LAFAYETTE

ENGINEERING COMPANY

Department of Civil and Environmental Engineering
Lafayette College
-
CE473 – Senior Capstone Design II
Spring 2015

Structural Design Report

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From: **Leikune Aragaw, Eleanor Beckwith, Andrew Burnett, Dennis O'Heney, Peter Taggart, Zili Wang, and Nathan Witmer**

Group: Structural Team

Executive Summary:

The structural team of the Lafayette Engineering Company designed the architectural and structural components of the Elevating Easton Project. The list of tasks completed is outlined below.

- Structural system and support design for the Inclined Elevator System which includes the Intermodal Transportation and Welcoming Center, the Elevator Superstructure, and the Marquis Landing
- Design of the elevator mechanisms including an emergency breaking system, de-icing system, counterweight, and motor specifications

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1. Introduction

Current transportation issues hinder the connectivity between Lafayette College's campus and downtown Easton. In order to combat this disconnect, an inclined elevator design has been proposed in conjunction with several other transportation, sustainability, and safety design features. Through the solutions proposed in the Elevating Easton project, the connectivity between Lafayette College and the Easton community will be enhanced.

This project includes designs for three separate structures: the Intermodal Transportation and Welcoming Center, the Elevator Superstructure, and the Marquis Landing. In this report, each structure is introduced, the applied loads are identified and a final structural design is recommended. In addition, designs for the elevator mechanisms including emergency braking, track de-icing, counterweight, and motor have been recommended.

2. Intermodal Transportation and Welcoming Center

2.1 Introduction

Lafayette College takes pride in the arts community that has grown on campus. The Williams Arts Campus is expanding, so it is important that the transportation between the campuses be addressed. The Williams Arts Campus expansion will help develop and increase the arts culture at Lafayette. A central node of transportation is needed for this expanding campus. We believe that a new building tying in multiple forms of transportation is the best way to facilitate this new node. This new building will be named The Intermodal Transportation and Welcoming Center pending a donor.

This building will incorporate the inclined elevator proposed in this report. It will tie directly into the structure, which is shown in Attachment 1: Figure 4. Other forms of transportation incorporated into the design are:

- Pedestrian
- Cycling
- Vehicular
- LCAT Shuttle

The Intermodal Transportation and Welocming Center will also serve as a solution to the accessibility issue with the Spot. Currently, the second and third floors of the Spot are not in use, due to non-ADA compliant stairs and elevators. The Intermodal Transportation and Welcoming Center will provide ADA accessible Stairs and a new elevator to access the upper floors of the existing building.

2.2 Objectives

During the design process there were several objectives that were target goals for the end product. These objectives are:

- To provide a new node of transportation at Lafayette College
- To facilitate multiple modes of transportation including the proposed inclined elevator
- To improve the aesthetic appearance of the area between the Spot and 248 N. Third Street.
- To improve the access and use of the spot.
- To provide green areas for students to congregate.

- To practice sustainable new building design solutions.
- To promote and add to the arts culture at the Williams Arts Campus and in downtown Easton.
- To keep costs low while still achieving the design vision.

2.3 *Unfactored Design Loads*

According to the International Building Council (IBC) 2012 Design Code, the design loads are listed below.

2.3.1 Live Loads

- 100psf Pedestrian load for lobby of office buildings
- 20psf wind load

2.4 *Final Design*

The architecture for this building design follows the recommendations laid out in the Historical and Architectural Design Considerations section of the full Capstone report. The dimensional considerations for this new building were somewhat challenging due to the difference in the two buildings surrounding it. The solution was to have two different roof levels for the two different components of the building. The main inclined elevator lobby has the same roof elevation of 248 N. Third Street, where the connection to the Spot has the roof elevation of the Spot.

The façade of the new building was designed in accordance with the recommendations stated earlier. It is a brick façade with large glass curtain walls. The exposed steel also conforms to the surrounding buildings. This is shown in *Attachment 1: Figures 1-4.* The building materials are also in accordance with the recommendations. Most of the building is red brick façade. The layout of the building was limited due to space in the area.

Since the college owns both of the buildings on the proposed site, construction approval for this project will be fairly straightforward. A simplified initial design test was completed in SAP 2000 to ensure feasibility of the building design. The structural steel for the structure was part of the scope of this project. W shapes were chosen for the columns and main spanning beams. After the initial analysis was acceptable, a full analysis of the structure was completed in SAP. The columns that were sized were mostly W12 x 65. The main spanning beams were W12 x 35. There were k-joists used for the main part of the lobby and the roof of the structure attached to the spot. These beams are two feet deep and are spaced every two feet. Member sizing was done through AISC Steel Construction Manual Parts 3-7.

3. Inclined Elevator Supports

3.1 Introduction

The inclined elevator structure includes two 48ft^2 elevators with a 282ft^2 structural glass as the main structural support. The elevators are supported by beams and controlled by a counterweight that runs right under the elevators.

In the following sections, the design for the elevator tracks and concrete columns will be discussed. The design outlines two separate tracks with emergency access and exits in between. The columns will be precast post-tensioned concrete piers. The foundations for this structure are discussed separately in the Geotechnical Engineering Study and Design Report.

3.2 Unfactored Design Loads

Unless otherwise noted, the design loads listed below were determined in accordance with the International Building Council (IBC) 2012 Design Code.

3.2.1 Dead Loads

- Elevator Car Structural Steel: 40psf
- Elevator Car Structural Glass: 131.25psf
    - A 175pcf unit weight, ¾ inch thick structural glass with a total surface area of 282ft^2.
- Stairs: 20plf
- Elevator tracks: 250plf
    - This load corresponds to one track system which includes two elevator tracks, two counterweight tracks, diaphragms, stringers, and connections.
- Concrete piers: 1130plf
- Counterweight: 6920lbs
    - Determined in accordance with ASME A17.1 Section 2.19.3 Emergency Brake. Refer to Attachment 2: Table 1 for detailed calculations for the given value.

3.2.2 Live Loads

- Maximum construction loads 1661.2plf
    - These are loads resulting from cantilevered track beams used to launch the micropile equipment and piers up the hill side during construction. Refer to Attachment 2: Table 2 for detailed calculations for the given value.
- Passengers and cargo: 100psf

- Emergency break dynamic loads: 1302lb parallel to track
  - In accordance with ASME A17.1 Section 2.19.3 Emergency Brake, this load is from an emergency stop that leads to the elevator car decelerating from 4mph to a full stop at a stopping distance of 5.3feet.
- Water through pipes dynamic loads: 22plf

3.2.3 Wind Loads

- Lateral pressure 25psf
- Parallel to span 20psf

3.3 Final Design of Elevator Superstructure

The elevator superstructure was designed using ASTM A992 COR-TEN steel. In addition to having the same properties as typical structural steel, COR-TEN erodes over time to create a rustic look. This, eliminates the need for application and maintenance of paint on the structure.

During the design process, close attention was given to sustainability, construction on a steep slope, and user safety. The design was completed using SAP 2000® using the loads specified in Section 3.2 of this report (Attachment 2: Figure 1). The elevator tracks will be supported on W27x194 section beams which run along the hillside. The W27x194s will be supported by post-tensioned concrete piers. The connection between the two will be a pinned-connection with the pin bolted to both the W27x194 and the concrete pier. This pin connection will be have an expansion slot parallel to the track for a more ideal pin support. The W27x194 will run from pier to pier and be connected with gusset plates at each pier. This will simplify fabrication and construction.

The tracks for the counterweight will also run along the hillside track structure and be supported by W8x35 section beams. The W8x35s will be supported by the same W-Shapes which will be perpendicular to the hillside. The perpendicular W8x35s will placed at each pier and at thirds of each span. They are connected to the elevator tracks using simple bolted connections.

For the comfort of passengers and avoid vibrations, an elastomer bearing pad will be added between the elevator tracks and the W27x194s.

For storm water management, two 8 inch PVC pipes will be run underneath the counterweight, supported by the concrete piers. For the design of the piers, both PVC pipes were considered to be operating at full capacity. For emergency egress, galvanized steel grate stairs have been added in between the two tracks supported by the concrete piers.

The full dimensions and details of the elevator track design can be found in the drawing "AE 102 TYPICAL SPAN DETAILS - STEEL SUPERSTRUCTURE."

3.4 *Final Design of Support Piers*

Based on the design of the elevator superstructure, many similarities to typical highway overpass construction were observed. Additionally, a need for the substructure components to be small and light enough to be placed by small pieces of machinery with limited lifting capacity was noted. Based on this criteria, investigations of substructures constructed from steel and concrete were conducted. Based on the loads imposed on the structure, steel construction was eliminated due to the excessively large column size required for a single pier support. This guided the analysis to conventional cast in place concrete and newer precast technologies. Due to the anticipated aggressive schedule and top-down construction methods that will be employed, CIP concrete was determined to be infeasible due to the cure time required. As a result, precast post-tensioned concrete sections were selected for the substructure.

3.4.1 Precast Post-tensioned Components

Precast post-tensioned segmental columns are a relatively new technology with respect to the construction of highway overpasses. They consist of relatively small (2-4 feet tall) precast segments that feature open ducts to accept post-tensioned (PT) strands, as well as an interlocking alignment mechanism that allows each segment to mesh with the next. The segments are hollow in the middle, allowing for significant weight and material savings. Segments are stacked as shown in Attachment 2: Figure 2, then caped with a beam. At this point, the PT strand is tensioned by a jack, and grout is pumped into the precast columns with the strands. After the grout has cured, the constructed pier has extraordinary stiffness with respect to its size and weight.

3.4.2 Final Design

With the selection of a mono-pier system, due to environmental and foundation considerations, the eccentric loading produced by the elevator car applies significant moments to the substructure. Additionally, we must consider the forces of cars moving up and down the slope, braking forces, and the additional dead loads imposed by the superstructure components. The concrete used shall be no less than 5,000 psi due to the significantly higher compressive forces imposed by post-tensioning the structure. A grout of at least 6,000 psi strength shall be used to grout the PT elements into the structure. Additional information including reinforcement detailing and PT element specification is included in the drawing “AE 103 TYPICAL SPAN DETAILS - PRE-CAST CONCRETE PIERS”.

3.4.3 Construction Considerations

Even though construction is primarily governed by the size of equipment on site, for this project, the construction sequence governs the size of the equipment. In this sequence, pre-constructed elevator superstructure sections are utilized to build subsequent sections, so small construction equipment will be selected to reduce loads. In order for all components to be light enough to be lifted by conventional small equipment, both the pier columns and hammerheads will be constructed in segments (Attachment 2: Figure 3). Refer to Construction Sequence & Budget Report for a full description of the construction sequence.

Construction of the pile cap will be coordinated with the geotechnical engineering team to endure a top elevation that corresponds with the eventual pier elevation and the height of each segment. PT duct will be cast into the pile caps to allow for a looped PT strand to be used. Additional PT strand will be used in the hammerhead, again to allow for smaller components without sacrificing structural performance.

4. Marquis Landing Point

4.1 *Introduction*

The Marquis Landing connects the inclined elevator to main campus. Objectives for this structure and the surrounding area include creating a welcoming and open environment for people entering campus, restoring pathways to encourage safe traffic to the elevator, constructing a machine room to house the elevator equipment, and establishing a versatile space for future development.

4.2 Unfactored Design Loads

According to the International Building Council (IBC) 2012 Design Code, the design loads are listed below.

4.2.1 Dead Loads

○ Concrete Slab	120	kips
○ Plastic Cover	1.5	kips
○ Connections and Other material Costs	50	kips
○ Total	171.5	kips

4.2.2 Live Loads

○ Design Passenger Load	100	psf
○ Design Wind Load	20	psf

4.3 Final Design

To comply with ADA regulations, the main pathway connecting the platform to Marquis Hall meets the 5% slope requirement. The path extends 118.5 feet from where the platform ends and where the path connects to existing Marquis paths, which requires that the platform be raised above existing grade by a maximum of 17.5 feet. The platform is 20 feet wide and 40 feet long, with a covered portion extending 30 feet from the elevator doors towards campus. The design loads and procedure are presented in Attachment 3. The covered structure will provide protection from weather for people waiting to use the elevator and can comfortably accommodate approximately ninety people at a time, which will appropriately fit the number of people anticipated to wait for the elevator in any foreseeable circumstance.

The machine room for the inclined elevator equipment is to be constructed below the waiting platform. The inner dimensions of this room are 12 feet by 10 feet, 11.5 feet high, which is large enough to accommodate all the machinery and provide additional storage for Plant Operations. The machine room floor is a concrete slab on top of a compacted stone base, which will support the equipment load. There is a load-bearing retaining wall extending the width of the platform and staircases on either side (approx. 108 feet), which supports the platform and fill along the pathways towards main campus and along the stairs. There are two micropile foundations supporting the structure where the elevator tracks intersect the platform (see geotechnical report for complete detailing). The machine room and the surrounding area are accessible by vehicle, which will be necessary for construction and maintenance.

The existing pathway that connects Easton and Ruef Halls is used regularly by students but intersects the inclined elevator so the pathway will be reconstructed to pass under the platform, next to the machine room. In a step to revitalize this area, the currently closed-off path leading from behind Easton Hall to the existing staircase will be reconstructed and widened to match standard brick pathways on campus. This path will pass beneath the inclined elevator with clearance levels exceeding twelve feet and will provide a useful connection point to students on the southwestern parts of campus wishing to avoid the elevator or the walk down Sullivan Trail to access downtown Easton.

5. Elevator Car and Propulsion System

5.1 Introduction

This section specifies the elevator mechanisms including emergency braking, track de-icing, counterweight design, and motor sizing. The information detailed below is essential for the operation of the inclined elevator.

5.2 Elevator Car Braking System and De-icing

For the braking and de-icing systems of the elevator tracks, the following specifications have been provided. Both systems will be contracted out and further custom designed by the respective companies. Operation braking will be performed through the motor's governor and gearing system, while the designed braking system will only be used in the case of an emergency, which may include a track obstruction or a cable tensioning problem. The true functionality of the brakes is not one of slowing down and regulating the speed of the car.

5.2.1 Emergency Braking System

The braking system will consist of an onboard system that will be positioned between the sets of wheels underneath the car. The brake will be positioned so that one brake pad is on either sides of the rail. The brake operates by clamping the rail tightly to bring the elevator car to a stop. These brakes are similar to emergency brakes found on some roller coasters called Skid Brakes. The brake will have no contact with the wheels and will only be in contact with the rail. As far as maintenance is concerned, this brake will not be regularly used it is only for use in emergency situations such as failure of the cable or propulsion system.

The emergency braking system has been designed in accordance to *ASME A17.1 Section 2.19.3 Emergency Brake*. In a simple stopping distance calculation, it was found that at the operating speed of two miles per hour the stopping distance is 1.3 feet while at the maximum allowable speed of four miles per hour the stopping distance is 5.3 feet.

The mechanisms of the brake will include steel braking pads fixed to steel plates which are housed above rail and below car deck. The brakes will be engaged using a hydraulic system which moves the pads together and against the rail. A similar emergency braking system is illustrated in

Attachment 4: Figure 1. The recommended system is similar what is shown in the figure except that the wheels are turned ninety degrees with the two wheels positioned side to side then the one wheel oriented on top. The braking pads that would clasp the rail are noted on the figure.

These brakes' sole purpose is to be used in the case of emergency including a snap in the cable or in the case of an obstruction in the track. The brakes' deployment is determined using data from a number of sensors including a cable strain gauge, speed restraint, and an object sensor. The job of the cable strain gauge is to protect against cable failure by detecting excessive changes in the cable tautness. The speed restraint sensor applies the brakes when the car travel speed exceeds four miles per hour, which is twice the normal operating speed. The track obstruction sensor uses similar technology as a parking sensor found on many modern cars and applies the brakes if an object is detected within 8 ft of the elevator car. This safety mechanism reduces the likelihood of a collision if a branch or person is on the tracks.

5.2.2 De-Icing

In the winter months, the rails of the inclined elevator can be maintained using a resistive heating system for the rails and possibly a snow plow attachment to remove accumulated snow. A resistive heating de-icing system is recommended instead of using a de-icing solution since there it eliminates the potential for negative environmental impacts from chemical runoff.

One company that provides internal rail heating cable is Thermal-Flex Systems Incorporated who is based out of Northford, CT. The cable and power regulator, sold under the product name Raychem, automatically adjust power output to compensate for temperature changes. Heat is generated as electric current passes through the conductive polymer core between the conductors. As the temperature drops, the number of electrical paths through the core increases and more heat is produced. Conversely, as the temperature rises, the core has fewer electrical paths and less heat is produced.

Due to the porous nature of the track structure, there is relatively little opportunity for snow to accumulate on the tracks. It is expected that light accumulation can be dealt with by operating the elevator during the snow event. If heavy snow is allowed to build-up on the tracks, Lafayette College could use a plow attachment to clear the rail surface. Alternatively, accumulated snow could be cleared using hand-operated equipment from the service stairway located between the sets of tracks.

5.3 Counterweight

The counterweight reduces the energy required to move the elevator car up the track and prolongs the life of the braking components in the drive system. The counterweight is designed to weigh 6,920 pounds which is in accordance *ASME A17.1 Section 2.21.1 Emergency Brake* that mandates the counterweight be the dead weight plus 40 to 50 percent of the live load. The counterweight was design considering the dead load plus 40% of the live load since the car is expected to be less than half full on average. The dimensions and the location of the counterweight can be found in the drawing "AE 102 TYPICAL SPAN DETAILS - STEEL SUPERSTRUCTURE." The counterweight measures 3.5 ft by 0.75 ft when viewed in the running direction of the rails and spans 5.38 ft by viewed normal to running direction of the rails. The counterweight will be attached to a set of rails of similar composition to the elevator rail that hang from diaphragm beams that are attached to the main stringers. The counterweight will be constructed of individual slabs of steel which will be bolted together. The counterweight is connected to the opposite end of the cable as the elevator car. Together, the elevator car and counterweight are moved by the drive system using a combination of reduction gears and pulleys.

5.4 Motor Specifications

The motor used as part of the elevator drive system will be housed in the mechanical room described in Section 4. The drive system includes a 2:1 cabling pulley system to ease the load on the motor. The motor will be supplied 220 volts which will be monitored by an electronic control unit (ECU). Also included in the motor components is a reducing gear transmission to prevent motor damage. The basic performance parameter of the drive system include: a maximum velocity of 5.74 ft/sec and 60% efficiency. The performance requirements can be met using a motor that is capable of producing approximately 21 horsepower at 2000 ft-lbs of torque. A suitable AC powered electric motor manufactured by Imperial Electric (VVVF 324T Frame Elevator Hoist Motor) was selected since AC motors have easier access to power than DC motors which are less common.

Attachment 1: Intermodal Transportation and Welcoming Center Renderings

Figure 1. N. Third Street Courtyard

Figure 2. Main Lobby

Figure 3. Study Room

Figure 4. View from Bushkill Drive

Attachment 2: Inclined Elevator Track Figures and Diagrams

Table 1. Counterweight Load Calculation

Car Dimensions		
Perp. To Slope	6	ft
Par. To Slope	8	ft
Car Weight		
Dead Load	40	psf
Car Area	48	ft^2
Empty Wt.	5004.375	lbs
Live Load		
Design Load	100	psf
Full Car Wt.	9804.375	lbs
Counterweight Calc.		
Weight	6924.375	lbs
Typ. convention for counterweight is: Dead + 0.4Live		

Table 2. Drill Rig Construction Loads

Weight	Max	10900	lbs
	Min	8700	lbs
Car Dims	Length	3.54	ft
	Width	3.28	ft
Span		28	ft
Dist. Load	Max	1661.16	plf
	Min	1325.88	plf
Shear (while drilling)	Column	372.43	lbs
	Footing	5513.57	lbs
Moment (while drilling)	M_u	9150.078	lbs

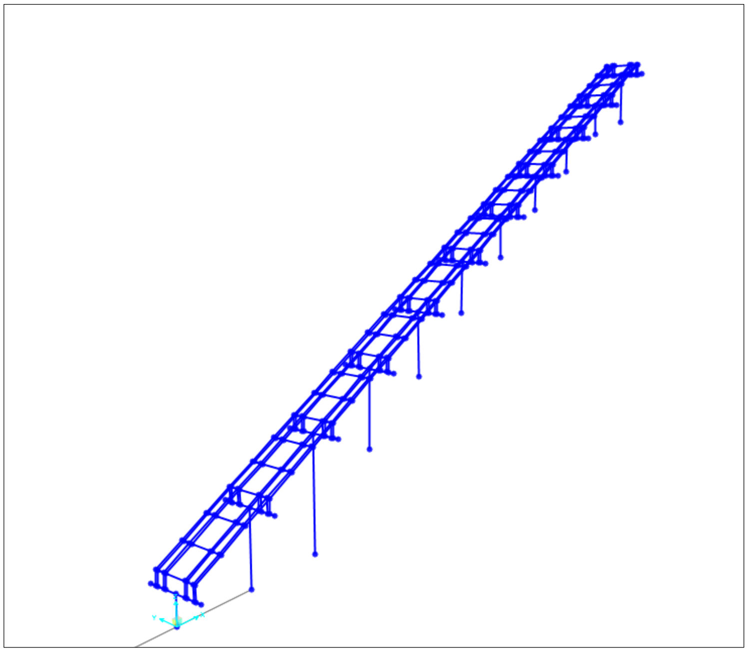

Figure 1. SAP Model of Elevator Superstructure

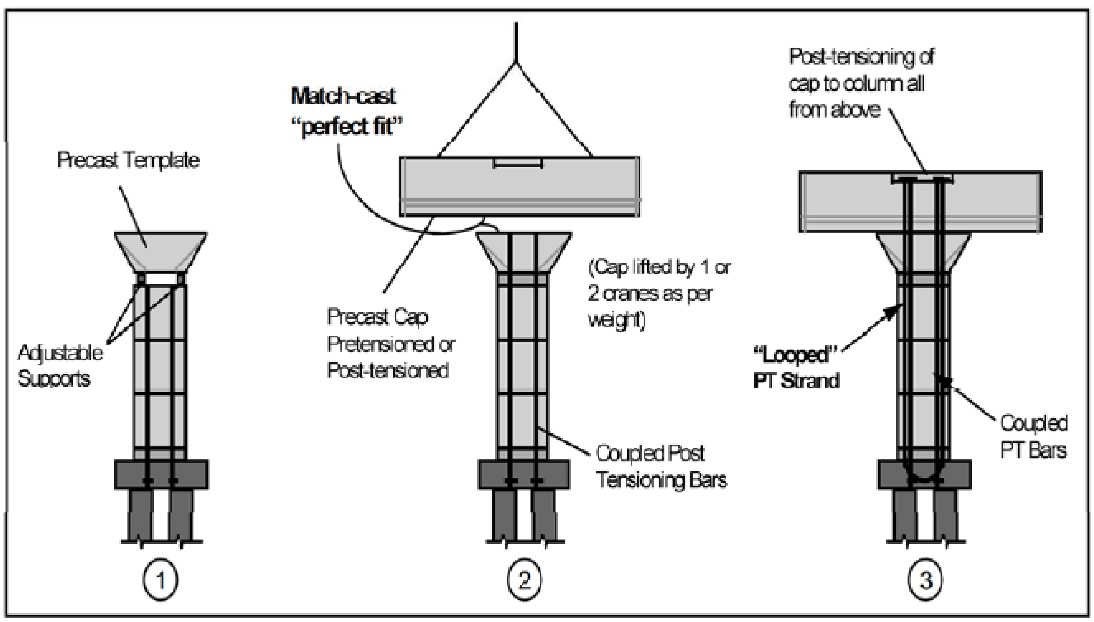

Figure 2. Schematic Representation of Precast Post-tensioned Column (Source: "A Precast Substructure Design for Standard Bridge Systems"; https://fsel.engr.utexas.edu/publications/docs/1410-2f.pdf)

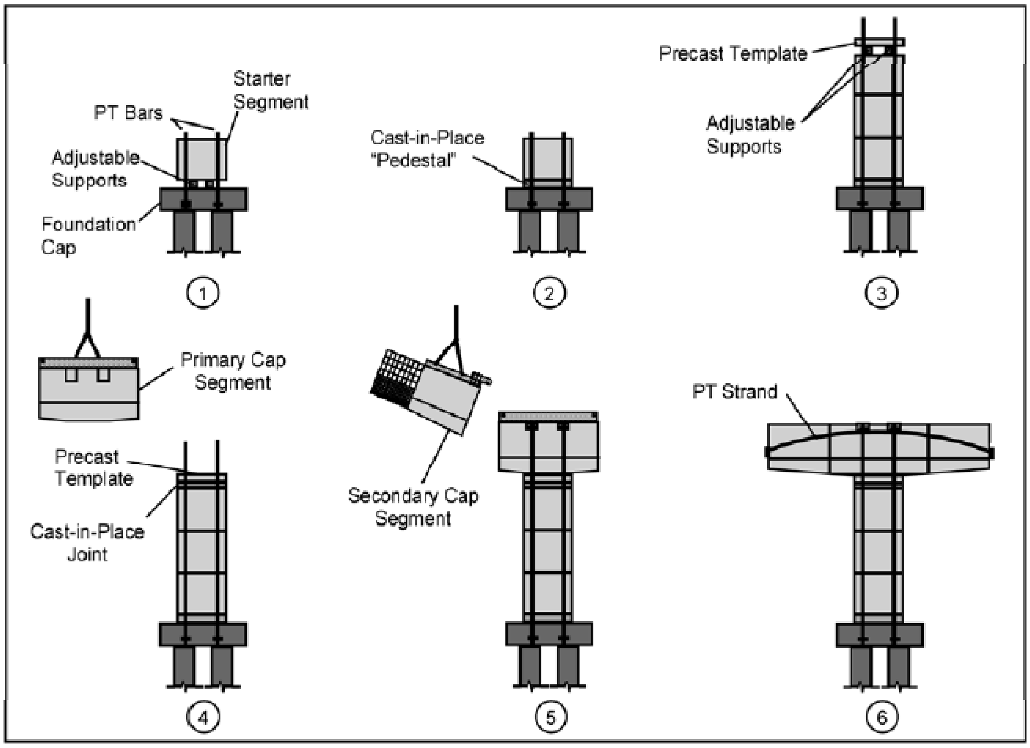

Figure 3. Erection Sequence for Precast Post-tensioned Column with Segmental Cap (Source: “A Precast Substructure Design for Standard Bridge Systems”; https://fsel.engr.utexas.edu/publications/docs/1410-2f.pdf)

Attachment 3: Marquis Landing Design Calculations

Concrete Slab Design

The platform will be constructed using a single steel reinforced concrete slab. And the concrete slab is designed for every foot. Since the south side of the platform is supported by the machine room. The design concrete span is going to be 24 ft. The strength of the concrete will be 3000psi.

<u>Loads:</u>

<u>Design Load</u>

Dead Load	200	psf
Live Load	100	psf

<u>Load Combination</u>

1.2 D + 1.4 L	380	lb

<u>Design Procedure:</u>

$$\text{Ln} = 0.85L = 0.85 * 24 = 20.4\ ft$$

$$\text{d} = h - 1.5 = 12 - 1.5 = 10.5\ in$$

$$Mu = W * \ln^2 = 380/1000 * (20.4*12)^2 = 23971 \text{ lb·ft}$$

$$\rho \sim \frac{Mu}{\emptyset b d^2} = \frac{23971*12}{0.9*12*10.5^2} = 241.56 = 0.0043$$

$$A_{smin} = \rho * b * d = 0.0043 * 12 * 10.5 = 0.542 \text{ in}^2$$

Therefore, the steel reinforcement will be #6 bar at every 9 inches.

Attachment 4: Elevator Car and Propulsion System Diagrams

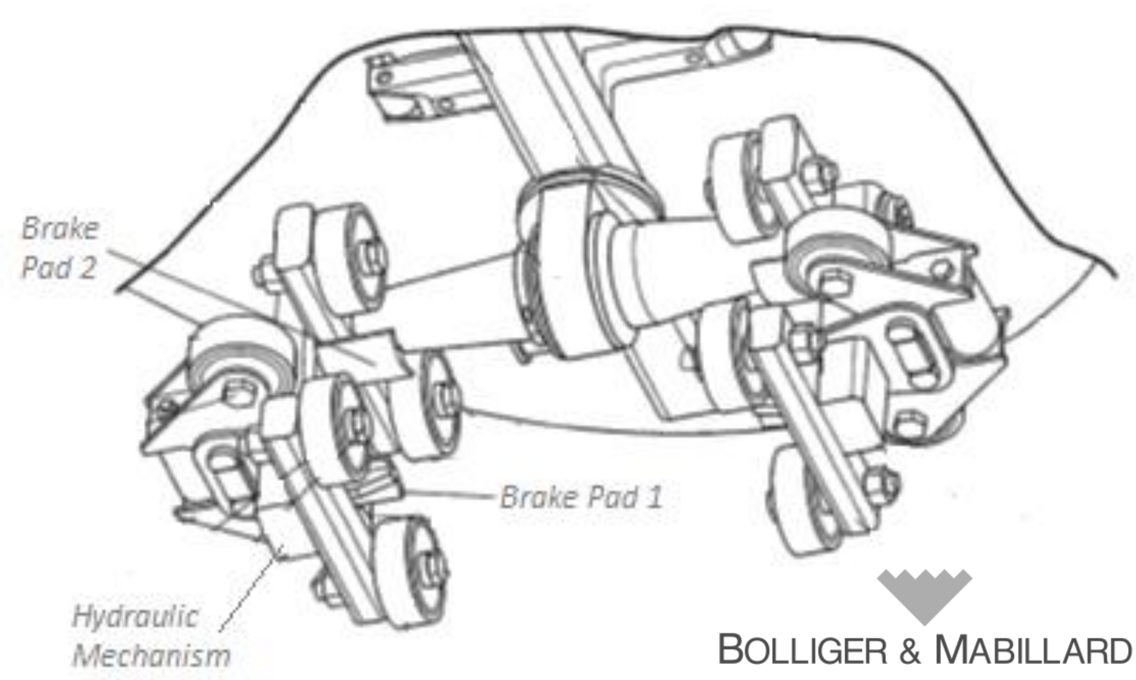

Figure 1. Wheel and Braking Diagram
(Source: http://www.akitarescueoftulsa.com/techwin-coaster-brake-diagram)