VERTICAL VEINS:
DIGITAL COMMONS REFLECTION

ARCE SENIOR PROJECT
Ryan Millward & Nicole O’Connor
Table of Contents

Introduction 1
Narrative 2
Executive Summary 3
Reflections 9
Introduction:

The SOM High Rise Studio was a collaboration between 3rd year Architecture students and primarily 4th year Architectural Engineering students. The studio consisted of 20 weeks, with consistent check points marked by SOM partner reviews. The overall aim of the collaboratory nature of the studio was to expose each discipline to the decision-making process of the other to better facilitate understanding of the overall system and narrative of the high-rise tower.

Each quarter had a distinct goal that was the focus of submittals and reviews. Winter Quarter was primarily focused on the form finding aspect of our design through means of precedent studies, physical modeling, and simplified studies on tall building behavior analyses. At the end of Winter Quarter, teams had the general structural system for their tower set and had begun looking at massing for wind mitigation and programming.

Spring Quarter was more focused on specific components of the tower, though the exact components differed it can be generalized as performative envelope studies, structural connections and compatibility, tower behavior, and simplified member sizing for idealized wind and seismic conditions. At the end of Spring quarter, teams were expected to have a functioning performative envelope, both architecturally and structurally, details showing working connections, and a functioning computer model.

The reviews were an essential part of our form finding process. The feedback provided by SOM and Tom and Kevin gave us guidance on what parts of the project to pursue more in depth and what to work past. Additionally, it was an incredible experience to hear Mark’s thought process as he walked us through potential structural issues he could identify and the ways that we could
begin to address them. His reviews helped us change the way we approached the structural design, learning to see both the big picture and small interactions as one cohesive unit.

Each step of the process involved constant communication going back and forth between the engineering and architecture team members to ensure that all programmatic and structural needs were being met.

**Narrative:**

Our team was the Vertical Veins group that utilized a structural diagrid as both the primary gravity and lateral system. The origin of our tower was centered around making as much of the site usable as possible and allowing for programmatic flexibility within the floorplans of the tower, as opposed to many teams which looked towards the exterior form as the main creative focal point. As a team we focused our program on creating small, cul-de-sac type environments within each floor of the tower that would highlight four main views of San Francisco. In addition, there would be “clot communities” or areas where traffic would be deliberately increased and slowed down in order to encourage interactions among the community. These spaces would span up to five floors at a time, bringing together residents that would otherwise likely never meet. The large diagrid pattern was essential towards keeping lateral structure outside of the fluid floorspace but also towards maintaining nearly unbroken views of the city.

*Figure 1: Overall rendering of the tower*
Executive Summary:

As the Architectural Engineering students on the team, we were involved with architectural decisions, but the main focus was on the structural system and behavior. This summary will focus on the general studies done to understand tall building behavior as well as the project specific structural design.

Early design:

Early models were focused on getting vertical community spaces to feature prominently within our tower. A diagrid structure was chosen to allow for programmatic flexibility within the confines of the exoskeleton. A lot of thought was given to making our form more suitable for mitigating wind loads in the early designs evolving from a tapered shape to a site extrusion that contained designated wind/community reliefs shown in Figure 2. Eventually the focus on the main wind elements became secondary and moved towards other components that could act as interruptions to wind accumulation.

Analysis during the Winter Quarter was primarily done through simplified box studies to begin to understand the similarities and differences of behavior in comparison to the buildings we typically cover in our design labs. These studies delved into topics including core and diagrid aspect ratios and their impact on the tower behavior. They also began to investigate what concepts from familiar codes...
could be applied to our project and what concepts were no longer applicable because of the height. It was helpful to study these ideas in a simplified and more controlled environment before attempting to model and understand our individual projects. Figure 3 shows a study on megaframe lateral systems done on a simple box building.

By the end of Winter Quarter a semi-functional ETABS model had been created and used to form a basis of understanding for the expected behavior of the tower. This model was unnecessarily complicated and resulted in computational errors and strange output results that did not provide us with usable numbers for a design basis. This was a helpful learning experience in beginning to understand what to look at within our computer model to start questioning how trustworthy the results were and how much can be gleaned from the model without even looking into specific numbers.

**Final Design:**

Our final design was composed of a series of construction documents with typical plans and details as well as a computer analysis to understand the behavior of our tower and go through preliminary member sizing. Figure 4 shows the final framing plan of our tower. The organization of girders has shifted from a rectilinear layout to one that extends radially outwards from the columns, connecting directly to the diagrid. Direct connection to the diagrid member was prioritized on this framing plan to remove the need to consider out-of-plane...
moments in our node connection design. We added a floor truss highlighted in blue to an area lacking in diaphragm to transfer lateral loads. The idea behind it was to provide a continuous load path through the space next to the atrium, which required large sections of structural diaphragms to be removed, so that skinny, unbraced diaphragm areas did not exist. A typical MEP floor which lacks the exterior and interior atrium space within the diaphragm opening was also developed but follows the same themes as the typical housing plan.

Detailing of our project was mainly focused on developing the connection between the performative envelope structure, our node, and the ring beams. Shown on in Figures 5-8 are a few of the details created to address all of the issues brought up during the studio. The performative envelope section allows for horizontal and vertical deflection to occur using slotted bolt holes and finger tightened bolts. This was intended to alleviate daily deflection loads from thermal expansion and wind loading, as well as facilitate deflection compatibility between the limits of the glazing deflection and the structural deflection.
The node connection was developed with constructability in mind. The design borrowed heavily from its precedent study, the Hearst Tower in New York, to come up with the node structure. The plates within the wide flange shapes could be prefabricated off site allowing for only field bolting to be necessary during construction.

A simplified ETABS model was created and finalized to understand the overall behavior of our tower and to look at sizing members for wind deflection and seismic loading. Because of the pandemic, wind tunnel testing was not possible thus the wind loads applied were simplified uniform loads across the entirety of the tower height. Another main simplification made in the interest of understanding the outputs of the model was that diaphragms were assumed to be rigid and free from openings that may cause discontinuities. Shown in Figure 9 was the final axial loading diagram used to understand the load path of our structure. Because the tower shape was completely encompassed by the diagrid, the building acted as a tube or like a truss rather than a...
braced frame system. The out-of-plane faces experienced either nearly pure compression or tension forces. The in-plane faces experienced somewhat unusual loading, the axial load diagrams initially resembled the standard behavior of a concentrically braced frame. Each brace took an equivalent amount of force and experienced it as tension and compression depending on the direction of loading. However, as the loads “wrapped” around corners, the usual pattern was interrupted. As seen in the enlarged line in green, the out-of-plane wall, which is expected to be in pure compression, sees an axial tension force at its last brace and an uneven compression force throughout the other braces. This can be explained by the in-plane brace at the base of the east side which is connected to the line highlighted in green. As it is pulled into tension it also pulls on the entirety of the line it is attached to, this transferred tension force cancels out some of the chord’s compression force, creating a dominating tension force on the predominately compression side.

*Figure 9: Load Path Analysis*
One of the final items of our tower analysis that we closely examined was the deflection and torsion of our building. From the beginning of design, because of the asymmetrical nature of the site that we were extruding, we knew that twisting may be a significant issue. After learning more from SOM and our professors, we understood that this issue would be amplified by the uneven aspect ratios of the west and east walls. As seen in Figure 10, because the floorplan consistently followed the footprint of the site, the center of mass is naturally shifted towards the west side. This meant that the center of mass (CM) and center of rigidity (CR) were much more closely aligned than we had anticipated. Additionally, despite the west side having an aspect ratio of ~4.5 and the east side having a ratio of ~17, the CR did not shift much over the height of the tower. Finally, despite these fortunate discoveries there was some torsion still seen in our model in both directions, about 4% in the NS and 6% in the EW direction. This would not meet the requirements to be considered an irregularity in ASCE7 but would still create undesirable moments within our tower that would have to be dealt with in a more detailed analysis. A short study we did which could’ve been an eventual solution to our torsion issue was to iteratively adjust member sizes for deflection, changing each sides stiffness. With further studies this may have converged on a layout that would push the CR and CM together and reduce twisting within
our tower. By the final computer model, we learned to evaluate the trustworthiness of our model using quick checks including base shears, deflected shapes, and building periods.

Reflections, Lessons Learned, Next steps?

This studio was an incredible learning experience that allowed us to grow immensely as young engineers. The mentorship from SOM as well as from professors Kevin and Tom helped us begin to view the building type in a new light. It was previously an incredibly daunting task, being told that the building would be 60-70 stories tall and the familiar codes were not technically applicable. However, we quickly learned how to distill a complex system first into a much simpler version and slowly work our way back towards a system more representative of the project. It was a new experience to slowly iterate complexity into the design, since in our design labs we are used to simply analyzing the exact structure immediately and taking the results. We often had to be pulled back by Tom and Kevin for “going too far into the weeds” as we reverted to more familiar things involving numbers and calculations.

Another one of our main takeaways from this studio was looking at elements of the structure that did not comprise the main lateral or gravity systems, notably the performative envelope. It was extremely valuable to wait to address the performative envelope until Spring quarter. We are not exposed to it in our main classes and so much of the structural design revolved around understanding the architectural goals of the exterior. Without the 10 weeks that had been spent learning how to communicate architectural ideas and simplify structural ones, it seems unlikely it would have gone smoothly.

Finally, the last and most important lesson that we have learned from this experience is communication. This refers to the many types of communication skills that we had to develop
over the course of these 20 weeks, ranging from communicating structural ideas in a simplified manner to learning the purpose behind architectural choices, to figuring out what information is actually important to communicate with limited time and a diverse audience. Learning to speak to our architects was one of the most important skills we gained during this studio. If we could not explain our structural design intent to them in a way that could be understood it almost always meant that we did not actually fully understand it ourselves. It was a good litmus test for the viability of the solution before actually implementing it. Learning to highlight only important information during presentations was another valuable skill learned. The studio gave us a healthy distrust of computer modeling outputs and showed us how little the numerical outputs mean to most people outside of our team. Instead we learned to speak about the ideas behind the behavior of our tower and graphically show whether that was beneficial or harmful towards the desired structural behavior.

Finally, knowing what we know now there are a few things that we wish there would’ve been time for or we had been aware of sooner. At the end of the quarter we had finally developed a 3D computer model that produced trustworthy behavior, results we could explain, and numbers that could be used for preliminary member designs. However, it was a very idealized model not including many of the irregularities that make our tower interesting such as multiple atrium openings and an almost completely separated diaphragm. If there were more time it could’ve been very interesting to see what new challenges those would create both for modeling and further member design. Another item is that if we had foreseen the final state of our framing plan, we could’ve planned our column placements better before architectural elements had been set. This may have allowed us to make our structure more efficient and regular than what we ended up because the columns were placed to follow the previous rectilinear pattern.