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Rapid bridge deck replacement using finite element modeling as a construction aid

Justin Pelletier

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RAPID BRIDGE DECK REPLACEMENT USING FINITE ELEMENT MODELING AS A CONSTRUCTION AID

BY

JUSTIN PELLETIER

B.S. Civil Engineering, University of New Hampshire, 2010

THESIS

Submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Civil Engineering

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ABSTRACT

RAPID BRIDGE DECK REPLACEMENT USING FINITE ELEMENT MODELING AS A CONSTRUCTION AID

by

Justin Pelletier

University of New Hampshire, May, 2013

Many bridges in the nation are listed as structurally deficient. This calls for new and innovative ways to repair these bridges that cause as little impediment to traffic flow as possible. A modular deck replacement system using full-depth precast prestressed concrete panels has been tried and proven in the field as a time efficient and cost effective deck replacement option.

The goal of this research project was to improve upon this modular system of deck replacement by investigating the viability of using finite element analysis software to aid in the construction process. The purpose of using a finite element model is to predetermine the necessary leveling device settings for individual deck slabs as to produce a constant grade top-of-slab elevation profile under full dead load. It was found that the proposed use of finite element analysis software does provide an adequate means for the determination of leveling device settings.
CHAPTER I

INTRODUCTION

The main contribution of this research project was the development of a procedure that could predetermine the necessary length of precast bridge deck slab leveling devices by integrating a finite element model (FEM) into the construction process. By using this procedure, after placing all deck slabs on the girders, a target top-of-slab elevation profile can be met.

1.1 - Problem Statement

The US has many bridges that were constructed in the 1950s and 1960s that are in need of major repair or replacement (AASHTO, 2008). “As of last year, 11.5 percent of US bridges, crossed by an average of 282,672,680 vehicles daily, were graded as structurally deficient” (Nisen, 2012). This creates a need for improved repair and replacement methods.

Conventional methods for bridge deck replacement can cause disruptions to the flow of traffic for extended periods of time, resulting in increased travel time for infrastructure users, as well as dangerous working environments for laborers (Eberhard, Hieber, Stanton, & Wacker, 2005). The goal of this research is to develop a method for full-depth bridge deck replacement that will expedite the construction process, thus minimizing traffic pattern disruptions and increasing worker safety, as well as reducing construction and
maintenance costs. Through the integration of finite element modeling and staged construction analyses with the real-world construction process, it is theorized that construction time can be decreased.

Precast prestressed concrete panels can be used to replace bridge decks. The use of panels ensures quality control and provides a quicker method for in-field concrete placement compared to cast-in-place decks since the concrete has already cured (PCI, 2010). However, due in part to size constraints, panels must be designed for use in a modular system. This creates issues with placing the panels on a girder system because the weight of the panels must be distributed properly across all girders in the system, and the panels must be leveled appropriately during placement to ensure the desired final elevation profile grade is met. Some methods of bridge deck replacement call for initially placing all concrete deck slabs on the girders and subsequently leveling them one by one with shims. Another method would be to cast temporary adjustable leveling devices into the slabs, which improve the speed and ease of construction over using shims (Culmo, 2002). The research conducted during this project suggests that, while using the temporary leveling device method, construction time can be reduced by pre-determining the length of the leveling devices used to achieve the desired elevation profile for the bridge deck with the help of an accurate FEM. More about the finite element modeling procedures and integration into the construction process will be discussed in Chapter III: Methodology.
1.2 - Purpose of Study

The purpose of this study is to use finite element modeling as a construction aid, allowing for quicker erection times during bridge deck replacement projects that use precast concrete components. The proposed process includes building a FEM of the abutment-girder system and updating that model post demolition of the existing deck to ensure the model is geometrically accurate to the physical system prior to beginning construction. The model is updated and calibrated with the physical system by using data collected from beam elevation surveys and structural health monitoring systems in real-time. By then analyzing the model under the full dead load of all new bridge deck components, the haunch depth along the length of each girder necessary to achieve the prescribed top-of-slab elevation profile can be determined. The haunch depths are temporarily set through the use of leveling devices known as leveling screws, which transfer the dead load of the slab onto the girders.

Determining the lengths of the leveling screws and setting them to those lengths prior to placing the slabs on the girders is the key component to this research. Significant time savings can be obtained by accurately setting the leveling screws prior to slab placement. Minor adjustments to the leveling screws can be made post slab placement to assure appropriate loading on each leveling screw; however, great care must be taken in doing this to avoid cracking the slabs or over stressing a girder.
1.3 - Importance of Study

“In total, one in nine of the nation’s bridges are rated as structurally deficient, while the average age of the nation’s 607,380 bridges is currently 42 years” (ASCE, 2013). There are many short to medium span composite beam/slab bridge systems using steel girders in the US that require deck replacement due to excessive deterioration. The following section describes why this research is important, relevant to current engineering and construction practices and US infrastructure needs.

1.3.1 - Road Closures and Traffic Pattern Disruptions

The traveling public relies heavily on consistent travel routes and travel times for every day transportation needs. In order to minimize disruptions to traffic flow, construction should be fast and efficient, thus warranting the use of precast concrete bridge components. By minimizing the use of cast-in-place (CIP) concrete in the replacement process, the time required for the concrete to cure is virtually removed from the construction timeline (Eberhard, Hieber, Stanton, & Wacker, 2005). Using precast components also removes the time it takes to place the deck form work and concrete reinforcement from the construction timeline.
1.3.2 - Worker Safety

While constructing only certain segments of a bridge at a time allows for some lanes to remain open to traffic, thus decreasing traffic flow impairment, it also makes for an unsafe working environment. The proposed approach is applicable when a full bridge closure for the entire duration of the replacement process is feasible; laborers see less hazardous working conditions due to diverted traffic patterns (Eberhard, Hieber, Stanton, & Wacker, 2005). This also allows the laborers to focus entirely on the construction tasks at hand, instead of worrying about traffic hazards.

1.3.3 - Cost Savings

It is often said that “time is money”. By reducing construction time, every entity involved in the project can benefit by the resulting reduced project costs. For the construction contractors, fewer man-hours are required to complete the project. The bridge project can be scheduled at selected short term intervals thus alleviating traffic disruptions and congestion during commuting times, which saves travelers commuting cost. The use of precast prestressed deck components fabricated in a controlled environment has the potential to extend the service life of the deck, thus decreasing maintenance costs. “A smaller percentage of prestressed concrete bridges were found to be structurally deficient than cast-in-place bridges of similar span and age” (Dunker & Rabbat, 1992). Any potential cost saving device is worth exploring.
1.3.4 – Improved Service Life

Since the use of precast deck slabs is already warranted by the desire for faster construction, it is worth noting the other benefits of using factory built components. Prestressing a concrete slab results in uniform internal compression throughout the slab, making it less susceptible to cracking, spalling, interior reinforcement deterioration, and damage due to thermal effects (PCI, 2010).
1.4 - Scope of Study

The following section describes what the study is meant to observe, and to what extent. This section describes the UNH High Bay test that was conducted during the summer of 2011, as well as how that research was meant to impact future real-word projects.

1.4.1 - High Bay Test

During the summer of 2011, a study was conducted to develop a new system for rapid bridge deck replacement using SAP2000™, a finite element analysis software package, as a construction aid. The software was used to build FEM of the High Bay test setup, and then used to determine the length of the deck leveling screws necessary to achieve a prescribed constant slope along the top of the slabs. The details of this test will be discussed throughout this report.

1.4.2 - Real-World Feasibility and Implementation

The ultimate goal of this on-going research project is to integrate finite element modeling and classical engineering practices into the bridge deck rehabilitation process. The New Hampshire Department of Transportation (NHDOT) strives to decrease construction time for bridge rehabilitation projects in order to minimize traffic pattern disruptions and improve worker safety, while still improving the overall quality and longevity of the state infrastructure at a lower
cost. The process developed through this research may be used on a NHDOT project as a pilot program, which will be discussed more in later chapters.
2.1 – Previous UNH Research

As mentioned in Chapter I: Introduction, this research has been an on-going project for many years, beginning in 2006 with a post-tensioning system feasibility study. This research was conducted to determine if post-tensioning slabs together using a coupled threaded rod system could be done on a slab-by-slab basis. The theory behind this technique was borrowed from those used in prefabricated segmental bridge construction, in which matched cast precast bridge elements must be post-tensioned together to achieve structural stability before construction can continue. While the reasons for employing this technique are different, the theory is still applicable. This research ensured that two independently cast slabs could be fully post-tensioned together, and then a third slab and subsequent slabs could be post-tensioned to the previous two or more using the same post-tensioning system/apparatus (Salzer, 2008).

This post-tensioning feasibility study was followed by a post-tensioning sealant study in 2007. This study was conducted to develop an efficient way to protect the post-tensioning system from environmental damage and to transfer shear across the transverse joint between two adjacent slabs. The sealing process included applying a sealant along the transverse joint, and injecting methyl methacrylate (MMA), a waterproof monomer, into the post-tensioning
ducts after post-tensioning is complete. The MMA solidifies after a short period of time, creating a continuous water-tight layer surrounding the post-tensioning system effectively protecting the system from the elements, even if the concrete cracks.

From 2008 to 2009, research was conducted to determine the best transverse joint configuration to transfer shear between slabs, while still allowing for enough tolerance to facilitate construction. Multiple transverse joint configurations were tested, including: standard shear key, single angular tongue and groove, double rounded tongue and groove, and double angular tongue and groove. The double angular tongue and groove configuration was determined to transfer shear force through the joint most effectively, while still being economical to fabricate. The double rounded tongue and groove also transferred shear well, but it was much more expensive to fabricate (Robert, 2009). Figure 1 depicts the angular double tongue and groove joint design. Current and future research concerning this project will be discussed in later sections.

Figure 1 - Transverse Joint Configuration
2.2 - Past Outside Research

Rapid bridge construction is a hot topic in the construction industry today, as the desire to decrease bridge construction time is high. This section will outline a few of the notable recent research projects used to push forward the development of rapid bridge construction.

2.2.1 - Partial Depth Precast Deck Elements

A common practice in bridge deck replacement is to use partial depth precast prestressed concrete panels (typically 3 to 5 inches deep) as the bottom layer of the new deck, and a CIP layer on top of the precast layer (Fallaha, Chuanbing, Lafferty, & Tadros, 2004). While this technique does save time over conventional full depth CIP decks in that forming is not required, the cure time for the top layer of the deck adds to the construction timeline. This also does not produce a fully prestressed deck. It results in a cold joint along the interface between the two deck layers.

Since partial depth precast deck elements are so thin, limitations must be placed on the length and width of the panels as to make sure the elements can be moved to the construction site and lifted without cracking. Due to these limitations, multiple panels are required to deck the full width of the bridge. The easiest and most logical place to start a new panel is along or near the girder center lines. This way, the bottom of the deck is prestressed along the areas of maximum positive moment. However, it is worth noting that if full composite
action between the two concrete layers is not developed, then the moment of inertia for the deck is significantly reduced in the areas of positive bending moment. Another drawback to this technique is that costly form work must be used to cast the deck overhangs.

2.2.2 - Flat Full Width, Full Depth Precast Panels

Another Commonly used construction technique is to use flat full width, full depth precast prestressed panels. This technique, while supplying the deck with uniform pretensioning transverse to traffic flow, does not incorporate a crown. This requires extra material, either Portland cement concrete or asphalt, to make up the crown of the roadway if one is required. The extra dead load from this material is unnecessary and increases the stresses induced in the girders, especially the interior ones.

2.2.3 - The NUDECK System

The University of Nebraska, under the direction of Dr. Maher Khalil Tadros, has developed a system to pretension concrete slabs that can incorporate a crowned shape. This system allows for the slabs to be cast on a flat prestressing bed. The slabs are cast with a physical separator in the middle of the slab in the direction of traffic flow. After the bed is pretensioned, and the slabs are cast and cured, the prestressing strand is cut at both slab ends and at the physical separator in the middle of the slabs. This effectively produces two prestressed
slabs connected by a hinge. The slab is then lifted at the hinge to the desired
crown height. Grout is then poured along the crown and allowed to cure,
resulting in one continuous deck member. Large voids are left in the concrete
along the entirety of each girder line. In order for the continuous prestressing
strand to develop a prestressing force in the entire slab, the internal forces must
bridge the voids over the girder lines. This is done by casting a reinforcement
cage around each strand, which places the reinforcement in compression and
transfers the prestressing force across the voids (Fallaha, Chuanbing, Lafferty, &
Tadros, 2004).

As innovative as this technique is, the deck system is left with some
inherent problem areas. The large voids above the girders running the entire
length of the bridge must be closed with what are known as “zipper pours” (this
name comes from the resemblance of zippers running along the girders). The
areas of the deck that see maximum negative moment are directly above each
girder. The use of zipper pours to close these voids result in large cold joints in the
areas of maximum negative moment. This can easily result in cracks above the
girders, exposing the structural steel and concrete reinforcement to potential
corrosive damage due to environmental effects.
2.3 - Real World Projects

This section will outline a few of the noteworthy real-world rapid bridge construction projects, some of which UNH has been involved with.

2.3.1 - Massachusetts DOT’s “Fast Fourteen”

During the summer of 2011, the Massachusetts Department of Transportation (MassDOT) replaced 14 deteriorated bridges in Medford, MA over the course of 10 weekends. Using conventional bridge replacement methods, this feat would have taken over four years to complete, during which drivers would have had to endure long-term lane closures and increased traffic congestion and travel times (MassDOT, 2011). This was a high profile project which received a lot of attention for its successes.

The MassDOT managed this feat by producing precast composite beam-slab segments and tying them together on site. The segments, which run longitudinally to the flow of traffic, were tied together via cast-in-place zipper pours. Zipper pours run the entire length of the bridge, leaving long cold joints between the precast segments. These cold joints, over time, could become a deterioration problem area for the bridge deck.
2.3.2 - Laconia Bypass over NH-11A in Gilford, NH

The New Hampshire Department of Transportation (NHDOT) has a plan to replace the deck of the Laconia Bypass over NH-11A Bridge in Gilford, NH in the spring of 2014. The current bridge is a single span simply-supported system that carries two lanes of traffic over NH-11A. The roadway also has a shoulder on either side. This bridge is a composite beam-slab system with seven steel girders and a 7 ½ inch cast-in-place concrete deck. The deck is highly deteriorated and in need of replacement. The NHDOT has allotted a 60 hour window in which the deck must be fully replaced and re-opened to traffic. The research documented in this thesis paper was conducted to develop a system for use with this project, and will be discussed in more detail throughout the paper.

2.3.3 - Utah Department of Transportation Prefabricated Superstructure

In 2007, the Utah Department of Transportation replaced the 4500 South bridge over the I-215 East Loop in Salt Lake City over the course of a weekend. The bridge carries four lanes of traffic over a 172 ft. span. This project was completed by prefabricating the entire superstructure in an adjacent lot and lifting the entire structure into place using self-propelled modular transporters (SPMTs). The new structure was constructed off site over a four month period. The new abutments were constructed underneath the existing bridge without impacting traffic flow. This procedure was estimated to cut six months of road closures and detours from the construction process (FHWA, 2007). While this process was highly successful, it is only a viable option if the bridge does not
span over water, and if there is plenty of room for construction in a nearby plot of land.

2.3.4 – Mill Street Bridge over Lamprey River in Epping, NH

In 2004, The Mill Street Bridge over the Lamprey River in Epping, NH was replaced in eight days (Shutt, 2005). This was done by utilizing full span precast prestressed high strength concrete box girders. The girders span 115 feet and are 3 feet deep. There are a total of seven girders placed side by side. Each girder is joined to the adjacent girders using shear key joints that run the entire length of the bridge. The girders are post-tensioned together transverse to traffic flow. The substructure system was also constructed completely of precast segments. The crown in the roadway was made by varying the thickness of the wearing surface along the cross-section of the bridge (Stamnas & Whittemore, 2005).

While this project was successful and received a lot of attention for its timely construction, the replacement method that was used can only be considered if the entire superstructure or entire bridge system needs replacement. If only the deck needs replacement, then this method would prove to be excessive and expensive.
CHAPTER III

METHODOLOGY

3.1 – Proposed Deck Replacement Approach

This section outlines the proposed Rapid Bridge Deck Replacement technique developed by UNH researchers, as well as goes over the integration of finite element analysis in the construction process. A summary of the technique will be provided at the end of the chapter. Presentation of the findings and conclusions will be discussed in later chapters.

3.1.1 – Full Deck Demolition and Replacement

The first step in bridge deck replacement projects is to remove the existing deck. This technique requires the complete demolition of the entire bridge deck, as opposed to some techniques which allow for partial demolition. After all concrete is removed, the top surface of the girders must be ground down until a smooth surface is achieved. Proper preparation of the steel girder top surface is required to develop full composite action between the deck and beam system using studs. Preparation of the top surface of concrete girders has not been investigated as a part of this research project. Due to the complete removal of the bridge deck, traffic must be diverted during construction. A possible diversion method is to make a temporary traffic circle using the on and off ramps for the
overpass if available. Any suitable method of traffic diversion will do, so long as it is approved by the project management team.

3.1.2 - Sequential Deck Slab Placement

Opposed to other more commonly used techniques, this approach requires that deck slabs be placed and post-tensioned together in sequence from one abutment to the other. For example, the first slab should be placed on one end of the bridge. This slab should then be post tensioned longitudinally to the flow of traffic. The second slab should be placed adjacent to the first, and each slab thereafter should be place adjacent to the previous one. After the second slab is placed on the girders, it should be post-tensioned to the first slab prior to placing the third slab on the girders. Each transverse joint between two slabs should be sealed through the entire cross-section and length of the joint prior to post tensioning. Conventional post-tensioning using prestressing strand requires that post-tensioning occurs after all slabs are placed, aligned, and leveled. This can prove to be a tedious, time-consuming, and often problematic approach, especially in longer bridges. It is remarkably easy for flexible prestressing strand to get bound-up inside the post-tensioning duct while it is being threaded through multiple slabs. By using a coupled-threaded-rod system and post-tensioning the slabs together in a sequential manner, this issue is removed (Salzer, 2008). The post-tensioning technique was not investigated in this research project.
3.1.3 - Predetermined Leveling Screw Lengths

It is common practice to place all deck slab elements on the existing girders, and then proceed to adjusting the heights of the slabs iteratively by lifting them with a crane and shimming between the slabs and girders until the desired elevation is reached (Eberhard, Hieber, Stanton, & Wacker, 2005). This process can be quite time consuming and tedious. A more efficient way to set the elevation profile of the top of the slabs is to utilize preset leveling devices. In this research project, leveling screws are used. Leveling screws are oversized course-threaded rods that are cast vertically through the slabs. Leveling screws are approximately twice as long as the slab is thick. This is to ensure enough variation can exist in the leveling screws’ exposed lengths. Each slab has two leveling screws per girder to transfer the dead load of the slab onto the girders in a stable manner. The installation and use of leveling screws will be discussed later.

Since the girder system will deform under the additional dead load of the slabs, the leveling screw lengths must be set so that once all slabs are placed on the girders, a constant grade slab elevation profile will be developed. The bulk of this paper will discuss how the leveling screw lengths are determined for this proposed construction technique.
3.1.4 - Integration of Finite Element Modeling

The core research area for this thesis project was the development of a finite element analysis procedure that can be used to determine the proper leveling screw lengths and to integrate finite element modeling into the construction process. This includes building a FEM, calibrating that model to simulate the behavior of the real structure, and updating the geometry of the model to match that of the actual structure in real-time. Using elevation and deflection surveys, as well as structural health monitoring systems, the true behavior of the structure can be captured and used to calibrate the model.
3.2 - Lab Setup

The lab setup used to test the SAP2000 construction model will be described in this section. The setup consisted of three S15x42.9 beams, four C6X8.2 beams, six abutment blocks, six 16’x43.5”x8.5” reinforced concrete slabs, and 36 leveling screws (six per slab).

The abutment blocks were made by casting a 16”x16”x12” block of concrete with a 2” diameter solid steel rod embedded across the top. The steel rod provides for a contact point to support the steel beams. The clear span for each beam was set to 25 ft., and the beams were spaced 7 ft. on center. The High Bay girder layout can be seen in Figure 2.

Figure 2 - Girder and Abutment Setup in UNH High Bay

Partial web stiffener plates were welded on both sides of each beam along both abutment lines. The stiffener plates provided a connection location for diaphragms. Four C6x8.2 channel beams were used as diaphragms to give
lateral stability to the beam system. The diaphragm system was not designed to resist torsional loading.

The slabs were formed using ½” Oriented Strand Board (OSB) sheets. The forms were setup to create a volume that measures 16’ by 43.5” by 8.5”. Each sheet was painted with three coats of polyurethane, a coat of wax, and a coat of oil prior to casting to allow for an easy release when stripping the forms. The longitudinal reinforcement consisted of two layers of four #4 rebars spaced 12 inches on center and symmetrically about the center line of the slab. The two layers are spaced concentrically from the neutral-axis. The transverse reinforcement consisted of two layers of six #4 rebars, one on either side of all three pairs of leveling screws. This is shown in Figure 3.

![Form Work and Reinforcement Cage for Slabs](image)

Figure 3 - Form Work and Reinforcement Cage for Slabs
The leveling screws were tied loosely in with the reinforcement cage as to increase the leveling screw's stability prior to pouring the concrete, while still allowing for the leveling screw to spin freely after the concrete cures. The leveling screw pre-casting setup is shown in Figure 4.

![Figure 4 - Close-Up of Leveling Device in Place before Pouring Concrete](image)

In order to avoid bending the segment of the leveling screws that extends above the surface of the slabs during lifting, a strongback was built. It ensured that each leveling screw had the same amount of force applied to it during lifting. This also helped to avoid cracking the slabs. The strongback was made using four 16 feet long 2"x8" dimensional lumber. These were glued and bolted together side by side to make one laminated dimensional lumber beam. The beam was lifted in two locations, and connected to each slab by three pairs of lifting straps spaced to line up with the leveling screws. The straps in each pair were separated using spacer bars, resulting in six vertically hanging lifting straps,
one that lines up with each leveling screw. The strongback is pictured in Figure 5. The locations where the strongback was to be lifted were chosen to minimize differential deflection between the three slab lifting locations along the length of the beam. This was done using a trial and error process with the structural analysis package MASTAN2. The strong back has the following properties:

\[ L = 16 \text{ ft.} \]
\[ b = 4 \times b_{2x8} = 4 \times 1.5 = 6 \text{ in.} \]
\[ h = h_{2x8} = 7.25 \text{ in.} \]
\[ l = \frac{b \times h^3}{12} = \frac{6 \times 7.25^3}{12} = 190.5 \text{ in.}^4 \]
\[ E = 1,420,000 \text{ psi} \]
\[ \sigma_{\text{allowable}} = 7,250 \text{ psi} \]

Figure 5 - Strongback Setup for Lifting Slabs
3.2.1 - Leveling Screw Assembly

The leveling screw device has a dual purpose: to transfer the dead load of the slabs to the steel girders while allowing the slabs to be leveled appropriately, and to provide lifting points for transporting the slabs. The leveling screw apparatus consists of an 18" long ¼" diameter coil-thread-rod that goes through the slab vertically. Part of the rod protrudes through both the top and the bottom surfaces of the slabs. On the top of the rod, a lifting hook is threaded on. See Figure 6 for a picture of the lifting hook setup.

![Figure 6 - Lifting Hook Eye and Level Adjustment Nut](image)

Under the lifting hooks are double nuts to provide a place for a wrench to grip to make leveling screw adjustments.
Cast into the slab is a coil-thread insert at each screw location used to transfer the load from the screws into the slab, which is pictured in Figure 7. The inserts are tied directly into the reinforcement cage for stability and secure load transfer. Pictured below is an example of the insert with a rod threaded through.

Figure 7 - Coil-Threaded Rod and Insert
The leveling screws are cast into the slabs along with the inserts. Each leveling screw is coated with a thin layer of grease and threaded through the coil inserts to prevent the concrete from bonding to the screws during casting. This gives the screws more contact area for load transfer, and it ensures the leveling screws stay vertical throughout the fabrication process.

It should be noted that the use of a coil-threaded rod is not necessary. Coil-threaded rods simply provide the best option for the lab trials because of the low cost and ease of rotation required to set leveling screw lengths. The large coil threads make for less contact area than smaller threads, resulting in less resistance while rotating. However, large threads also result in greater longitudinal travel per rotation. This translates to more sensitive leveling screw adjustments. Care must be taken when making adjustments; large rotations could lead to undesirable force concentrations. While a rod with smaller threads would allow for more precise adjustments, smaller threads may prove to be too hard to rotate due to the increased contact area with the concrete.
3.3 - Data Gathering Methods

This section will discuss the various methods used to gather real-time data for model updating and structural monitoring of the bridge.

3.3.1 - Elevation Surveys

Elevation surveys using a total station or auto-level are done after the removal of the deck to build the correct elevation profile of each beam. An elevation should be taken at five locations along the bottom flange of each beam to build a 4th-order polynomial function that represents the beam elevation profile. The elevation of the bearing seats must be known, as well as the elevation of the bottom flange at 1/3 span, 1/2 span, and 2/3 span. For the lab test conducted during this research project, the elevations were collected along the top flange of the girders. Elevations along the bottom flange of the girders in a real-world project may be easier to collect.

These elevation surveys should also be taken after each slab is placed to ensure the bridge is deforming as expected according to the FEM. If the bridge is not deforming as expected, then adjustments must be made to the model to achieve consistency.
3.3.2 - Structural Health Monitoring Systems

Structural Health Monitoring (SHM) instrumentation systems are used in a variety of ways to capture real-time bridge behavior. One of the more innovative uses of SHM instrumentation is for live model updating, where a structural FEM of a bridge is automatically updated based on information gathered by SHM systems. This can be useful in long-term bridge performance monitoring (Bell, Brenner, Phelps, Sanayei, & Sipple, 2012).

When placing precast components on a bridge, it is important to realize that the components have a stiffness associated with them. This is opposed to cast-in-place components, which do not develop stiffness until curing is well underway. Because of this, the dead load of the precast deck slabs does not necessarily distribute evenly to all supporting girders. It is essential to monitor the girders to make sure that they are not getting over or under stressed. Since full-depth precast panels are often much thicker than the cast-in-place deck being replaced, the increased dead load can severely alter the performance of the bridge as a whole if care is not taken to make sure the dead load is properly distributed.

Structural Health Monitoring systems can be used to gather important data in real-time during the construction process. Strain gauges are used to measure the strain longitudinally to the direction they are applied on the component that they are installed. By multiplying the strain value by Young’s Modulus, we can obtain the stress value at the location of the gauge. This can then be compared to the strain values on the other girders to see if they are
being subjected to equal stresses, and then the values can be compared with those predicted by the FEM to ensure consistency between the model and the real system. This process was not investigated as a part of this thesis, but should be looked at in future projects.
3.4 - SAP2000 Model

The focus of this research was on the development of a SAP2000 structural FEM that is useful during the construction process by helping to minimize construction time. The model that was tested was used to predetermine the length of the leveling screws that protrudes from the bottom of the slab prior to setting the slabs on the girders so that a smooth top-of-slab profile would develop once all dead load is placed on the girders. Therefore, this model needs to consider girder deflection due to future dead load to ensure the final profile matches the design profile. A means of progressive profile checking is also required to ensure the model represents the behavior of the structure well. If there are discrepancies between the computer model behavior and the real structural behavior, then the model must be re-calibrated.

The following steps are involved in making a structural model in SAP2000, which will be discussed in this section:

1. Create a geometric description of the bridge elements.
2. Assign material and other properties to the elements in the model.
3. Create load cases.
4. Check computer model stability.
5. Create Excel macro commands to automate the computer model updating process.
6. Calibrate computer model to real world structure.
3.4.1 - Geometric Description

The first step in creating the computer model is describing the geometry of the structure. This entails creating each structural element needed to appropriately model the bridge (i.e., abutments, girders, slabs, etc.). The girders and slabs were modeled using solid elements, the abutments were assumed to be fixed (which is an appropriate assumption to obtain results to the desired level of accuracy), and the leveling screws were modeled using gap link elements.

The girders were created first. This was done by obtaining the cross-sectional measurements of the girders from the AISC Steel Design Manual, and making a layout with nodes in SAP2000. The nodes were placed as to outline the girders, as well as provide locations where deflection readings could be taken and connections could be made to the slabs above.

Since connections between the slabs and the girders need to be made along the centerline of the girders, the flanges must be comprised of at least two separate elements. The best way to model the beams was by making each flange out of three elements and the web out of one element through the cross-section of each girder. The top surface of the top flange was modeled using three equally spaced nodes, one node at each end of the flange, and one node in the middle. The bottom surface of the top flange was modeled using four nodes, one on each end of the flange, and one on either side of the connection with the web. The bottom flange was modeled by mirroring the top flange about the neutral axis of the beam. The nodes were then connected using poly-area elements. This resulted in seven area elements per girder: three
for the top flange, three for the bottom flange, and one for the web. Refer to Figure 8 for a graphical representation.

After the full cross-section of the girder was modeled with the area elements, they were then extruded along the length of the girders to create solid elements. This resulted in multiple continuous solid elements running the full length of the girder. Each flange was made up of 3 solid elements, while the web consists of one solid element. Each beam model for this research was simply supported.
The continuous elements then needed to be divided along the length of the girder to create points where the leveling screw elements could connect. Since the distance between leveling screws within one slab is not equal to the distance from the second leveling screw in one slab to the first leveling screw in the next slab, the nodes that were created by dividing the elements needed adjustment. The nodes were adjusted manually to the location where the leveling screws would fall. The final girder model can be seen in Figure 9.

A similar method was followed in creating the slabs. A cross section outline was created with nodes. Area elements were drawn connecting the nodes. The poly areas were extruded to make solid elements. The solid elements were divided and the division locations were adjusted to line up with the girder center line nodes. A longitudinal cross-section of the slab and beam layout can be seen in Figure 10.
The leveling screws were modeled using gap link elements. These element types are considered nonlinear, and thus only behave the way they are designed to behave in nonlinear analyses. In linear analyses, gap links are treated as linear link elements. Gap link elements are only capable of transferring compressive loads, which is why they were chosen as the ideal element type for modeling leveling screws. Gap link elements also have the unique ability of having a built in gap. The compressive load applied to the element will not be transferred until this gap is closed. Building a small gap into each element allows for easy manipulation of the element in both SAP2000 and Excel. Changing the length of the gap is an easy way to adjust the effective leveling screw length. This type of link element must connect two nodes. Screenshots were taken of the adjustable parameters for gap link elements and can be seen in Figure 11 and Figure 12.
Figure 11 - Gap Link Property Definitions

Figure 12 - Gap Link Directional Properties Window
By allowing for a gap opening in each of the gap link elements, the model is left unstable. This instability must be corrected for in order to run the model. This is done by assigning highly flexible, linear elastic link elements to each slab, which establishes a stable condition. Single node link elements were used to model these stabilizers. Since the gap link elements do not provide any lateral resistance, the stabilizer elements must act in all three axes. Conventionally, these element types are used to model flexible foundations as it associates a prescribed stiffness to a given node. The stiffness of these elements is negligible when compared to the stiffness of the other elements in the model, but still provides the model with the necessary stability. Screenshots of the properties windows for the stabilizer links can be seen in Figure 13 and Figure 14.
A screenshot of the completed FEM used for the High Bay test prior to analysis is shown in Figure 15.
3.4.2 - Load Cases

“A load case defines how the loads are to be applied to the structure..., how the structure responds ..., and how the analysis is to be performed...” (Computers and Structures, Inc., 2011). The load cases necessary for the analysis of this model are: modal, dead, and staged construction.

The modal load case is strictly for error checking after creating the model. Under a modal analysis, errors within the model are noticed by viewing the deformed shape and playing the animation. Elements that display suspicious or unnatural vibrations during the animation suggest errors in the stability of the element, calling for further investigation of the geometric description and connectivity of the model.

The dead load analysis applies the self-weight of all objects in the model. By running this analysis, the deflections of the girders due to the dead weight of all slabs and the steel girders are obtained. These results are used to calculate the length of the leveling screws.

The staged construction analysis is a nonlinear analysis that is used to add objects and apply loads in sequential stages (a.k.a., steps). This load case is considered nonlinear because it incrementally applies the defined loads. The load case first adds the specified objects (i.e., abutments, girders, slab 1, slab 2, etc.), then applies the dead load of those object. This is done for each step in the load case, which is a good way to model successive slab placement. For example, in Step 1, the girders and support conditions would be added to the model and the self-weight of the girders would be applied. The second step
would call for adding the first slab and applying the self-weight of the slab to the model. The third step would add the second slab and apply its dead load, and so on for each slab. While this construction process calls for post tensioning each slab to the previous slab, the post tensioning process was not included in this research project due to difficulties in properly modeling the post tensioning for use in the staged construction analysis. Another modeling difficulty that surfaced when modeling staged construction was the aggregate deflection at the end of each step. This will be discussed more in later chapters. To fix the aforementioned problem, instead of placing a new slab at each stage and applying that slab’s dead load, all objects are removed from the model at the beginning of each step. All of the previously removed objects are then added back into the model, along with the new slab for each step, and then all objects are loaded. This effectively starts each step with a blank model. This process is well illustrated by following load case data screenshots and graphical model representations shown in Figure 16 through Figure 30.

Figure 16 - Expanded Stage Definition Data for the Nonlinear Staged Construction Load Case
**Initial Conditions**
- Select Zero Initial Conditions: Start from Unstressed State
- Select Continue from State at End of Nonlinear Case

**Important Note:** Loads from this previous case are included in the current case.

**Stage Definition**
- **Stage Duration (Days):**
  - 1
  - 1
  - 1
  - 1
  - 1
  - 1
- **Provide Output:**
  - Yes
  - Yes
  - Yes
  - Yes
  - Yes
  - Yes
- **Output Label:**
  - BEAMS
  - SLAB 1
  - SLAB 2
  - SLAB 3
  - SLAB 4
  - SLAB 5
- **Comments:**
  - Add
  - Add Copy
  - Modify
  - Insert
  - Delete

**Analysis Type**
- Select Linear
- Select Nonlinear
- Select Nonlinear Staged Construction

**Geometric Nonlinearity Parameters**
- Select None
- Select P-Delta
- Select P-Delta plus Large Displacements

**Data For Stage 1 (1. days; Output: BEAMS)**
- **Operation:** Add Structure
- **Object Type:** Group
- **Object Name:** All Beams
- **Age At Add:** 1
- **Type:** Name: All Load Pattern: DEAD Scale Factor: 1

**Figure 17** - Stage 1 Data

**Figure 18** - Stage 1 Solid Model Graphic
Initial Conditions
- Zero Initial Conditions - Start from Unstressed State
- Continue from State at End of Nonlinear Case
  Important Note: Loads from this previous case are included in the current case

Stage Definition
- Stage Duration: (Days)
- Provide Output: Yes
- Output Label: SLAB 1
- User Comments: Add

Data For Stage 2 (1. days, Output: SLAB 1)
- Operation: Remove Structure
- Object Type: Group
- Object Name: ALL
- Age At Add: Remove
- Type: All Beams
- Name: 0
- Scale Factor: 0
- Load Pattern: Load Pattern
- Add: DEAD
- Modify: 1
- Delete:

Figure 19 - Stage 2 Data

Figure 20 - Stage 2 Graphic
## Stage 3 Data

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**Figure 21 - Stage 3 Data**

**Figure 22 - Stage 3 Graphic**
### Figure 23 - Stage 4 Data

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### Figure 24 - Stage 4 Graphic
### Data For Stage 5 (1. days, Output: SLAB 4)

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**Figure 25 - Stage 5 Data**

**Figure 26 - Stage 5 Graphic**
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**Figure 27 - Stage 6 Data**

**Figure 28 - Stage 6 Graphic**
### Data For Stage 7 (1 days; Output: SLAB 6)

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**Figure 29 - Stage 7 Data**

**Figure 30 - Stage 7 Graphic**
After each slab is placed, the deflections and stresses in the girders can be cross-checked against the deflections and stresses surveyed in the lab. If significant deviations are seen between the model’s output and the data gathered at any stage in the slab installation process, then adjustments must be made to the leveling screws for the slabs that have not been placed on the girders. The full SAP2000 model definition in text format can be seen in Appendix A.

3.4.3 - Microsoft Excel™ Macro Commands

The macro commands are used to quickly and easily update the model’s geometry and other parametric definitions. The macro commands developed for this research are divided into four steps:

1. Create Elevation Profile Equations
2. Update Geometry
3. Update Leveling Screws
4. View Leveling Screw Settings

Although there are four major macro command steps, each step may contain more than one macro command. This section will discuss all of the macro commands used for this model and their purposes.
Elevation Profile Equations - The elevation profile equations macro command builds a 4th-order polynomial equation that describes the elevation profile of each beam. Elevations along the length of the beams are gathered in the field/lab and are used as the data points that define the equations. Since five elevation readings are taken along the length of each beam using this procedure (both abutments, 1/3 span, 1/2 span, and 2/3 span), a 4th-order polynomial curve was used to describe the elevation profile. A 4th-order polynomial is the simplest curve that can exactly fit through five points.

This macro command requires the "Table: Joint Coordinates" table be exported from the model. This table is under the "Joint Coordinates" section of the "Connectivity Data" within the "MODEL DEFINITION", as shown in Figure 31.
The command isolates the five nodes used to define the elevation profile equations. These nodes are located at both abutments, at 1/3 the span length, at 1/2 the span length, and at 2/3 the span length. After isolating these nodes, the macro command calculates all of the constants that each order variable term is multiplied by using the LINEST array function. The LINEST function in its standard form is used to calculate a linear best-fit curve based off a series of data points, similar to how a trend line is calculated on an XY Scatter Plot in Excel. However, by modifying the input format for the function, other regression types can be produced, as stated in the Excel help file:

...you can use LINEST to calculate a range of other regression types by entering functions of the x and y variables as the x and y series for LINEST. For example, the following formula:

\[
\text{=LINEST(yvalues, xvalues^COLUMN($A:$C))}
\]

works when you have a single column of y-values and a single column of x-values to calculate the cubic (polynomial of order 3) approximation of the form:

\[
y = m_1 x + m_2 x^2 + m_3 x^3 + b
\]

You can adjust this formula to calculate other types of regression, but in some cases it requires the adjustment of the output values and other statistics. (Microsoft)

The COLUMN function term simply counts the number of columns in the selected range that is highlighted in the parentheses. The example above would return a value of 3. For this example, four cells in a row would need to be selected prior to entering this array function to display each of the three constants and the base value for the formula. To calculate the values in a fourth-order polynomial, five cells in a row need to be selected. Pictured in Figure 32 is the result from running the macro command.
Since the calculations are made using the “GlobalY” column as the x-values and the “GlobalZ” column as the y-values, the case pictured above returns null values meaning the elevation profile is a straight line. To show that the LINEST() array function actually works in calculating a curve, the screenshot shown in Figure 33 displays the values returned if varying “GlobalZ” values are input.
<table>
<thead>
<tr>
<th>Joint</th>
<th>GlobalX</th>
<th>GlobalY</th>
<th>GlobalZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1 @ 0.00 L</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beam 1 @ 0.33 L</td>
<td>12</td>
<td>95</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam 1 @ 0.50 L</td>
<td>12</td>
<td>145.25</td>
<td>0.15</td>
</tr>
<tr>
<td>Beam 1 @ 0.66 L</td>
<td>12</td>
<td>195.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam 1 @ 1.00 L</td>
<td>12</td>
<td>290.5</td>
<td>0</td>
</tr>
<tr>
<td>Beam 2 @ 0.00 L</td>
<td>96</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam 2 @ 0.33 L</td>
<td>96</td>
<td>95</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam 2 @ 0.50 L</td>
<td>96</td>
<td>145.25</td>
<td>0</td>
</tr>
<tr>
<td>Beam 2 @ 0.66 L</td>
<td>96</td>
<td>195.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>Beam 2 @ 1.00 L</td>
<td>96</td>
<td>290.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam 3 @ 0.00 L</td>
<td>180</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beam 3 @ 0.33 L</td>
<td>180</td>
<td>95</td>
<td>0.33</td>
</tr>
<tr>
<td>Beam 3 @ 0.50 L</td>
<td>180</td>
<td>145.25</td>
<td>0.5</td>
</tr>
<tr>
<td>Beam 3 @ 0.66 L</td>
<td>180</td>
<td>195.5</td>
<td>0.67</td>
</tr>
<tr>
<td>Beam 3 @ 1.00 L</td>
<td>180</td>
<td>290.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 33 - Elevation Profile Input and Output

This Excel macro command Visual Basics for Applications (VBA) code in its entirety can be seen in Appendix B, along with the rest of the macro command VBA codes.

**Update Geometry** - The update geometry series of macro commands is used to adjust the elevations of each point along each beam using the equations that were developed from the gathered elevation points, as well as update the slab geometry to match a predefined slope. After these macro commands are run, the data is ready to be re-imported into SAP2000. This series of commands includes three macro commands:

1. Recalculate the beam elevation profiles
2. Recalculate the slab elevation profiles
3. Update and reorganize the spreadsheet for re-import into SAP2000
Recalculate the Beam Elevation Profiles - This macro command updates the elevation of all beam nodes in the model using the elevation profile equations developed from the previously discussed Elevation Equations command. Each beam has its own equation by which it is adjusted. The command first organizes the data by node name. The standard fourth order polynomial equation is used to calculate the new elevations using the coefficients determined from the LINEST array function, and the distance along the length of the beam as the variable.

Recalculate the Slab Elevation Profiles - This macro command updates the elevations of all slab nodes in the model to meet the desired top of slab elevation profile. This command calls for a minimum haunch thickness and desired final top of slab grade. Using these two parameters, each slab node can be adjusted by using the standard line equation of the form:

\[ y = m \cdot x + b \]

where \( y \) is the elevation of the node ("GlobalZ" column), \( m \) is the prescribed grade, \( x \) is the longitudinal distance from the starting abutment ("GlobalY" column), and \( b \) is the minimum haunch thickness. For nodes along the top surface of the slabs, the thickness of the slab itself must also be added in the equation.
Update and Reorganize Spreadsheet for Re-import - This macro command applies the updates found using the last two commands to the table. It then cleans up the spreadsheet and organizes it back into an acceptable form for a SAP2000 import. This command must be run after the other two macro commands for this step.

Update Leveling Screws - This macro command uses the node deflections from the dead load case and the gap distances for each gap link element. By subtracting the nodal displacement of one end of the gap link from the gap distance setting, we obtain a new leveling screw length that considers deflection under full dead load.

View Leveling Screw Lengths - The purpose of this macro command is to display the lengths that each leveling screw should be set to in an easily readable format. The script selects the defined length of all the gap link elements in the “Link Props 01-General” sheet and copies that column to the “Link Props 05-Gap” sheet. The macro then subtracts the opening distance from the defined length for each gap link, resulting in the effective leveling screw length. The script then cleans up the worksheet and organizes it so just the leveling screw lengths are presented in an easy to read format.
3.5 - Beam Type Comparison and Model Justification

Standard finite element analysis procedures suggest that each element should have a side length aspect ratio as close to 1 as possible. The aspect ratio is defined as the ratio of maximum to minimum characteristic dimensions, which in this case is the side length. Through prior research in the field of finite element modeling, it has been shown that maintaining an aspect ratio of 1:1 will yield the most accurate results. This is especially important when working with two-dimensional Constant Strain Triangular, a.k.a. CST, elements (Chandrupatla & Belegundu, 2012). Under the loading conditions applied in this research, the aspect ratios of the solid elements do not seem to play a major role in calculating the nodal deflections.

While accuracy is highly important in this research project, calculation time must be minimized in order for this construction aid to be viable for field use. A significantly higher number of elements than that used for the lab trials are required to achieve an aspect ratio of 1 for the beam elements. With each new element come new calculations that must be completed by the program, thus adding to the total calculation time for the analysis. Knowing this, it is clear that having fewer elements within the model is desirable to minimize calculation time. The beams used in the lab trial model were designed to have only the essential elements necessary to complete the analysis and yield useful results (a total of 98 solid elements per beam). A comparative analysis was done to justify such a low number of elements. The procedures used to justify the use of this computer
model will be described in this section, along with the results and a discussion of the results.

3.5.1 - Comparative Analysis Description

Four beams were analyzed under the same loading conditions and the results were compared. Each beam was modeled with the standard AISC S15x42.9 beam dimensions. The first beam is an exact replication of the beam model used for the lab trials. This beam has a total of 98 elements. This beam model setup is shown in Figure 34.

![Figure 34 - Lab Beam Model Elevation Section](image)

A second beam was modeled also using solid elements, but was subdivided to create a much finer element mesh. This beam has a total of 2688 elements, and can be seen in Figure 35.

![Figure 35 - Fine Mesh Solid Model](image)
A third beam was modeled using frame elements with only one subdivision, thus creating two elements (seen in Figure 36). A fourth beam was created by further discretizing the third beam so that 50 elements were created, which can be seen in Figure 37. A single point load of 2000 pounds was applied to the mid-span of each of the four beams in the negative Z-direction. The results from this analysis are displayed in the following results section, and can be seen in Table 1.

Figure 36 – Simple Frame Model

Figure 37 – Fifty Element Frame Model
The results from this analysis were also compared to those obtained using Timoshenko beam theory calculations. The deflection using beam theory was found using the following equation (McGuire, Gallagher, & Ziemian, 2000):

$$ \Delta = \frac{PL^3}{48EI} + \frac{PL \times 2(1 + \nu)}{4A_s E} $$

Where:

- $P = -2000 \text{ lb}$
- $L = 290.5 \text{ in.}$
- $E = 29,000,000 \text{ psi}$
- $I = 447 \text{ in.}^4$
- $A_s = 6.165 \text{ in.}^2$ (AISC, 2008)
- $\nu = 0.3$

### 3.5.2 - Results

<table>
<thead>
<tr>
<th>Beam Denotation</th>
<th>No. of Elements</th>
<th>Max. Deflection (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Model (solid)</td>
<td>98</td>
<td>-0.081079</td>
</tr>
<tr>
<td>Fine Mesh (solid)</td>
<td>2688</td>
<td>-0.08204</td>
</tr>
<tr>
<td>Simple Mesh (frame)</td>
<td>2</td>
<td>-0.080911</td>
</tr>
<tr>
<td>Fine Mesh (frame)</td>
<td>50</td>
<td>-0.080911</td>
</tr>
<tr>
<td>Beam Theory</td>
<td>N/A</td>
<td>-0.080911</td>
</tr>
</tbody>
</table>

Percent difference between fine mesh solid and lab model: 1.17%

Percent difference between fine mesh solid and frame element model: 1.38%
3.5.3 - Discussion

The beams modeled using frame elements yielded exactly the same deflection results. Since both beams were loaded in identical ways, the system of equations used to solve for the 50 element model was reduced to be the same system of equations used to solve for 2 element model. This was expected. These results were also equal to those obtained using beam theory. Again, this was expected.

The difference between the results obtained from the lab model and those obtained from the fine mesh solid model is 1.17%. This is an insignificant difference, thus proving that the model used for the lab trials is an acceptable alternative to a highly discretized model. While the lab model will not provide a stress gradient through the section or along the length of the beam that is as accurate as that which would be obtained from a finer meshed model, a detailed stress gradient is not required for this research project to be considered useful. The only result that is needed is displacement.

The difference between the results obtained from the fine mesh solid element model and those obtained from the frame element model is 1.38%. This is also an insignificant difference. Based on this finding, I would recommend that a frame element model be used for future work along this research path. The original purpose of using solid elements to make each beam was for the easy of pulling stress values at the extreme fibers of the beam at each stage of the construction process. After each stage in the analysis, the program user can simply compare the color of the beam at various locations to the corresponding
color on the color key to obtain an approximate value of stress at that location. While this simple approach has the benefit of easiness, the tradeoff of having to use calculation intensive solid elements invalidates the usefulness of using solid elements. If frame elements are used instead, stress values can be easily calculated with the fiber-bending-stress equation:

\[ \sigma = \frac{Mc}{I} \]

Where:

- \( \sigma \) = the stress at the extreme fibers
- \( M \) = the moment at the location of interest (where the load is applied)
- \( c \) = the distance from the neutral axis of the member to the extreme fibers
- \( I \) = the moment of inertia of the member

While this process does add an extra step at the user level, a simple excel macro command could be written to automate this step. This test does not fully justify the use of frame elements for the loading seen in the lab, but it does warrant further investigation into the use of frame elements.
3.6 - Procedure

This section will outline the proposed construction procedure step-by-step in detail. It will address the complete construction process and, more importantly, how finite element modeling is integrated into the construction process. Refer to Figure 38 at the end of the chapter, which shows a flow chart of the model development and construction process.

3.6.1 - Build Finite Element Model

Prior to beginning construction, a FEM must be developed for the existing structure. This was described in the previous section. This process is much easier if plan sets for the existing structure are available (preferably As-Built drawings), but can also be done using data gathered from field inspection.

3.6.2 - Write Excel Macro Commands

The use of Macro commands in Excel is vital to the timely updating of the model. Once the FEM is developed, the model data can be exported to an Excel file. The only data necessary for this part of the process is the "nodal coordinates". The data set contains the global x, y, and z location of all the nodes in the model (see "definition of terms" for info on nodes). One macro command is written to filter out all data, but that pertaining to the five key locations per girder. This command is also used to find a 4th-order polynomial.
curve for each girder from those five key data points that will produce an accurate estimation of the girder elevation profile. The command should yield the five constants (m4, m3, m2, m1, and b) shown in the equation below:

\[ y = (m4)x^4 + (m3)x^3 + (m2)x^2 + (m1)x + b \]

By plugging in the x-coordinate for the node in question, the elevation (y-coordinate) of the node is found. A separate macro command can be written that uses the beam equations to update each node along the length of the beam. The macro commands are discussed in greater detail in section 3.4.3.

3.6.3 – Full Deck Demolition

Before construction can begin, the existing deck structure must be removed. This can be done in a couple of ways. The deck can be jackhammered out completely, or as close to the beam surface as possible without causing any damage to the top flange. The crew would then come in with grinders to remove all concrete and shear studs on the top flanges of the girder, leaving a smooth surface free of any debris or damage to the girders.

Another method for deck removal is to take it out in large chunks. This can be done by making transverse and longitudinal saw cuts through the full depth of the deck, as well as along the bottom of the haunches. The sections of deck can then be safely lifted off the girders and disposed of. This makes for much easier cleanup and prevents any damage to underlying infrastructure, utilities, or environmentally protected areas; however, this method proves to be more time
consuming because of the care that must be taken. As with the previous method, the top surface of the beam must be ground down smooth.

3.6.4 – Girder Elevation Survey

As previously mentioned, elevation surveys must be taken at 5 key locations per girder: bearing seat at abutment A, bearing seat at abutment B, 1/3 span, 1/2 span, and 2/3 span. This is done for each girder and recorded by hand or in an excel table. The most sensitive equipment available that is suitable for survey use should be used. This guarantees the most accurate measurements possible. For large girders, the dead load of one slab placed near an abutment may result in very small deflections, thus necessitating the use of precise and sensitive equipment. Girder elevation surveys should be taken after demolition of the old deck, and after placing each panel.
Create model in SAP2000 & write Excel macro commands → Export from SAP2000 to Excel: "Table: Joint Coordinates" → Run Excel macro command: "Elevation Profile Equations"

Gather bridge geometry information via field survey and input → Run Excel macro commands: "Update Geometry" → Import Excel file into SAP2000 Model and update

Run full dead load analysis in SAP2000 → Export from SAP2000 to Excel: "Table: Link Property Definitions 05 - Gap" and "Table: Joint Displacements" → Run Excel macro command: "Update Leveling Screws"

Import results into SAP2000 → Run full dead load analysis and check elevation profile → Run Excel macro command: "View Leveling Screw Settings"

Set lengths on all leveling screws according to analysis output → Begin construction process and follow along in "staged Construction" analysis

Figure 38 - Model Development and Construction Process Flow Chart
CHAPTER IV

PRESENTATION OF FINDINGS

This chapter outlines the findings that were made during this research project. The results will be displayed on a step by step basis according to the staged construction analysis step progression, as follows:

- Stage 1: Add beams to model and apply beam dead loads
- Stage 2: Add “Slab 1” group to model and apply dead load of Slab 1
- Stage 3: Add “Slab 2” group to model and apply dead load of Slab 2
- Stage 4: Add “Slab 3” group to model and apply dead load of Slab 3
- Stage 5: Add “Slab 4” group to model and apply dead load of Slab 4
- Stage 6: Add “Slab 5” group to model and apply dead load of Slab 5
- Stage 7: Add “Slab 6” group to model and apply dead load of Slab 6

Due to the number of nodes in this model, the results for three nodes per beam will be presented: a node at 1/3 span, a node at 1/2 span, and a node at 2/3 span.
Prior to running the model, an initial elevation profile was taken along the top surface of the beams using a Topcon© automatic level and a 1/16" graduated fold rule. While in the field, these measurements would normally be taken at the bottom of the lower flanges of the beams, limitations within the lab setup call for taking the measurements at the top of the top flanges of the beams. The measurements were zeroed at the highest abutment elevation. Table 2 shows the beam profiles that were found.

<table>
<thead>
<tr>
<th>Zeroed Initial Beam Elevation Profile (in.)</th>
<th>Abut. A</th>
<th>1/3 span</th>
<th>1/2 span</th>
<th>2/3 span</th>
<th>Abut. B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>-0.1875</td>
<td>-0.0625</td>
<td>-0.1250</td>
<td>-0.1875</td>
<td>-0.1250</td>
</tr>
<tr>
<td>Beam 2</td>
<td>0.0000</td>
<td>0.1250</td>
<td>0.1875</td>
<td>0.1875</td>
<td>0.0000</td>
</tr>
<tr>
<td>Beam 3</td>
<td>-0.1875</td>
<td>-0.1250</td>
<td>-0.1875</td>
<td>-0.1250</td>
<td>-0.0625</td>
</tr>
</tbody>
</table>

The SAP2000 model geometry was exported to an excel spreadsheet. The “Elevation Profile Equations” macro command was then run on the exported geometry. The values in the table above were entered into the excel spreadsheet after running the macro command, thus producing the elevation profile equation for each beam. The “Recalculate the Beam Elevation Profiles” macro command was then run to update the nodes for each beam, producing a reasonably accurate representation of the beam profiles.
The first step in producing usable results within the SAP2000 model is to analyze the beams under their own dead load only, then compensate for the deflection due to the dead load by adjusting the starting locations for each node post analysis. After each node was corrected for using the Excel Macro commands, the staged construction analysis can be run to gather the deflection data. The first step in the staged construction analysis applies the dead load of the beams again, which yields the same deflection as in the dead load analysis, thus resulting in a beam profile congruent with that as observed in the laboratory. The nodal displacements after Stage 1 in the SAP2000 analysis can be seen in Table 3.

Table 3 - Step 1 Nodal Displacements in Z-Direction from SAP2000 Staged Construction Analysis

<table>
<thead>
<tr>
<th>Step 1 Nodal Displacements in Z-Direction (in.)</th>
<th>@ 1/3 Span</th>
<th>@ 1/2 Span</th>
<th>@ 2/3 Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>-0.02216</td>
<td>-0.02578</td>
<td>-0.02216</td>
</tr>
<tr>
<td>Beam 2</td>
<td>-0.02216</td>
<td>-0.02578</td>
<td>-0.02216</td>
</tr>
<tr>
<td>Beam 3</td>
<td>-0.02216</td>
<td>-0.02578</td>
<td>-0.02216</td>
</tr>
</tbody>
</table>

The second step in the staged construction analysis adds the first slab to the model and applies the dead load of that slab to the model. These deflections are shown in Table 4.
Table 4 - Step 2 Cumulative Nodal Displacements in Z-Direction from SAP2000 Staged Construction

<table>
<thead>
<tr>
<th>Beam</th>
<th>@ 1/3 Span</th>
<th>@ 1/2 Span</th>
<th>@ 2/3 Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>-0.04949</td>
<td>-0.05383</td>
<td>-0.04407</td>
</tr>
<tr>
<td>Beam 2</td>
<td>-0.05296</td>
<td>-0.05731</td>
<td>-0.04677</td>
</tr>
<tr>
<td>Beam 3</td>
<td>-0.04948</td>
<td>-0.05382</td>
<td>-0.04407</td>
</tr>
</tbody>
</table>

In a staged construction analysis in SAP2000, the deflections shown represent the total accumulative deflection from all previous steps along with the current step. This being said, the above deflections must be adjusted to negate the deflection caused by the dead load of the beams themselves. The adjusted deflection values after placing each slab are shown in Table 5.

Table 5 - SAP2000 Adjusted Nodal Displacement Results

| Beam No. | Stage 2 | SAP2000 Nodal Displacements in Z-Direction (in.) | | Description |
|----------|---------|-----------------------------------------------|-----------------|
|          | @ 1/3 Span | @ 1/2 Span | @ 2/3 Span | |
| Stage 2  | 1 | -0.02733 | -0.02804 | -0.02191 | Slab 1 results |
|          | 2 | -0.03081 | -0.03153 | -0.02461 | |
|          | 3 | -0.02732 | -0.02804 | -0.02191 | |
| Stage 3  | 1 | -0.08308 | -0.08725 | -0.06883 | Slab 2 results |
|          | 2 | -0.08956 | -0.09389 | -0.07402 | |
|          | 3 | -0.08307 | -0.08724 | -0.06882 | |
| Stage 4  | 1 | -0.1515  | -0.1653  | -0.1326  | Slab 3 results |
|          | 2 | -0.1601  | -0.1749  | -0.1404  | |
|          | 3 | -0.1515  | -0.1653  | -0.1326  | |
| Stage 5  | 1 | -0.2157  | -0.2436  | -0.2008  | Slab 4 results |
|          | 2 | -0.2256  | -0.2555  | -0.2113  | |
|          | 3 | -0.2157  | -0.2436  | -0.2008  | |
| Stage 6  | 1 | -0.2632  | -0.3034  | -0.2569  | Slab 5 results |
|          | 2 | -0.2737  | -0.3166  | -0.2694  | |
|          | 3 | -0.2632  | -0.3034  | -0.2569  | |
| Stage 7  | 1 | -0.286   | -0.3325  | -0.2851  | Slab 6 results |
|          | 2 | -0.2967  | -0.3461  | -0.2985  | |
|          | 3 | -0.286   | -0.3325  | -0.2851  | |
The lab deflection results after placing each slab can be seen in Table 6.

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Lab Displacements in Z-Direction (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 1/3 Span</td>
</tr>
<tr>
<td>Slab 1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>&lt; -0.0625</td>
</tr>
<tr>
<td>2</td>
<td>&lt; -0.0625</td>
</tr>
<tr>
<td>3</td>
<td>&lt; -0.0625</td>
</tr>
<tr>
<td>Slab 2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.0625</td>
</tr>
<tr>
<td>2</td>
<td>-0.0625</td>
</tr>
<tr>
<td>3</td>
<td>-0.0625</td>
</tr>
<tr>
<td>Slab 3</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.125</td>
</tr>
<tr>
<td>2</td>
<td>-0.125</td>
</tr>
<tr>
<td>3</td>
<td>-0.125</td>
</tr>
<tr>
<td>Slab 4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.1875</td>
</tr>
<tr>
<td>2</td>
<td>-0.1875</td>
</tr>
<tr>
<td>3</td>
<td>-0.1875</td>
</tr>
<tr>
<td>Slab 5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.25</td>
</tr>
<tr>
<td>2</td>
<td>-0.25</td>
</tr>
<tr>
<td>3</td>
<td>-0.25</td>
</tr>
<tr>
<td>Slab 6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.25</td>
</tr>
<tr>
<td>2</td>
<td>-0.3125</td>
</tr>
<tr>
<td>3</td>
<td>-0.3125</td>
</tr>
</tbody>
</table>

The margin of error for the measurement equipment, being half of the smallest measurement (0.5*1/16" = 1/32" = 0.03125"), is greater than the difference between the readings for the two data sets in most cases. While the deviation between the readings is outside of the error tolerance for 22.2% of the readings, the difference is so close to that tolerance, that the deviation could be easily attributed to user error while taking the readings.
While comparing the SAP2000 data with the laboratory deflection results does not provide a good measure for the accuracy of the SAP2000 model, simply looking at the final profile of the slabs does.

Pictured in Figure 39, the top surface of the slabs are not smooth due to fabrication procedures. The tolerance for the top surface of the slabs was 1/8 inch. This makes the profile appear significantly flawed. The bottom surface of each slab, however, follows a nearly perfect constant grade due to it being cast against a smooth, flat surface.
CHAPTER V

CONCLUSIONS

This chapter presents the conclusions that were drawn from the results obtained during the research project. The process investigated for this research project has proven to be a viable option for determining the required leveling screws lengths prior to placing the slabs for the lab setup that was tested. Because the lab setup used had such small deflections, the measuring equipment that was used did not return precise enough data to be able to find an error between the lab setup and the SAP2000 model. The measurement tolerance was usually larger than the error between the lab deflection measurement and SAP2000 analysis results.

5.1 - Technique Successes

This technique proved to be successful at predicting the required leveling screw lengths needed to make a smooth straight slab profile when the girders are under full dead load. The error between the model deflection and the lab setup deflection that was seen was always smaller than the detectable tolerance of the measuring equipment. This fact leads to two suggested improvements that can be made to the test setup, which will be discussed in Chapter 6.
It has also proved to be successful in providing a means of error checking during the construction process. Through the use of the Staged Construction load case, the analysis results for each stage can be cross-checked with the real behavior of the structure. This allows for early detection of inconsistencies between the model and the real structure, thus preventing detrimental error propagation throughout the construction process.

The FEM that was used for this project proved to be a satisfactory representation of the setup in the lab based on the results obtained. A replication of the beam model used for the lab trials was analyzed under a single point load applied at mid-span. A second beam was analyzed under identical loading and restraint conditions. The second beam was comprised of a finer mesh discretization (2688 solid elements, as compared to 98 in the model used for the lab trials). There was a 1.17% difference in deflection at mid-span between the two models. Such a small difference proves that the model used is acceptable.
5.2 - Challenges Faced

5.2.1 - Slab Placement and Girder Bracing During Lab Trial

Care was not taken when placing the slabs on the girders during one of the lab trials. The first slab was placed so that the leveling screws were approximately one inch off the center line of each beam. Each slab thereafter was aligned with the previous slab. Upon placing the fifth slab, enough torque was built from the weight of the off-center slabs to shear off the bolts used to connect the beams with the diaphragms at the center girder. All five slabs fell off the beams once the far ends tipped under the torsional load, creating a very hazardous working environment.

While this trivial error proved to be embarrassing at the time, it was advantageous to have occurred in a lab setting. The additional project cost would be detrimental if it had happened in the field. A lesson was learned the hard way.

5.2.2 - SAP2000 Post-Tensioning Element Deflection in Staged Construction Case

The construction process dictates that the slabs should be post-tensioned together after they are placed on the beams. Using a staged construction model in SAP2000, post-tensioning the slabs together must be done in a separate step after placing each slab. However, due to the nature of the way loads are added in the staged construction load case, there was a problem with getting the elements used to model the post-tensioning rod to induce any load into the
slab elements. The attempt to model the PT rods as tendons failed. The tendons needed to be added at the same time as the slabs so the tendons would deflect with the slab. Since each slab is added to the model in a separate step, the tendon that deflects with the slab loses connection with the previously placed slab. Since the tendon element requires two locations for the element to be anchored to work properly, the tendon failed to induce load into the slab. The use of tendon elements to model post-tensioning is not recommended. Frame elements should be used instead.
CHAPTER VI

FUTURE WORK AND RECOMMENDATIONS

This chapter discusses recommendations for future work continuing in this line of research. Both afterthoughts and suggestions are presented.

6.1 - Afterthoughts

While testing proved that this process is effective in predicting the required leveling screw lengths to achieve the desired elevation profile, the three girder setup limited our potential areas of investigation for troubleshooting. For example, if the leveling screws that contact the middle girder for one slab were set longer than the leveling screws for the other two girders, the slab would teeter on the middle girder creating a see-saw out of the slab. This effect wouldn’t have been as troublesome if more flexible beams were used. Because of this teetering effect, we were unable to investigate any leveling screw adjustment algorithms that would be usable in bridge systems that have more girders.

The beam system should be designed with diaphragms that provide adequate torsional resistance to avoid hazardous unstable structures. The cross bracing failure seen in the high bay was a lesson learned the hard way. The diaphragm setup used in the three girder system was solely there to provide
additional lateral support to the beams under no induced torsional loading. The unaligned placement of the slabs was not an issue that was foreseen, thus it was not accounted for in the design of the diaphragms.

Another afterthought was to use deflection measuring equipment that has a higher degree of accuracy. The survey equipment used in the lab trails was accurate to 1/16". The margin of error seen between the model and the lab setup was always less than 1/16", thus necessitating higher accuracy, considering the maximum deflection of the girders was only 0.346".

6.2 - Recommendations for Future Work

I recommend testing a bridge system that has four or more girders. This will allow for the development of correction algorithms for leveling screw lengths if differences in deflections or stresses are seen between girders. I would also recommend that the slabs be cast to incorporate a skew angle to bring the lab demonstration even closer to the real world bridge that the research is being done for.

The modeling process has proved to be time consuming, tedious, and sensitive. An improved modeling procedure should be investigated. Solid elements were used to model the beams and slabs to have the highest level of accuracy. Solid elements allow for the user to graphically and numerically see the deflection and stresses at each node after running an analysis. This was desirable because of the speed in which stresses and deflections could be
checked against those seen in the real world. However, these element types are much more computationally demanding, resulting in slower calculation times. Frame elements can also graphically and numerically display the deflection values, but stresses are not directly available. They must be calculated from the moment diagram of the beam and the fiber-bending-stress equation:

$$\sigma = \frac{M \times c}{l}$$

While this adds another step to the construction process, it would significantly reduce calculation time for a model with many elements. I recommend using frame element models as this line of research moves forward.

I would recommend modeling the slabs with area elements. Since the slabs are solely providing dead load in this model, the increased accuracy of using solid elements is not necessary.

Future work should also involve the use of an Application Programming Interface (API) for streamlined interactions between SAP2000 and Excel. The process of exporting data to an excel file, opening the excel file, manipulating the data, and re-importing the data back into SAP2000 is rather cumbersome and can seem complicated to those who are inexperienced with this method. If this technique is to be adopted for use in the field, the process will need to be made more user friendly. Using an API, or some other way to reduce the number of steps required to update the model should be investigated further.
LIST OF REFERENCES

AASHTO. (2008). *Bridging the Gap: Restoring and Rebuilding the Nation's Bridges*. AASHTO.


### TABLE: "PROGRAM CONTROL"

- **ProgramName**: SAP2000
- **Version**: 15.1.0
- **LicenseNum**: EE75
- **LicenseOS**: Yes
- **LicenseSC**: Yes
- **LicenseBR**: No
- **LicenseHT**: No
- **CurrUnits**: "lb, in, F"
- **SteelCode**: AISC-LRFD 93
- **ConcCode**: "ACI 318-05/IBC2003"
- **AlumCode**: "AA-ASD 2000"
- **ColdCode**: AISI-ASD96
- **BridgeCode**: "AASHTO LRFD 2007"
- **RegenHinge**: Yes

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- **Notes**: "Normal weight f’c = 6 ksi added 6/12/2011 11:52:57 AM"

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80
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<td>Mass=0</td>
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### TABLE: "LINK PROPERTY DEFINITIONS 03 - MULTILINEAR"

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| Link=6400000 | TransOpen=1.92256523807568 |
| Link="Screw 1.1B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.80804561636269 |
| Link="Screw 1.1C" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.92166762703887 |
| Link="Screw 1.2A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.8064859486878 |
| Link="Screw 1.3A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.92256613367437 |
| Link="Screw 1.3B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.80805072572129 |
| Link="Screw 2.1A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.7681659519341 |
| Link="Screw 2.1B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.68925997822 |
| Link="Screw 2.2A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.76636437162143 |
| Link="Screw 2.2B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.6858953672667 |
| Link="Screw 2.3A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.76817360716172 |
| Link="Screw 2.3B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.68893815842944 |
| Link="Screw 3.1A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.6687458173499 |
| Link="Screw 3.1B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.63869375216521 |
| Link="Screw 3.2A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.66476102189829 |
| Link="Screw 3.2B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.6365242382188 |
| Link="Screw 3.3A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.66689001141455 |
| Link="Screw 3.3B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
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| Link="Screw 4.1A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.63889231508429 |
| Link="Screw 4.1B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.66897322494519 |
| Link="Screw 4.2A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.63652541384511 |
| Link="Screw 4.2B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.664761132934043 |
| Link="Screw 4.3A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.63871186529879 |
| Link="Screw 4.3B" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
| Link=6400000 | TransOpen=1.66689108553189 |
| Link="Screw 5.1A" | DOF=UI | Fixed=No | NonLinear=Yes | TransKE=6400000 | TransCE=0 |
TABLE: "REBAR SIZES"

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TABLE: "LOAD PATTERN DEFINITIONS"

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TABLE: "AUTO WAVE 3 - WAVE CHARACTERISTICS - GENERAL"

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TABLE: "FUNCTION - RESPONSE SPECTRUM - USER"
### TABLE: "FUNCTION - TIME HISTORY - USER"
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Name=UNIFR5

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Name=RAMPTH
Time=1 Value=1
Name=RAMPTH
Time=4 Value=1
Name=UNIFR5
Time=0 Value=1
Name=UNIFR5
Time=1 Value=1

### TABLE: "FUNCTION - POWER SPECTRAL DENSITY - USER"

Name=UNIFPSD Frequency=0 Value=1
Name=UNIFPSD Frequency=1 Value=1

### TABLE: "FUNCTION - STEADY STATE - USER"

Name=UNIFSS Frequency=0 Value=1
Name=UNIFSS Frequency=1 Value=1

### TABLE: "GROUPS 1 - DEFINITIONS"

**GroupName=ALL**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=Yes
Aluminum=Yes ColdFormed=Yes Stage=Yes Bridge=Yes AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Red

**GroupName="Slab 1"**
Selection=Yes SectionCut=Yes Steel=No Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Green

**GroupName="Slab 2"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Orange

**GroupName="Slab 3"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Cyan

**GroupName="Slab 4"**
Selection=Yes SectionCut=Yes Steel=No Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Slab 5"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Slab 6"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Gage Points"**
Selection=Yes SectionCut=Yes Steel=No Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Beam 1"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Beam 2"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Beam 3"**
Selection=Yes SectionCut=Yes Steel=Yes Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="Abutments"**
Selection=Yes SectionCut=Yes Steel=No Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

**GroupName="LvL Screws"**
Selection=Yes SectionCut=Yes Steel=No Concrete=No
Aluminum=No ColdFormed=No Stage=Yes Bridge=No AutoSeismic=No AutoWind=No
SelDesSteel=No SelDesAlum=No SelDesCold=No MassWeight=Yes Color=Blue

### TABLE: "GROUPS 2 - ASSIGNMENTS"

**GroupName="Slab 1"**
ObjectType=Joint ObjectLabel="Slab 1.1"

**GroupName="Slab 2"**
ObjectType=Joint ObjectLabel="Slab 1.2"

**GroupName="Slab 3"**
ObjectType=Joint ObjectLabel="Slab 1.3"

**GroupName="Slab 4"**
ObjectType=Joint ObjectLabel="Slab 1.4"

**GroupName="Slab 5"**
ObjectType=Joint ObjectLabel="Slab 1.5"

**GroupName="Slab 6"**
ObjectType=Joint ObjectLabel="Slab 1.6"

**GroupName="Slab 7"**
ObjectType=Joint ObjectLabel="Slab 1.7"

**GroupName="Slab 8"**
ObjectType=Joint ObjectLabel="Slab 1.8"
GroupName="All Beams" ObjectType=Joint ObjectLabel="Screw 1.2B"
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<td>Screw 6 6C</td>
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**TABLE: "GROUPS 3 - MASSES AND WEIGHTS"**

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<th>Group Name</th>
<th>Self Mass</th>
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<th>Total Mass X</th>
<th>Total Mass Y</th>
<th>Total Mass Z</th>
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TABLE: "JOINT PATTERN DEFINITIONS"
Pattern=Default

TABLE: "MASSES 1 - MASS SOURCE"
MassFrom=Elements

TABLE: "FUNCTION - PLOT FUNCTIONS"
PlotFunc="Input Energy" Type=Energy Component=Input Mode=All

TABLE: "NAMED SETS - DATABASE TABLES 1 - GENERAL"
DBNamedSet="UPDATE GEOMETRY" SortOrder="Elem, Cases" Unformatted=No ModeStart=1
ModeEnd=All ModalHist=Envelopes DirectHist=Envelopes NLStatic=Envelopes
BaseReacX=0 BaseReacY=0 BaseReacZ=0 Combo=Envelopes
NumSets=0 NumCases=1 NumGenDisp=0 NumSectCuts=0 NumVLSSets=0
NumNLSets=0 NumPMFSets=0 NumLoadS=1 NumCSets=1 NumSectCuts=0 NumVLSSets=0
NumNLSets=0 NumPMFSets=0

TABLE: "NAMED SETS - DATABASE TABLES 2 - SELECTIONS"
DBNamedSet="UPDATE GEOMETRY" SelectType=Table Selection="Joint Coordinates"
DBNamedSet="UPDATE GEOMETRY" SelectType=LoadPattern Selection=DEAD
DBNamedSet="UPDATE SCREWS" SelectType=Table Selection="Load Pattern"
DBNamedSet="UPDATE SCREWS" SelectType=Table Selection="Joints"

TABLE: "LOAD CASE DEFINITIONS"
Case=DEAD Type=LinStatic InitialCond=Zero DesTypeOpt="Prog Det"
DesignType=DEAD DesActOpt="Prog Det" DesignAct=Non-Composite AutoType=None
RunCase=Yes CaseStatus="Not Run"

TABLE: "CASE - STATIC 1 - LOAD ASSIGNMENTS"
Case=DEAD LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=LVL SCREWS LoadType="Load pattern" LoadName=LVL SCREWS LoadSF=1
Case=STAGED-OLD LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW LoadType="Load pattern" LoadName=DEAD LoadSF=1

TABLE: "CASE - STATIC 2 - NONLINEAR LOAD APPLICATION"
Case=LVL SCREWS LoadApp="Full Load" MonitorDOF=U3 MonitorJt="Slab 1.3"
Case=STAGED-OLD LoadApp="Full Load" MonitorDOF=U1 MonitorJt="Slab 1.3"
Case=STAGED LoadApp="Full Load" MonitorDOF=U1 MonitorJt="Slab 1.3"

TABLE: "CASE - STATIC 4 - NONLINEAR PARAMETERS"
Case=LVL SCREWS Unloading="Unload Entire" GeoNonLin=No ResultsSave="Final State"
MaxTotal=200 MaxNull=50 MaxIterCS=10 MaxIterNR=40 ItConvTol=0.0001
UseByStep=No EVJumpTol=0.01 LGPerIter=20 LSTol=0.1
LSSStepFact=1.618 FrameTC=Yes FrameHinge=Yes CableTC=Yes LinkTC=Yes
Load Type = "Load pattern"  Load Name = "DEAD"  Load SF = 1

Stage 1: Operation = "Add Structure"  Obj Type = "Beam"  Obj Name = "All Beams"

Stage 2: Operation = "Add Structure"  Obj Type = "Slab 1"

Stage 3: Operation = "Add Structure"  Obj Type = "Slab 2"

Stage 4: Operation = "Add Structure"  Obj Type = "Slab 3"

Stage 5: Operation = "Add Structure"  Obj Type = "Slab 4"

Stage 6: Operation = "Add Structure"  Obj Type = "Slab 5"

Stage 7: Operation = "Add Structure"  Obj Type = "Slab 6"

Stage 8: Operation = "Add Structure"  Obj Type = "Slab 7"

Stage 9: Operation = "Add Structure"  Obj Type = "Slab 8"

Stage 10: Operation = "Add Structure"  Obj Type = "Slab 9"

Stage 11: Operation = "Add Structure"  Obj Type = "Slab 10"

Stage 12: Operation = "Add Structure"  Obj Type = "Slab 11"

Stage 13: Operation = "Add Structure"  Obj Type = "Slab 12"

TABLE: "CASE - STATIC 6 - NONLINEAR STAGE DATA"

Case = STAGED-OLD Stage = 1 Operation = "Add Structure"  Obj Type = "Group"  Obj Name = "All Beams"

Stage = 2 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 1"

Stage = 3 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 2"

Stage = 4 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 3"

Stage = 5 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 4"

Stage = 6 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 5"

Stage = 7 Age = 0 Operation = "Load Objects If New"  Obj Type = "Group"  Obj Name = "Slab 6"
Case=STAGED Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 2"
Age=0
Case=STAGED Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 3"
Age=0
Case=STAGED Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 4"
Age=0
Case=STAGED Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 5"
Age=0
Case=STAGED Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 6"
Age=0
Case=STAGED Stage=7 Operation="Load Objects If New" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=1 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
Case=STAGED-NEW Stage=1 Operation="Load Objects If New" ObjType=Group ObjName="ALL
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=2 Operation="Remove Structure" ObjType=Group ObjName="ALL
Case=STAGED-NEW Stage=2 Operation="Load Objects" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=3 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
1" Age=0
Case=STAGED-NEW Stage=3 Operation="Load Objects If New" ObjType=Group ObjName="ALL
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=4 Operation="Remove Structure" ObjType=Group ObjName="ALL
Case=STAGED-NEW Stage=4 Operation="Load Objects" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=5 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
1" Age=0
Case=STAGED-NEW Stage=5 Operation="Add Structure" ObjType=Group ObjName="Slab 2"
Age=0
Case=STAGED-NEW Stage=5 Operation="Load Objects If New" ObjType=Group ObjName="ALL
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=6 Operation="Remove Structure" ObjType=Group ObjName="ALL
Case=STAGED-NEW Stage=6 Operation="Load Objects" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=7 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
1" Age=0
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Age=0
Case=STAGED-NEW Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 3"
Age=0
Case=STAGED-NEW Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 4"
Age=0
Case=STAGED-NEW Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 5"
Age=0
Case=STAGED-NEW Stage=7 Operation="Add Structure" ObjType=Group ObjName="Slab 6"
Age=0
Case=STAGED-NEW Stage=7 Operation="Load Objects If New" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=8 Operation="Remove Structure" ObjType=Group ObjName="ALL
Case=STAGED-NEW Stage=8 Operation="Load Objects" ObjType=Group ObjName="ALL
LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=9 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
1" Age=0
Case=STAGED-NEW Stage=9 Operation="Add Structure" ObjType=Group ObjName="Slab 2"
Age=0
Case=STAGED-NEW Stage=9 Operation="Add Structure" ObjType=Group ObjName="Slab 3"
Age=0
Case=STAGED-NEW Stage=9 Operation="Add Structure" ObjType=Group ObjName="Slab 4"
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Age=0
Case=STAGED-NEW Stage=9 Operation="Add Structure" ObjType=Group ObjName="Slab 6"
Age=0
Case=STAGED-NEW Stage=9 Operation="Load Objects If New" ObjType=Group ObjName="ALL
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=10 Operation="Remove Structure" ObjType=Group ObjName="ALL
Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="All Beams" Age=0
Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="Slab 2"

TABLE: "CASE - MODAL 1 - GENERAL"
Case=MODAL ModeType=Eigen MaxNumModes=12 MinNumModes=1 EigenShift=0
EigenTo=0.000000001 AutoShift=Yes

TABLE: "BRIDGE DESIGN PREFERENCES - AASHTO/LRFD07"
HingeOpt="Auto: AASHTO/Caltrans Hinge"

TABLE: "JOINT COORDINATES"
Joint="bm 1.1" CoordSys=GLOBAL CoordType=Cartesian XorR=9.25 Y=0 Z=0
SpecialJoint=Yes GlobalX=9.25 GlobalY=0 GlobalZ=0
Joint="bm 1.2" CoordSys=GLOBAL CoordType=Cartesian XorR=9.25 Y=0 Z=0.622
SpecialJoint=Yes GlobalX=9.25 GlobalY=0 GlobalZ=0.622
Joint="bm 1.3" CoordSys=GLOBAL CoordType=Cartesian XorR=9.25 Y=0 Z=14.378
SpecialJoint=Yes GlobalX=9.25 GlobalY=0 GlobalZ=14.378
Joint="bm 1.4" CoordSys=GLOBAL CoordType=Cartesian XorR=9.25 Y=0 Z=15
SpecialJoint=Yes GlobalX=9.25 GlobalY=0 GlobalZ=15
Joint="bm 1.5" CoordSys=GLOBAL CoordType=Cartesian XorR=11.795 Y=0 Z=0.622
SpecialJoint=Yes GlobalX=11.795 GlobalY=0 GlobalZ=0.622
Joint="bm 1.6" CoordSys=GLOBAL CoordType=Cartesian XorR=11.795 Y=0 Z=14.378
SpecialJoint=Yes GlobalX=11.795 GlobalY=0 GlobalZ=14.378
Joint="bm 1.7" CoordSys=GLOBAL CoordType=Cartesian XorR=12 Y=0 Z=15
SpecialJoint=Yes GlobalX=12 GlobalY=0 GlobalZ=15
Joint="bm 1.8" CoordSys=GLOBAL CoordType=Cartesian XorR=12.206 Y=0 Z=0.622
SpecialJoint=Yes GlobalX=12.206 GlobalY=0 GlobalZ=0.622
Joint="bm 1.9" CoordSys=GLOBAL CoordType=Cartesian XorR=12.206 Y=0 Z=14.378
SpecialJoint=Yes GlobalX=12.206 GlobalY=0 GlobalZ=14.378
Joint="bm 2.1" CoordSys=GLOBAL CoordType=Cartesian XorR=91.25 Y=0 Z=0
SpecialJoint=No GlobalX=91.25 GlobalY=0 GlobalZ=0
Joint="bm 2.2" CoordSys=GLOBAL CoordType=Cartesian XorR=91.25 Y=0 Z=0.622
SpecialJoint=No GlobalX=91.25 GlobalY=0 GlobalZ=0.622
Joint="bm 2.3" CoordSys=GLOBAL CoordType=Cartesian XorR=91.25 Y=0 Z=14.378
SpecialJoint=No GlobalX=91.25 GlobalY=0 GlobalZ=14.378
Joint="bm 2.4" CoordSys=GLOBAL CoordType=Cartesian XorR=91.25 Y=0 Z=15
SpecialJoint=No GlobalX=91.25 GlobalY=0 GlobalZ=15
Joint="bm 2.5" CoordSys=GLOBAL CoordType=Cartesian XorR=95.795 Y=0 Z=0.622
SpecialJoint=No GlobalX=95.795 GlobalY=0 GlobalZ=0.622
Joint="bm 2.6" CoordSys=GLOBAL CoordType=Cartesian XorR=95.795 Y=0 Z=14.378
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Joint="bm 2.7" CoordSys=GLOBAL CoordType=Cartesian XorR=96 Y=0 Z=15

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Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="Slab"

3" Age=0
Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="Slab"

4" Age=0
Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="Slab"

5" Age=0
Case=STAGED-NEW Stage=11 Operation="Add Structure" ObjType=Group ObjName="Slab"
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1
Case=STAGED-NEW Stage=12 Operation="Remove Structure" ObjType=Group
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1

Beams:" Age=0
Case=STAGED-NEW Stage=13 Operation="Add Structure" ObjType=Group ObjName="Slab"

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Case=STAGED-NEW Stage=13 Operation="Add Structure" ObjType=Group ObjName="Slab"

2" Age=0
Case=STAGED-NEW Stage=13 Operation="Add Structure" ObjType=Group ObjName="Slab"

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Case=STAGED-NEW Stage=13 Operation="Add Structure" ObjType=Group ObjName="Slab"

6" Age=0
Case=STAGED-NEW Stage=13 Operation="Load Objects If New" ObjType=Group
ObjName=ALL LoadType="Load pattern" LoadName=DEAD LoadSF=1

TABLE: "CASE - MODAL 1 - GENERAL"
Case=MODAL ModeType=Eigen MaxNumModes=12 MinNumModes=1 EigenShift=0
EigenTo=0.000000001 AutoShift=Yes

TABLE: "BRIDGE DESIGN PREFERENCES - AASHTO/LRFD07"
HingeOpt="Auto: AASHTO/Caltrans Hinge"
Joint="bm 1.34" Coordsys=GLOBAL CoordType=Cartesian XorR=12.206 Y=51 Z=0.622
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SpecialJointNo GlobalX=14.751 GlobalY=51 GlobalZ=0
Joint="bm 1.37" Coordsys=GLOBAL CoordType=Cartesian XorR=14.751 Y=51 Z=0.622
SpecialJointNo GlobalX=14.751 GlobalY=51 GlobalZ=0.622
Joint="bm 1.38" Coordsys=GLOBAL CoordType=Cartesian XorR=14.751 Y=51 Z=14.378
SpecialJointNo GlobalX=14.751 GlobalY=51 GlobalZ=14.378
Joint="bm 1.39" Coordsys=GLOBAL CoordType=Cartesian XorR=14.751 Y=51 Z=15
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Joint="bm 1.40" Coordsys=GLOBAL CoordType=Cartesian XorR=9.25 Y=63.5 Z=0
SpecialJointNo GlobalX=9.25 GlobalY=63.5 GlobalZ=0
Joint="bm 1.41" Coordsys=GLOBAL CoordType=Cartesian XorR=9.25 Y=63.5 Z=0.622
SpecialJointNo GlobalX=9.25 GlobalY=63.5 GlobalZ=0.622
Joint="bm 1.42" Coordsys=GLOBAL CoordType=Cartesian XorR=9.25 Y=63.5 Z=14.378
SpecialJointNo GlobalX=9.25 GlobalY=63.5 GlobalZ=14.378
Joint="bm 1.43" Coordsys=GLOBAL CoordType=Cartesian XorR=9.25 Y=63.5 Z=15
SpecialJointNo GlobalX=9.25 GlobalY=63.5 GlobalZ=15
Joint="bm 1.44" Coordsys=GLOBAL CoordType=Cartesian XorR=11.795 Y=63.5 Z=0
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Joint="bm 1.45" Coordsys=GLOBAL CoordType=Cartesian XorR=11.795 Y=63.5 Z=14.378
SpecialJointNo GlobalX=11.795 GlobalY=63.5 GlobalZ=14.378
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LinkProp=None Link=x-14 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-15 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-16 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-17 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-18 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-19 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-20 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-21 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-22 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-23 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link=x-24 LinkType="MultiLinear Elastic" LinkJoints=SingleJoint LinkProp=FAKE
LinkProp=None Link="Screw 1.1A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.1A"
LinkProp=None Link="Screw 1.1B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.1B"
LinkProp=None Link="Screw 1.2A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.2A"
LinkProp=None Link="Screw 1.2B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.2B"
LinkProp=None Link="Screw 1.3A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.3A"
LinkProp=None Link="Screw 1.3B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 1.3B"
LinkProp=None Link="Screw 2.1A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.1A"
LinkProp=None Link="Screw 2.1B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.1B"
LinkProp=None Link="Screw 2.2A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.2A"
LinkProp=None Link="Screw 2.2B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.2B"
LinkProp=None Link="Screw 2.3A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.3A"
LinkProp=None Link="Screw 2.3B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 2.3B"
LinkProp=None Link="Screw 3.1A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.1A"
LinkProp=None Link="Screw 3.1B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.1B"
LinkProp=None Link="Screw 3.2A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.2A"
LinkProp=None Link="Screw 3.2B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.2B"
LinkProp=None Link="Screw 3.3A" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.3A"
LinkProp=None Link="Screw 3.3B" LinkType=Gap LinkJoints=TwoJoint LinkProp="Screw 3.3B"
SolidP6=Gray6 SolidEdge=Black Floor=Gray4 Background=White
BGLowLeft=White BGLowRight=Black BGUpRight=White Darkness=0.5
DeviceType="Color Printer" Points=Black LinesFrame=7303023 Lines Frm DL=Blue
LinesCable=Green LinesTendon=Green SpringLinks=Green Restraints=9408399
Releas=Green Axes=Black ShadEqu=Gray8 Dark
Guidelines=10461087 Highlight=Red Selection=10504778 AreaFillBot=16634568
AreaFillTop=14277119 AreaFillId=16634568 AreaEdge=7303023 SolidP1=10122991
SolidP2=16756912 SolidP3=11599795 SolidP4=12713983
SolidP5=White SolidP6=16777128 SolidEdge=7303023 Floor=13619515
Background=White BGLowLeft=White BGLowRight=14671839 BGUpRight=White Darkness=0.5

**TABLE: "OPTIONS - COLORS - OUTPUT"**

<table>
<thead>
<tr>
<th>Background</th>
<th>BGLow Left</th>
<th>BGLow Right</th>
<th>BG Up Right</th>
<th>Darkness</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>White</td>
<td>White</td>
<td>White</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Device**

- **Device Type**: "Color Printer"
  - Points=Black LinesFrame=7303023 Lines Frm DL=Blue
  - LinesCable=Green LinesTendon=Green SpringLinks=Green Restraints=9408399
  - Releas=Green Axes=Black ShadEqu=Gray8 Dark
  - Guidelines=10461087 Highlight=Red Selection=10504778 AreaFillBot=16634568
  - AreaFillTop=14277119 AreaFillId=16634568 AreaEdge=7303023 SolidP1=10122991
  - SolidP2=16756912 SolidP3=11599795 SolidP4=12713983
  - SolidP5=White SolidP6=16777128 SolidEdge=7303023 Floor=13619515
  - Background=White BGLowLeft=White BGLowRight=14671839 BGUpRight=White Darkness=0.5

**TABLE: "DATABASE FORMAT TYPES"**

- Units Curr=Yes Override B=No

**TABLE: "PROJECT INFORMATION"**

- Item="Company Name" Data=UNH
- Item="Client Name"
- Item="Project Name"
- Item="Project Number"
- Item="Model Name"
- Item="Model Description"
- Item="Revision Number"
- Item="Frame Type"
- Item="Engineer"
- Item="Checker"
- Item="Supervisor"
- Item="Issue Code"
- Item="Design Code"

**TABLE: "MATERIAL LIST 1 - BY OBJECT TYPE"**

- Object Type=Solid Material=A36 Total Weight=3088.33293611112
- Object Type=Solid Material=6000Psi Total Weight=36975

**TABLE: "MATERIAL LIST 2 - BY SECTION PROPERTY"**

- Section="A36 Steel" Object Type=Solid Total Weight=3088.33293611112
- Section=6000Psi Object Type=Solid Total Weight=36975

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Section = "Screw 2.2B" Object Type = Link Num Pieces = 1 Total Weight =
Section = "Screw 2.3A" Object Type = Link Num Pieces = 1 Total Weight =
Section = "Screw 2.3B" Object Type = Link Num Pieces = 1 Total Weight =
Elevation Profile Equations Visual Basic for Applications Code

Sub ElevationEqs()
    ' ElevationEqs Macro

    Rows("1:3").Select
    Selection.EntireRow.Hidden = True
    Columns("A4").Activate
    ActiveWorkbook.Worksheets("Joint Coordinates").Sort.SortFields.Clear
    ActiveWorkbook.Worksheets("Joint Coordinates").Sort.SortFields.Add
    Key:=Range("A1:A993")
    .SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
    With ActiveWorkbook.Worksheets("Joint Coordinates").Sort
        .SetRange Rows("4:993")
        .Header = xlGuess
        .MatchCase = False
        .Orientation = xlTopToBottom
        .SortMethod = xlPinYin
        .Apply
    End With
    Selection.EntireRow.Hidden = False
    Rows("19:993").Select
    Selection.EntireRow.Hidden = True
    Columns("B:G").Select
    Selection.EntireColumn.Hidden = True
    Columns("K:X").Select
    Selection.EntireColumn.Hidden = True
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    With Selection.Borders(xlEdgeLeft)
        .LineStyle = xlContinuous
        .ColorIndex = 15
        .TintAndShade = 0
        .Weight = xlThin
    End With
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlThin
    End With
    Selection.Borders(xlInsideHorizontal).LineStyle = xlNone
    Rows("8:8").Select
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlThin
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Selection.Borders(xlInsideHorizontal).LineStyle = xlNone
    Rows("13:13").Select
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
    End With
End Sub
Range("M14").Activate
With Selection.Interior
 .Pattern = xlSolid
 .PatternColorIndex = xlAutomatic
 .Color = 15773696
 .TintAndShade = 0
 .PatternTintAndShade = 0
End With
Selection.Font.Bold = True
Range("M5:Q5").Select
Selection.FormulaArray = 
Selection.Copy
Range("M10:Q10").Select
ActiveSheet.Paste
Application.CutCopyMode = False
Selection.Copy
Range("M15:Q15").Select
ActiveSheet.Paste
Application.CutCopyMode = False
Range("A1").Select
End Sub
Sub beams_elev()
    ' beams_elev Macro
    
    Cells.Select
    Selection.EntireRow.Hidden = False
    Selection.EntireColumn.Hidden = False
    Range("L19").Select
    ActiveCell.FormulaR1C1 = 
    Range("L19").Select
    Selection.Copy
    Range("L20").Select
    ActiveSheet.Paste
    Range("L212").Select
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = 
    Range("L212").Select
    Selection.Copy
    ActiveSheet.Paste
    Range("L405").Select
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = 
    Range("L405").Select
    Selection.Copy
    ActiveSheet.Paste
    Cells.Select
    Selection.EntireRow.Hidden = False
    ActiveWindow.ScrollRow = 4
    Range("A1").Select
    Application.CutCopyMode = False
End Sub
Recalculate the Slab Elevation Profiles

Sub slabs_elev()

' slabs_elev Macro
'

' Range("L634").Select
ActiveCell.FormulaR1C1 = "=RC[-2]-MIN(R634C10:R993C10)+MAX(R4C10:R633C10)+4"
Range("L634").Select
Selection.Copy
Range("L635:L993").Select
ActiveSheet.Paste
ActiveWindow.ScrollRow = 4
Range("A1").Select
Application.CutCopyMode = False
End Sub
Sub adjust()
    ' adjust Macro
    '    
    Range("L19:L993").Select
    Selection.Copy
    Range("J19").Select
    Range("J4:J993").Select
    Selection.Copy
    Range("F4").Select
    Columns("L:V").Select
    Application.CutCopyMode = False
    Selection.Delete Shift:=xlToLeft
    ActiveWindow.ScrollRow = 4
    ActiveWindow.ScrollColumn = 1
    Range("A1").Select
End Sub
Update the Leveling Screws

Sub adjust_screws()
    ' adjust_screws Macro
    ' 
    Rows("4:942").Select
    Selection.EntireRow.Hidden = True
    Range("F943:F978").Select
    Selection.Copy
    Sheets("Link Props 05 - Gap").Select
    Range("J4").Select
    Range("L4").Select
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = "=RC[-4]+RC[-2]"
    Range("L4").Select
    Selection.Copy
    Range("L5:L19").Select
   ActiveSheet.Paste
    Range("L4:L39").Select
    Application.CutCopyMode = False
    Selection.Copy
    Range("H4").Select
    Columns("I:M").Select
    Application.CutCopyMode = False
    Selection.Delete Shift:=xlToLeft
    Sheets("Joint Displacements").Select
    Cells.Select
    Selection.EntireRow.Hidden = False
    Range("A1").Select
    ActiveWindow.ScrollRow = 4
    Sheets("Link Props 05 - Gap").Select
    ActiveWindow.ScrollRow = 4
    Range("A1").Select
End Sub
Sub view_screw_lengths()
    ' view_screw_lengths Macro
    '    
    Sheets("Link Props 01 - General").Select
    Range("H5:H40").Select
    Selection.Copy
    Sheets("Link Props 05 - Gap").Select
    Range("J4").Select
    ActiveSheet.Paste
    Range("L4").Select
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = "+RC[-2]-RC[-4]"
    Range("L4").Select
    Selection.Copy
    Range("L5:L39").Select
    ActiveSheet.Paste
    Range("L4:L39").Select
    Range("L39").Activate
    Selection.Font.Bold = True
    With Selection.Interior
        .Pattern = xlSolid
        .PatternColorIndex = xlAutomatic
        .Color = 65535
        .TintAndShade = 0
        .PatternTintAndShade = 0
    End With
    Range("L3").Select
    ActiveCell.FormulaR1C1 = "Screw Length (inches)"
    Columns("L:L").EntireColumn.AutoFit
    Range("L3").Select
    With Selection.Interior
        .Pattern = xlSolid
        .PatternColorIndex = xlAutomatic
        .Color = 15773696
        .TintAndShade = 0
        .PatternTintAndShade = 0
    End With
    Selection.Font.Bold = True
    Range("A1").Select
End Sub