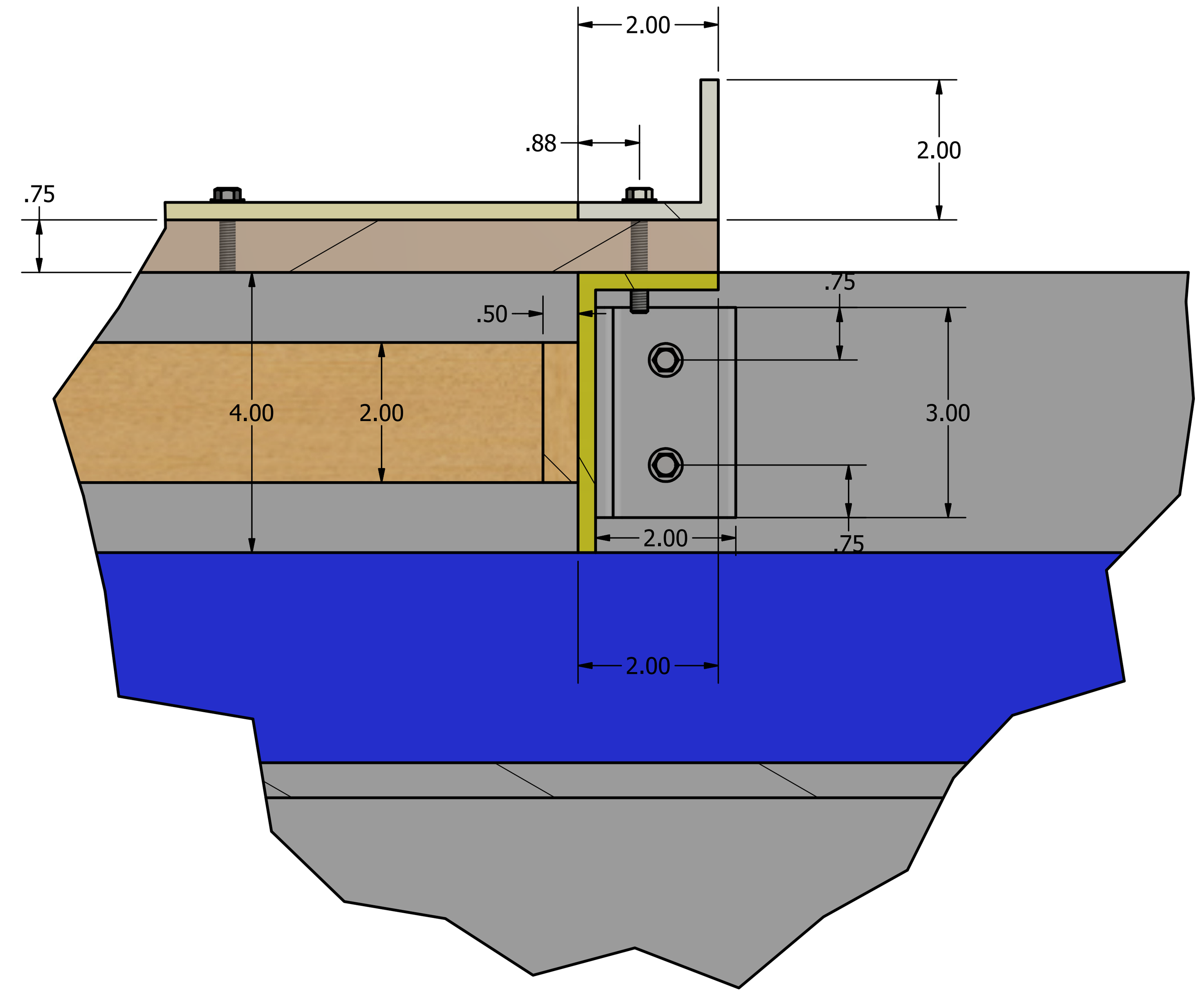

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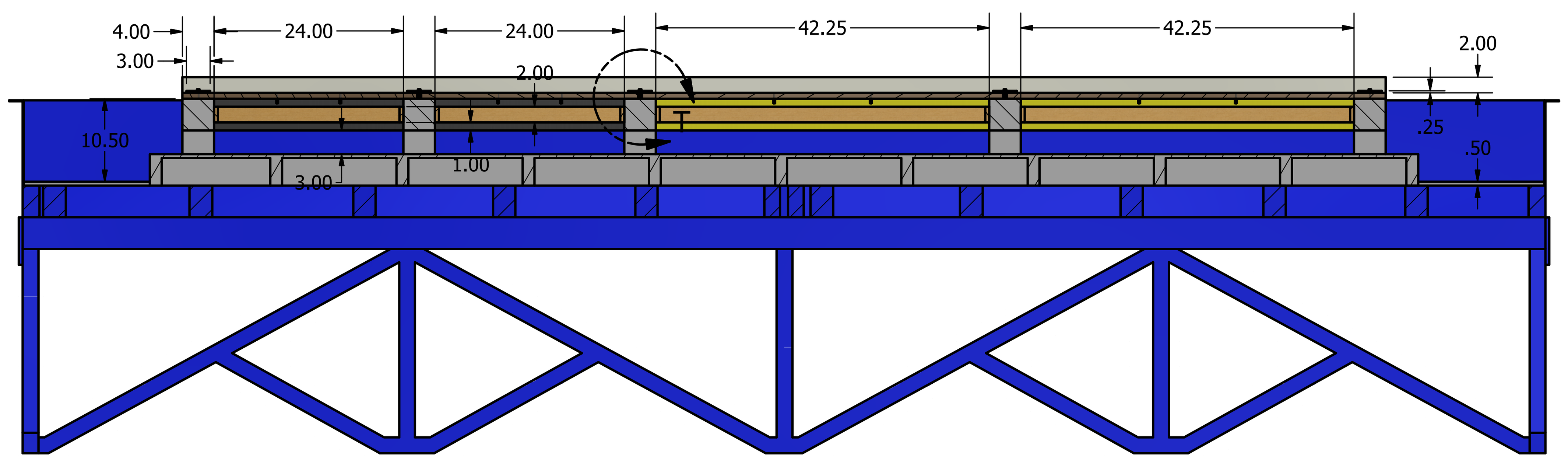

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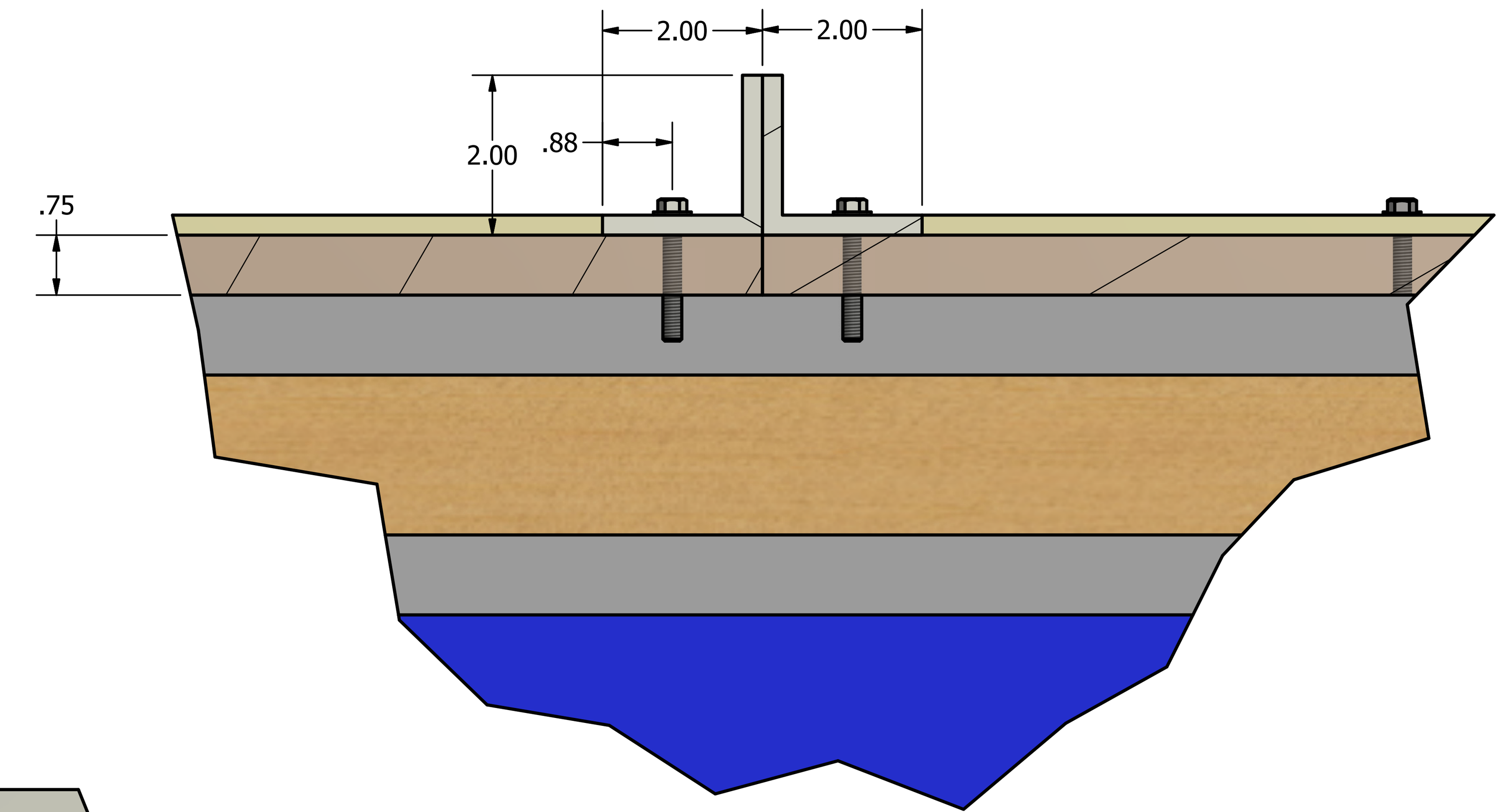

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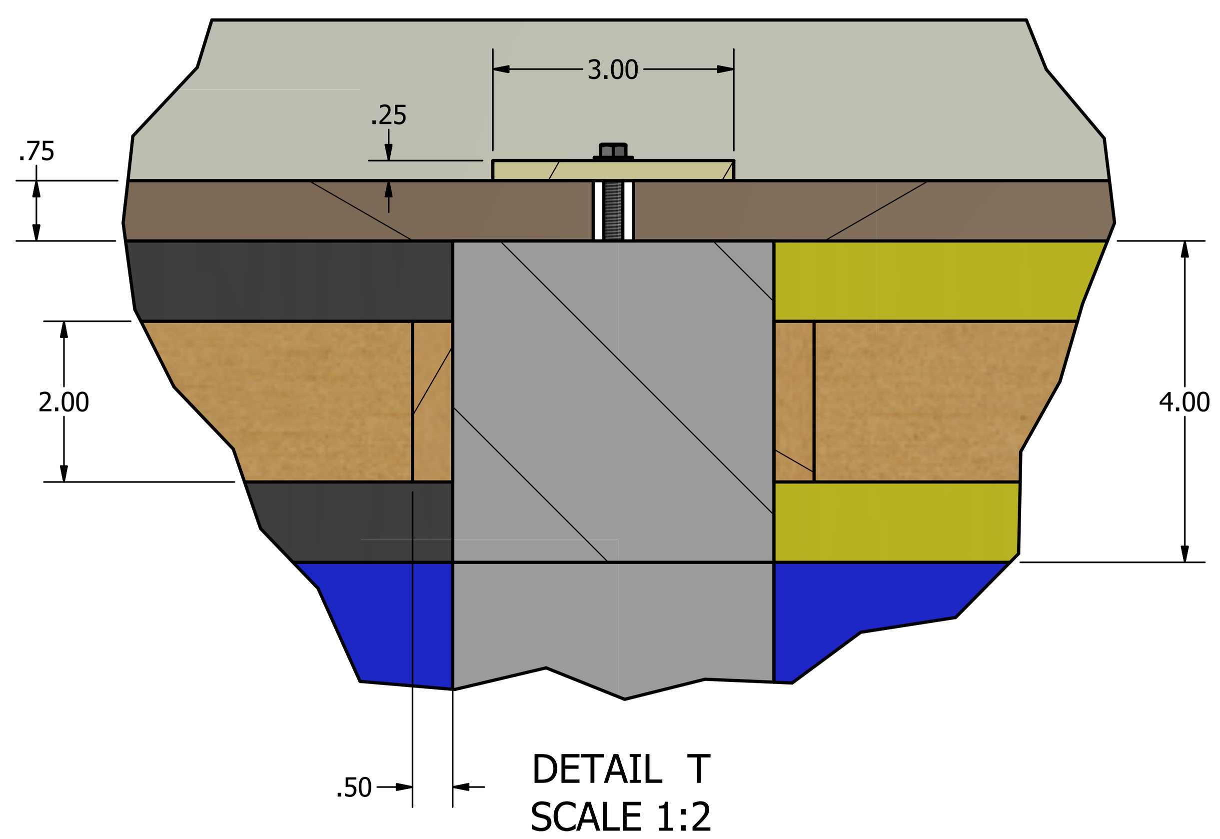

DETAIL T
SCALE 1:2

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MFG		
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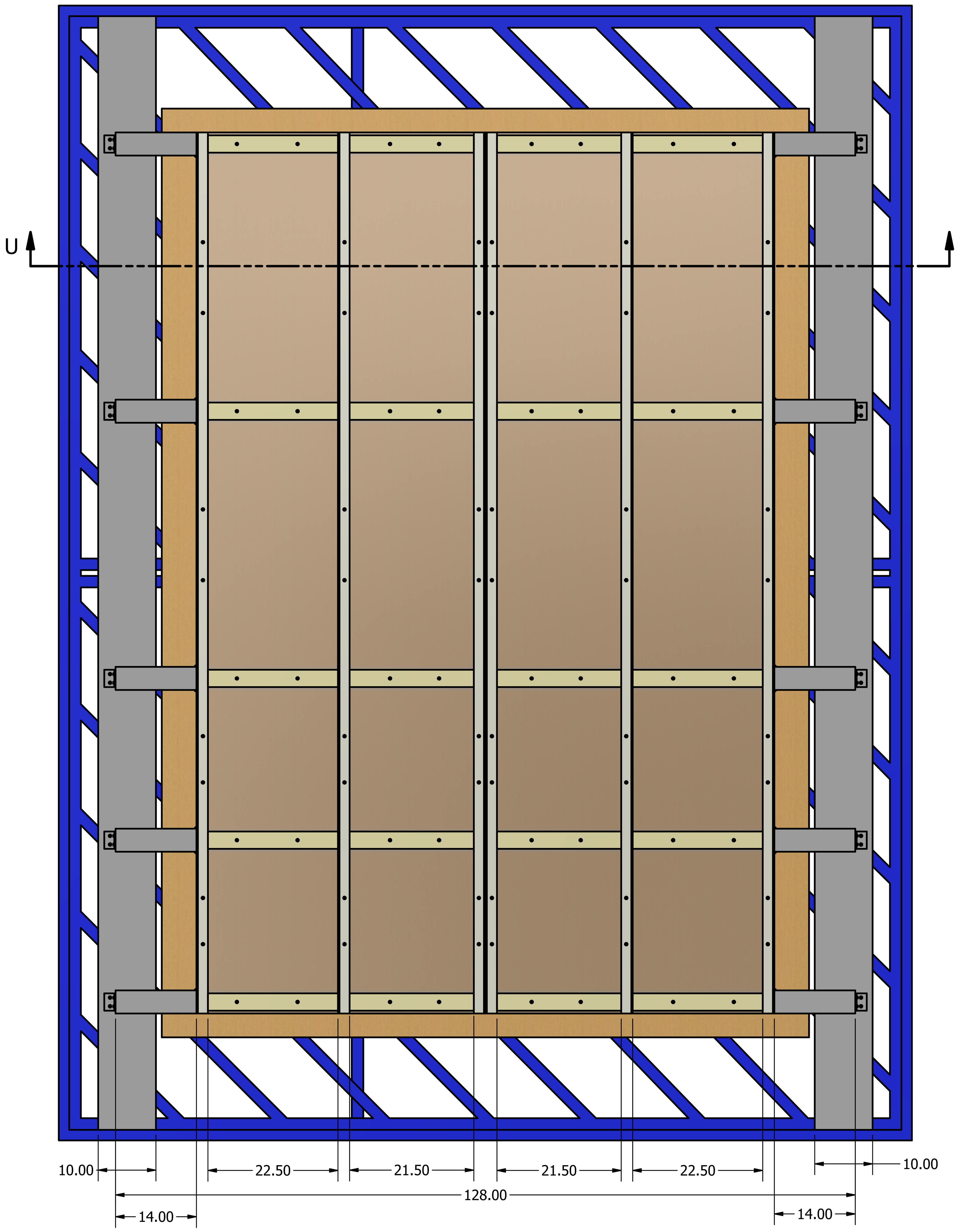
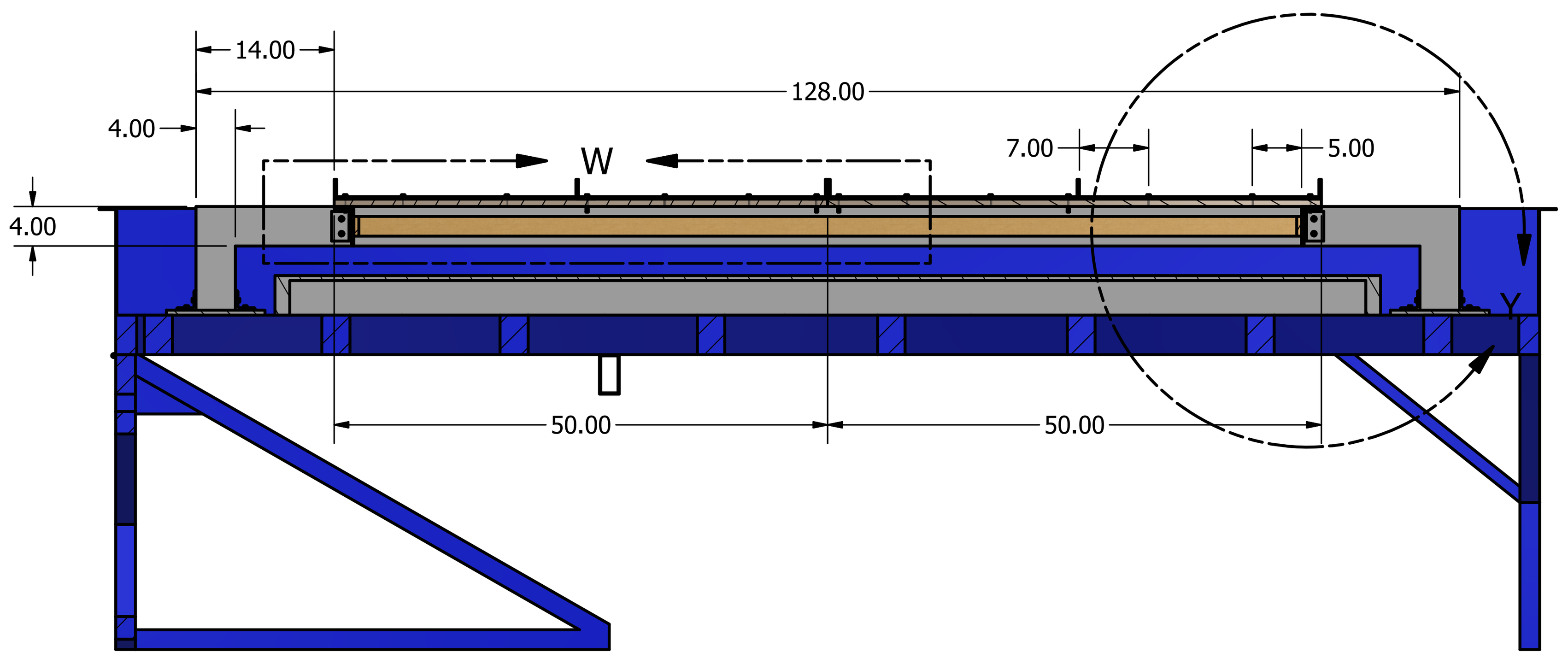
		SCALE 1 / 15 · SHEET 2 OF 4





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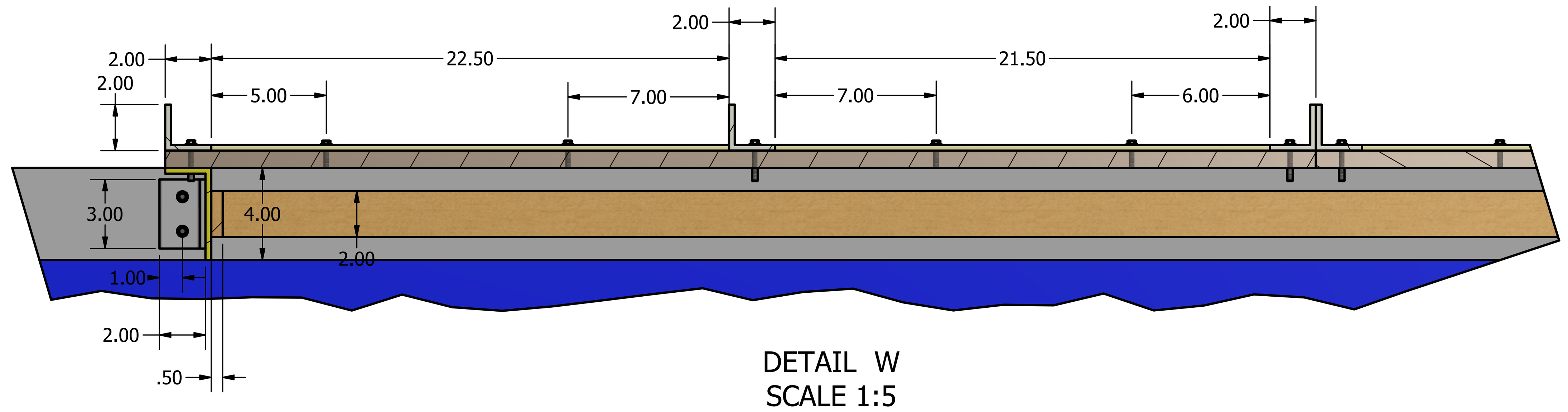

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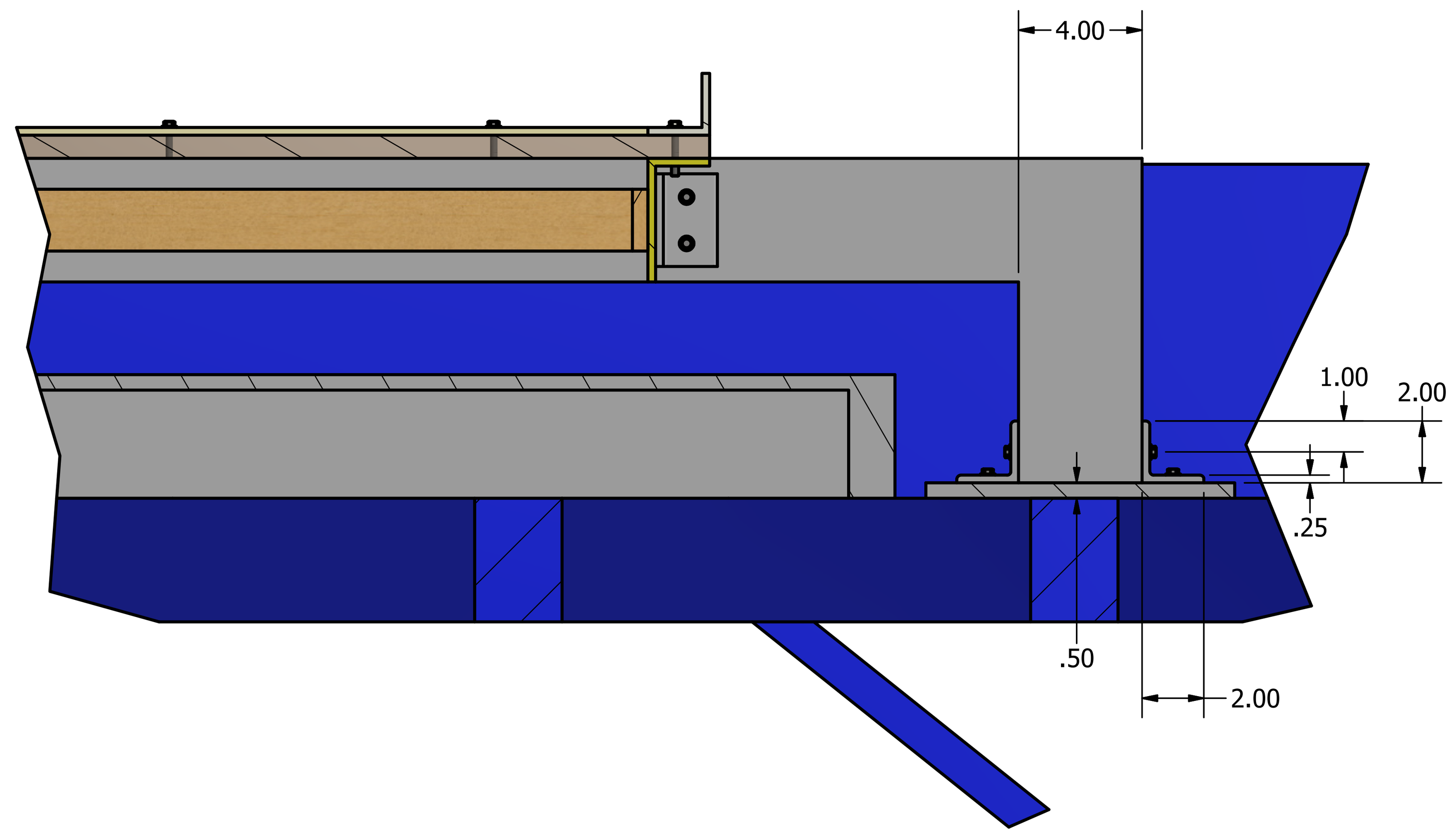

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MFG		
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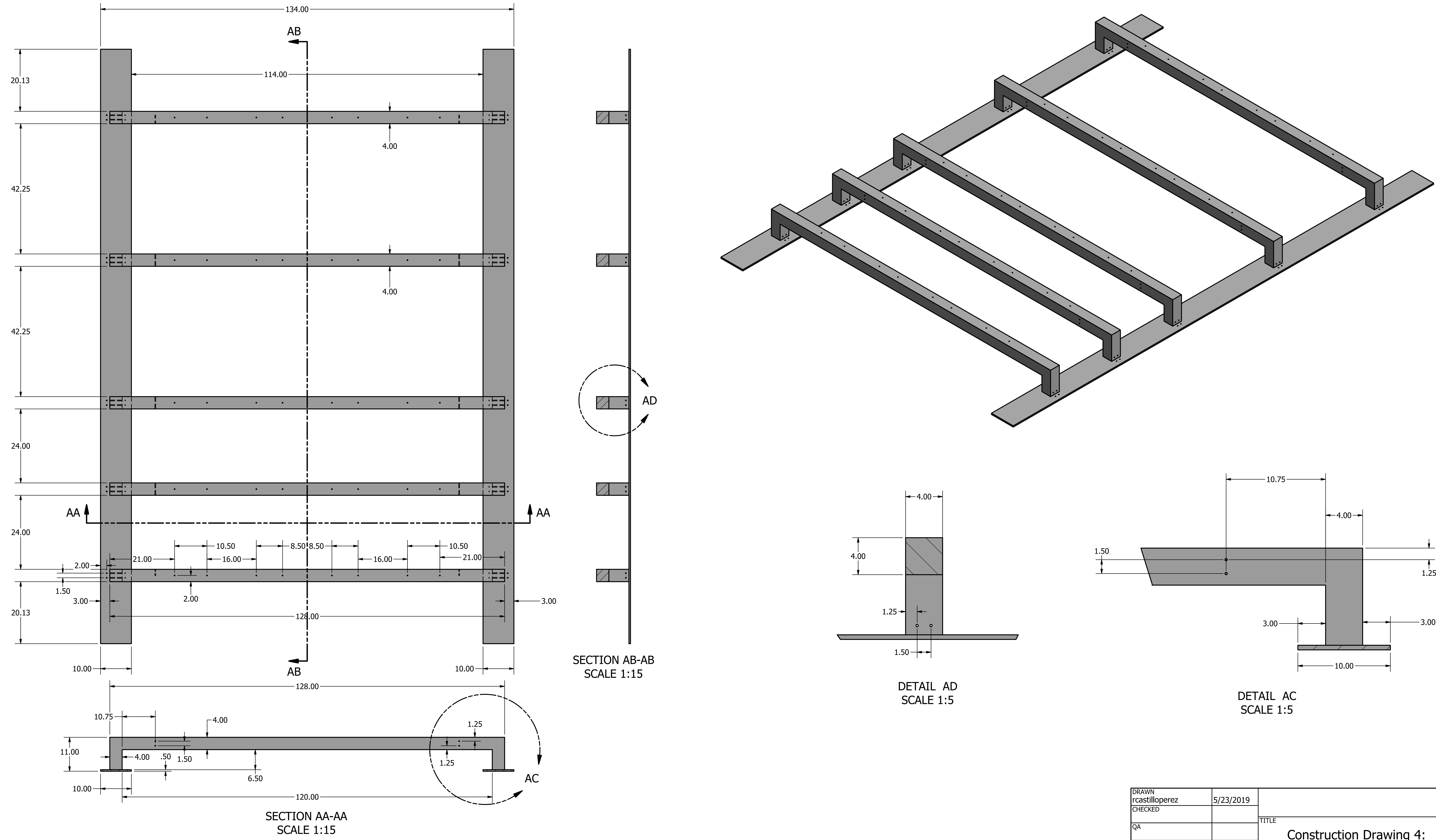
		SCALE 1 / 15 · SHEET 3 OF 4



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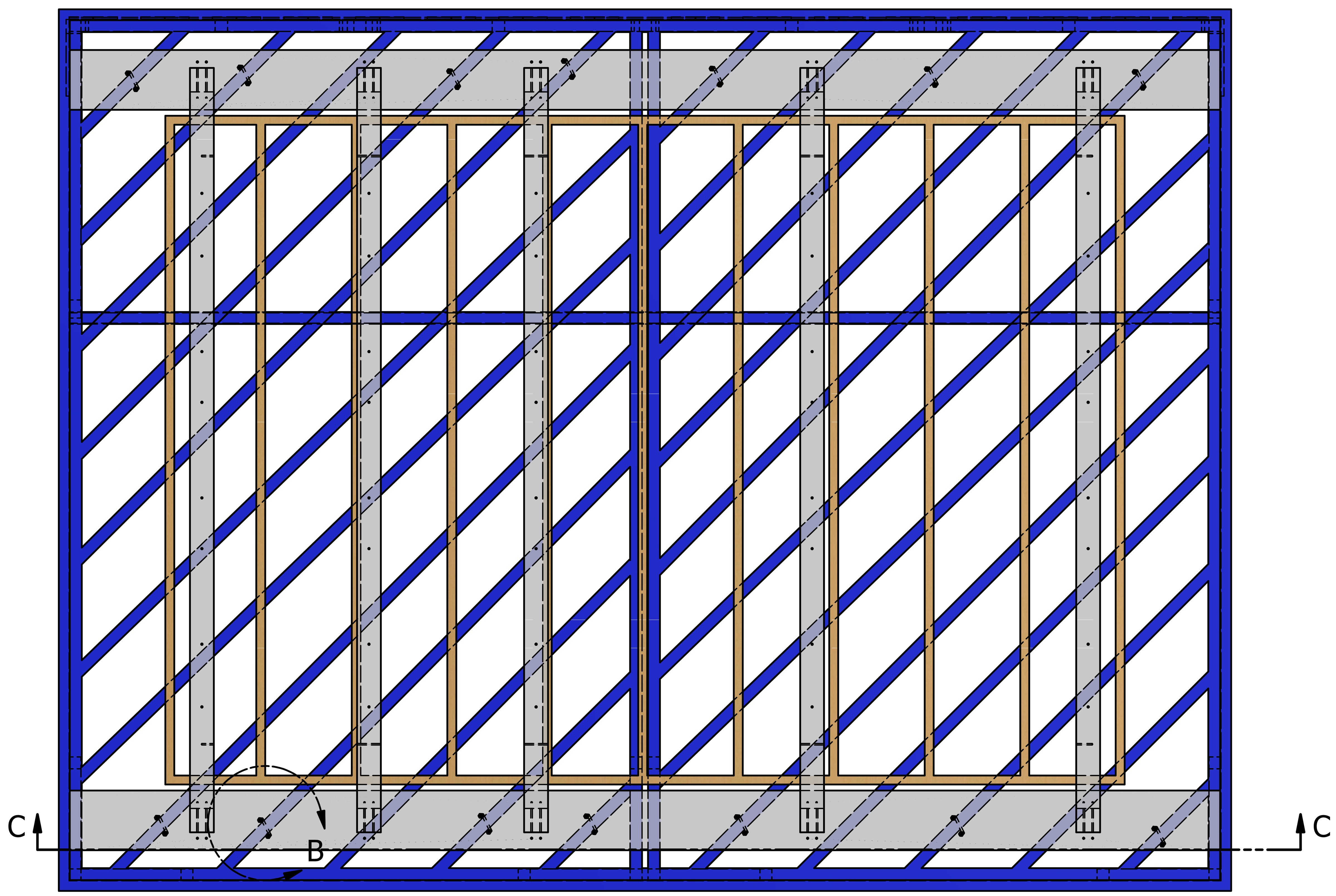

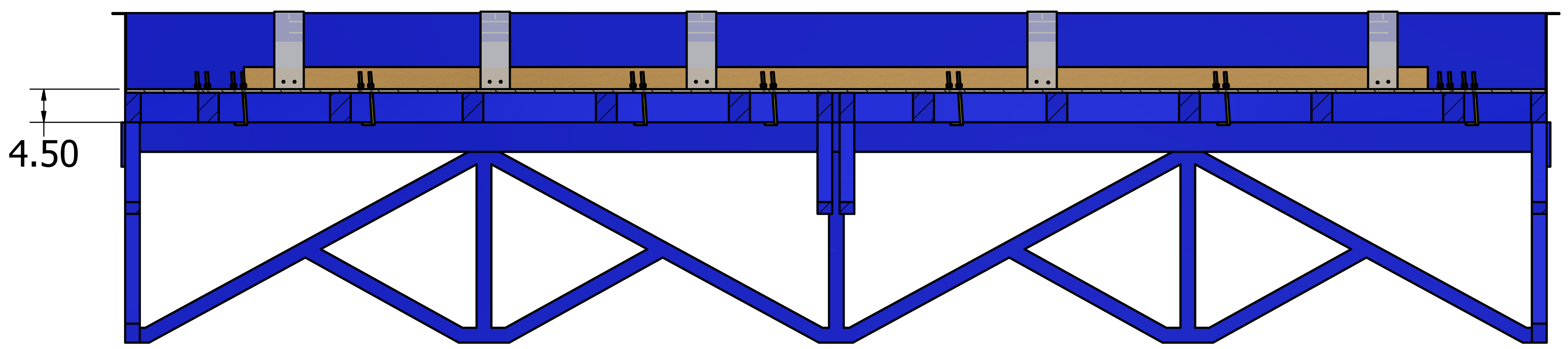

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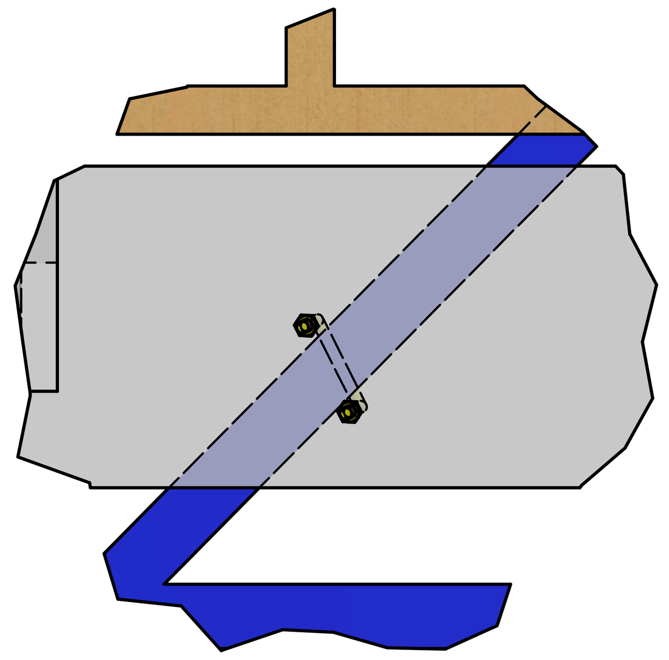

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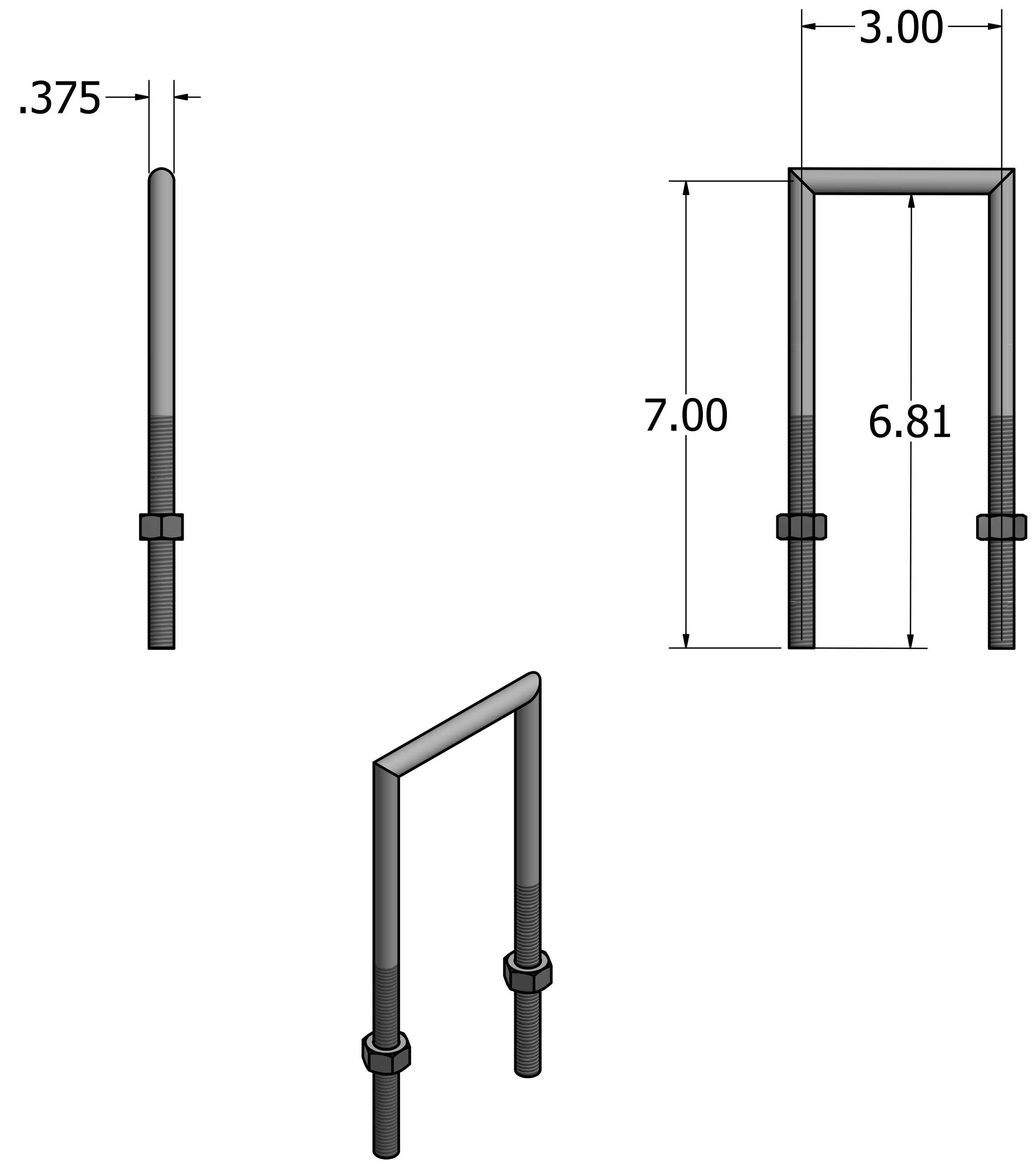
SCALE 1:5



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QA			
MFG			
APPROVED			
		SIZE D	DWG NO 2. EXPERIMENT ubolts	REV
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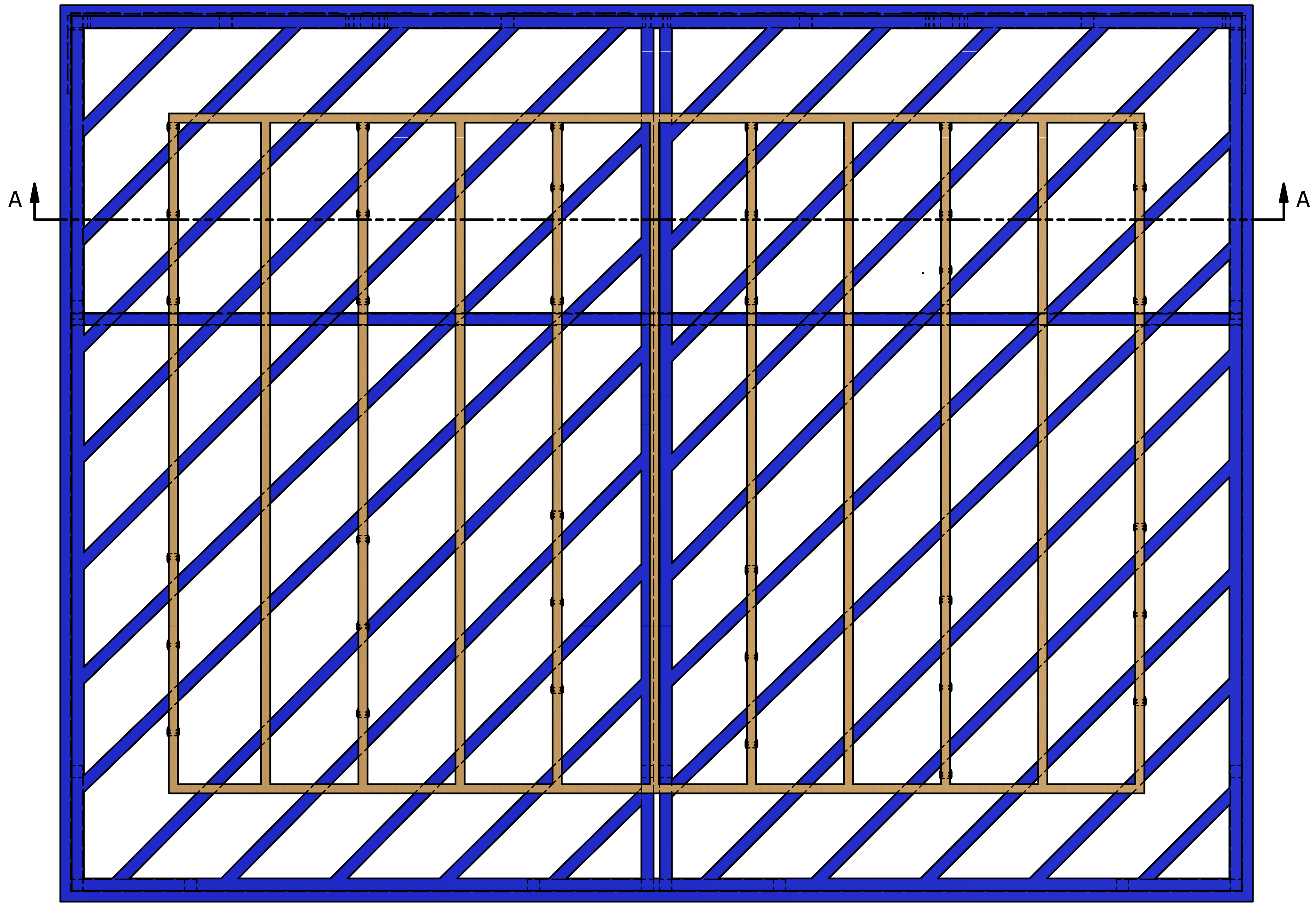

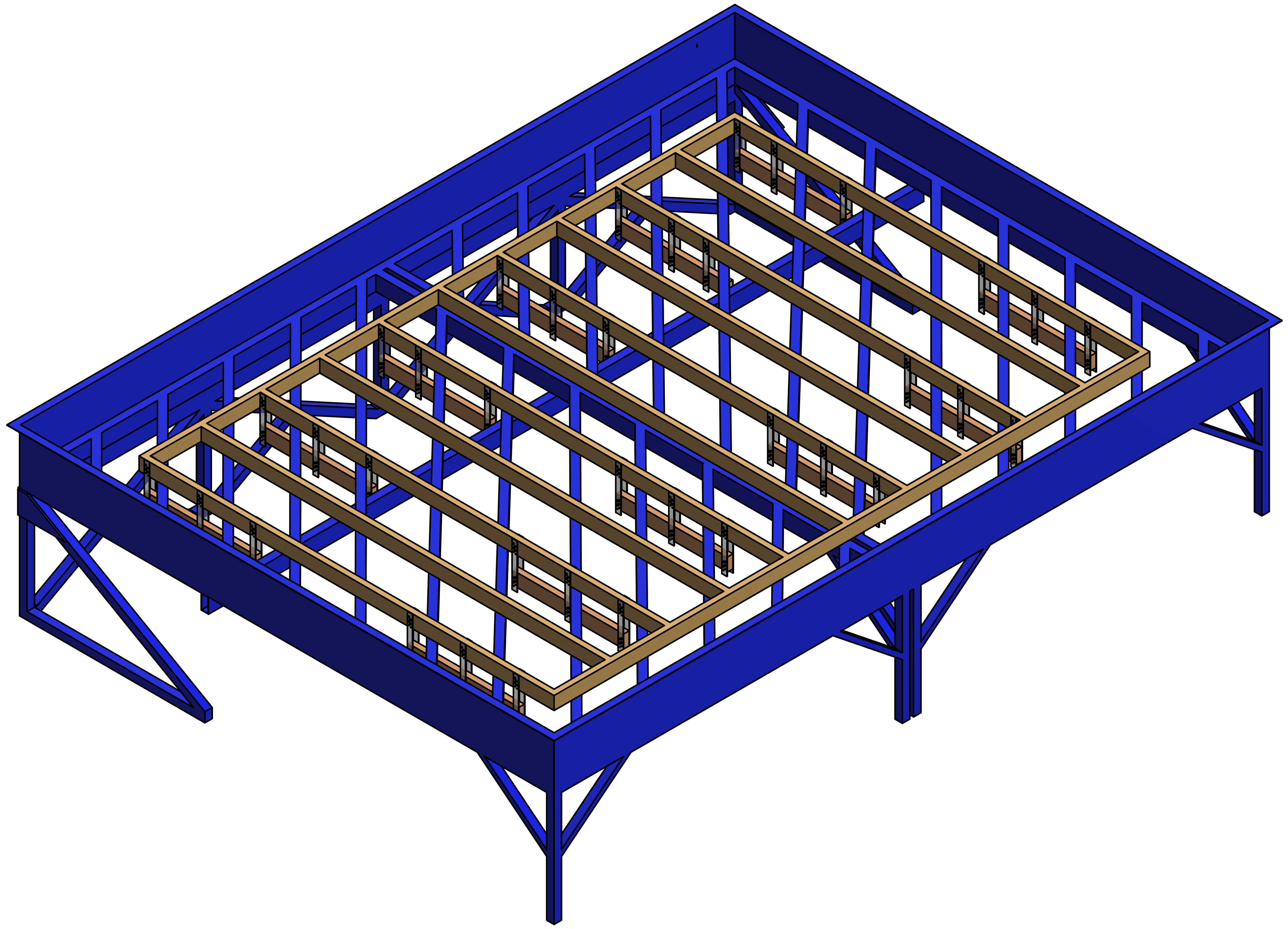

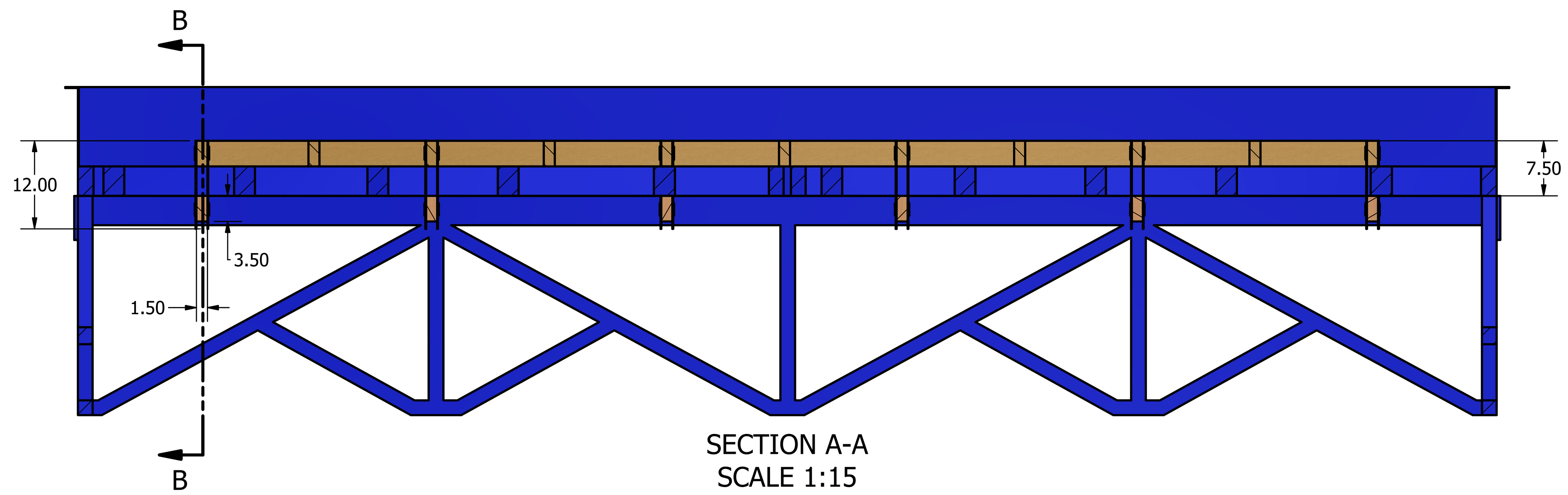

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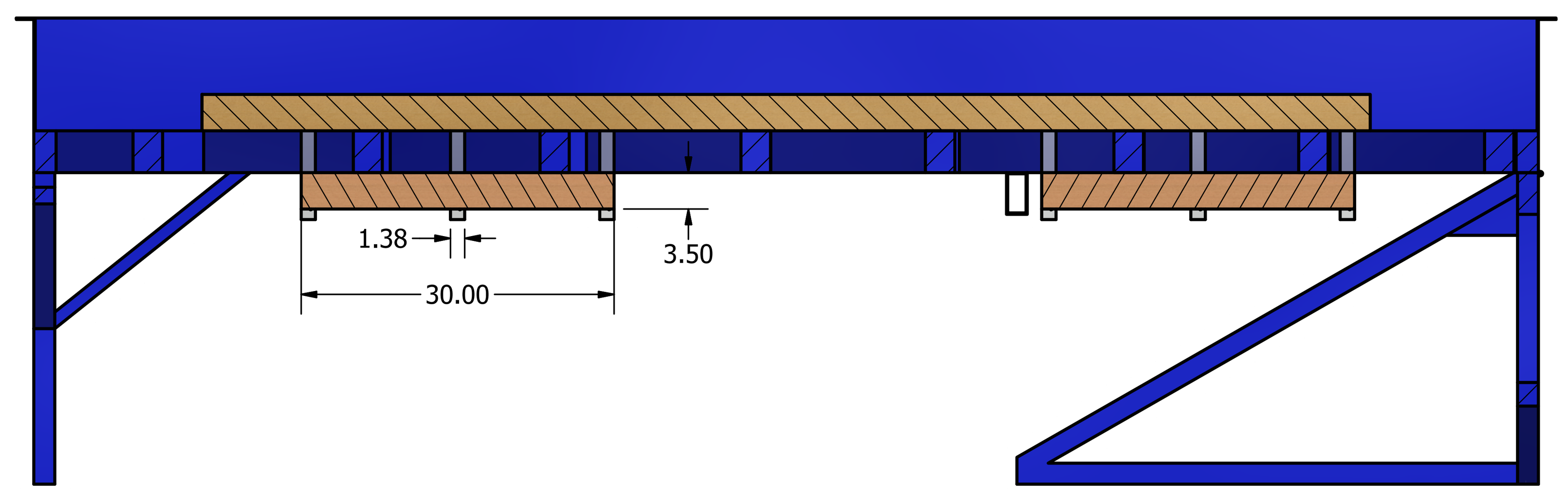

SECTION B-B
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QA		
MFG		
APPROVED		SIZE D · DWG NO 2. Specimen connection · REV
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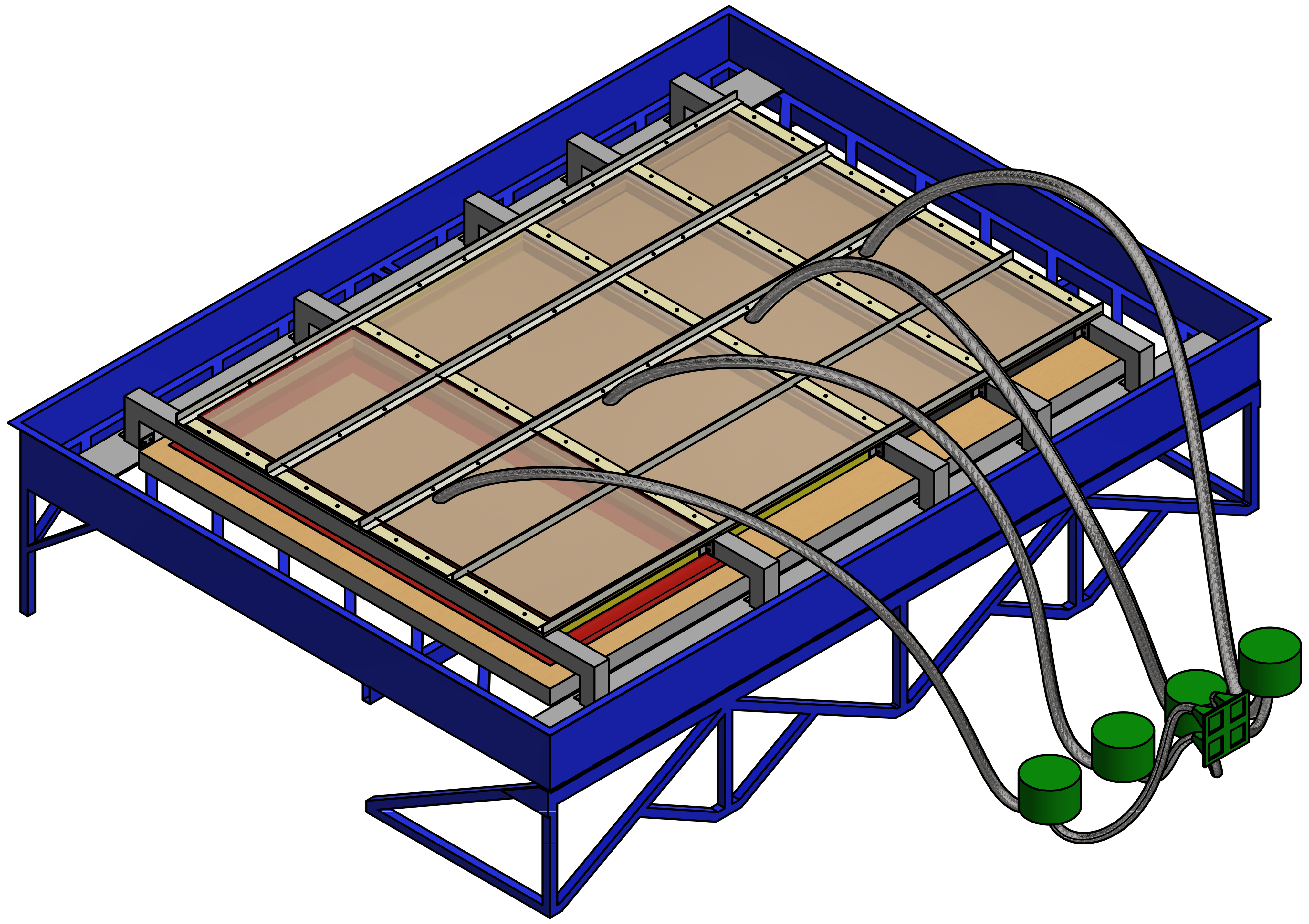

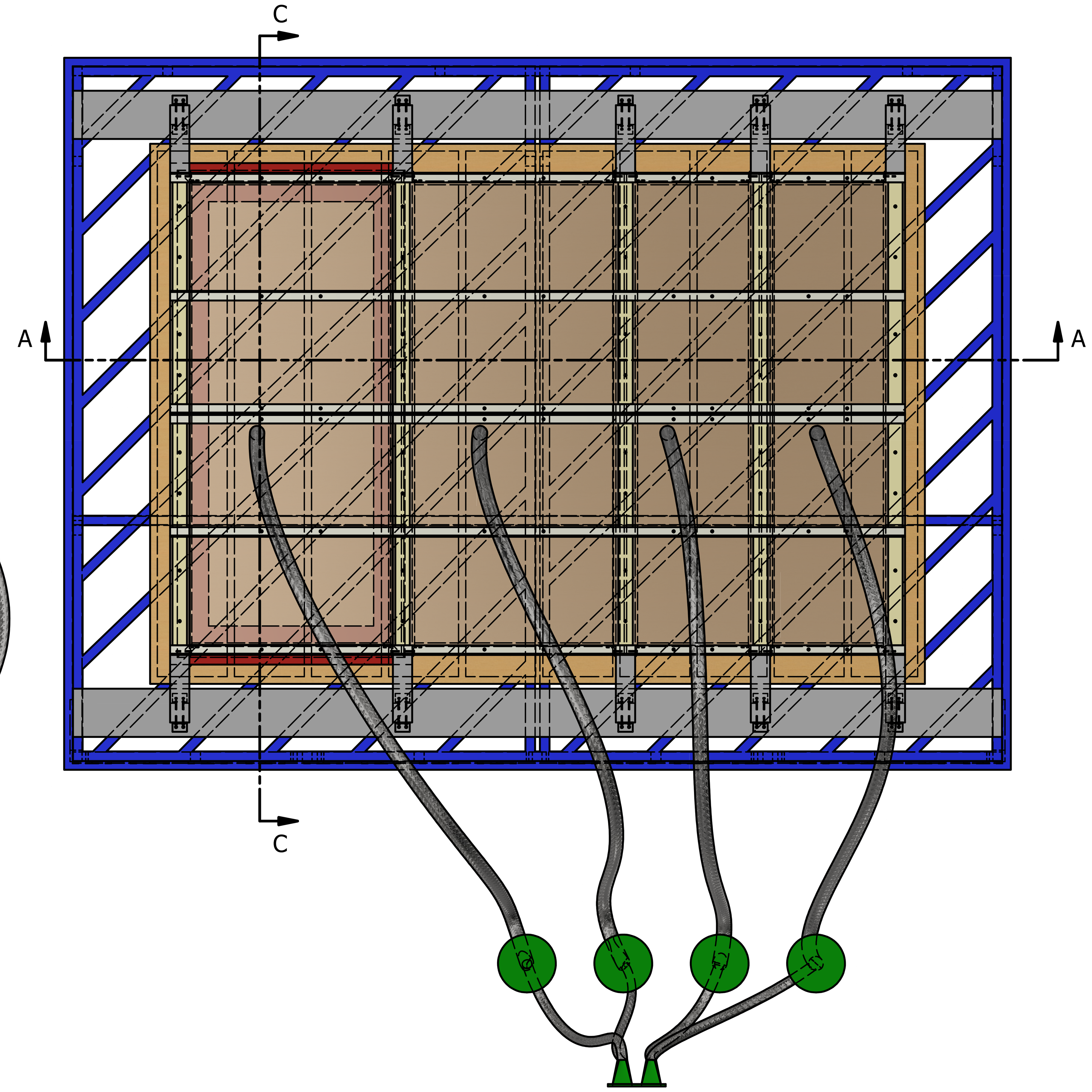

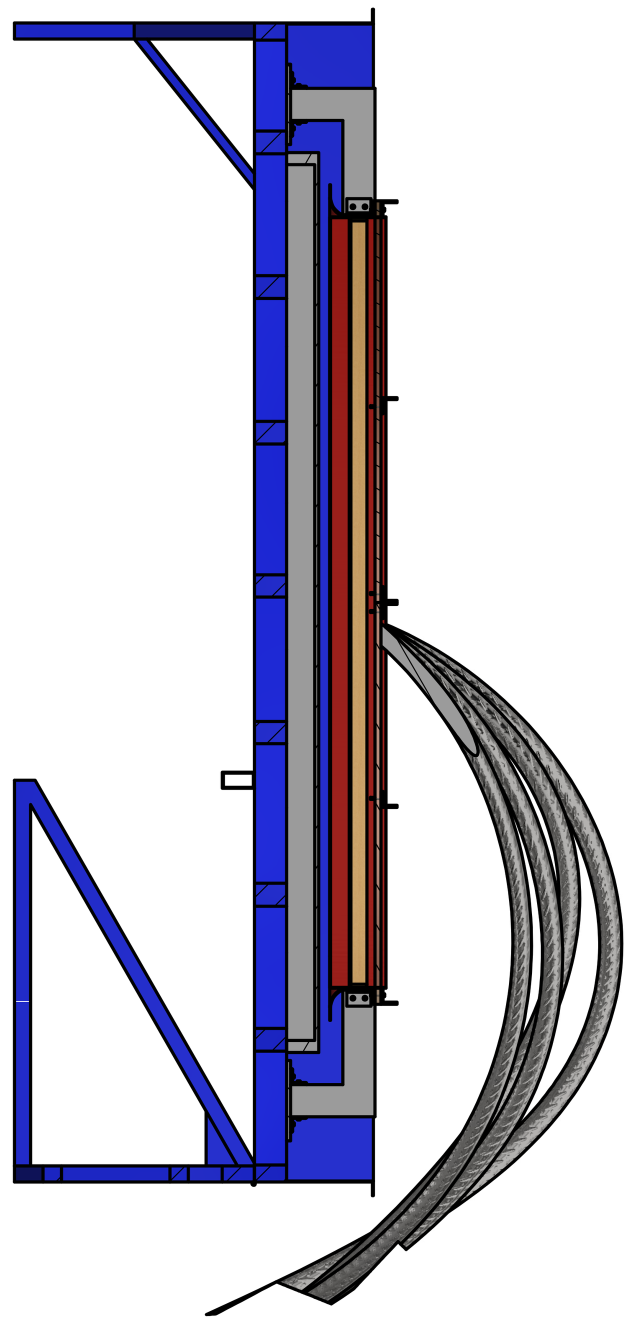

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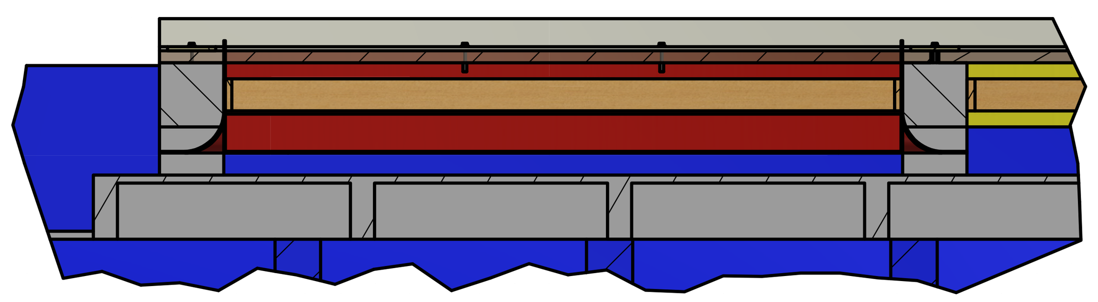
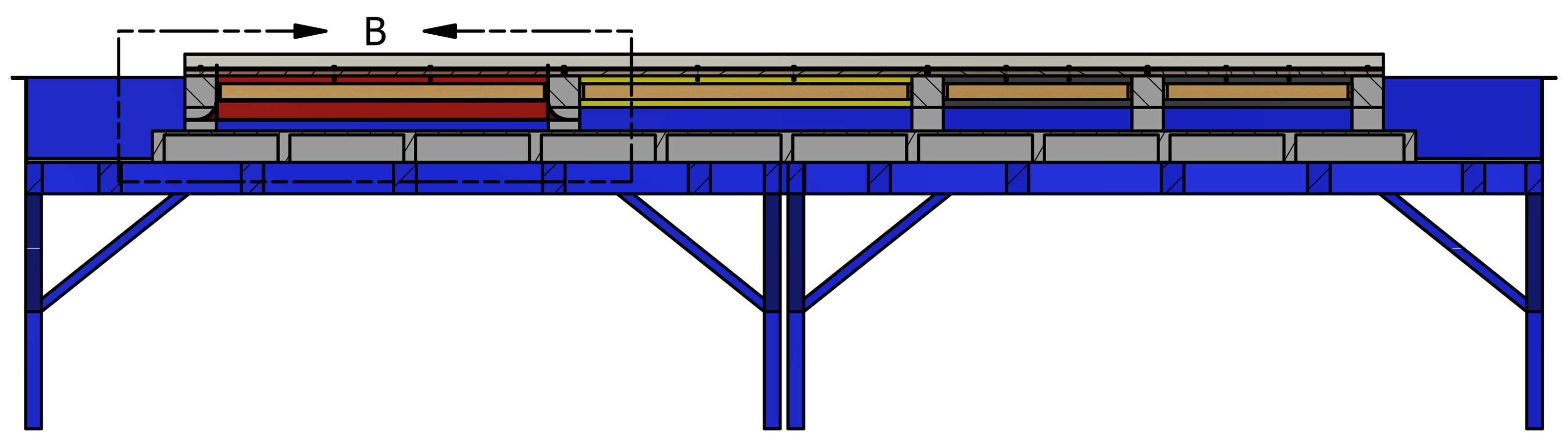


DETAIL B
SCALE 1 / 10



SECTION A-A
SCALE 1:20

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QA		
MFG		
APPROVED		SIZE D — DWG NO — REV
		SCALE 1:20 — SHEET 1 OF 1

APPENDIX B: EMAIL MATTHEW DOBSON- VINYL SIDING INSTITUTE

The principal investigators discussed the vinyl siding and soffit systems study with Matthew Dobson, Vice President of the Vinyl Siding Institute, Inc. on June 3, 2019. Current test standards, manufacturing standards, and building code upgrades regarding vinyl siding are discussed in this correspondence. These modifications will be incorporated in the future test development.

From: Matt Dobson <mdobson@vinylsiding.org>
Subject: Evaluation of Wind Resistance of Vinyl Siding and Soffit Systems
Date: June 3, 2019 at 9:17:27 AM EDT
To: "Prevatt,David" <dprev@ce.ufl.edu>, "dbr0011@auburn.edu" <dbr0011@auburn.edu>
Cc: Fernando Pages Ruiz <fernandopages@live.com>, "mo.madani@myfloridalicense.com" <mo.madani@myfloridalicense.com>

Dear Dr. Prevatt and Dr. Roueche:

The Vinyl Siding Institute serves as the trade organization to the polymeric cladding industry. In this capacity, we work through the ASTM consensus process with other stakeholders in the development of product performance standards and sponsor a third party administered certification programs for many of the products our members manufacture.

These standards and certifications include testing requirements and third-party quality control. We also conduct field inspections of product performance following significant wind events. The results of these field inspections and subsequent research lead us to work collaboratively toward improving the built environment and in some cases, changes to the building code.

The industry supports post-hurricane research and remains open to constructive recommendations from any agency or educational institution. We recently collaborated closely with FEMA and the insurance industry on changes to soffit requirements in both the Florida Building Code and International Residential Code.

We also hope to participate in and help inform research done by others on our products.

As manufacturers of these products for over 50 years, our decades of product testing and standards development provides a wealth of research, including field performance and manufacturing experience that can help to provide an understanding of polymeric cladding and soffit.

For example, after an initial survey following Hurricane Irma, a University of Florida data sample of 171 homes cataloged under vinyl siding, misidentified many of the cladding materials resulting in a reduction of the sample size to 25 valid examples. The Vinyl Siding Institute could have assisted in correctly categorizing vinyl cladding, and even in making finer distinctions between vinyl siding, polypropylene siding, insulated siding, and cellular PVC claddings that correspond, each one, to different ASTM manufacturing standards and obey regulation under different sections of the building code.

The Interim Report, Evaluation of Wind Resistance of Vinyl Siding and Soffit Systems, and Performance During the 2017 Hurricane Irma, cites studies dating from as early as 2005 but did not mention the updated 2017 ASTM standards with increased wind-resistance requirements that the industry has adopted, exceeding current code requirements. Neither do we see the updated code language approved under the 2018 i-Codes on soffit or the proposed FBC upgrades in consideration.

Advancement in manufacturing standards and code upgrades should come under consideration before any proposed testing or modifications to the code are considered.

Field surveys of older siding applications yield historical data. Historical data serves to predict likely damage to older structures, but not to establish a baseline for future codes. Any survey of a dynamic system, such as polymeric cladding, which undergoes continual assessment and improvement, must reference current standards in evaluating future performance. For recommendations on testing and future code requirements for polymeric siding and soffits, we offer – once again – our institutional support in providing updated information that will provide a present-day perspective from which to asses future product performance.

We are more than willing to work with you moving forward as we have done in the past. I know our representative Fernando Pagés Ruiz has been in touch with you in the past and we hope we can continue to work collaboratively to find real results to real problems based on current codes and standard requirements.

Please let us know how we can be a part of these efforts moving forward.

Respectfully,

Matt

Matthew Dobson, CAE
Vice President
Vinyl Siding Institute, Inc.
4010 Cullen Court
Burlington, NC 27215
(703) 244-2930

APPENDIX C: HURRICANE IRMA AND MICHAEL VINYL SIDING, VINYL SOFFIT AND FASCIA DATASET

									Siding Damage												Soffit Damage								Fascia Damage								
Record ID	Assigned Damage State	Latitude	Longitude	Actual Year Built	Number of Stories	PeakWindSpeed_mph (FPHLM)	PeakWindDir (Nautical)	Front Elevation Orientation (Nautical)	F-1	L-1	R-1	B-1	F-2	L-2	R-2	B-2	F-0	L-0	R-0	B-0	F-1	L-1	R-1	B-1	F-2	L-2	R-2	B-2	F-1	L-1	R-1	B-1	F-2	L-2	R-2	B-2	Soffit and Fascia Damage Overlap, %
023e2267-0fd5-46ac-9d0e-06cefbd0defa	Minor	30.18008158	-85.6198977	2007	1	104	324	0	M	5	30	15	—	—	—	—	—	—	—	—	P	10	P	P	—	—	—	—	40	50	P	P	—	—	—	—	P
8c4b97de-a694-4a49-8758-184198733186	Moderate	30.18010158	-85.6191701	2007	1	104	324	0	M	0	0	0	—	—	—	—	—	—	—	—	10	0	5	P	—	—	—	—	20	0	5	0	—	—	—	—	50
fcf7d64e-ca41-4cc8-be89-11b2e355a373	Moderate	30.181018	-85.620224	2009	1	104	324	270	M	M	0	0	—	—	—	—	—	—	—	—	P	5	P	10	—	—	—	—	10	80	P	70	—	—	—	—	10
5e9424ad-161b-42c0-8817-0855cee4e943	Moderate	30.18134233	-85.6202538	2007	1	104	324	270	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
3ea3281d-bc3e-4eb9-b472-90e843081e4e	Moderate	30.18169621	-85.6203104	2006	1	104	324	270	M	0	0	0	—	—	—	—	—	—	—	—	P	0	0	P	—	—	—	—	0	0	P	0	—	—	—	—	—
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ce466855-440f-4ad4-9c9b-c07bb872cc8c	Minor	30.180973	-85.622063	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—

e12e7613-07e9-4d4a-878f-7403f9258963	Minor	30.181402	-85.621539	1998	1	104	324	180	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	0	—	—	—	—	0	0	0	0	—	—	—	—	—
716c8113-529b-41da-a67a-c55059afffad	Moderate	30.18089	-85.621186	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	5	5	0	0	—	—	—	—	0	5	10	0	—	—	—	—	0
92774111-596b-45ae-b0e8-574ed0beae84	Minor	30.181373	-85.621213	1998	1	104	324	180	M	M	M	M	—	—	—	—	—	—	—	—	0	0	5	P	—	—	—	—	0	0	0	P	—	—	—	—	—
eb7fd43b-1993-4c34-803e-eafc0e7bf185	Moderate	30.180969	-85.62088	1997	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	0	5	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
3d823ed1-3ffc-45c9-99f1-ce791c7ec22e	Minor	30.181393	-85.620877	1998	1	104	324	180	M	M	M	M	—	—	—	—	—	—	—	—	0	0	5	P	—	—	—	—	0	0	0	P	—	—	—	—	—
f62d80e0-9d45-478c-a730-5262a1ffc667	Minor	30.181443	-85.620728	1998	1	104	324	180	M	M	M	M	—	—	—	—	—	—	—	—	M	M	M	M	—	—	—	—	M	M	M	M	—	—	—	—	—
a468cc0c-a977-40c6-b82c-177b15bc4149	Destroyed	30.181575	-85.620725	1998	2	104	324	180	M	M	M	M	M	M	M	M	—	—	—	—	—	—	—	—	100	100	100	P	—	—	—	—	100	100	0	50	70
a8bd6ec6-6636-48ea-92f5-716dd2554c08	Moderate	30.180936	-85.619728	2015	1	104	324	0	M	5	0	0	—	—	—	—	—	—	—	—	30	0	0	30	—	—	—	—	60	10	0	0	—	—	—	—	10

8bb8d017-118a-427a-8803-0ee05443dbac	Moderate	30.180978	-85.619284	2016	1	104	324	0	15	0	25	0	—	—	—	—	—	—	—	—	25	0	5	5+	—	—	—	—	50	20	0	0	—	—	—	—	30
a388fc64-009d-449c-8f35-102d4861222d	Moderate	30.180998	-85.618991	2011	1	104	324	0	M	0	5	0	—	—	—	—	—	—	—	—	0	0	0	0	—	—	—	—	20	5	20	0	—	—	—	—	0
6a36d8f3-5f28-4a22-b0e0-6086249f981e	Minor	30.180913	-85.61874	2008	1	104	324	0	M	P	5	0	—	—	—	—	—	—	—	—	0	P	10	P	—	—	—	—	10	P	0	0	—	—	—	—	P
f1da7dc5-3a79-4c07-b696-0853963eaa60	Minor	30.181373	-85.618732	2006	1	104	324	180	M	10	0	0	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	P	—	—	—	—	—
de36a0c9-5060-45c6-afd4-939111c3d150	Minor	30.181399	-85.618512	2006	1	104	324	180	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	P	—	—	—	—	—
41f3806c-9e07-4301-9199-56e086679797	Minor	30.18135972	-85.6183926	2006	1	104	324	195	M	M	M	M	—	—	—	—	—	—	—	—	0	0	P	P	—	—	—	—	0	0	P	P	—	—	—	—	—
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8a2845af-8ea0-4553-a5c7-9c67c19f827a	Minor	30.180963	-85.617731	2006	1	104	324	210	M	0	0	0	—	—	—	—	—	—	—	—	0	0	P	P	—	—	—	—	0	0	0	0	—	—	—	—	—
5f6dd132-4ba2-4746-b0ee-8d0d4ae78d40	Minor	30.180506	-85.617804	2006	1	104	324	30	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	50	0	0	0	—	—	—	—	0

4c59311f-0ef0-49ba-a32d-4e5f58fe86d9	Minor	30.180756	-85.617391	2007	1	104	324	210	M	0	0	0	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	P	—	—	—	—	—
23f210a3-1488-4e50-a5f3-985865a65000	Minor	30.180253	-85.617579	2006	1	104	324	30	M	25	0	0	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	15	0	0	0	—	—	—	—	0
6232f673-9676-4836-a82b-cd112a5a2a4c	Minor	30.180643	-85.61726	2006	1	104	324	210	M	0	0	0	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
f43462ad-f065-4378-a29c-83455fcfdadf	Minor	30.180196	-85.617389	2006	1	104	324	30	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
c8cc248f-32fe-4192-97b6-b6ea95747b94	Minor	30.180628	-85.617033	2007	1	104	324	210	M	5	0	0	—	—	—	—	—	—	—	—	0	P	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
00a50fc0-80c0-4d51-af6f-901c4666f310	Minor	30.180489	-85.616873	2007	1	104	324	240	M	0	0	0	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	25	0	0	0	—	—	—	—	0
bd71b852-355f-4582-ab52-0fd76d196c83	Minor	30.180061	-85.617013	2006	1	104	324	345	M	M	M	M	—	—	—	—	—	—	—	—	0	P	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
2cd51d90-815a-4341-9d7b-63481d3bd3ce	Minor	30.180295	-85.616831	2006	1	104	324	285	M	M	M	M	—	—	—	—	—	—	—	—	0	0	P	0	—	—	—	—	0	0	0	0	—	—	—	—	—
d42ff787-429c-4546-9234-4d82d057daa5	Moderate	30.181358	-85.619811	2006	1	104	324	90	M	0	10	5	—	—	—	—	—	—	—	—	0	0	5	0	—	—	—	—	0	0	0	0	—	—	—	—	—
3ecd769b-8e32-46cd-bf45-274e9621ade1	Moderate	30.181535	-85.619832	2006	1	104	324	90	M	30	50	25	—	—	—	—	—	—	—	—	0	P	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
7ae1555e-0b64-4217-833c-60dc327424f6	Minor	30.181708	-85.619175	2006	1	104	324	270	10	10	25	0	—	—	—	—	—	—	—	—	0	0	5	P	—	—	—	—	20	25	15	P	—	—	—	—	0

150cdc73-856e-4887-ae81-4dba6af3ef5b	Undamaged	30.182045	-85.619374	2017	1	104	324	210	M	0	0	0	—	—	—	—	—	—	—	—	0	10+	P	P	—	—	—	—	0	0	0	0	—	—	—	—	—
12b54184-fa3f-4dbe-9369-5c646a5e2ca9	Minor	30.18204	-85.622563	1998	1	104	324	90	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
6de5e7a8-99d1-4353-b556-e4d202f7897c	Moderate	30.181811	-85.622173	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	—
d1157a91-e06e-4b65-99dc-a6b55649c2db	Moderate	30.181885	-85.622054	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	10	P	—	—	—	—	0	0	0	0	—	—	—	—	—
0bcada42-cc48-4889-a497-b3f757b308e0	Severe	30.182333	-85.621599	2006	1	104	324	180	0	10	0	0	—	—	—	—	—	—	—	—	0	20	0	0	—	—	—	—	0	20	0	0	—	—	—	—	100
f1d7da45-68fc-4578-bb17-7d7faf62d574	Severe	30.18181477	-85.6215566	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	P	5	20	P	—	—	—	—	40+	5	10	0	—	—	—	—	20
2947e3aa-5d6e-4178-9617-2a4807f5a542	Minor	30.181911	-85.621214	1998	1	104	324	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	P	P	—	—	—	—	0	0	P	0	—	—	—	—	P
c1e64953-1817-4056-ac32-db781fa99536	Minor	30.182347	-85.621049	2006	1	104	195	180	M	0	0	0	—	—	—	—	—	—	—	—	0	P	P	P	—	—	—	—	0	0	0	0	—	—	—	—	P
cbf50cf1-a8c7-47b5-9ac8-936d65ec2132	Minor	29.915987	-85.375957	2017	1	124	195	315	M	M	M	M	—	—	—	—	—	—	—	—	40	5	P	10	—	—	—	—	30	25	50	80	—	—	—	—	20
9df7c56c-ad01-484c-8b77-1fc3908f8388	Minor	29.916994	-85.376119	2014	1	124	195	90	M	M	M	M	—	—	—	—	—	—	—	—	10	0	0	P	—	—	—	—	60	0	0	0	—	—	—	—	0
41ff8295-1b17-4423-b6ce-eb28a9d6a94c	Minor	29.917348	-85.376041	2015	1	124	195	90	M	M	M	M	—	—	—	—	—	—	—	—	0	5	5	P	—	—	—	—	60	0	0	30	—	—	—	—	0

fc20674a-2672-4649-b99b-4bb5a984e7d1	Minor	29.91744	-85.375563	2017	1	124	195	270	M	M	M	M	—	—	—	—	—	—	—	—	30	5	0	20	—	—	—	—	0	0	0	0	—	—	—	—	0
b53c3fef-02f7-4698-bc55-01dc4e66a37b	Minor	29.917691	-85.376089	2017	1	124	195	90	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	25	0	0	15	—	—	—	—	0
126578b3-b0d4-456c-b18d-6537545139c1	Minor	29.917043	-85.375641	2017	1	124	195	180	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	30	0	0	0	—	—	—	—	0
f12db53c-cbc3-447e-b544-c46c164618bc	MInor	29.916618	-85.375438	2013	1	124	195	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	70	—	—	—	—	0
d1c86efb-dec9-4fbe-88a5-25bb28df1794	Minor	29.917061	-85.375347	2013	1	124	195	180	M	M	M	M	—	—	—	—	—	—	—	—	0	5	0	P	—	—	—	—	30	30	0	0	—	—	—	—	10
7201d4f8-34a3-4fc5-8fec-ec0d34e5b11e	Undamaged	29.916631	-85.374999	2013	1	124	195	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	0	—	—	—	—	0
e9fcbb08-0319-4dc2-9a6d-4a00854d431c	Minor	29.916636	-85.374566	2015	1	124	195	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	25	—	—	—	—	0
e6b072ed-5218-4f7f-908b-e6cc3e657c3c	Undamaged	29.916638	-85.374157	2015	1	124	195	0	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	30	—	—	—	—	0
cc11458b-0e91-4450-9ea9-a67fb92b73f3	Minor	29.917056	-85.373913	2015	1	124	195	270	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	15	0	20	0	—	—	—	—	0
2f880cd3-71d2-4a3e-a013-a7a7b963569a	Minor	29.917457	-85.373913	2016	1	124	195	270	M	M	M	M	—	—	—	—	—	—	—	—	0	P	0	P	—	—	—	—	30	0	0	0	—	—	—	—	0
023751a8-a3af-42c1-b6b1-3b71e5423637	Moderate	29.91429085	-85.3758056	1998	2	124	195	135	M	M	M	M	M	M	M	M	—	—	—	—	—	—	—	—	30	0	30	0	—	—	—	—	0	0	0	0	0

5e73bb05-ddc3-4f4c-8172-7f9569d303ea	Severe	29.91319932	-85.3730523	1991	2	124	195	0	0	10	90	10	0	50	100	90	—	—	—	—	0	10	75+	0	25+	100	0	30+	0	0	75	0	25	100	0	50	90
b0473324-22b5-4e86-baa5-94978307b1e1	Moderate	29.91158263	-85.3742379	1999	2	124	195	315	0	80	90	20	0	90	90	95	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	85	0	0
b83f722e-a952-475f-ba87-3568af659f9d	Moderate	29.91234404	-85.3732833	1994	2	124	195	315	M	M	M	M	20	M	M	M	—	—	—	—	—	—	—	—	0	0	P	P	—	—	—	—	50	0	0	0	0
77e29d4b-9be2-4cf2-adb2-29269ac460df	Minor	29.91250272	-85.3730275	1996	2	124	195	315	M	M	M	M	M	M	M	M	—	—	—	—	—	—	—	—	50	0+	P	P	—	—	—	—	50	65	20	80	25+
867051a1-05b4-4b2a-a839-6ed115fd9650	MInor	29.91298688	-85.3731516	1997	1	124	195	120	0	0	5	0	—	—	—	—	—	—	—	—	0	25	85	P	—	—	—	—	70	75	95	P	—	—	—	—	30
7323b002-e851-4f59-8c2d-54fa95cc7d1e	Minor	29.912979	-85.372504	1997	1	124	195	270	M	M	M	M	—	—	—	—	—	—	—	—	0	0	10	30	—	—	—	—	10	0	10	5	—	—	—	—	40
af5a84d5-7cb6-430d-96a7-64e34a90c175	Minor	29.91384709	-85.3730228	1987	1	124	195	90	0	30	0	P	—	—	—	—	—	—	—	—	85	80	5+	P	—	—	—	—	80	40	0	P	—	—	—	—	70
881ffab8-78f8-41a1-99b8-b6265d746342	Minor	29.914606	-85.37245	2018	1	124	195	270	M	M	M	M	—	—	—	—	—	—	—	—	5	P	P	P	—	—	—	—	50	P	0	0	—	—	—	—	5
77492385-ebe7-4dbc-a4b8-c40434978e47	Minor	29.91466747	-85.3729853	1987	1	124	195	90	5	15	30	0	—	—	—	—	—	—	—	—	0+	5+	0+	0+	—	—	—	—	20	40	0	15	—	—	—	—	5
3c5d82f9-e2ec-4cc0-a02a-6d1209079a74	Moderate	29.91575986	-85.3730235	1990	2	124	195	15	0	5	0	0	0	0	75	0	—	—	—	—	P	0	0+	0	0	0	0+	0	0	0	40	0	0	0	0	0	0
f0dcab56-b381-46fc-9834-2a03be6c94c3	Minor	29.9157648	-85.3737631	1998	1	124	195	0	0	70	0	5	—	—	—	—	—	—	—	—	0	0+	0	0	—	—	—	—	0	50	50	0	—	—	—	—	0

b1b14ec5-3651-4bdb-a195-25ab93683ad6	Undamaged	29.9157061	-85.3745768	1997	1	124	195	345	0	0	0	0	—	—	—	—	—	—	—	—	0	0+	0+	P	—	—	—	—	0	0	0	0	—	—	—	—	0
5f6ff155-6a1e-49b7-8151-6d05835e92b0	Undamaged	29.915975	-85.375121	2015	1	124	195	135	M	M	M	M	—	—	—	—	—	—	—	—	0	0	0	P	—	—	—	—	0	0	0	P	—	—	—	—	0
b2bed098-ecc5-40ed-a737-1e07aa59770f	Moderate	29.91574039	-85.3754673	1988	1	124	195	135	10	0	0	P	—	—	—	—	—	—	—	—	0	0+	0+	P	—	—	—	—	0	0	0	0	—	—	—	—	0
dd7c95a9-a325-427f-b0ee-f304fb650b01	Minor	29.91516267	-85.375349	2018	1	124	195	315	M	M	M	M	—	—	—	—	—	—	—	—	0+	0	0+	P	—	—	—	—	0	0	0	0	—	—	—	—	0
233b6b94-c1e6-4795-9e7d-8db3666dc454	Moderate	29.91460935	-85.3760665	1992	2	124	195	300	0	0	P	0	0	85	10	0	—	—	—	—	—	—	—	—	10+	0+	100	P	—	—	—	—	10+	0	100	10+	—
6e9fe3cb-1187-42cc-8957-a57f71b9e36e	Moderate	29.91448439	-85.3730396	1997	2	124	195	180	0	0	40	0	0	5	20	0	—	—	—	—	0	40	100	0	90	50	95	10	0	75	100	0	90	50	95	0	70
285b19f1-6c5f-45bf-be9f-78df9b6529c9	Minor	29.91315572	-85.3747029	1984	1E	124	195	225	0	0	0	0	—	—	—	—	M	M	M	M	40	5	0	P	—	—	—	—	60	0	60	P	—	—	—	—	40
315b484c-c769-4018-9bf1-331ddc361720	Severe	29.91318973	-85.3755475	1999	2	124	195	45	M	M	M	M	70	0	0	50	—	—	—	—	0	0	P	—	0	5	10	60	0	0	0	—	0	0	0	50	0
41806904-aa63-4ca0-8ced-3eadd24ce379	Severe	24.678703	-81.389528	1968	1	121	176	270	0	50	0	100	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cacd978c-77f5-43b2-a5fd-9b2b863eb387	Minor	24.67794	-81.392963	2006	1	121	176	0	0	10	P	P	—	—	—	—	0	0	P	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32c1b935-d086-4d5d-8f23-2bd154ee20ec	Moderate	24.677912	-81.394068	2006	1	121	176	0	0	0	P	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

da865048-cdeb-4ee4-8dde-fdc5089f5f56	Moderate	24.655569	-81.385183	1998	1	125	176	90	P	100	P	50	—	—	—	—	M	P	M	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9cea39b8-23c9-489c-90c9-373dddfd5328	Moderate	24.655576	-81.38537	1997	2	125	176	180	20	P	100	P	90	P	20	P	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
dff7311c-bf75-47ea-95f5-098df6b001c7	Minor	24.689876	-81.396175	1985	1	121	176	195	0	P	10	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6235bee2-a740-4f47-b7dd-7a0ed23c001e	Minor	24.679144	-81.392485	2006	1	121	176	0	0	P	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33e31a9b-935f-41f3-b6b4-c0fe9950cd63	Moderate	24.689699	-81.398169	2000	1	121	176	270	0	P	0	P	—	—	—	—	0	P	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51628a86-03f0-41fc-b013-8705964c31e9	Moderate	24.688449	-81.398368	2006	1	121	176	270	0	0	0	P	—	—	—	—	0	P	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9f0b199d-515a-4da1-96ef-ca8bba1581d9	Moderate	24.689171	-81.396545	1987	1	121	176	195	70	P	40	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9ad76948-5b0c-4fbb-ade5-3c0bec5aa8b2	Moderate	24.689533	-81.397747	2006	1	121	176	90	0	0	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60d8f46a-15d4-4f97-86d4-aeb921c373fc	Severe	24.689214	-81.399728	1985	1	121	176	105	50	0	P	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
c87859d1-3708-4b64-a3a1-ec27ec0d2654	Moderate	24.688432	-81.397913	2007	1	121	176	90	0	P	50	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
d8c6d213-1b31-486c-bddf-1f4930df547d	Minor	24.678578	-81.393613	2004	1	121	176	0	50	0	5	P	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

8a687902-0fa7-4b43-926e-9e190e329094	Moderate	24.687328	-81.397769	2006	1	121	176	0	80	0	P	P	—	—	—	—	60	0	P	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
a5c0e534-7c49-42d3-96fc-bab95a6ca9ad	Moderate	24.677903	-81.389968	1958	1	121	176	90	0	0	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
558619af-0dcf-4e86-a388-188559c60eaa	Moderate	24.678866	-81.389673	1996	1	121	176	270	10	20	10	80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
01bd7e22-b78d-49be-b3ff-d9bdfbb686ac	Moderate	24.690018	-81.398649	2000	1	121	176	195	1	P	5	P	—	—	—	—	0	P	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51c09ee6-40ec-4944-a50f-e8f4a89181df	Moderate	24.655323	-81.405149	1998	2	125	176	0	0	0	0	1	0	10	1	50	P	0	M	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
454bbca1-de2e-4dd0-8590-f3ed2887ca2f	Severe	24.656112	-81.405712	2006	1	125	176	0	0	40	1	30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7a62025e-e719-4a4c-9033-f8447a022689	Severe	24.654928	-81.406002	1995	1	125	176	180	0	0	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
649ff91b-3c15-4978-a96b-f0e844cb4b13	Moderate	24.654959	-81.404956	1984	1	125	176	180	90	0	P	50	—	—	—	—	0	5	P	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7ee2fc09-7277-450f-a044-fd8dec8fa8b7	Moderate	24.654906	-81.40671	1995	1	125	176	180	0	1	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4d5f3fed-bce5-4b62-bdb9-e345de291200	Minor	24.665816	-81.409096	1998	1	125	176	165	0	0	10	P	—	—	—	—	0	0	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
445ebb21-b149-43f0-a093-eb52fd195b49	Moderate	24.665682	-81.409791	1997	1	125	176	165	90	P	100	P	—	—	—	—	M	P	M	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

a17b24a2-bf5b-433c-b001-7a4a94647b25	Moderate	24.667503	-81.363726	2008	1	127	151	90	40	20	5	P	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
59c0c6c4-5c90-4bdf-8a5a-29e791b504d0	Moderate	24.66684	-81.363732	1987	1	127	151	90	0	30	0	20	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
fb11f220-b792-44fe-a5d2-d7dfce514d6e	Minor	24.670789	-81.346126	2003	1	130	119	0	5	10	20	50	50	10	0	0	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
bb2dae2a-e217-4c94-a819-634b377a9836	Moderate	24.671695	-81.339281	2004	2	130	119	180	5	95	10	50	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7a86ec00-fc86-4a85-998d-0be3b3d9fe40	Moderate	24.672478	-81.345998	2005	1	130	119	180	0	0	P	0	0	20	P	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4f4e7107-30ab-436b-8e15-b29505cf87b8	MInor	24.72593	-81.396403	1993	2	120	98	270	P	90	P	5	P	90	P	60	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2404227c-c2c9-4a94-9f79-f8882ed50931	Moderate	24.668702	-81.365592	1993	2	127	151	90	10	40	0	P	90	60	P	P	M	30	M	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9444b1db-e26c-400d-b99b-1120b19742b8	Moderate	24.662811	-81.483648	1987	2	117	195	105	P	P	30	P	P	P	80	P	P	P	M	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17c104d8-31e0-4f1c-87e1-d8eae9362cce	Moderate	24.660924	-81.474428	1995	2	117	195	0	P	P	0	P	0	P	0	20	P	P	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8c5e5701-fe6c-45c4-9449-4d5d1313ec0f	Moderate	24.649933	-81.444586	1997	2	117	81	255	P	P	90	0	P	P	90	0	P	P	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
56178b1e-f6a2-4a90-8347-bcd22df8fca1	Moderate	24.648256	-81.440969	1999	2	117	81	195	P	P	0	0	P	P	30	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

b9688985-46e5-4836-aa94-50be1da4191b	Severe	24.670362	-81.528897	1958	2	113	50	180	0	60	P	5	0	30	P	0	0	0	P	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
b886e99d-720d-434b-9404-7f877b20c6d0	Severe	24.670214	-81.528307	1996	2	113	50	195	10	P	0	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1b9a1968-2668-4859-b8c1-28351476efb6	Minor	24.667966	-81.526832	1953	1	114	57	75	0	50	0	0	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1c671342-fd75-4245-bb2e-45190d0d75b7	Moderate	24.719417	-81.056247	2001	1	90	112	270	15	90	60	95	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
53130e37-f266-4242-b6cb-b4394263277d	Severe	24.719515	-81.055558	1997	1	90	112	270	80	0	5	90	30	0	0	50	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
06dc1f61-25e3-4168-9e01-c10c5f53ea0f	Moderate	24.805674	-80.842441	1984	2	67	123	345	30	0	0	P	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
73d1c9aa-e581-4758-a353-e0d595640f04	Minor	24.721549	-81.05154	1997	1	90	112	270	P	90	90	0	—	—	—	—	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
83d51d77-2535-47de-a9a2-4af9872a6aa8	Severe	24.624706	-81.593166	2011	1	113	25	60	P	0	5	5	P	0	25	5	P	0	0	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11dce33b-2bb6-4528-8a3f-0bcb680726d2	Severe	24.621793	-81.601218	2004	2	113	25	270	5	0	0	P	90	0	0	P	M	M	M	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9e64a15f-58ab-4b72-b9d2-6453ce9a0e6f	Moderate	24.567435	-81.744917	2007	2	99	303	270	0	P	95	90	0	P	10	90	M	P	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17ad0986-7d84-4892-8b18-338fb5db7e70	Moderate	24.791368	-80.890296	1981	2	67	123	195	0	0	0	10	20	0	0	60	M	M	M	M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—