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EARTH SHORING FOR CAST-IN-PLACE AND POST TENSIONED BRIDGE CONSTRUCTION

A Thesis
Presented for the
Master of Science
Degree
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Michael T. Dempster

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ABSTRACT

This thesis offers engineers, contractors, and planners a model for the design, selection, and construction of cast-in-place and post-tensioned concrete bridges. Concrete bridges have traditionally been built using conventional falsework to support the loads, but failures have sometimes occurred in conventional falsework because of improper design or construction. The results of such failures are increased costs, reduced safety, time delays, and lowered profits. In addition, increases in construction cost, stiffer competition, and fewer construction projects require the adaptation of innovative concepts, such as those illustrated in this thesis, for the design and construction of temporary support systems. In particular, earth shoring represents an effective alternative to conventional falsework.

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CHAPTER I

INTRODUCTION

1.1 PROBLEM DEFINITION

Falsework is the temporary structure that enables a bridge or building to be constructed and be retained until the permanent structure is self-supporting. Bridges have traditionally been built using conventional falsework to carry live, construction, and dead loads; even during the Roman Empire, for example, a great many arches and domes were constructed using falsework. More recently, with the invention of portland cement concrete, the construction of temporary support structures has extensively used conventional falsework design (36).

Generally, the conventional supporting falsework structure is constructed of wood, steel, aluminum, concrete, or a combination of the those materials. Because these falsework structures are temporary, some contractors do not give enough attention to falsework design and construction. Accordingly, failures have resulted, causing worker safety concerns, construction delays, increased costs, higher insurance premiums, and lost revenue.

Experience has shown that conventional falsework failures for cast-in-place and post-tensioned bridge construction have taken place for many reasons, but a significant number of failures are the result of incorrect design or poor construction practices (36). During a 23 year period, 36 bridges collapsed and 53 people died; approximately 70 to 75 percent of these failures were associated with scaffold-type falsework systems (34). Figure 1.1 illustrates a conventional falsework structural system for a cast-in-place concrete bridge.

In contrast to the problems of conventional falsework, earth shoring is an attractive alternative for constructing short cast-in-place or post-tensioned concrete bridges. Figure 1.2 shows an example of earth shoring for a cast-in-place concrete box girder bridge. Earth shoring offers a quicker, safer, and less expensive method to construct a temporary support system.

This thesis offers a general guide for engineers and contractors in the design and construction of cast-in-place and post-tensioned concrete bridges, with emphasis on the construction side of the project. Relative safety and the cost of building earth shoring are then compared with the data for conventional falsework to evaluate earth shoring's feasibility.

1.2 EARTH SHORING

The general procedure for constructing earth shoring is to construct a temporary embankment to the bottom of the box girder elevation after the bridge foundations are complete. Trenches are excavated in the top of the temporary shoring to drive piling and to construct abutments at each end of the structure. A thin concrete slab called a waste slab is poured and finished to serve as a foundation and a form for the concrete box girder bridge. Upon completion of the superstructure, the earth shoring is excavated prior to the bridge being put into service. Figures 1.2, 1.3 and 1.4 illustrate typical earth shoring details.

1.3 DEFINITIONS

For this thesis, the following definitions apply.

Conventional falsework - A temporary construction work used to support the permanent structure until it becomes self-supporting (see Figure 1.1). Falsework would include steel or timber beams, girders, columns, piles and foundations, and any proprietary equipment, including modular frames, post shores, and adjustable horizontal shoring (14).

Figure 1.1 Conventional falsework

Figure 1.2 Earth shoring

Figure 1.3 Earth shoring embankment

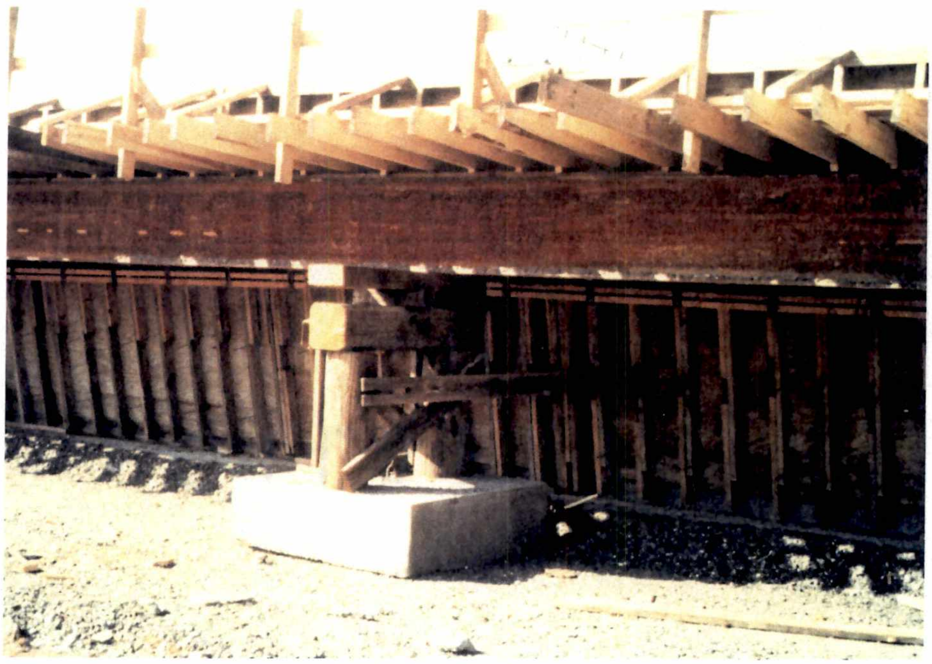

Figure 1.4 Earth shoring waste slab

Earth shoring - A temporary soil embankment used to support the permanent bridge structure until it becomes self-supporting (see Figure 1.2). Earth shoring consists of existing or compacted soil elevated to a proper elevation to construct a permanent bridge structure.

Formwork - A temporary structure or mold used to retain the plastic or fluid concrete in its designated shape until it becomes self-supporting. Formwork must have sufficient strength to resist the fluid pressure exerted by the plastic concrete and any other generated loads.

CHAPTER II.

LOADINGS

2.1 GENERAL

Determining the loads on earth shoring and conventional falsework systems can be difficult because of the placement schedule, location, and type of equipment used in assembling a bridge. Estimations of the dead and live loads on a structure may have reasonable accuracy; but the loads from formwork, impact, moving support equipment, concrete ponding, and accidently applied loads may be underestimated. However, earth shoring offers an advantage over conventional falsework because both horizontal and impact loads may by omitted in the design of earth shoring.

2.2 CONCRETE PLACEMENT

Controlling the rate and sequence of placement of concrete is necessary to ensure that adverse loadings are not allowed to develop. Ideally, it is desirable to uniformly distribute the pressures exerted on the shoring by adjusting the rates of pour and locations of construction joints in the area of the pour. However, non-uniform loading may occur in almost any cast-in-place concrete construction project. Consequently, careful consideration to uniformly distributing the placement of concrete on the structure should be taken. In addition, the methods used to place concrete on the formwork, and its distribution, can impose impact or surge effects on the formwork and ultimately on the shoring (14).

2.3 DEAD LOADS

Dead loads include the weight of the reinforcing steel, concrete, formwork, and falsework. Concrete and reinforcing steel typically weigh 150 to 160 pounds per cubic foot (pcf) for normal weight concrete and 120 to 130 (pcf) for light weight concrete (1). The formwork itself weighs between 3 and 15 pounds per square foot (psf). Some designers suggest that the weight of the form is small compared with the imposed live load. Because formwork weight is small in relation to the weight of the reinforced concrete and the live load, the form weights are frequently ignored; but ignoring the form dead load may create a dangerous situation.

The concrete dead load includes the volume of concrete placed on a bridge deck and beams. Calculations of the total concrete dead load by estimating the quantity of concrete should be as precise as possible. The additional load of concrete resulting from superelevation, crowns, settlement and deflection of formwork, shoring, or falsework can be substantial. To determine the weight of a slab, an engineer might multiply the slab's dimensions by the unit weight of concrete and reinforcing steel. By calculating the deck loads or pressures in such a manner, one might exclude the crowns and superelevation, which may require an additional 1 to 2 inches of concrete or a pressure of 12.5 to 25 psf (18). Ponding of the concrete from deflections in the forms, shoring, or falsework may produce additional dead load. By "pre-adjusting" the shoring or falsework, one can account for ponding of the concrete. The preadjustment entails adding camber to the form system to account for the expected deflections.

A consideration of the additional dead loads imposed may not be warranted when compared with the variability of all other loads placed on the structure such as live, accidental, and environmental loads; however, caution must be used when neglecting dead loads from items such as forms, crowns, superelevations, and heavy reinforcement.

2.4 LIVE LOADS

The weight of stored materials, moving equipment, workers, and falling concrete during placement produces both static and dynamic live loads. Because of the impact forces generated in placement, the rate of pour must receive careful attention. Two important items for consideration are the method of concrete placement and rate of placement. Also, the movement created by construction equipment on the falsework makes equipment loading an important factor.

Impact loads result from a number of construction activities, but some of the most common are

- Concrete falling from a bucket or from a chute,
- Horizontal forces due to equipment movement, and
- Concrete pumping (19)(29).

Impact forces from the dropping of material such as concrete onto the deck can create significant force or pressure increases in the falsework. Impact forces can be very localized, creating a high pressure on the support system. An example by Hover (18) shows that a 1.5 cubic yard (cyd) bucket being emptied in 5 seconds can result in an additional force of 606 pounds (lbs) on the structure. Moreover, Wang (34), in his study on falsework failure, indicates that the main cause of falsework failures is impact from concrete pouring operations.

Localized impact forces should be recognized in conventional falsework systems and in formwork but are not necessarily significant when dealing with earth shoring, because the impact loads are distributed over a larger area, thus reducing the pressure. Also, the forces are immediately directed to the ground rather than to joists, stringers, and columns.

Motorized carts, deck finishers, and other equipment used in the construction of bridges may induce additional vertical and horizontal loads on the form system. Starting, stopping, pumping, and centrifugal activity of equipment may produce significant forces that may require additional design considerations. Ratay (31) provides a list of common construction equipment and their loads.

Horizontal loads are mentioned because they affect the design of conventional falsework systems, but they do not influence the design of earth shoring. Forces that create horizontal load include wind, equipment, construction activities and concrete placement. When the bridge is built on earth shoring, the mass of the structure is much greater than any overturning force.

2.5 ACCIDENTAL LOADS

Accidental loads create a probability of serious overloading to a falsework system. For example, materials handled by cranes have the possibility of suddenly applying loads to the structural system as a result of a mishap during operation of the crane (19). Conventional falsework needs to be designed to allow for any type of load a crane may carry on the structure. In contrast, earth shoring does not need to be designed for an accidental load because of its ability to distribute the load over a large area.

2.6 RECOMMENDED DEAD AND LIVE LOADS

The previous discussion in this chapter related to the loading on shoring and falsework systems highlights critical concerns that an engineer must consider when determining loads for a temporary support structure. In light of such concerns, several regulatory agencies and other organizations have established guidelines regarding loads and support structures. The Federal Highway Administration, for example, has issued Guide Design Specification for Bridge Temporary Works, an excerpt from which is given below:

- Dead load shall be the weight of the concrete, construction materials, and falsework. The weight of concrete, reinforcing steel, and formwork shall not be less than 160 (pcf) for normal concrete or 130 (pcf) for lightweight concrete.

• Construction live load shall consist of the weight of any equipment, applied as a concentrated load, plus a uniform load of 20 (psf) applied over the area, plus 75 (plf) applied at the outside edge of falsework deck.

• Impact design loads shall be applied to steel members and manufactured components when impact can occur during these operations.

1.) Concrete placing operations - increase dead load by not less than 30 percent of the weight of the material being placed.

2.) Lifting operations - increase the static load by not less than 30 percent for mechanical equipment and not less than 15 percent for manual equipment.

3.) Motorized carts - increase the uniform live load by an additional 25 (psf).

• Horizontal load shall be the sum of all horizontal forces acting at various heights on the structure. For heavy-duty falsework supporting greater than 30 (kips) per leg, the horizontal forces shall be designed by the Uniform Building Code.

• The minimum design vertical load shall be not less than 100 (psf) for both the dead and live load, regardless of any increase for impact loading.

CHAPTER III

DESIGN OF EARTH SHORING

3.1 INTRODUCTION

An earth shoring foundation is designed to limit stress levels in the soil, to provide an adequate factor of safety against a bearing capacity failure, and to limit settlement of the structure. Because candidate sites are limited to locations where earth shoring can be applied, the technique cannot work in place of every falsework structure. Considerations of traffic maintenance, geological features, topography, stream crossings, soil type, and related topics limit the design possibilities. Therefore, a thorough investigation should precede construction to determine the suitability of the site for earth shoring.

The contractor is ultimately responsible for the design and construction of a safe and adequate temporary support structure that should support all loads imposed and provide sufficient strength to produce a permanent structure which satisfies the requirements of the plans and specifications. A construction engineer should perform a safety review and approve all work on a temporary structure; and the engineer's responsibilities do not stop with the completion of the plans and specifications. Communication with the field personnel, for instance, should be established before construction begins so that the engineer can be directly involved in the construction process. Through such involvement, the engineer can oversee the entire construction process to ensure that the design follows specifications and can assist in solving problems at the construction site.

3.2 FOUNDATION DESIGN FOR EARTH SHORING

A foundation provides a means of transferring the loads of a structure to the ground in a manner that provides adequate stability for the structure. An allowable foundation support requires that there be no danger of a bearing failure which would result in detrimental settlement or collapse of the structure.

Typically, in earth shoring projects, the compacted soil is wide enough to store materials, maneuver trucks, operate cranes, and have a general work space on both sides of the bridge. Often a mat-type foundation is used. The mat serves a dual purpose: it acts as a foundation and as formwork for the bridge. A typical cross section of a mat foundation is constructed of a 2.5 to 4 inch thick unreinforced concrete slab, with the foundation cast directly onto the soil embankment and extending past the outer edges of the bridge deck (see Figure 3.1). A bond inhibiting agent is spread on top of the waste slab surface to prevent the bottom of the bridge deck from adhering to the foundation.

In addition to the foundations, slope stability is an essential part of the earth shoring system. Slope stability refers to the restraining of a failure wedge by shear resistance along a rupture surface of the earth embankment. A slip can result from an increase in surcharge load, a reduction in shear strength of the soil, a change in pore water pressure, erosion, or any combination of these factors.

In an earth shoring embankment, the foundation and slopes are designed to limit the stress levels in the embankment to provide adequate safety against bearing capacity failures, slip plane failures, and detrimental settlement. The soil design pressure is chosen on the basis of measured properties of the earth embankment that were determined from a complete site investigation. The construction engineer should be familiar with the soil investigation and any design assumptions to confirm that the design is consistent with the conditions in the field (14).

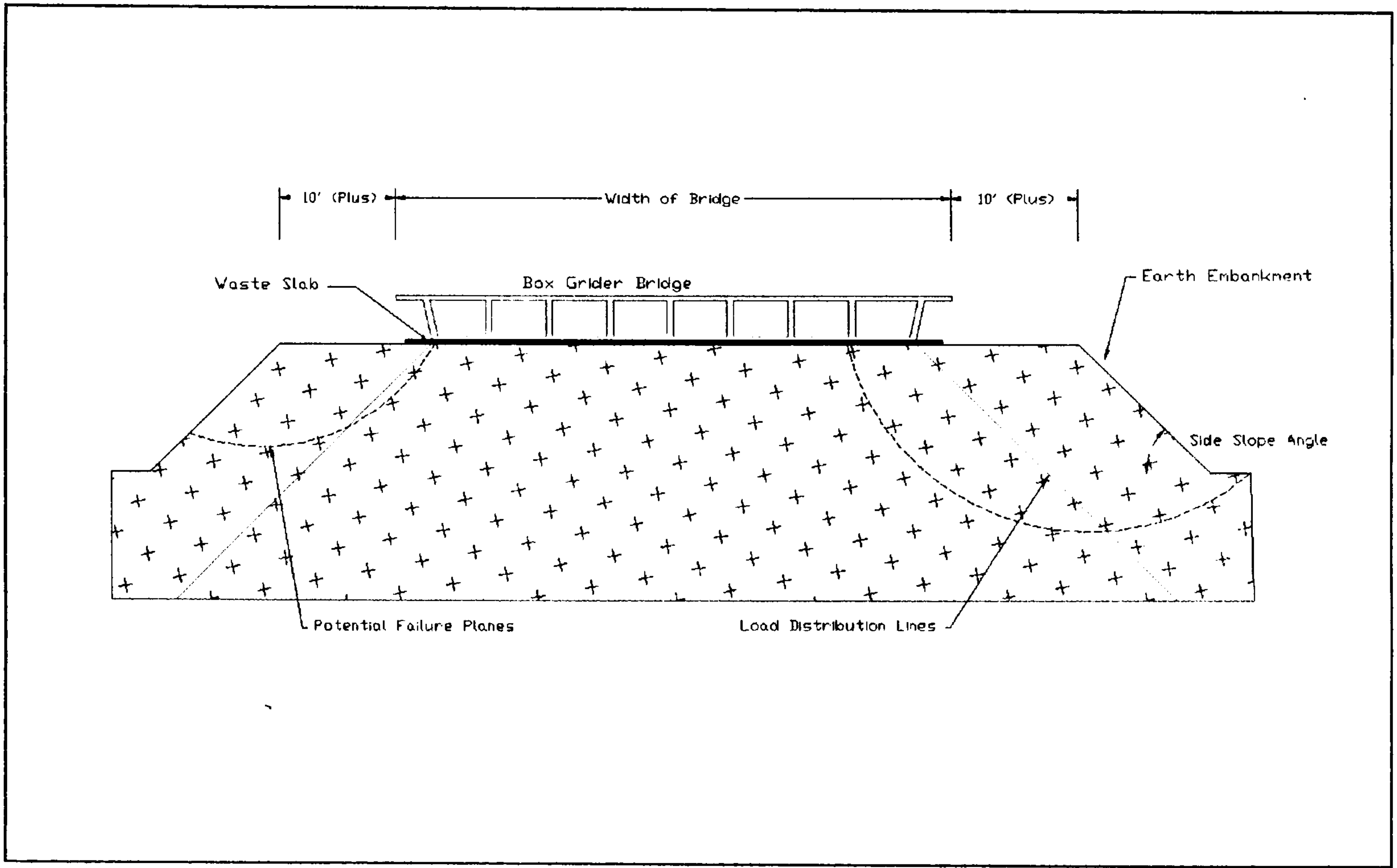

Figure 3.1 Typical foundation cross section

After the soil properties have been determined, the area adjacent to the foundation should be protected. Because an earth shoring foundation is generally very shallow, it is susceptible to detrimental conditions such as changing moisture content, frost action and erosion. Thus, steps should be taken to limit the development and effects of these possible conditions. Furthermore, the general stability of the ground under and beside the foundation will depend on the surrounding ground's remaining unaffected by some of the following conditions: extreme rainfall, melting snow, severe frosts, excessive hot dry weather, equipment movement on the embankment, excavation of the surrounding ground, compaction operations, and any other loads or pressures adjacent to or on the earth shoring.

For the design of a foundation and slopes for an earth shoring system, a qualified engineer specializing in foundations and soil mechanics should examine and evaluate each construction situation. However, some general design guide-lines for construction of foundations and slopes for an earth shoring system are listed in Tables 3.1 and 3.2.

3.3 COMPACTION REQUIREMENTS FOR EARTH SHORING

Compacting is the controlled placement of soil in layers of predetermined thicknesses and moisture content and compressing it by suitable mechanical or static equipment to achieve a specific density (20). Compaction reduces the voids within the soil, improving its engineering properties and resulting in a reduction in settlement, increased shear strength, improved stability of slopes, and increased bearing capacity. Different types of compaction are used to build an earth shoring system. Primarily, mechanical compaction is used although preloading also works.

The mechanical properties of a given soil type are directly related to its density. Proctor (4) established a relationship in the compaction of cohesive soil

Table 3.1 Properties of compacted soils.

Group Symbol	Soil type	Dry density (pcf)	Optimum moisture %	Cohesion (psf)	Friction angle	CBR values	Subgrade Modulus (lb/in^3)
GW	Well graded clean gravels, gravel sand mixtures	125 to 135	11 to 8	0	>38	40 to 80	300 to 500
GP	Poorly graded clean gravels, gravel sand mixture	115 to 125	14 to 11	0	>37	30 to 60	250 to 400
GM	Silty gravels, poorly graded gravel sand silt	120 to 135	12 to 8		>34	20 to 60	100 to 400
GC	Clayey gravels, poorly graded gravel sand clay	115 to 130	14 to 9		>31	20 to 40	100 to300
SW	Well graded clean sand, gravelly sands	110 to 130	16 to 9	0	38	20 to 40	200 to 300
SP	Poorly graded clean sand, sand gravel mixture	100 to 120	21 to 12	0	37	10 to 40	200 to 300
SM	Silty sands, poorly graded sand silt mixture	110 to 125	16 to 11	1050	34	10 to 40	100 to 300
SM-SC	Sand silt clay mix with slightly plastic fines	110 to 130	15 to 11	1050	33		

Source: Hunt, Roy E., Geotechnical Engineering Analysis and Evaluation. New York: McGraw Hill, 1986.

Table 3.1 (Conc).

Group Symbol	Soil type	Dry density (pcf)	Optimum moisture %	Cohesion (psf)	Friction angle	CBR values	Subgrade Modulus (lb/in^3)
SC	Clayey sands, poorly graded sand clay mixture	105 to 125	19 to 11	1550	31	5 to 20	100 to 300
ML	Inorganic silts and clayey silts	95 to 120	24 to 12	1400	32	15 or less	100 to 200
ML-CL	Mixture of inorganic silt and clay	100 to 120	22 to 12	1350	32		
CL	Inorganic clays of low to medium plasticity	95 to 120	24 to 12	1800	28	15 or less	50 to 200
OL	Organic silts and silt clays of low plasticity	80 to 100	33 to 21			5 or less	50 to 100
MH	Inorganic clayey silts, elastic silts	70 to 95	40 to 24	1500	25	10 or less	50 to 100
CH	Inorganic clays of high plasticity	75 to 105	36 to 19	2150	19	15 or less	50 to 150
OH	Organic clays and silty clays	65 to 100	45 to 21			5 or less	25 to 100

Table 3.2 Suggested slope angles

Classification		Side slope	Compaction
AASHTO	USCS		
A-1	GW, GP, SW	1.5 to 1	95% or greater
A-3	SP	1.5 to 1	100% or greater
A-2-4, A-2-5	Most GM and SM	2 to 1	95% or greater
A-2-6 or 7	GC or SC	2 to 1	95% of greater
A-4, A-5	ML, MH	2 to 1	95% of greater
A-6, A-7	CL, CH	2 to 1	95 to 100%

Source: Winterkorn, Hans F. and Fang, Hsai-Yang., Foundation Engineering Handbook. New York: Van Nostrand Reinhold, 1975.

between moisture and density. Four variables influence the compaction of soil: dry density, water content, compactive effort, and soil type.

When the maximum dry density and water content have been determined in a laboratory, specifications can be established for compaction in earth shoring. Generally, the moisture content of the soil needs to be on the dry side of optimum; shear strength and settlement properties are particularly improved when soil with this characteristic is compacted. Standards for compacting soil in the laboratory by the standard Proctor and the modified Proctor test are given by ASTM Standard D-698 and D-1557 respectively.

Field equipment used in compaction should be selected for the type of material being compacted. The most common types of machines include sheepsfoot, pneumatic, and smooth drum rollers. A sheepsfoot roller is most effective for cohesive soils, whereas the pneumatic and drum roller preform better with cohensionless soils. The number of passes required to produce the needed compaction for a project depends on the lift thicknesses and the properties of the soil. Caterpillar's Performance Handbook (8) gives different specifications and performance information on compaction equipment.

Another means of improving the existing soil is to preload the area where the bridge will be erected. Preloading serves its purpose when an area soil does not have the density needed for the induced loads. In preloading a site, storage tanks or fill material is placed over the weak soil to reduce the voids in the soil. The time to compact soil with preloading takes considerably longer than mechanical compaction.

In either case, monitoring of the operations plays a major role in obtaining good compaction. There are two phases in the compaction of a quality fill: observation and testing. The compacting operations should be supervised to assure the filling and compacting procedures are properly achieved. Testing will be needed to demonstrate that proper soil density is achieved.

The borrow source is another important element in the successful completion of an earth shoring system. Evaluation should be made of the on site material from excavating operations and from off site borrow sources. Fill characteristics may change from location to location thus altering the engineering properties of the earth embankment. Hence, at each site suitable for earth shoring, an in-depth investigation of the soil should be conducted.

CHAPTER IV

GUIDE-LINES FOR CONSTRUCTING, MONITORING, AND REMOVING EARTH SHORING

4.1 INTRODUCTION

Erection, monitoring, and removal of shoring are important steps in constructing concrete bridges. Failure to give proper consideration to these points can result in a failure or incomplete service of the shoring. Therefore, attention must be given to each of these areas to ensure that the shoring performs properly. Each of these construction sequences is discussed in this chapter.

4.2 CONSTRUCTION OF SHORING EMBANKMENTS

The general construction procedure for an earth shored bridge is to compact a temporary embankment to the bottom of the box girder elevation. After compaction the top layer is graded and a 2.5 to 4 inch thick concrete slab is poured and finished to serve as a foundation and the bottom formwork for the box girder (33). After completion of the bridge, the earth fill is excavated from under the waste slab.

Construction of the earth shoring can be accomplished using two different techniques. The first is to haul and compact all the material required for the support system. Abutments, piers, and pilings should be completed before compaction and hauling efforts begin. During the hauling and compacting of soil, care must be taken not to damage the bridge foundation structure. Figures 4.1 and 4.2 illustrate the construction of earth shoring using 100 percent of borrow material.

A second technique is to use the existing ground contours of the construction site. This possibility is limited to certain geographical locations of a proposed bridge

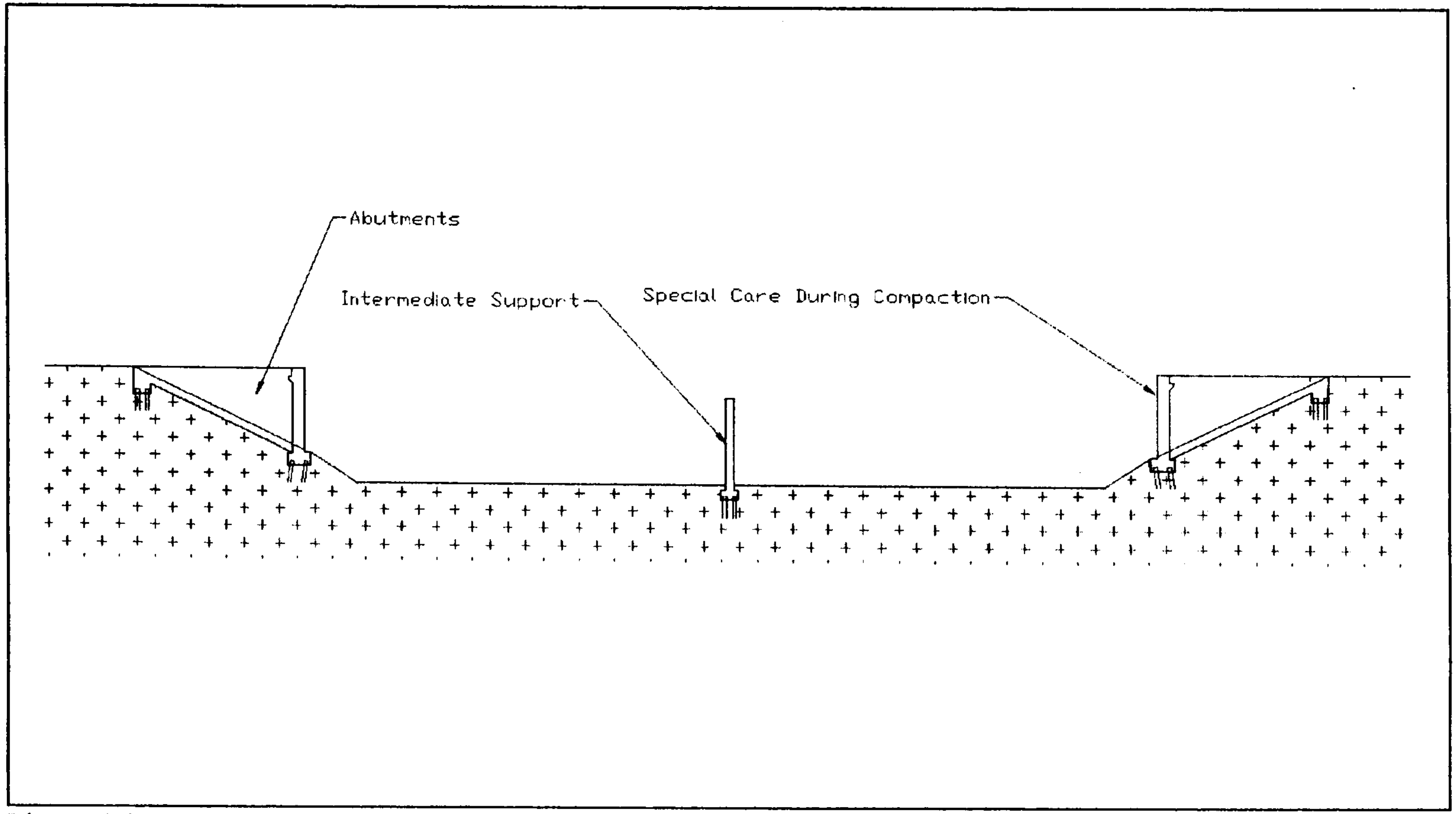

Figure 4.1 Starting the compacting process

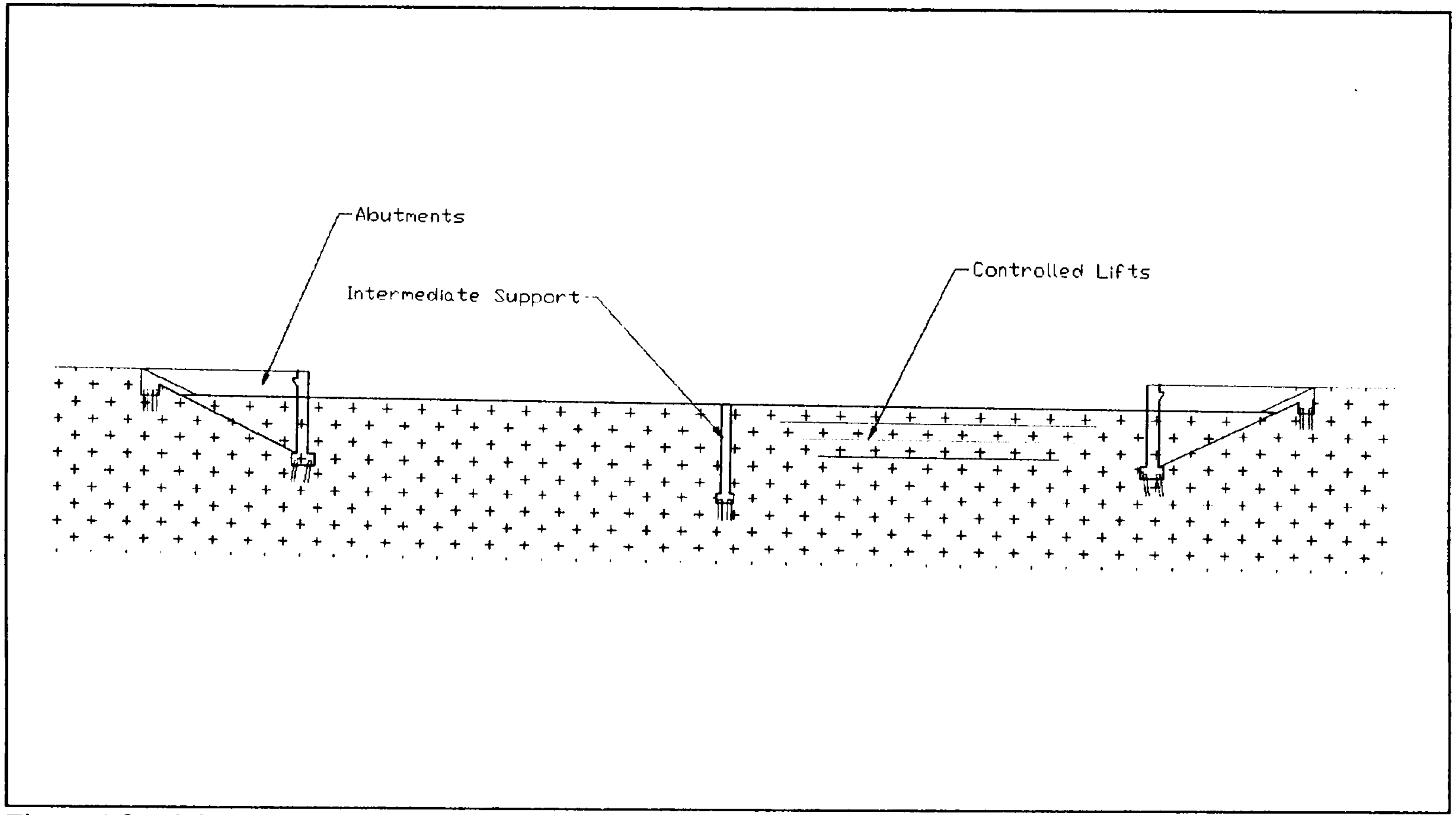

Figure 4.2 Finished embankment

site. Trenches are excavated so that foundations can be placed within the existing hillside. After the piers and abutments are complete, backfilling and compaction around the bridge foundations occurs. For this technique, the in situ properties of the soil control the feasibility of construction.

In both cases, after the earthen material has been placed with heavy equipment (ie, trucks, scrapers), a grader is used to add superelevations to compensate for settlement. A waste slab is cast onto the graded ground and usually consists of 2.5 to 4 inches of unreinforced concrete that act as a temporary foundation for the concrete bridge. The slab increases the strength and stability of the shoring by spreading the load across the shoring. Once the temporary slab has had proper time to cure, a barrier is placed on top of the slab to prevent the bottom of the bridge from bonding to the waste slab. The construction of the formwork and other bridge components can be implemented after the waste slab's bond breaker has been finished. Figure 4.3 shows construction of a concrete box girder bridge on earth shoring.

4.2.1 COMPACTION

Controlling the compaction efforts on the fill plays a major role in the design and behavior of the supporting system. The strength and compressibility of the soil, either in place or being put in place, must be evaluated and, if necessary, improved. The relationship between moisture and density for a particular soil is an important relationship and should be an important determinant of design density. After the density required to support the structure has been defined, an inspection and evaluation of the shoring fill during construction is needed. The evaluation should reveal if the compaction meets the specifications set in the design of the shoring. The most accurate way to determine whether the density is correct is testing. Field testing the compacted material represents the best way to assess the compactive effort. A nuclear density gauge or other field test equipment can test for the required properties quickly.

Figure 4.3 Construction of a cast-in-place concrete box girder bridge

Source: Knoxville News Sentinel Company, January 29, 1992.

Lift thickness of the fill material is another important consideration in achieving proper soil densities. The height of soil placed in one pass of construction of the shoring can affect the settlement and strength of the soil. The type of soil used and the type of equipment used to compact the soil should determine the lifts. In general, the thickness in cohesive soils should range from 6 to 9 inches because a greater thickness will not achieve the required compaction at the bottom of the lift. Additionally, the partial compaction of the lower half of each lift creates a greater chance of settlement and improper behavior in the shoring.

4.3 MONITORING OF THE EMBANKMENT

To determine if the structure is behaving as designed, measurements of settlement and slope movement of the shoring should be taken. If these measurements are significantly different from predicted values, then the loading sequences should be altered and sufficient compensation should be implemented. Observations of the fill material serve two functions; monitoring the existing job and assisting in the design of similar projects.

4.3.1 MONITORING SETTLEMENT

Settlement of the waste slab and selected points on and around the bridge structure should be evaluated to see the extent to which settlement is occurring during construction. Because the settlement observations provide information on the amount, rate, and distribution of settlement, compensation or construction sequencing can be altered to offset some settlement. The three most common field observations for settlement in bridge construction are discussed in this section.

The most frequently used method for monitoring settlement is that of a bench mark and a surveying level. Readings from a known elevation can be compared with previous readings to see if settlement is occurring and, if so how much and at what location around or on the bridge. Accurate measurements of settlement movement generally require seating the measuring point below the actual surface. Figure 4.4 illustrates a suitable measuring point for surface leveling. Placing the measuring point below the actual surface prevents it from being altered during construction activities.

A second way to determine settlement requires the use of settlement platforms which are square plates of steel, wood, or concrete placed on the original ground surface and to which a riser pipe is attached (10). Figure 4.5 illustrates a settlement platform. During the construction of the embankment, a rod is connected the center of the plate. As the fill proceeds upward, additional riser pipes are attached to keep the pipes above the ground surface. When the compaction has been completed, measurements are taken to determine the initial height. Similarly, additional readings are taken throughout the project and compared with pervious readings. The primary advantage of using settlement platforms is their simplicity. Limitations include negative friction on the connecting rods and the potential for construction equipment damaging the platform during compaction.

The third method of settlement detection involves the use of piano wire stretched taught between the abutments and/or piers. Calculating the distance off the straight piano wire can be used to measure settlement. The piano wire and settlement platform methods show settlement only along the edges of the bridge.

The use of a surveyor's level is an easy accurate means of determining settlement. The other two methods are simpler but not as effective. All three methods are mentioned here, however, because using a level may not always be the best choice. The time elapse between reading on the equipment is dependent upon the type soil and the bridge tolerances.

4.3.2 MONITORING SLOPE STABILITY

Throughout the construction phase, movement of the side slopes must be

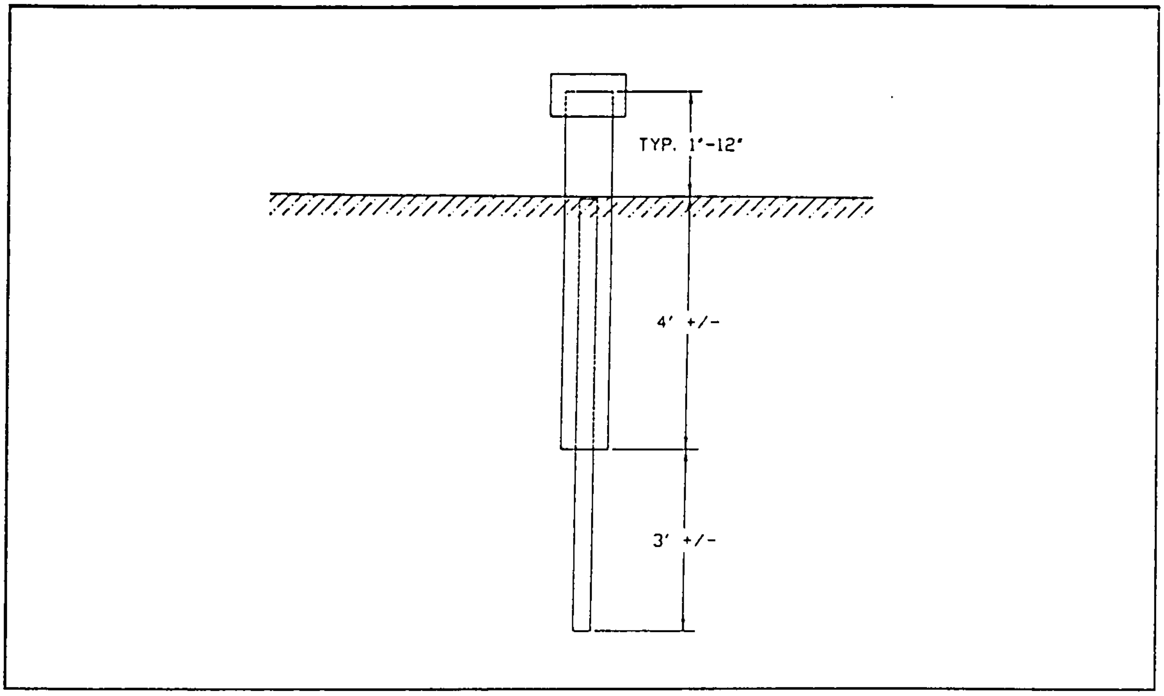

Figure 4.4 Typical measuring point

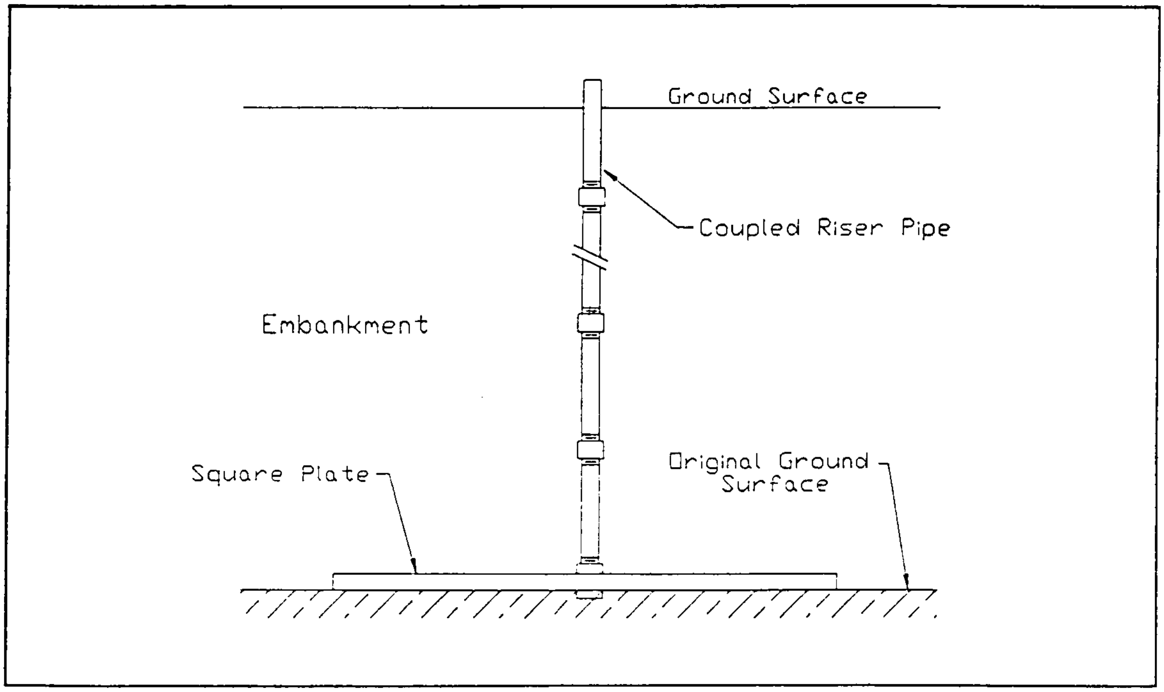

Figure 4.5 Settlement platform

measured in order to determine that the earth shoring has adequate slope stability. Movement on an embankment slope can affect the settlement and overall integrity of the bridge during construction. As with settlement measurements, slope observations detect the movement of the embankment slope.

Slope movement can be determined by either surface or subsurface measurements. Several commonly used surface and subsurface measuring instruments are available, but only surface surveying techniques are described in this thesis. Additional methods and other types of equipment are available and are described in Dunnicliff Geotechnical Instrumentation for Monitoring Field Performance (10).

Surveying slope stability is similar to measuring settlement, except for the location of measuring points. The monitoring holes are located on the top, middle, and/or bottom of the slope, with the location depending upon the soil type and the slope angle present. Figures 4.6 and 4.7 illustrate locations where reference points should be located for slope, toe, and base slope failures.

Monitoring the behavior of the shoring should begin at zero load and proceed until full load is applied. Observations should continue during pouring of concrete and extend well after concrete has been placed to ensure that the shoring is functioning adequately. This monitoring throughout the construction phases is a response to the numerous failures that have occurred during and after the placing of the concrete (34). If potential problems are detected early, counter-measures may be implemented to decrease the chance of failures.

4.4 REMOVAL

Earth shoring beneath a bridge can be removed more quickly and safely than conventional falsework. Less time is required to excavate the soil because of the simplicity of the shoring system compared to conventional falsework. Also, the material taken from under the earth shoring can sometimes be used on the existing construction site as fill material.

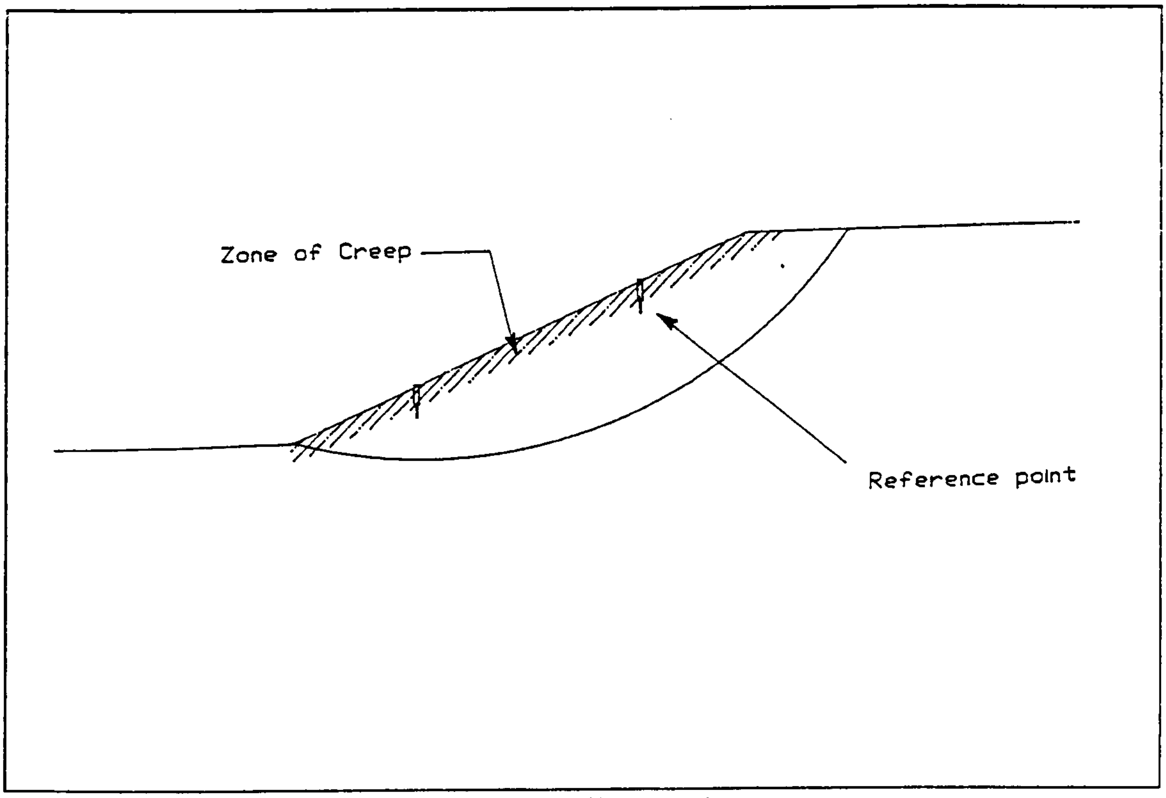

Figure 4.6 Reference points for toe slope failure wedge

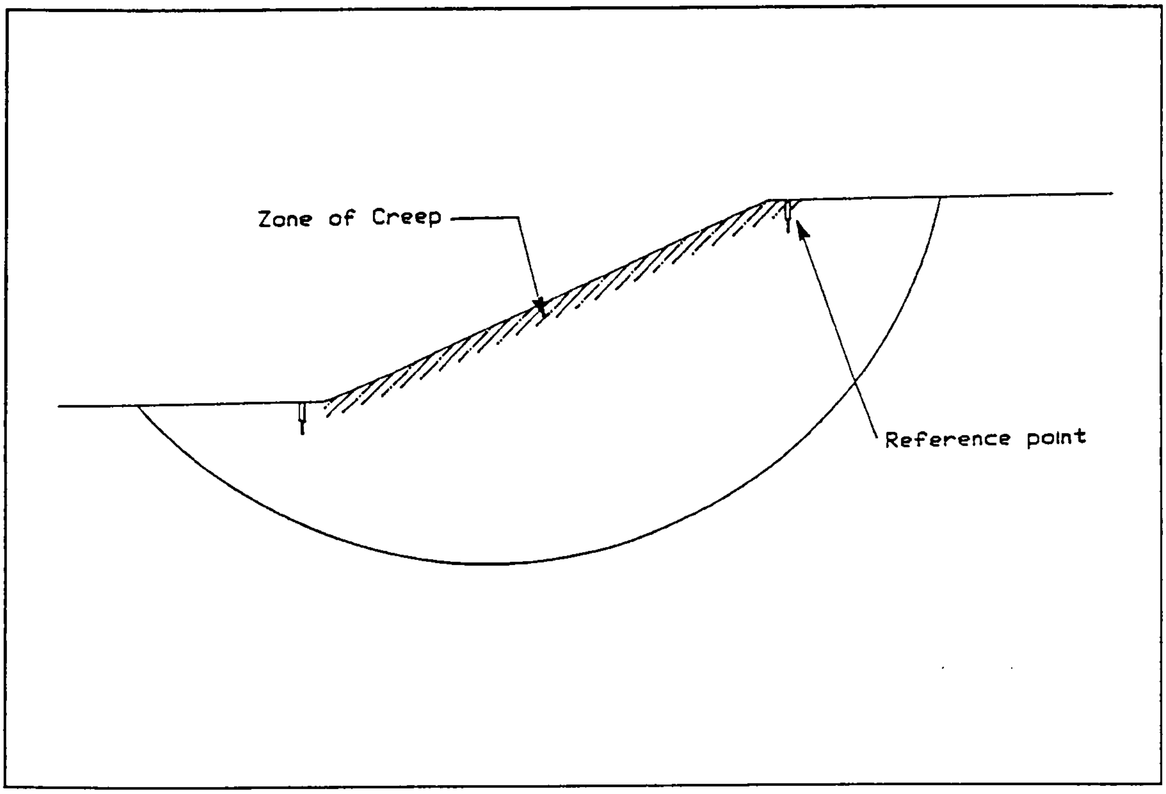

Figure 4.7 Reference points for base slope failure wedge

Greater safety is ensured in the removal of earth shoring because heavy steel beams, wooden joists, formwork, and similar items do not have to be dismantled as is done with conventional falsework. With earth shoring, as opposed to conventional falsework, workers are not required to dismantle the earth shoring by hand, but rather with heavy equipment generally consisting of a loader/shovel and dump trucks. Figures 4.8 and 4.9 illustrate removal operations using a loader and trucks.

State highway construction departments offer guidelines for the removal of falsework or shoring, but such guidelines do not remove the contractor's responsibility for the stability of the bridge.

Several procedures may reduce the liability of the contractor removing earth shoring from a bridge. First, the shoring should not be removed before the designed compressive strength requirements have been satisfied. Premature removal of the shoring can result in failure of the bridge if concrete sections do not have sufficient strength to support the dead load. Second, post-tensioned units should be stressed properly before digging away the shoring, and the remaining engaged prestressed units should be released in a manner that permits the concrete to accept its own weight and to distribute stress gradually (12). Third, in multi-span bridges, removal of the earth shoring should start around the midspan and proceed to the supports. Excavating in this manner minimizes load reversal and allows the bridge to deflect as designed.

4.5 INSPECTION

During construction, monitoring, loading, and removal operations for earth shoring, periodic inspections should occur. A general list of some items to be checked is given by the Federal Highway Administration:

1) All the drawings and written instructions have been strictly complied with.
2) Only the correct materials in serviceable condition have been employed.
3) The ground has been adequately prepared and step taken to prevent erosion.

Figure 4.8 Starting removal operations

Figure 4.9 Removal operation continued

4) Suitable foundation pads or other bases have been provided and have been properly leveled.
5) Foundations and other load distribution members on sloping ground are adequately prevented from movement down the slope.
6) Any chocks or other supports are the correct shape and are adequately secured (14).

4.5.1 INSPECTION DURING AND AFTER CONCRETE PLACEMENT

During the placement of concrete, the shoring should be inspected frequently. Settlement of the structure should be measured and compared with earlier readings to determine the extent of the settlement that may have occurred. If a serious problem arises, the concrete placement should be temporarily stopped until satisfactory corrective measures have been taken and the construction engineer agrees that further danger will not occur.

After placement of concrete is complete, inspection should not stop but should be continued regularly until the shoring is removed. Continuing inspection is particularly important in cast-in-place and post-tensioned structures because of the load redistribution that occurs as the deck concrete shrinks or when the post-tensioning forces are applied (14).

CHAPTER V

SAFETY BENEFITS OF EARTH SHORING OVER CONVENTIONAL FALSEWORK

5.1 INTRODUCTION

In bridge construction, temporary falsework structures hold the bridge in place until the bridge can withstand its own weight and any other design loads. Erecting falsework structures can be very time consuming and expensive; thus, a failure could prove to be especially detrimental,even resulting in a loss of life if falsework suddenly collapses. Traditional falsework presents several hazards that are not present in earth shoring.

5.2 HAZARDS IN CONVENTIONAL FALSEWORK

Falsework is the oldest and most common form of temporary support structures used in the construction of concrete bridges. Falsework supports the formwork and fresh concrete until the bridge can support the applied loads. The most commonly used materials for falsework include steel and lumber, but many other patented steel shoring systems are available.

The potential hazards found in conventional falsework could lead to a partial or full collapse of a bridge during construction. Often, if one element of the temporary structure fails, a chain reaction of failures occurs and the entire structure collapses.

Wang's research of falsework collapses identified four major categories of failures that occurred in concrete box girder and other concrete bridges: vertical shoring, scaffold shoring, horizontal shoring, and moveable formwork. Figure 5.1, parts (A) and (B), shows the distribution of failures for box girder bridges and other

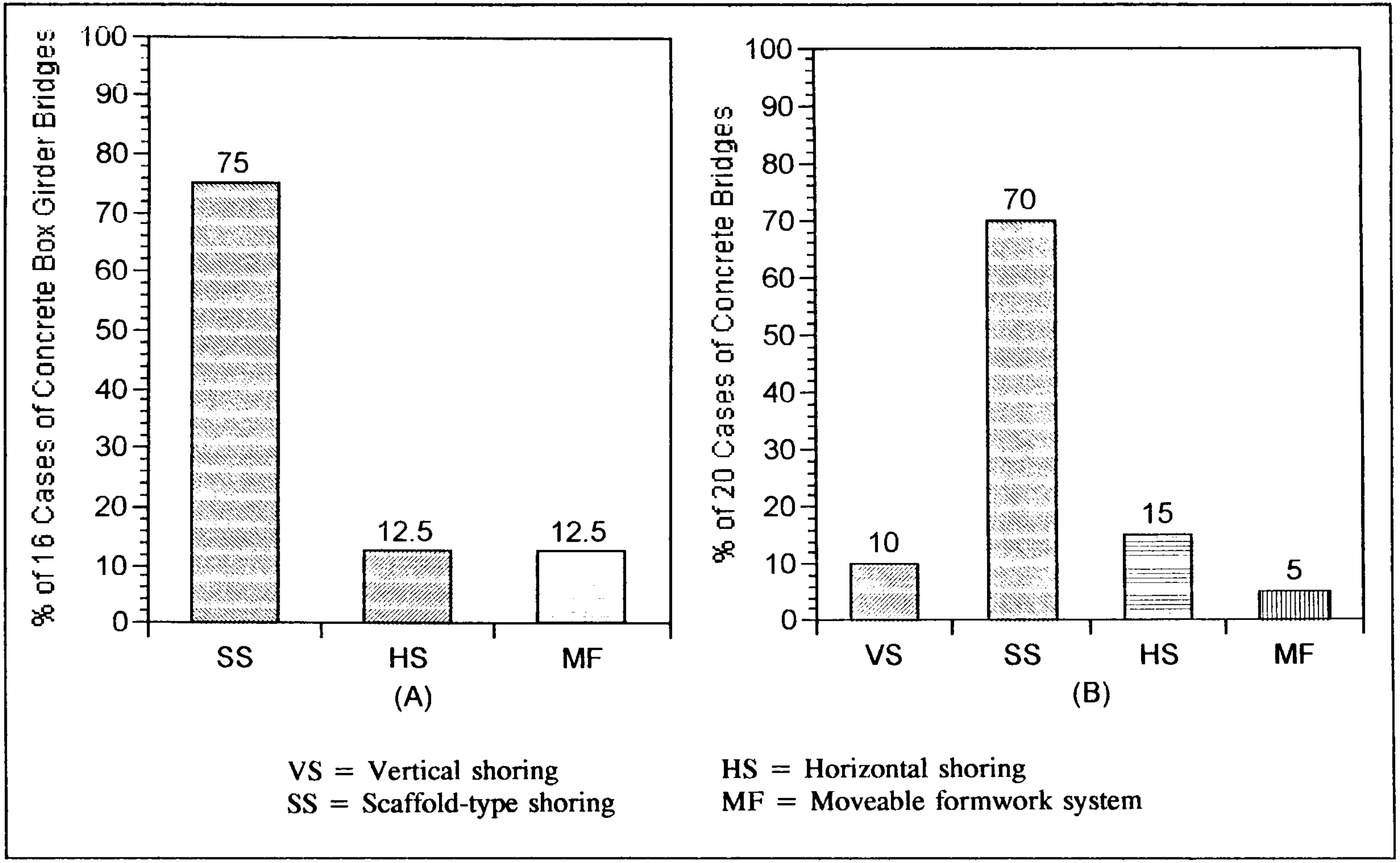

Figure 5.1 Type of collapsed falsework systems; (A) Box girder bridges, (B) Plate bridges

Source: Wang, H. K. "Investigation of and Preventive Measures Against Falsework Collapses," Thesis presented to the Ohio State University, 1984.

concrete bridges. As seen in the figure, "Scaffold-type shoring accounted for 75% to 70% of collapsed formwork [in concrete box girder and concrete bridge construction]. Due to the increasing popularity of moveable formwork systems in bridge construction (especially in concrete box girder bridges), the chances of collapse of these systems in the future may be higher...."(34)

With the collapse of falsework, human casualties and, secondarily, economic loss can occur. Loss of life for a 23-year period, for example, showed 53 fatalities, numerous injuries, and over 36 bridge related collapses (34). In addition to these failures, many cases have gone unreported because complete failure did not occur, but the temporary structure did not preform as designed. Wang (34) discusses three categories of potential failures that resulted in a temporary or permanent failure in conventional falsework: triggering causes, enabling causes, and procedural causes. Triggering causes are external and/or construction related events that can initiate failure of the falsework. Some potential triggering causes are as follows:

- Heavy rain causing falsework foundation slippage
- Strong river currents causing foundation slippage
- Strong winds
- Fire
- Failure of equipment for moving formwork
- Impact of formwork component failure
- Concentrated load from improper prestressing operations
- Concentrated load from construction material
- Other imposed loads
- Impact from concrete pouring operations
- Impact load from construction equipment
- Vibrations from nearby equipment
- Improper or premature falsework or formwork removal

Enabling causes are construction and/or maintenance inadequacies of the structure. They can include the following:

- Inadequate falsework cross bracing or lacing
- Inadequate falsework components
- Inadequate falsework connections
- Inadequate falsework foundations
- Inadequate falsework design
- Insufficient number of shoring
- Inadequate reshoring
- Failure of formwork component
- Improper installation or maintenance of heavy equipment
- Failure of permanent structure components
- Inadequate foundation soil
- Inadequate permanent structure design or construction

Procedural causes are a result of inadequate design and/or inadequate construction monitoring. Procedural causes are listed as follows:

- Inadequate verification of falsework design
- Inadequate inspection of falsework and formwork before, during or after concrete pouring
- No proper concrete test prior to removing falsework or formwork
- Employment of inexperienced or inadequately trained workers
- Inadequate communication between parties involved
- Change of falsework design concept during construction

From the three potential failure categories, Wang (34) has established that impact from concrete pouring operations, inadequate falsework cross bracing or lacing, and inadequate inspection of falsework and formwork before, during or after concrete pouring resulted in the highest number of failures.

In addition to the number failure categories, the potential for injuries to a worker from falling off a falsework system presents another concern. Of the total percentage of accidents, falls account for 29% of the total causes of fatalities in the construction industry. (15)

5.3 BENEFITS IN EARTH SHORING

Earth shoring offers a different means of supporting a cast-in-place concrete or post-tensioned bridge during construction. A comparison of the safety benefits of earth shoring versus conventional falsework shows an impressive margin of advantages for earth shoring. For example, the M. and M. Construction Company has used earth shoring construction for some of their box girder bridges and has recorded 35,000 workhours without a lost-time accident (5). Another advantage of earth shoring is the greater accessibility for monitoring activities during the building and removal of the support system. Furthermore, a number of items on falsework must be designed and inspected but these same items are not required in earth shoring.
They are

- cross bracing of lacing,
- second-hand materials,
- detailed connections,
- isolated foundations, and
- alignment of falsework.

Other advantages associated with earth shoring include the following:

- Workmen are located on or closer to the ground than in conventional falsework which improves the overall safety on the construction site.

- Hand rails and/or safety belts are sometime not needed.
- Crane operators can be positioned so that they do not need to depend on hand signals but can visually see the workers.
- Concrete trucks can be placed on the shoring so placing concrete from a bucket is reduced.
- Establishes a more productive work environment.

In earth shoring the complexity of the shoring system is reduced over conventional falsework. Decreasing the number of supporting members and connections, for instance, reduces the probability of failure.

Injury from falling off earth shoring is still possible but the height from which a person could fall will be reduced. Figures 5.2 and 5.3 illustrate the significant height differences between conventional falsework and earth shoring. The reduction in vertical height suggests that a worker might receive less severe injuries in a fall.

Figure 5.2 Conventional falsework height

Figure 5.3 Earth shoring height

CHAPTER VI

COST COMPARISON OF CONVENTIONAL FALSEWORK vs. EARTH SHORING

6.1 INTRODUCTION

Cost issues are a major responsibility for falsework designers. Preliminary cost estimates must be determined during the bidding phase as part of determining the most economical choices. Many variables (e.g., location, labor, materials, structure type, safety, insurance, workers compensation insurance, and site condition) influence the cost of bridge construction. Estimators and value engineers must account for all these cost factors.

6.2 BIDDING

A bridge contractor is normally selected by an owner on the basis of competitive bidding. A major proportion of the construction in the United States is performed by contractors who obtain their work in bidding competition with other contractors. In bridge and highway construction funded by public agencies, competitive bidding is required by law. When bidding a project, the contractor estimates how much the structure will cost by using working drawings and specifications as a basis (9).

Because heavy construction is a competitive field, the contractor must prepare an accurate estimate. If estimates are too low, the contractor may lose money on the project. Conversely, if the estimate is significantly higher than actual cost, the contractor will probably not be awarded the job. Therefore, the estimate must be based on the most economical construction system available (28).

6.3 ESTIMATING

For comparison purposes, estimates for both conventional falsework and earth shoring systems are calculated for the same bridge. The sample bridge is a straight concrete box girder spanning 255 ft, 92.5 ft across, and 16 ft high. Figures 6.1 and 6.2 illustrate the cost estimate comparisons. The price data are taken from Means Heavy Construction Cost Data (30). All material items, direct and indirect labor, and equipment cost used in the estimates are assumed to have the same inflation rate. The estimates show that earth shoring typically has a lower cost.

Figure 6.3 shows how cost estimates differ between bridges when the height of the bridge is adjusted and length is held constant. The estimates indicate that the effectiveness of earth shoring is greatest when the bridge height is less than 20 ft high. Figure 6.4 illustrates how cost is affected when the length of the bridge is adjusted and height is a constant 16 ft. There is little difference in price until about 125 ft. After 125 ft earth shoring proves to be the more cost effective system.

Several assumptions were made in preparing the estimates and graphs used to compare support systems. Consequently, estimates for both earth shoring and conventional falsework would be affected by such factors as working conditions, labor, materials, reusage of material, site conditions, and haul distances.

The time required to erect earth shoring is less than the time needed for conventional falsework. In the sample estimate, the time to erect conventional and earth shoring structure is 3671 and 1354 workhours respectively. Again, the estimate would have to be adjusted for weather conditions, soil availability, materials characteristics, and working conditions.

6.3 WORKERS' COMPENSATION

Safety in building any type of structure saves money and time for the contractor. Reducing the cost of workers compensation insurance can lower the

		MATERIAL			EQUIPMENT/ LABOR				
Description	Quantity	Unit	Unit Cost	Total	Craft	Unit	Hours	Rate	Total
Sheathing 3/4" x 4' x 8'	24768	S.F.	$0.48	$5,945	F-2	0.013	322	$21.87	$7,042
Bridge deck 92.5' x 255'			2 reuses						
Joist 2" x 10" x 10'	20000	L.F.	$0.67	$6,700	F-2	0.018	360	$21.87	$7,873
10 Bays, 255' long			2 reuses						
Stringers W18 x 40	2710	L.F.	$14.20	$19,241	E-5	0.083	225	$33.44	$7,522
			15 reuses						
Stringers W 24 x 76	2439	L.F.	$26.00	$4,228	E-5	0.072	176	$33.44	$5,872
			15 reuses						
Bents HP 10 x 42	2464	L.F.	$12.00	$1,971	E-2	0.1	246	$36.15	$8,907
28' per leg; 88 legs			15 reuses						
End Columns HP 10 x 42	114	L.F.	$15.00	$114	E-2	0.1	11	$36.15	$412
3' tall; 19 bays			15 reuses						

Figure 6.1 Conventional falsework estimate

Source: R. S. Means Company. Means Heavy Construction Cost Data. Kingston: Construction Consultants and Publishers, 1987.

		MATERIAL			EQUIPMENT/ LABOR				
Description	Quantity	Unit	Unit Cost	Total	Craft	Unit	Hours	Rate	Total
Framing Steel	925	L.F.	$9.50	$8,788	E-2	0.01	9	$36.15	$334
HP 10 x 42									
Concrete Footings	118	C.Y.	$74.00	$8,732	C-17B	1.18	139	$24.14	$3,361
6' x 6' x 12"									
Miscellaneous Wood	200	L.F.	$0.80	$160	F-2	0.1	20	$21.87	$437
Elevation jacks; etc									
Wooden piles (abutments)	300	V.L.F.	$3.40	$1,020	B-19	0.102	31	$36.43	$1,115
20 piles; 15' long									
Removel of falsework	7613	L.F.			B-13	0.28	2132	$25.59	$54,549
Totals				$56,898			3671		$97,425
Total Material & Labor	$154,323								

Figure 6.1 (continued)

Source: R. S. Means Company. Means Heavy Construction Cost Data. Kingston: Construction Consultants and Publishers, 1987.

	MATERIAL				EQUIPMENT/ LABOR				
Description	Qunatity	Unit	Unit Cost	Total	Craft	Unit	Hours	Rate	Total
Dirt 116.5' X 255' X 16' Slope 2 to 1	22440	C.Y.	$0.00	$0					
21 C.Y. Scraper 5000' Haul bulldozer included	22440	C.Y.	$0.00	$0	B-33E	0.022	494	$114.88	$56,714
Compaction 3 - passes	22440	C.Y.	$0.00	$0	B-10G	0.003	67	$43.21	$2,909
Fine grading 74' X 255'	2100	S.Y.	$0.00		B-32C	0.01	21	$46.39	$974
4" concrete slab cast on grade 74' X 255'	233	C.Y.	$63.00	$14,679	C-17C	1.1	256	$25.61	$6,564
Removel of shoring	22440	C.Y.			B-34F B-34D	0.023	516.1	$84.75	$43,741
Total				$14,679			1354		$110,902
Material & Labor	$125,581								

Figure 6.2 Earth shoring estimate

Source: R. S. Means Company. Means Heavy Construction Cost Data. Kingston: Construction Consultants and Publishers, 1987.

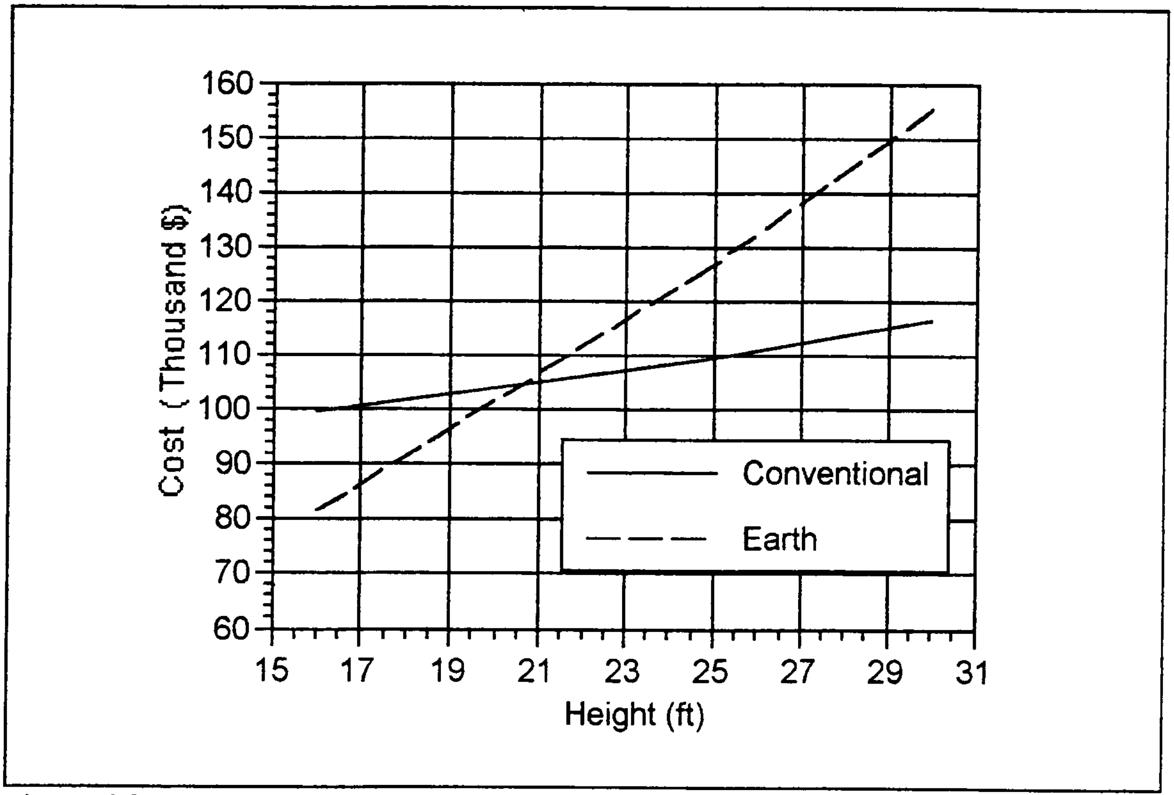

Figure 6.3 Cost with varying height

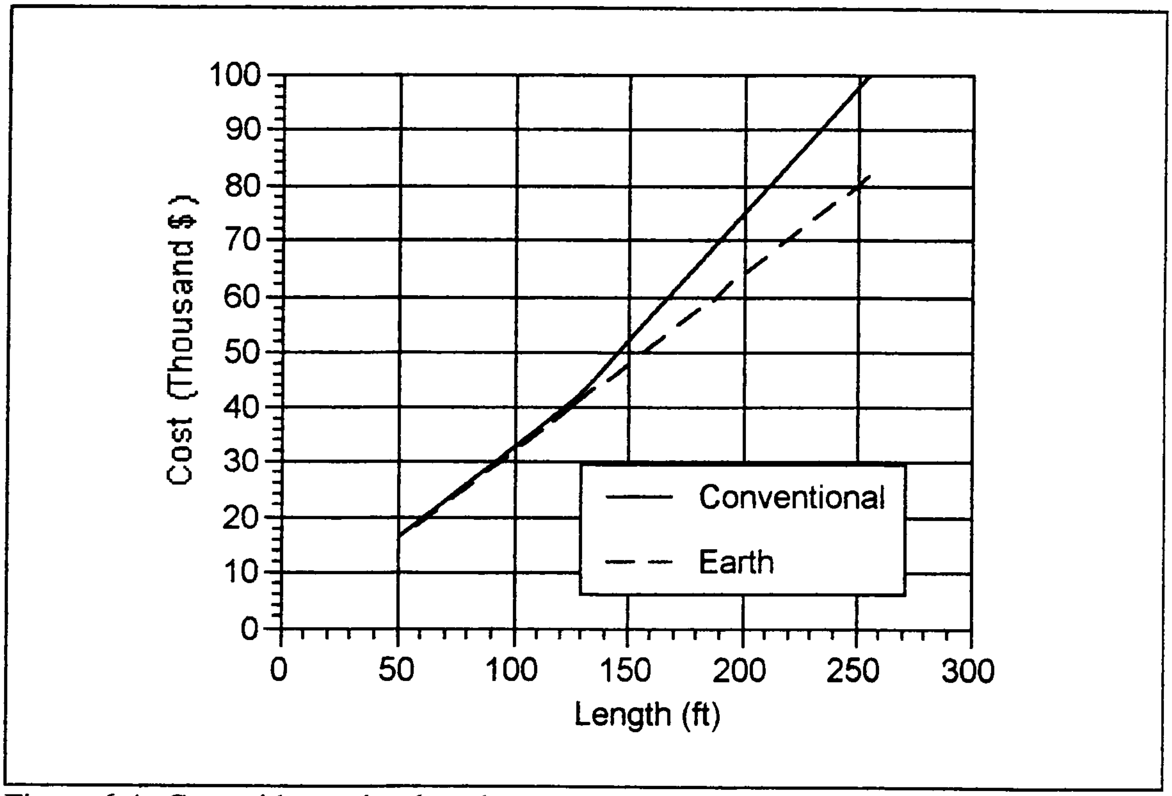

Figure 6.4 Cost with varying length

operating cost of a construction project. Workers' compensation insurance is defined as payments to be made by the insurance company to the employee in the event that the worker is injured on the job. Every employer who has five or more employees must provide workers' compensation insurance coverage or be self-insured. Compensation covers the cost of medical care and partial payroll continuation as long as the worker remains injured and unable to return to work up to a maximum of 400 weeks.

Contractors sometimes do not realize that they bear the financial brunt of most accidents. Contractors that have workers' compensation insurance must pay a standard rate times an experience modification rating. A contractor who experiences more accidents pays higher premiums as a result of the higher experience modification rating. Accidents cost may be as much as 4 to 17 times direct cost of the accident (15). Some indirect cost of accidents include the following:

- Investigation expense
- Fines and/or citations (OSHA & civil)
- Job delays
- Overtime
- Replacement for disabled worker
- Damage to the structure (15)

By making a safer working environment, construction companies can lower premium rates, giving the company an competitive edge over its competition. Earth shoring provides an effective means for lowering costs, improving safety, and increasing the speed of cast-in-place and post-tensioned concrete bridge construction given the heights, span lengths and topographic conditions described in this thesis.

CHAPTER VII

CASE STUDY

7.1 DESCRIPTION OF BRIDGE

A connector arterial road has been constructed between the South Knoxville Bridge over the Tennessee River and Chapman Highway in Knoxville, Tennessee. This project offered the opportunity to study the formwork and falsework systems described in this research.

The bridge which used earth shoring is located on Sevier Avenue over the South Knoxville Boulevard. The bridge is a 2-span, continuous, cast-in-place concrete box girder bridge. Its dimensions are 255 ft long by 92.5 ft wide. Two lanes of traffic flow in both directions across the bridge.

The bridge which was constructed using conventional falsework is a 2-span, continuous, cast-in-place concrete box girder. Its dimensions are 220 ft long by 85 ft wide.

7.2 DESIGN CRITERIA

The topography on the bridge site required approximately 70% of an existing hill side to be excavated prior the construction of the proposed bridge. The existing ground contours are illustrated in Figure 7.1 against the proposed bridge. Due to these elevations, the contractor investigated the possibility of using earth shoring as an alternative over conventional falsework.

A complete subsurface investigation revealed that the soil type and rock contours were suitable for earth shoring. Additionally, the staggered construction activities of the South Knoxville Boulevard allowed the overpass bridge to remain traffic free during its construction. By having sufficient ground elevations, suitable

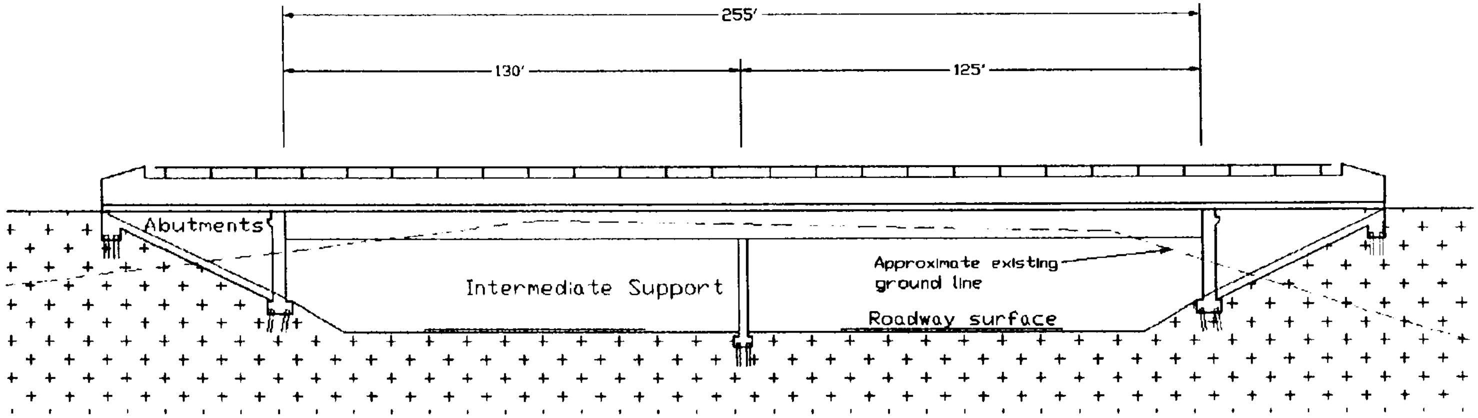

Figure 7.1 Existing ground contours of case study bridge

soii rock conditions, and no traffic, the contractor had the option to use earth shoring over conventional falsework.

With conditions suitable for earth shoring, the contractor designed the shoring system to adequately support the applied loads during construction. A summary of the design conditions used follows:

- The sandy, clayey (SC) soil was compacted to 95 to 100 percent of optimum.
- The width of shoring should extend at least 50 ft past the edge of the bridge.
- Side slopes were at least greater than a 2 to 1 or greater.
- Chamber adjustments were used to compensate for deflections in the shoring
- A 10" thick binder base was placed on top of the subgrade
- A 4" unreinforced concrete waste slab provided the foundation and formwork
- Johnson's wax was used as a bond inhibitor between the waste slab and the cast-in-place box girder.

7.3 CONSTRUCTION OF EARTH SHORING

The first step in constructing the shoring process entailed preparing the ground to the proper density and elevation. Sheepsfoot rollers, scrappers, and bulldozers were used to adjust the ground height to its proper elevation and compaction. Second, trenches were excavated in the top of the shoring for placement of abutments and intermediate supports. Third, after completing of the bridge's foundations, backfilling and compacting took place around the supports to the desired levels.

Once the subgrade was completed, a base material was spread approximately 10 inches thick and then compacted. On the base material, the contractor cast a 4 inch concrete waste slab and finished with a motorized deck finisher. The concrete for the waste slab was poured directly from the trucks into position. Before casting the bottom deck of the bridge, a bond inhibitor was placed on the waste slab to prevent concrete from adhering to the temporary slab.

7.4 MONITORING AND INSPECTION

The monitoring of the earth shoring was performed using a surveyor's level and a grade rod. Both settlement and slope movement were checked regularly throughout the project. Measuring points were taken at various locations around and on the bridge, but no seated measuring points were placed in the embankment. There was no unusual settlement or slope movement throughout the construction period.

Routine inspections were conducted during the construction process to evaluate the behavior of the shoring system. No problems arose during any concrete placement which would have required corrective measures.

7.5 CONVENTIONAL FALSEWORK

Conventional falsework was used for the second bridge. The construction details for the falsework system was available for review in this research. The availability of these details is reflected in the cost analysis in Chapter VI.

CHAPTER VIII

CONCLUSIONS

This thesis has evaluated the use of earth shoring for cast-in-place and post-tensioned concrete bridge construction. The function of earth shoring and conventional falsework is the same in that both are used as a temporary foundation for a permanent bridge until it becomes self supporting, but problems have arisen in conventional falsework because of failures, increased costs, reduced safety, longer construction time, and lower profits. These problems with conventional falsework make earth shoring a viable alternative. The design and construction of earth shoring are quite different from those for conventional falsework in that the bridge is supported on a bed of soil rather than sheathing, joist, girders, and columns. The shoring is constructed either by using compacted or in situ soil as a foundation upon which the bottom of the bridge is cast. Because of its design and construction, the shoring does not need to consider horizontal and accidental loadings in its design. Having a soil plug eliminates the connections and supporting members found in conventional falsework, thus reducing the possibility of failure.

Monitoring during all phases of construction should be conducted in an effort to check the shoring and to determine if it is performing as expected. The critical time to monitor is during and after a concrete pour. Three methods are adequate to monitor shoring: surveyor's level, settlement platform, and piano wire.

The removal of shoring is quite different than that of traditional falsework because heavy equipment is used to excavate the underlying soil, which increases safety and decreases work time. With falsework, each structural member must be individually removed, thus increasing costs and worker hazards.

With earth shoring, greater safety also results from the elevation of the ground in relation to the constructed bridge. The bridge deck in traditional falsework typically is at a greater elevation than earth shoring. In earth shoring, having a shorter height difference between the bridge deck and the ground permits equipment operators and workers greater ease in working and communicating with one another. In addition to these enhanced working conditions, significant time savings are achieved by the elimination of working on elevated scaffolding.

Providing a safer and more productive work environment reduces construction cost. In an increasingly competitive market with fewer construction jobs available, cost savings are very important. Cost estimates show that earth shoring is most effective when the height of the bridge is less than 20 ft and the length is greater than 125 ft. In addition to direct cost savings, indirect savings can be achieved as a result of reduced premiums for workers' compensation insurance.

Clearly, earth shoring can be a better alternative to conventional falsework for constructing safer and more economical cast-in-place or post-tensioned concrete bridges.

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