The horizontal profile gage was installed at five locations and performed well to a settlement depth of 3 to 3.5 feet. Below that depth the gage literally came apart and was no longer functional. Within the limits of the gage a good bottom of fill profile was obtained.

The anchor post settlement gages were installed at selected locations in the soft foundation soil primarily for research purposes, i.e., in an attempt to measure the amount of consolidation occurring at various depths.

"Inclinometers" or "slope indicators" were employed only where stability was considered critical and adjacent improvements could be affected. At Dumbarton a radio station was located in the mud flats immediately adjacent to the new roadway embankment and could have been jeopardized by a slope failure.

Heave stakes generally reveal little about what is happening until after it happens. When employed under certain conditions, however, heave stakes are considered appropriate and can be installed at relatively low cost.

The simplest instrument is usually the best. Thus, the pipe riser settlement platform was chosen over the hydraulic settlement gage or settlement sensor. The open tube piezometer was also used effectively and showed very rapid response to increased loading. Increased pore pressure due to added loading was reflected within one day. This device is inexpensive and can be installed at low cost using a drill rig.

The "key" instruments in soft soils are the settlement platform and the piezometer. The importance of proper installation and monitoring of these devices cannot be over emphasized. A recommended minimum of one settlement platform per centerline station and two or three piezometers installed at variable depths at each centerline and hinge point location are needed for pore pressure verification. Once the critical height of fill has been reached and stability is marginal, the decision to stop, delay, or advance will be based on an interpretation of the data developed from these devices.

A rule-of-thumb used by Caltrans Engineers in applying restraint to construction progress is to cease fill placement when piezometric readings reach 50% of the applied load. However, readings exceeding 60% of applied load were recorded at Dumbarton and on other Caltrans wick drain projects without the development of instability. This was due possibly to the amount and rate of strength gain plus other stability considerations at these greater pore pressures. Re-evaluation of the 50% rule of thumb is therefore suggested when the effects of reinforcing or stabilization fabrics beneath the embankment are considered. Sixty percent of the applied load may be a reasonable value when using fabrics.

The sequence of instrumentation installation is also important and the following is a recommended sequence:

Settlement Platforms:	Before placement of fill if possible or immediately as a suitable working table is established.
Piezometers:	Immediately following installation of wicks, in order to avoid loss of instruments to wick driver.
Horizontal Profile Gage:	Before placement of any fill, if possible, or trench through first 3 to 5 feet of fill. Also modify wick installation to miss instrumentation.
Anchor Post Settlement Gages:	Place through first 3 to 5 feet of fill.
Inclinometers:	Through completed strut fill but only as specifically required.
Heave Stakes:	After placement of first 5 feet ± of fill.

A reliable monitoring system is dependent upon the quality of the instruments employed, the care of installation, the competence of the installer-observer-recorder; and of course the interpretation being made by an experienced, knowledgeable engineer.

The best system in the world will be useless unless continuously observed, recorded and analyzed. The Soils Engineer will then be in a position to confidently advise the Construction Engineer on control of the project.

IMPACTS OF DESIGN AND SPECIFICATION REQUIREMENTS ON ACTUAL WICK DRAIN CONSTRUCTION

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While it is very important to carefully design a wick drain installation and include specifications that will result in the intended aims of the design, consideration of the practical and economical effects of the design and specification process on the actual installation of wick drains may be equally important. Frequently, standard design procedures or specifications are often used without recognizing their cost and/or practical effects on the project. From actual projects, examples include: (1) specifying wick drains to be installed at an elevation below water when stability and eventual fill height allowed installation above high tide; (2) specifying fixed exact depths which resulted in the need to install some drains into rock or very dense layers; (3) scheduling drains after bridge construction without proper headroom clearance to install drains under the bridge; and (4) solely specifying installation methods or types of drain materials which do not lend themselves to project climatic conditions (example: a jetting method with paper filter in freezing conditions). Therefore, an understanding of the methods of wick drain installation and careful consideration of actual project conditions will enable the designer to develop the best plans and specifications for an effective and economical wick drain solution.

Although this paper will concentrate mainly on the design and specification effects on the unit cost of installation wick drains, it is important that the reader comprehends: (1) the importance of the unit cost as compared with the total cost, and (2) the various methods of wick drain installation (TABLES 1 and 2. The designer should be aware of the need to evaluate the total cost variable items of time, allowable settlement, and surcharge, since their variance can significantly affect the total quantity of a wick drain installation. Obviously the methods of installation allowed must also be evaluated as to their applicability to soil characteristics, soil sensitivity, and environmental problems.

Table 1: Factors Affecting the Total Cost of Wick Drains

- o Soil Characteristics
- o Installation Methods
- o Allowable Consolidation Time
- o Allowable Post Construction Settlement
- o Preload and Surcharge
  1. Type and Material Available
  2. Reuse of Material
  3. Amount of Surcharge
- o Sand Blanket or Horizontal Drainage Path
- o Unit Cost of Installation
- o Construction Difficulties and Limitations

Table 2: Methods of Wick Drain Installation

- o Static (minimal disturbance)
  1. Chain Driven *
  2. Cable Pulldown
  3. Heavy Weight
- o Vibratory
  1. Offset Hammer - full supported mandrel *
  2. Direct Hammer - offset material *
  3. Inside Mandrel with Enlarged Shoe
- o Jetting
  1. Covered Mandrel with Outside Jets
  2. Jet Probe with No Covering Mandrel
- o System Combination
  1. Chain Driven with Vibratory *
  2. Chain Driven with Outside Jets *
  3. Vibratory with Outside Jets
  4. Multiple Drains - All Systems
- o Predrilling full depth

* Common use in the United States

Familiarization of all factors affecting the unit cost of installation of wick drains is essential in understanding the effects of design and specifications on installation costs. TABLE 3 outlines the most significant factors.

TABLE 3: Factors Affecting the Unit Cost of Installing Wick Drains

- o Work Surface
- o Characteristics of Soils to be penetrated
  1. Type
  2. Strengths
  3. Depth of each layer
- o Specifications
  1. Type
  2. Requirement
  3. Responsibilities
  4. Field Control
- o Size of Project
- o Depth of Drains
- o Cost of Material
- o Labor Costs
- o Potential Weather Hazards

This paper will concentrate on the following four areas from table 3 where design and specifications most affect installation costs:

1. Working surface
2. Soil characteristics or, more specifically, potential obstructions
3. Specifications
4. Design criteria - project size, depth, material, method.

WORKING SURFACE

Production is the key to the economics of wick drain installation and the working surface is most often the key to production. For maximum production, it is best to have a level, dry and stable working surface. Wick drains can be installed prior to pacement of the drainage layer if the existing surface is or can be made level and stable enough for the installation equipment. This will save the cost of the extra length of drains through the drainage blanket. Otherwise prior placement of the drainage blanket can be used to help create a working surface. Where it is difficult to create a working surface all at one elevation, consideration of benching should be given at the design stage. In such cases care should be taken to assure continuity of the drainage blanket.

While wick drains can be installed at angles up to 30 degrees by some methods, such an operation is more costly because of reduced production rates and more equipment breakdowns. In some cases personnel safety could be at risk if drain depths are deep and the working surface is at a significant slope. Where it is necessary to install wick drains on a slope, production will be at the maximum with a constant slope at a minimum angle. Consistency of subsoils and the potential for predrilling are major factors in determining if wick drains can be installed at angles greater than 10 degrees from the vertical, or on slopes greater than about 1 on 6.

The consistency of the working surface is very important. Granular soils are the most efficient in all types of weather. Working surfaces of clay and silt should be avoided where there is significant potential for rainfall.

Specifications should be written to avoid the possibility of stone, rocks, boulders, miscellaneous fill material, or any other potential obstruction from being used in any fill material placed prior to installation of wick drains.

If potential obstructions to mandrel penetration of the wick drain already exist in or on the subsoils, various alternate installation methods should be considered in the design stage rather than leaving the question open to arguments between the general contractor and installer or even the owner/agency. If these obstructions exist at or near the surface, they should be specified for removal, if possible, or a separate item for predrilling should be included in the specifications. If predrilling might be necessary, the working surface elevation should be as low as possible to minimize predrilling depths. For example, five to ten feet of predrilling can be one tenth the cost of twenty feet or more.

Concerning the elevation of the working surface and potential obstacles, care should be taken in the design stage to eliminate the possibility of overhead obstructions such as bridges or wires. Wick drains that must be installed without adequate headroom will result in a unit price approximately ten times that of normal prices; plus, there is a possibility of an increase in mobilization costs. Alternatives are lowering the installation elevation to allow normal installation, remobilization after obstructions have been removed or relocated, accepting less depth of drain, or permitting drains to be installed at angles from outside the obstruction area.

Finally, stability of the installation equipment is paramount to achieve significant production rates for wick drain installation. Consideration should be given to geotextiles for support of equipment and minimizing the drainage blanket thickness where necessary. Most types of installation equipment can penetrate one or two layers of stabilization or reinforcing fabrics. Specifications should also allow placement of some of the surcharge where necessary for stability of installation equipment. If it becomes necessary to install wick drains from equipment on mats, production rates could easily be one-fourth to one-tenth of normal production thereby increasing costs.

SOIL CHARACTERISTICS - POTENTIAL OBSTRUCTIONS

The second important factor affecting wick drain installation production is the characteristics of the soils to be penetrated. In essence, subsoils can be divided into two categories: (1) readily penetrated and (2) potential obstruction.

The difference between the two main categories of soil will vary depending on the method of installation, but once the method is determined the difference is very significant in terms of cost. Therefore, it is important that the owning agency or designer provide as much subsoil information with the plans and specifications as possible.

Contrary to popular belief, lack of subsoil data and/or disclaimers with minimum data often result in expensive claims or delays due to misunderstandings between the general contractor and wick drain installer. This will increase cost to both parties and only benefit lawyers! Usually due to time limitations and project size, wick drain installers cannot arrange for their own soil boring program and site visits do not clearly indicate what is below ground. Therefore, the installer must increase prices to cover potential installation problems or assign this risk to the general contractor (who knows less about the risk). Quite often, both are done.

Potential obstructions often result in substantial increases in wick drain installation rates. Basicially the two methods of overcoming potential obstructions are (1) predrilling or (2) major alterations of installation equipment. Predrilling is used for shallow obstructions (up to approximately twenty feet) and major equipment alterations are necessary for deep obstructions.

If specifications allow for predrilling for obstructions as a separate bid item on a unit price basis, the risk to drain installation will be minimized and the total cost of the wick drain solution will more accurately be reflected in bid prices. It is important to stipulate whether obstruction drilling is or is not for surficial stiff or dense soils which cannot be penetrated by "normal and accepted practices". Usually it is far less expensive to stipulate that shallow subsurface obstructions be removed than to attempt to drill through rubble, rocks, or concrete.

If deeper obstructions are anticipated, including dense or stiff layers, it may be worthwhile allowing impact or vibratory installation methods in the specifications even though closer pattern spacing might be necessary to overcome disturbance effects. In fact the best solution may be a jetting method even with environmental constraints. Another solution to potential deep obstructions is shallower drains with possibly a greater surcharge.

In addition, to achieve the most economical wick drain installation pricing, it is best to allow in the specifications (1) offsettinng obstructed drains, (2) elimination of isolated obstructed drains, and (3) payment of drains to obstructed depth. Specifying depths where bottom elevations result in substantial penetration of stiff or dense layers can lead to unnecessarily high costs.

SPECIFICATIONS

Much has already been written on the role of specifications in reducing the problems, risks, and pricing of wick drain installations. However, as stated in the beginning of this paper, it is important that specifications require an installation that achieves the intended aim of the design. Some engineers or agencies choose more of an end result specification allowing the contractor and/or installer to assume all potential installation risks while most others specify the method and control as to the intended result, thereby minimizing risk and pricing. In either case certain items must be included or defined in all specifications. The following is an additional list of basic "Do's and Don'ts" of wick drain installation specifications which have not been previously discussed.

1. Do set a vertical tolerance and don't just state that drains should be vertical. For short drains vertical tolerance is not critical. Adapt reasonable vertical tolerance requirements to each project.

2. Don't set specific depths but rather state a minimum distance (1/2 foot) into the bottom layer. Approximate depths to substantial layers, or defining layers to be penetrated result in a better definition of project.

3. Do allow for splicing of wick drain material providing there is a resulting continuity of flow in the drain. Failure to allow splicing results in slower production rates and significant materials wastage.

4. Don't specify a maximum installation speed. Rate of installation of wick drains has no bearing on their function in the subsoils.

5. Do specify a maximum mandrel size rather than stating that mandrel sizes should be a minimum design to avoid displacement.

6. Don't set elaborate testing requirements for acceptable drains. It is important to understand that inflow rates are as important as flow rates through the drains.

7. Do specify a minimum cutoff length above the surface (6 inches to 1 foot) if drains are installed prior to the drainage blanket, but don't specify any significant cutoff length if the drainage blanket is placed prior to installation.

8. Do allow for unit price bid quantity and if possible a separate amount for mobilization of specialized equipment. Don't specify a lump sum price unless detailed subsoil information is available.

9. Do consider the use of previous experience lists as qualification for wick drain installers; especially if minimal data is available, completion time is a critical matter, or unusual installation methods or alterations might be required.

The specifications should provide the wick drain installer as much flexibility as possible while achieving the intended aim. Providing for inspection services or field control which assures that specification requirments are met while not appreciably slowing down the installation process is just as important. Initial installation trial drains should establish standard procedures. At this stage such items as mandrel size, depth gages, splicing procedures, verticality, and materials should be carefully inspected for compliance. Visual observations and spot checks can then determine any variances or concerns once production has started.

One major advantage of the wick drain installation over other vertical drainage systems is the simplicity of field control. Once trial drains have been satisfactorily completed, inspection mainly consists of recording depths and locations of each drain, observing splices and verticality of equipment, taking occasional material samples for inspection and testing, and noting any major variances in procedure. Items which are often not specified but which should be monitored are physical measurement of drain sizes (thickness and width) for compliance to specifications and noting any variances from material submittals. If significant differences are noted, laboratory testing may be required to see if wick drain materials comply with specifications.

DESIGN CRITERIA

The effect of the design criteria on unit costs is really a matter of spacing, installation depth, method of installation, and total quantity of drains. While all these items usually affect pricing by minor amounts, there are occasions where they will have a significant effect. Smaller quantities of wick drains are usually more expensive on a unit price basis because of mobilization and equipment preparation, training of local labor, higher material costs, initial adaptations to individual project conditions, trial procedures, etc. Spacing of drains has little effect of production rates until the spacing is greater than eight feet. In such cases moving time from drain to drain can be greater than normal. Wick drain material costs do vary but it may be worthwhile to use a more expensive drain at a wider pattern spacing if it is more effective. Installation methods are much the same as material in that the static method which creates the least soil disturbance might be more costly on a unit basis if predrilling is necessary, but also might be used at wider pattern spacing; thereby reducing the total cost.

In conclusion, understanding the impact of design requirements on the actual installation of wick drains and the adaptation of specifications to specific project conditions will result in the most effective and economical wick drain solution. Furthermore, in many organizations, it is important to transmit this understanding to those in the inspection or field control phase of the actual installation.

Research Activities in Wick Drains

By

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The benefits of using wick drains (prefabricated vertical drains) instead of sand drains are well established. High installation speed, low transport costs, minor environmental impact, and less disturbance effects are some of the reasons wick drains are less expensive and more efficient than conventional sand drains. As a result wick drains have made sand drains obsolete in the United States and throughout most of the world in recent years.

The recent surge in popularity of wick drains has prompted FHWA to conduct a comprehensive research study to develop guidelines for using wick drains as a consolidation aid in the construction of highway embankments over soft, compressible soils. A preliminary review of current techniques revealed that most