

Pipe Falsework-Planning, Design and Installation

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In California, cast-in-place (CIP) box girder construction is widely used for highway bridges and pipe falsework is a common system for supporting the concrete while gaining strength to be pre-stressed and eventually self-supporting. There is an adequate amount of published material regarding the design of falsework systems, but research revealed that there is limited material on the installation of falsework systems. The intent of this paper is to describe the pipe falsework system in general terms and discuss the methods in which the system is installed. The paper begins with a description of the most common pipe falsework system used on box girder bridges that exceed approximately 35 feet from ground level. Then, the system installation is discussed and recommendations are made for efficient construction practices. The design calculations are not discussed in this paper. Safety is always a major concern in any construction operation for the health and welfare of the workers and the public. In this paper, safety is mentioned throughout, however, each contractor is responsible for performing all work under the state of California and federal OSHA regulations.

Key Words: Falsework, Formwork, Box Girder Bridge Construction, Pipe Falsework, Falsework Installation

Introduction

This document was prepared to assist the contractor in determining when Pipe Falsework should be used, describe the system and suggest common installation procedures. This information can be used to assist inexperienced members of a construction management team on how to plan work involving pipe post falsework for cast-in-place (CIP) box girder bridge construction. The intended audience should be familiar with common construction terms, have knowledge in the principal of statics and some exposure to strength of materials. Most state agencies require the services of a registered, licensed engineer either as an employee of the contractor or an outside engineering firm. It is not implied that these methods to be discussed are the best or most efficient methods for falsework construction erection and removal. These are methods used by three contractors on state projects that were considered successful by general bridge construction standards. The success of these projects is measured by the economics of the system, the safety during construction and the time element of the installation and removal process.

Safety is always the most important issue in any construction operation for the health and welfare of the employees and the public. In this paper, safety is mentioned throughout, however, each contractor is responsible for performing all work under the local state and federal OSHA laws and regulations. The safety goal for any contractor should be to minimize reportable accidents and eliminate recordable accidents. A safe operation is also a productive operation. When searching the subject of temporary structures, falsework is usually towards the top of the list. The sensitivity and the risk inherent to any type of falsework will draw considerable attention. The support of hydrostatic pressures due to concrete placement and soil loading on a cofferdam are very crucial. However, they do not get the attention from the owner, engineer and engineering contractor as much as falsework. The collapse of either system can be catastrophic and even fatal, but gravity seems to come out on top as the more predictable force (Cardin, Itani and Pekcan, 2006). If a falsework system collapses, the freefalling of material almost always causes serious property damage, personal injury and sometimes fatalities.

California is still a state that designs and constructs many cast-in-place, pre-stressed box girder concrete bridges. During the writing of this paper, there were over 24,000 box girder bridges in California according to the California Division of Structure Maintenance and Investigations. At this same time there are approximately 800 steel girder bridges within their jurisdiction. Structure Maintenance and Investigations is responsible for managing the department's transportation structures. This includes performing bridge inspections in accordance with federal

regulations on over 12,000 State Highway bridges and approximately 12,200 bridges owned by local government agencies. This type of construction requires a great deal of falsework and other temporary structures. Steel girder bridges, which are more popular in some other states, utilize form systems that are suspended from the permanent girders. The chance of a catastrophic failure is limited to a localized area that might experience concrete and light weight wood forms falling. Throughout this document, recommendations are made with respect to process and procedures. These are recommendations of the author and individual contractors should perform a thorough analysis and research their own methods for similar types of work. The system described in this paper can also be used in multiple classes of a Construction program such as Estimating, Scheduling, Methods Analysis, Temporary Structure Design and Plan Reading. Knowing the intricate details of a system is crucial to its educational potential.

Pipe Post Falsework System Description, Terms and Cost

Pipe post falsework can be used for cast-in-place concrete box girder bridge construction when a bridge soffit (underside of the bridge) is 35 to 40 feet above the ground surface or higher. Timber is not readily available in lengths exceeding 30 feet, is very expensive per board foot and is not structurally efficient for falsework construction in excess of 35 feet. Efficiency, in this case means costly bracing does not have to be added in order to decrease the unsupported length of the post (Ratay, 1996). When falsework is low enough to use wood post construction, this method can be more economical, especially when multiple uses are achieved from the materials. This paper focuses on falsework ranging in height from thirty five feet to over one hundred feet using steel pipe posts.

Although steel prices have increased considerably in the last five years, steel pipe, when considering its loading capacity compared to wood, is relatively inexpensive. Load capacities of wood posts are much less than steel pipe even when the slenderness is favorable (Tischer and Kuprenas, 2003). When wood posts are used over 30 feet in height, its load capacity is reduced to under 40,000 pounds (ASCE, 2002). It is very difficult to design post loads under 60,000 pounds in post and beam falsework construction. Also, when taking into account the pipe's reuse capability along with its ability to be welded together from smaller pieces into longer lengths, makes it the best choice for posts on taller falsework systems. Other bridge designs can be used by the state agencies such as pre-cast concrete girders with a cast-in-place concrete deck or steel girder systems supporting cast-in-place concrete decks. These designs usually eliminate the use of falsework and can span longer distances. However, California utilizes box girder construction whenever the design criteria will allow, so they are not relying on expensive steel beam costs and availability and can benefit from local materials such as concrete and reinforcing steel (rebar).

Costs for timber or pipe post falsework under 35 feet in height ranges between \$14.00 and \$17.00 per square foot depending on material costs and ownership. When pipe post falsework is compared to timber post falsework, the cost analysis can only be compared up to this height. The reason is that above this height, timber becomes impractical, whereas, below 35 feet in height, both systems are within approximately \$3.00 per square foot. On the other hand, when the heights increase above the limitations of timber, steel post costs only increase by \$0.06-0.07 per square foot for each one foot increase in falsework height (ENR, 2011). In other words, if the falsework was 65 feet in height, a \$17.00 per square foot cost would only be increased to approximately \$18.95 per square foot.

System Foundation

The foundation of the system generally consists of eight inch thick timber pads or prefabricated concrete pads. Falsework systems are designed for soils to withstand approximately 2500 to 4000 pounds per square foot of ultimate pressure. There will always be a slight amount of settlement, but this should be accounted for in the elevation calculations covered later and a minimum 1.25:1 factor of safety. Typically, the soil accounts for 1/2 inch to 1 inch of settlement. This is in addition to the crushing amount between timber components, which will also be discussed later. To achieve the area required for the maximum compacted soil pressure, three or four 18 inch wide pads are usually necessary. This would create either a 4 ½ foot wide pad or a 6 foot wide pad. The number of pads would be determined by the amount of load coming from each post and distributed to its tributary area through cross members called corbels (ASCE, 2002). Typically, a design would not allow more than 3 foot of cantilever from the centerline of a corbel (12 x 12 timbers) to the end of a pad or more than five foot between the centerline of two adjacent corbels.

Above the timber pads, the load path is transferred through the corbels which are cut to a length equal to the width of the pad. It is most effective to run all timber grain perpendicular to the adjacent piece, because this reduces splitting and provides a more stable bearing surface. Some designers prefer to distribute the corbels on a consistent spacing and others prefer to place the required amount underneath the posts only. This is strictly a designer and contractor preference but the latter sometimes amounts to a few less corbels.

In most falsework systems, ease of removal is as important as ease of installation. For this reason, to increase the ease of removal, every system has a means of releasing the components from the pressure, which can be in excess of 600 pounds per square inch in compression (Cheng, F, 1997). This pressure is created from the weight of the concrete structure. A typical falsework foundation is a series of sand jacks and wood wedges between the corbels and the bottom cap beam. The sand jacks are filled with sand and fabricated from plywood, 2 X 6's and wrapped with two to three steel bandings. These can be fabricated onsite; however, it is sometimes more economical to purchase them from a shop that fabricates within a controlled environment and sometimes, with non-union labor. The sand jacks are filled with sand and covered with plywood (and plastic if wet weather is a factor). Sand provides a firm base and is easily removed. The wedges are cut from 4 X 4s and offer the system a way to make minor adjustments with little effort. Wedges should be a minimum of 16 inches in length so that they will allow one inch adjustment upward or downward and still provide 12 inches of bearing surface.

Braced Frames (Bents)

Bottom cap beams are most commonly H section piles and rest on the wedges. When used as caps, these beams are used to transfer load through their webs and are not designed for bending. However, the designer must check the web of the beam in the load zone (below and above each pipe post) to assure resistance against web crippling. In this area, the load is transferred through the beam's web which acts like a small column and is susceptible to web crippling. If crippling is an issue, the web can be supported on each side with steel stiffeners or wood blocking.

Figure 1 shows a typical pipe falsework bent. Attached to the bottom cap beam is the steel pipe post. The bottom of the pipe post is attached to a steel base plate, which is $\frac{1}{2}$ inch in thickness. The plate thickness only has to be thick enough to weld to the pipe post. The overall dimensions of the plate are determined by the pipe size. At a minimum, the plate should be sized one inch larger on each side of the outside of the pipe. For example, a 20 inch pipe should require minimum plate dimensions of 22 inches X 22 inches. The plates use special steel friction clips to attach to the top flange of the bottom cap beam. The bolt goes through a hole in the plate while the steel clip squeezes the beam flange so the friction between the two plates resists horizontal movement. Lateral loading is usually not an issue, so the friction capacity generated by a minimum of 80 foot-pounds of torque is generally adequate. The clips also help keep the pipe post attached to the cap beams during erection.

The pipe size is determined by the axial load and its resistance to buckling. Pipe sizes typically range from 18 inches to 24 inches in diameter and $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in thickness. Pipe can be supported mid-length in order to reduce its unsupported length, thus increasing its axial load capacity. However, the labor involved to install these additional members can cost more than the increase in pipe cost for the larger, heavier pipe.



Figure 1: Typical Pipe Post Falsework Bent

The top of the pipe attaches to the top cap beam with a swivel cap. A swivel cap is fabricated from A36 steel and uses the same clips to attach to the bottom flange of the beam. Besides providing a connection point, the swivel cap can also provide a cross slope of up to ten percent. This is usually enough to handle most highway bridge super-elevations (cross slope). The least expensive design for a pipe post and beam system is to have a level bottom cap beam and a plumb post. This allows your post height and your swivel caps to accommodate the cross slope.

The top cap is placed on the swivel caps and fastened with the same friction clips as described in the bottom cap to pipe post connection. This beam is always similar in size to the bottom cap beam, except when it is used for falsework lowering in which case it may require more bending capacity. Generally, like the bottom cap, the top cap is used as a connection device and only transfers load through its web directly and is not put in a bending situation. For this reason, web crippling may occur and it may be necessary to add stiffener plates between the flanges. This whole system creates what is commonly called a bent. Bents are usually spaced between 30 and 40 feet apart depending on the bridge loads (bridge geometry) and the size of the stringers.

Stringers and Soffit (Decking)

Stringers are beams that span from one bent to the next. Stringers support the bridge weight between bents and are always, at a minimum, placed underneath the bridges interior and exterior stem walls. Stringers must be designed for bending stress as well as have adequate lateral buckling resistance. Sometimes, if beam availability is an issue, stringers of a certain depth can be doubled under an interior stem wall for more bending capacity without using a beam with more depth or section modulus. This occurs frequently over traffic openings, where a road underneath the falsework is open to live traffic. In this case, the stringer span is increased to accommodate the lanes of traffic required, hence, a larger section modulus is needed or beams need to be doubled-up under the heavily loaded areas.

When stringers have an excessive maximum moment in combination with their unsupported length, it is necessary to either increase the beams moment resisting capabilities (reducing the depth to flange width ratio) or add cross bracing to resist buckling between stringers. The most common cross bracing consists of 4X4 lumber cut to a length that will fit snug between top and bottom alternating flanges and wrapped by steel banding. It is recommended to place softening devices on the flanges to protect the banding from the inherent sharp edges of beam flanges. Stringers will always deflect under the load of the concrete even when they are under-stressed. This does not mean the beam is overloaded. If this condition were to exceed the allowable deflection by the specifications, this could cause an excessive beam camber which reflects in the permanent structure.

The contractor and bridge authority perform numerous deflection calculations for each stringer under each load and span condition. A beam camber list is created that identifies the exact deflection anticipated for each stringer. From this list, the contractor cuts (usually from 2 inch thick lumber) individual tapered strips to be placed on top of the stringers. At each end of the stringer, the camber strips have a thickness of zero inches and increase in thickness towards the mid-span of the stringers. At the mid-span, the thickness equals the anticipated maximum deflection of that particular beam. Once the beams are in place with camber strips installed, cross bracing is installed and joists and decking material can be placed.

Accessories to a Pipe Falsework System

In addition to the components mentioned thus far, there are other structural components that compliment any falsework system during erection, for stability reasons and lateral loads such as seismic action. The most common practice for lateral and longitudinal bracing is to use reinforcing bars and wire rope (cable) in tension. As shown in Figure 1, cable bracing is attached to the bent after it is fabricated and before it is erected into its final vertical position. During erection, the cables are temporarily attached to a weight, typically concrete blocks called "dead men". Dead men are built to weight specification, depending on the load requirement to hold the bent in place (Hurd, 2004). The dead men resist lateral loads using a combination of their weight and their coefficient of friction

between the ground and the concrete. Once a series of bents have been placed, the cables may be transferred to the bottom caps of the adjacent bent. This sequence continues until all the bents are erected and permanently braced.

Longitudinal wire rope bracing is attached to the cap beams by placing a clevis through a hole in the flange of the beam and wrapping the wire rope through the shackle with a cable softener. Bents made from 3 to 5 posts are laterally braced with wire rope, post tensioning strand or reinforcing steel welded to a 6 inch piece of 'C' channel (C6X8.2) which is welded to the pipe post. If reinforcing steel is used for this application, it must be a grade of reinforcing steel that can be welded.

Falsework Design and Planning

Owner and Design Responsibilities

The State of California and many local municipalities today require falsework to be designed by an engineer that is registered as a Civil Engineer in the State of California (CalTrans, 1995). Many times the specifications require that falsework be over ten feet in height (from the supporting surface to the top of the plywood decking) and beam spans in excess of sixteen feet before they enforce this specification. In bridge construction, it is rare that the falsework does not qualify. It is common for a highway construction company to have a registered engineer on staff to design formwork, falsework and various types of earth shoring (Ratay, 1996). Other companies will hire an outside design firm registered and familiar with falsework design. To meet the demands of the construction industry and to avoid the high cost of errors and omissions insurance, a contractor with in-house capabilities may hire an outside firm.

Whether a firm uses inside or outside engineering, the responsible person should be familiar with the company's falsework material inventory. If the designer is familiar with the company inventory, he or she can incorporate their inventory material into the design, thus reducing the cost of the falsework system. This includes, but is not limited to, beams, posts, joists and plywood types that are already owned by the company. If the falsework design can utilize some or all of the material types already owned by the company, this will reduce the cost of the system, because they will only have to pay for trucking to the jobsite.

Design Characteristics

The permanent structure design, for the most part, dictates the design decisions for the falsework. Others factors include location and the supporting terrain which will dictate access, footing and hoisting requirements. The characteristics of a cast-in-place box girder bridge including stem spacing, wall and slab thickness, bridge spans and widths determine the weight of the components. The thickness of the concrete element also affects the weight of the structure. In turn, the box girder bridge stem wall spacing and bottom slab thickness govern the stringer spacing, number of posts and joist size by increasing or decreasing the tributary areas and per linear foot loads. Additionally, the spans determine the number and spacing of the falsework bents and the bridge width determines the length of the bent, hence, the number of posts.

During falsework erection some parts of the system are constructed in-place and some can and should be prefabricated and erected in large frame sections (bents). Bent prefabrication requires a great deal of pre-planning on behalf of the contractor's office staff prior to the start of work. For each span of falsework, a contractor's staff could expect to spend between 10 to 20 man hours of planning and calculations to make sure the completed falsework is constructed to the correct elevations so the final structure matches the drawings for elevation and horizontal location. It begins with the contour drawings (top deck topography map) provided by the bridge agency. The contour drawings show the deck elevations, cross slopes, super-elevations and crowns of the finished driving surface on the bridge.

If the stringers are all the same depth, the falsework should have only one elevation variation, the post length. In this case, the post is the only component of the system that is not a set dimension. The pads, corbels, wedges, sandjacks, bottom caps, top caps, stringers joists and plywood are all set dimensions based on the size of material called out by the design. A spreadsheet becomes very convenient to organize the elevations at each post location so that the post

length can be determined. Several factors in falsework construction cause the contractor to have to construct the falsework at a higher elevation than the planned contract contour elevations. These factors are bridge camber, stringer camber, settlement and crushing. This means the falsework is constructed with the anticipation that these factors will, during the course of construction, lower the falsework system.

When determining the post height required, several items need to be considered. The top elevation needs to be known and the total bridge thickness, including the top deck, inside walls and bottom deck concrete (CalTrans, 1995). Then the ground elevation (at the time the falsework will be in place) needs to be calculated or determined through surveying. The difference between the bottom of concrete and ground elevation is the height required for the total system, not necessarily the post height requirement. For post heights, subtract the dimension occupied by the decking, stringers, caps, corbels, sandjacks, wedges and pads. It is not unusual for this material to be between five and seven feet in overall height. When the calculations are complete, a drawing should be created that represents, graphically, what the bent will look like and the location of each pipe within the bent. The pipes should be labeled in the field according to the drawing. The first set of digit(s) is the bent number from the lower station to the higher stations and the second is a letter designation from left to right, ie. 2A, 2B, 2C, etc.

Bridge camber is the anticipated deflection in a bridge span once the bridge is post tensioned and the falsework is removed. The self weight of the bridge combined with the span length dictates how the bridge will deflect within a span. These dimensions are shown in the contract documents and illustrated with a camber sketch. Bridge camber is handled by constructing the falsework within a bridge span higher than the designed plan elevations in anticipation that the bridge spans will deflect the calculated amount.

Beam camber is the anticipated deflection of a temporary falsework beam caused by the load applied during placement of the concrete. The concept is the same as bridge camber except the self weight of the beam itself has little effect on the amount of deflection. These calculations cannot be completed until the contractor selects the stringers for the system. Once the stringers are selected and submitted to the bridge agency, camber can be calculated for each stringer. Strips of wood are cut at a prescribed slope and place on a steel beam to preset the camber into the beam as mentioned earlier (CalTrans, 1995). These strips of wood are called camber strips and usually rest on an additional piece of wood (2X4 placed flat) called a sleeper. The local bridge authorities typically issue a list of stringer camber dimensions for the contractor to use. Their dimensions are sometimes given to the nearest 1/32 inch, but should be rounded to the nearest 1/8 inch. For ease of installation, the camber strips and sleepers are placed on the stringers while on the ground before the crane lifts them into place.

Settlement occurs in the soil directly underneath the falsework pad. Due to the load placed on a falsework bent and distributed to the ground, the soil is compressed. Settlement ranges from 1/2 inch to 1 inch depending on the preparation of the soil prior to pad placement, the addition of compacted aggregate base or sand under the pad and the soil type itself. Settlement can be reduced by increasing the soil density with additional compaction effort prior to placing the falsework pads.

When the concrete loads are applied to the falsework system, the wood materials are compressed. This is referred to as crushing. Steel does not crush by any significant amount, so the wood to wood and wood to steel contact points are the only crushing locations considered. Every contact point, whether it is plywood to joist, stringer to top cap or bottom cap beam to wedges, creates some amount of crushing. Most wood species used in construction only allow between 450 and 600 pounds per square inch in compression perpendicular to its grain. The rule-of-thumb is to add 1/8th of an inch between all wood-to-wood joints and 1/16th of an inch between all wood-to-steel joints. For example, the system discussed above has four wood-to-wood joints and two wood-to-steel joints. The anticipated crushing would be 5/8 of an inch. If this is added to an anticipated settlement of 1/2", the falsework, due to crushing and settlement, would have to be raised 1 1/8th of an inch plus whatever is the bridge camber in that area .

Beam camber, settlement and crushing are measured after concrete placement by comparing the stringer elevation before and after. The majority of the weight comes from the bottom slab and stem wall concrete placement. Therefore, if any of the three move excessively, they can be compensated for later during the survey of the top deck elevation. System costs are always an important concern for the contractor.

Installation of Pipe Falsework

Prefabrication of Pipe Bents

To satisfy the construction schedule and to keep crews at their maximum productivity output, falsework bents are typically assembled prior to the day they are installed (erected). Assuming all the engineering is complete which includes calculating the post length for each location and the material is on site, the prefabrication of the pipe bents can begin. The location for this work should be close to where the bent will be placed. The bents are usually too large and cumbersome to be transported from one area of the project to another. Assembly will be much more efficient if beams or K-rail sections are used to support the falsework bents during prefabrication. This keeps all the work off the ground, allows space for workers to crawl underneath and positions the work closer to the employee's waist level, making it more comfortable for the workers.

Whenever possible, bracing hardware should be installed before the bent is erected. Some additional hardware that is usually installed while the bent is on the ground is the longitudinal wire rope bracing and stringer blocking. Stringer blocking is used to match the tops of different size stringers. It is also recommended to mark the stringers and their directions on top of the top cap prior to erection. This will eliminate confusion during the stringer placement. If pipes are reused on the same project, a pipe fabrication yard can be established on site. This yard, equipped with cutting torches and welding machines, can facilitate a crew to resize the pipes to new lengths so the pipe can be put back into operation in another bent.

Surveying and Grading for Pads

Survey is the first item of the falsework installation operation. Before the grading can begin, a survey crew should establish, at a minimum, the centerlines of the bents and offsets to the edge-of-deck. From these points, the falsework layout operation is self-sufficient.

It is very important that falsework is placed on level, compacted ground. If aggregate base or engineered fill can be placed under the pads, stability will be enhanced and settlement will be reduced. There is an additional cost for this material, labor and equipment so the contractor should analyze the risk versus the reward when deciding to what extent. In addition to being level, if the falsework will be in place during the winter, the pad foundation should be constructed a couple tenths of a foot higher than the original ground so water will drain away from the falsework pad and subsequently, the grade between the bents should have some sort of slope to help persuade the water away from pad locations. This slope should be a minimum of one percent.

Most projects have some sort of grading equipment onsite. Falsework pads can be graded with equipment as basic as a front end loader with a back drag box or a motor grader can be used for larger (longer) pads. Compaction should be achieved with a smooth drum roller when there is good access or a walk behind compactor (vibratory plate) when access is limited and there are several elevation changes. The goal is to reduce or eliminate most of the anticipated settlement; therefore, ninety to ninety-five percent relative compaction (by standard proctor test methods) should be achieved. The more time spent on compaction can reduce the anticipated settlement. On steep terrain, falsework grading can be more complicated. Depending on the slopes encountered, benching of the slope can be required and sometimes a retaining wall system is necessary if there are large elevation changes between falsework bents.

Placing Pads, Corbels, Sand Jacks, Wedges and Bent Frames

Before beginning, the crew should lay out the pad and corbel location from the survey points. The falsework installation drawings should have the corbel locations dimensioned from the survey offsets. The tolerances are typically less than two inches horizontally and a quarter inch in elevation. This operation can be accomplished with a small 2-3 person crew and with the support of a forklift. Many of the smaller pieces can and should be placed by hand. The sand jacks should be prepared before this operation begins to eliminate delays. Sand jack prefabrication involves compacting the sand into the prefabricated box, covering with a vapor barrier such as a plastic membrane (visqueen), placing the plywood plate on top and stockpiling on a pallet. Before any bents are placed, the elevation at the top of the wedges should be surveyed to an exact elevation that is shown on the bent drawing. At this point,

everything has been determined by the pre-engineered falsework drawings. Therefore, the elevation which was determined for the top of wedges can be checked and adjusted prior to bent placement. It is much more economical to make changes now, before a bent is set and braced.

As mentioned in “Prefabrication of Pipe Bents”, the bents should be located close enough to their final location so a crane can set up, stand and place a bent without moving. If it is necessary for the crane to travel (walk) with the bent, the contractor should check company policies and local government regulations before continuing. This would only be possible with a fixed-latticed boom, crawler type crane. A double check of the anticipated weight is recommended prior to bent placement. This requires the contractor to know the unit weight of every component within the bent. It is also recommended to use a “pre-lift” checklist to assure proper calculations and approvals.

Placement of Stringers and Soffit (joists and plywood)

Prior to placing the stringers, the falsework drawings should be double checked to assure the stringers go in the correct location. This is also when beam camber can be placed and secured on top of the beam. The camber should be nailed to a 2X4 which can be wired to the top flange of the stringer so it does not fall off during hoisting. If the blocking was not placed on the bents during their installation, the blocking should be placed on the stringer so the person receiving the stringer can position the blocking in its proper location before the stringer comes to rest on the top cap beam. Once a few rows of stringers are placed, the crane can hoist units of joists and plywood so the decking crew can begin their decking operation. The plywood direction should be determined by the engineer before the placement begins. The design may call for the face grain to be parallel to the plywood span or perpendicular to the plywood span. In addition, the bridge authority may require particular plywood direction as well.

During this operation, the personnel on the front line, placing the joist and plywood, are required by law to be protected from falls 100% of the time. As the decking is placed and handrail is constructed on each side, this requirement should be restricted to any personnel within a certain distance of the leading edge, usually 10 to 15 feet. There are several methods in which contractors provide tie off anchorage points for their employees. This should be determined by the contractor and designed by a Civil Engineer, registered in the state in which the work is to be performed.

Setting Falsework to the Proper Grade (elevation adjustment)

Falsework adjustment is necessary when the elevation of the plywood decking at any known point is higher or lower than the contour drawings indicate. These plan elevations are typically adjusted for settlement and camber. Checking the deck elevation includes surveying specific points on the plywood deck and comparing the actual elevation to a predetermined elevation which was calculated on the falsework drawings. Grading is probably the most dangerous operation during both the erection and the removal of the falsework. Many falsework accidents happen during the grading operation. Because grading involves raising or lowering the falsework bents, the longitudinal cables almost always have to be loosened, adjusted and tightened again. Even though this requires a crew of at least eight people, something can go wrong if there is not good communication between the crew members.

Hydraulic jacks are generally used to raise and lower a bent if necessary. It is more accurate if this is done after most of the reinforcing steel has been placed. Adding this extra weight assures that the various materials that make up the falsework are in contact with each other. Before beginning any grading operation, the beam clamps must be installed. Beam clamps attach the top flange of the top cap to the bottom flange of the stringers. The clamps are originally designed to transfer longitudinal load throughout the system during the concrete loading period, however, they serve a second purpose during the elevation adjustment process. Usually, with proper planning and engineering the actual elevation is not more than one inch higher or lower than the planned elevations. The next step is to survey the elevation of the falsework and make final adjustments.

This concludes the falsework erection process. At this time, the falsework should be ready for reinforcing steel, post tensioning, formwork and concrete placement. During the concrete placement, it is recommended and usually mandatory by the bridge authority to measure the combination of total settlement and crushing of the falsework system. This can be achieved by attaching metal bands to the bottom of the joists in a location where displacement is to be measured. Metal bands work well because they do not stretch easily. Directly below the band location, place a

fixed device such as a driven wood or metal stake and a mark representing the end of the band. Most of the settlement and crushing occurs during the bottom deck and stem wall concrete placement. The top deck placement usually does not add any significant measurement. At this time, the mark should be checked against the original mark. This indicates the amount of crushing within the materials and the settlement to the soil under the pads. One half of one inch up to one inch could be expected.

Conclusion

Pipe post falsework is the premier system of falsework for California bridge builders when the height exceeds that which makes wood post falsework economically favorable or impractical because of the height. Adequate knowledge of the installation and removal of pipe post falsework is crucial to lowering operational costs and improving safety experiences. In addition, hardware has been developed by bridge building contractors over the years making pipe post falsework a staple to the industry. The system has been refined and most tradesman, who perform this work on a regular basis, are familiar with the installation and removal process and can achieve the lowest possible costs while reducing reportable accidents and eliminating recordable accidents.

Although the system can be common to the average management staff, newly hired engineers need to be educated about the use of the system. Most engineering firms, specializing in design of temporary structures, are familiar with the pipe post falsework system and can provide economical designs utilizing company inventories most efficiently. These engineers can step in when a contractor's in-house engineering department is either too busy or inexperienced. The system described in this paper can be used in multiple classes of a Construction program such as Estimating, Scheduling, Methods Analysis, Temporary Structure Design and Plan Reading. Due to the page limitations of this paper, photos and illustrations had to be left out, but are available.

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