

Evaluation of Standard Right-of-Way Fence Post Anchors Versus Drive Anchors

FINAL REPORT
February 2001

Submitted
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In cooperation with

New Jersey
Department of Transportation
Division of Research and Technology
and
U.S. Department of Transportation
Federal Highway Administration

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		TECHNICAL REPORT STANDARD TITLE	
1. Report No. FHWA 2000-07	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Evaluation of Standard Right-of-Way Fence Post Anchors Versus Drive Anchors		5. Report Date February 2001	
		6. Performing Organization Code CAIT/Rutgers	
7. Author(s) Mr. Patrick Szary, Mr. Judson Wible, and Dr. Ali Maher		8. Performing Organization Report FHWA 2000-07	
9. Performing Organization Name and New Jersey Department of Transportation CN 600 Trenton, NJ 08625		10. Work Unit No.	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Federal Highway Administration U.S. Department of Transportation Washington, D.C.		13. Type of Report and Period Covered Final Report 6/27/1997 - 3/31/1999	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
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17. Key Words right of way, drive anchor, concrete, footing, fence post, fencing,		18. Distribution Statement	
19. Security Classif (of this report) Unclassified	20. Security Classif. (of this Unclassified	21. No of 64	22. Price

Acknowledgements

The authors wish to express their appreciation to the New Jersey Department of Transportation for the allotment of funds making this research possible. Special thanks are extended to Mr. Raj Chawla and Mr. Frank Palise of the NJDOT for their support and extending the opportunity to participate in such a significant and extensive research program. The authors would also like to thank Dr. Gary R. Consolazio and Jae H. Chung of the Univ. of Florida, Dept. of Civil Engineering for their efforts on the Finite Element Modeling and Analysis of Fence Post Anchorage Systems portion of this report.

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ABSTRACT

Right-of-way fence installation has not received a great deal of attention in literature during past years, because traditionally common construction practice used concrete for the fencing footings.¹ In hard to access areas like wetlands, steep roadway cuts, and wooded terrain commonly associated with locations that need right-of-way fencing, alternative simple system footings are sometimes used. Recent roadside field installations have demonstrated a potential for satisfactory performance of the simple systems. The main objective of this research is to compare the viability of these simple systems to concrete foundations.

Field testing was conducted to evaluate the deflection performance of the posts installed in “concrete” versus “drive anchors.” A static load was applied to each post system at two feet above grade. Also, an FEM analysis was conducted to simulate actual site testing conditions.

Based on this research, the drive anchors and the concrete systems both performed within tolerable limits established in this study. It was also determined that in areas where only manual means of installation could be used there was a significant cost savings in favor of the drive anchors. In summary, the results indicate that the drive anchor and the concrete systems can be used interchangeably.

INTRODUCTION

The failure of a right-of-way fence post is both dangerous and unsightly. Public safety concerns that are posed by a failed post and fabric present the need for quick and inexpensive replacement. Current remedial procedures require considerable labor time and maintenance funds to remove and replace the damaged posts. This study will determine whether fence post installation crews should continue with current installation procedures or, based on economic, time, and performance factors, change to the anchor post method.

A concrete fence footing system is comprised of a uniform hole with a post set in a vertical position, and then backfilled with concrete. Depending on the materials used, the initial curing time can take up to several days. Fence fabric cannot be stretched, thus burdening the fence post, until the concrete has set. The necessary time delay, to allow the concrete to reach sufficient strength to withstand loading, accounts for part of the disruption and difficulty in working with concrete footing systems. Replacement is another dilemma with the concrete system. Replacement procedures require removing the fence post by either cutting the post at its base or by removing the post and footing, digging a new hole usually right next to the old hole, and then re-setting the new post in concrete. Since these installations are along the right-of-way, workspace is limited, and in addition, the new post must be set very close to the previous one that is being removed. This procedure is both time and labor intensive.

An anchor footing system is comprised of a fence post driven into the ground and an accompanying anchor system. The anchor blades, which are part of the anchor system,

are "L" angle-shaped beams roughly 30 inches long and about 1.5 inches wide with a thickness of 0.25 inches. The anchor blades are secured to the post by a shoe. The shoe is a dual-screw clamp with slotted openings on its sides, as shown in Figure 1. During installation, the shoe is placed around the post and the screws are tightened on both sides of the shoe, thus clamping it securely in place. In a typical installation the shoe is positioned such that when the anchor blades are driven they will be completely below the ground surface. After the shoe is secured the anchor blades are inserted and aligned in the slots. The blades are then driven into the soil at a downward 45-degree angle through the slots in the shoe, as shown in Figure 2, thus creating a rigid connection between the anchors blades and the post.

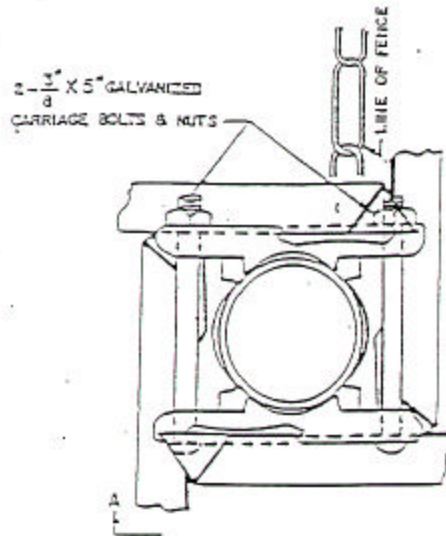


Figure 1 Diagram of an anchor shoe with two sets (four "L" angle-shaped beams) of anchor blades.²

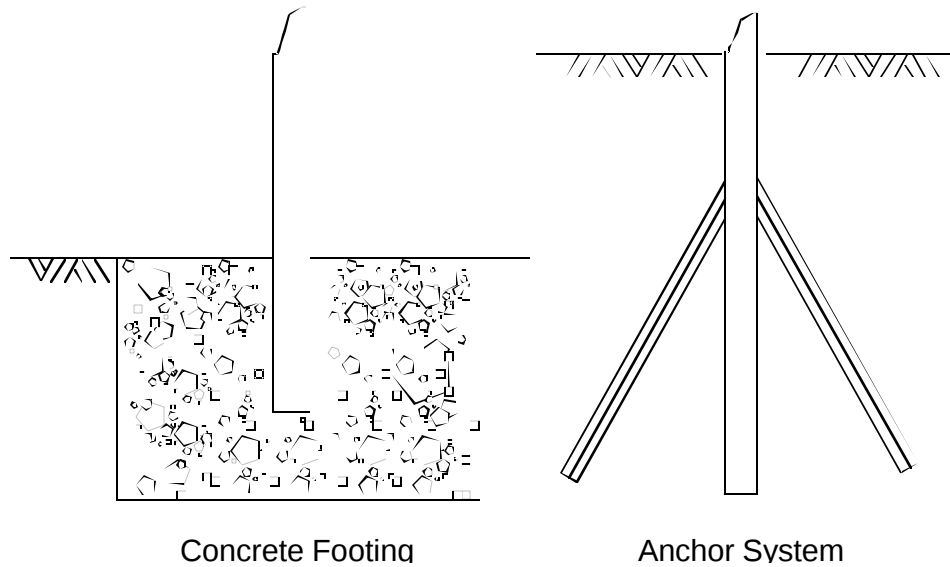


Figure 2 A typical section of two types of fence post systems.

Mechanisms of Failure

Failure in right-of-way fencing is typically the result of vandalism, high winds, a fallen tree, frost heaving the footings upwards, an impact with a vehicle, or several other factors. There are two main types of failure that can occur as a result of loading; post failure and foundation failure.

Post failure is when the steel post yields and/or permanently bends or twists. Yielding generates a plastic hinge at the base of the post. This occurs when there is a strain concentration resulting from a large enough generated moment to bend the post.

Foundation failure covers various types of failures within a fence post system below the ground. For a concrete foundation, this could be failure within the material properties of the concrete; excessive lateral compression of the concrete such that failure occurs; or, theoretically, the post and foundation being removed from the ground. There are several cases of foundation failure for the anchor foundation as well; bending of the blades, separation of the blade from the shoe, and the post slipping upward and out of the shoe are a few potential mechanisms. Another more likely failure is compression of the soil substructure allowing free body rotation of the post about the shoe, thus leading to excessive post inclination.

Comparison

A direct comparison of the yielding of the two fence post systems will generate an improved understanding of the failure mechanisms, and a better overall comparison of the two post foundations.

As a force acts at a given height upon the post embedded in concrete, the post pushes against the concrete footing to resist the force. The force is then transferred and distributed through the concrete to the soil. This allows numerous points of stress where the system could possibly fail. For the post attached to an anchor post system, the force is

exerted on the post and is transferred to the shoes, blades, and soil. However, not only does the post push on shoes and anchors, but also pushes directly against the soil. Hence, the post is acting as part of the anchor subsystem. It is the subsystems movement and resistance to the loading that is studied in this report.

The following is a drive anchor description as per Anchor Fence, Inc.:

The “Drive Anchor” grip upon the sub-soil can be compared to a 39” root grip of a tree. Any pressure on the post must move the equivalent of 30” of solid earth before uprooting and a force necessary to do this will bend or snap off the post before the footing gives.

Unlike concrete set posts, “Drive Anchors” set posts are unaffected by frost, thaws, etc., and the fence line stays permanently in initial alignment. Moreover, a fence set with “Drive Anchors” can be readily removed and relocated if protective requirements change.³

In Table 1 there is a general comparison of the characteristics of the drive anchors and the concrete footings. Several items have been identified as claims by either previous studies or manufactures literature. The results of this study have not disproved any of the claims.

Table 1 Drive Anchors versus Concrete Footings^{4, 3}

DRIVE ANCHORS	CONCRETE
Temporary can be removed and reused *	Permanent installation
Easier to install in hard to reach places **	Elaborate foundation makes it more difficult to install
Does not require any vehicles for installation	Requires a cement truck near the ROW or bags of cement and wheelbarrows
Little if any soil is removed	Requires disposal of soil
Not affected by frost **	Damaged by frost
Not affected by loose soil **	Weakened by loose soil
Can be installed in wetlands	Difficult to install in wetlands
Anchor material costs are more expensive ***	Concrete material costs are inexpensive ***
More posts can be installed per day	Fewer posts can be installed per day
Fence fabric can be immediately installed	Requires concrete cure time (few days) before fence fabric can be installed

* N.J. Turnpike Study

** Claimed by Anchor Fence Inc.

*** See Table 5 for material cost breakdown

NJDOT Approved Fence Contractors

The literature search included contacting all fourteen of the NJDOT approved fencing contractors. Table 2 summarizes the opinions of the contractors. Figure 3 and Figure 4 provide a visual depiction of the results/satisfaction with the drive anchors and the contractor's preference for either concrete or drive anchors.

Several of the NJDOT approved fence contractors that were contacted to discuss installation procedures stated that the amount of time needed for installing anchor fence posts and concrete fence posts was about the same. Both methods were estimated at roughly 100 posts per day. The basis for the fence post estimate is the basic manual installation of the anchor post using a post driver and sledgehammers. The basis for the concrete estimate is using a mechanical hole driller and a cement concrete truck.⁵ However, our results indicated that by utilizing only manual methods of installation the drive anchor systems could be installed two times faster than the concrete (one hour versus 30 minutes). Plus the anchor system is ready immediately for the fence fabric to be stretched whereas the concrete requires setting time. Even though the contractors estimate is based on mechanical assistance this approximation is believable. The anchor posts are many times installed in areas where mechanical assistance cannot be used due to accessibility limitation like wetlands, steep roadway cuts, and wooded terrain. Hence, given the advantage of using a mechanical hole digger for posts in concrete versus manual installation of anchor posts, the number of posts installed per day should be approximately the same. However, if both systems are installed using like methods, the anchor system appears to be significantly faster.

Table 2 Summary of NJDOT approved contractors⁶

Company	Have Used Drv. Anchors		Never Used Drv. Anchr.	Favor		
	Satisfied	Dissatisfied		Concrete	Drv. Anchr.	Other
1		X				X
2	X			Larger jobs	Smaller jobs	
3	X				X	
4	X				X	
5	X				X	
6			X	X		
7	No Longer In Business					
8	**			X		
9		X		X		
10	X				X	
11			X	X		
12		X		X		
13	X			X	***	
14		X		X		

* Uses Company #4 to install fencing

** Uses drive anchors only in wetlands

*** Indifferent towards drive anchors

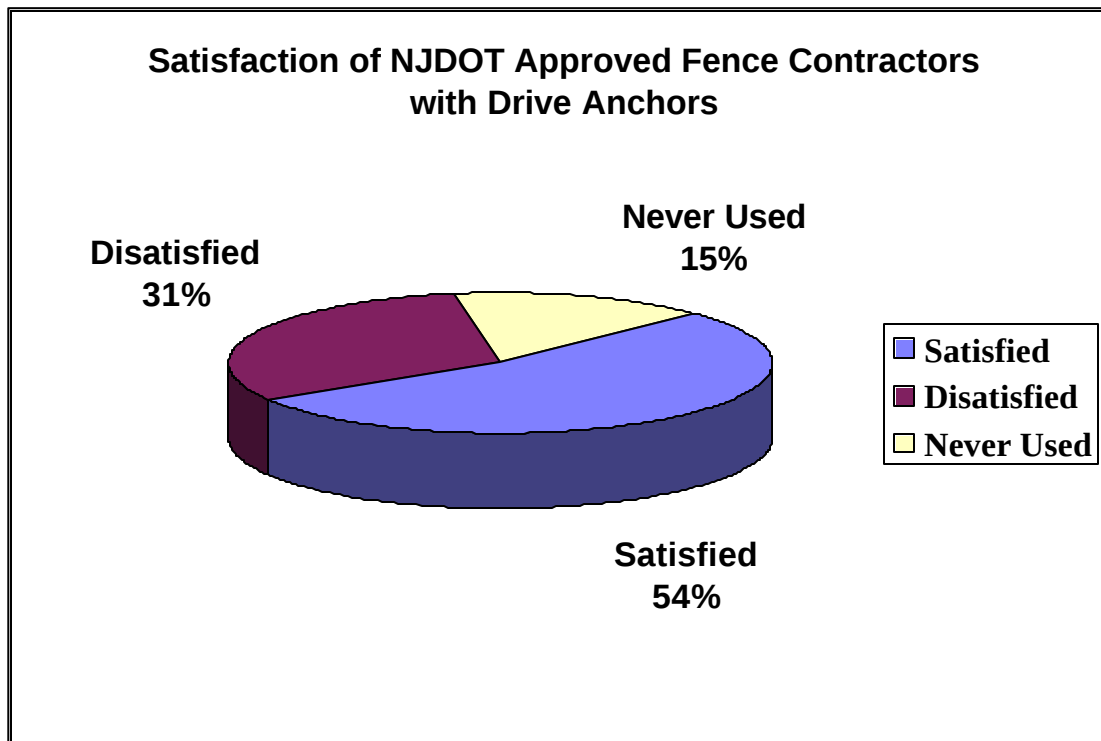


Figure 3 Satisfaction of NJDOT approved fence contractors with drive anchors.⁶

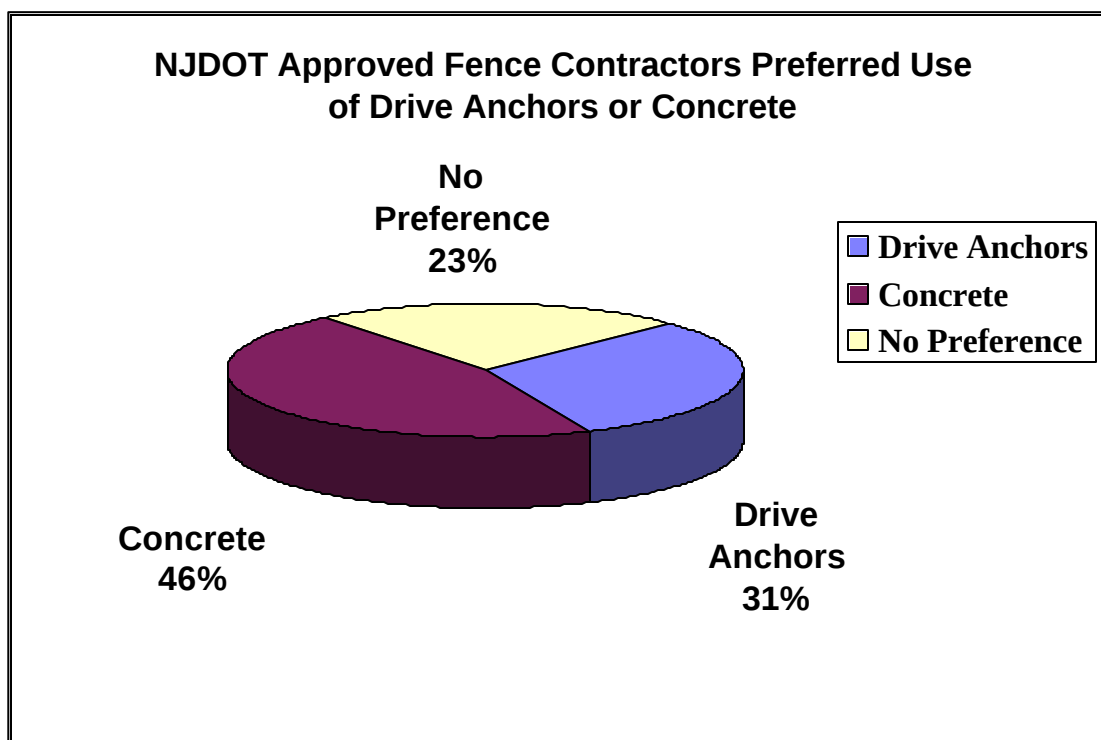


Figure 4 NJDOT approved fence contractors preferred use of drive anchors or concrete.⁶

Post Type

Right-of-way fence posts are the vertical members of the fence. Several different fence post arrangements are shown in Figure 5. Each configuration is detailed with a description in the following section.

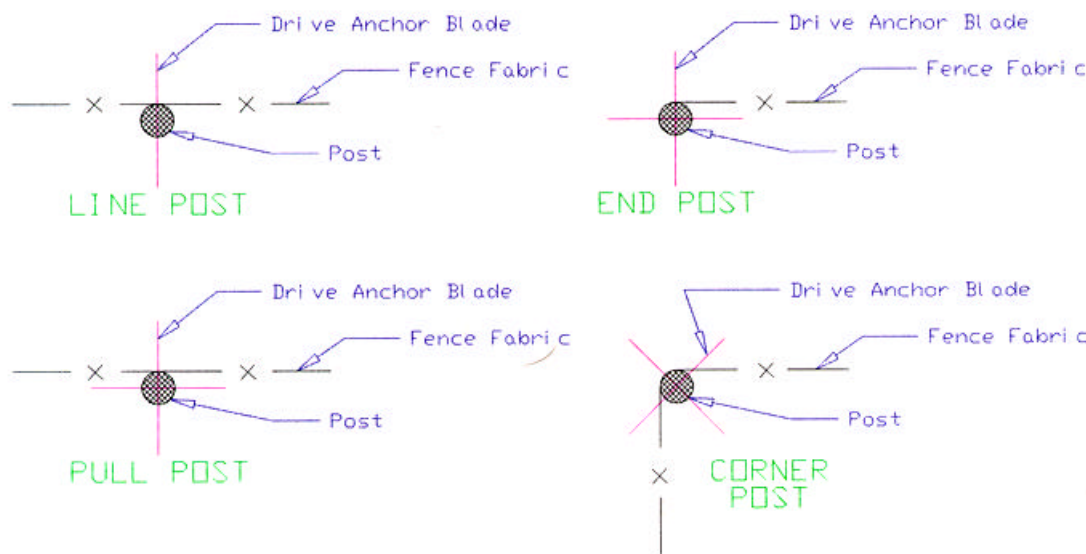


Figure 5 Diagram showing different positions and alignments of a fence post installation.⁷

End, Corner, and Pull Posts

End, corner, and pull posts (all of which will be referred to as “End Posts” for the remainder of the report) must be strong enough to endure the strain of the fabric which is stretched between them. It was mentioned in a PennDOT report that in common construction practice a pull force of 925 lbs. is applied to the fence fabric during installation. When the fabric is stretched, sufficient tension must be applied to remove all slack from the chain-link. Therefore the minimum bending strength required for these posts is either the maximum environmental load or the tension applied while stretching the fabric.¹

End Post:	Used where the fence fabric terminates
Corner Post:	Used where the direction of the fence changes
Pull Post:	Used to brace fence fabric along a lengthy stretch, or used to achieve a change in grade along the fence line

Line Posts

Line posts attach to the fabric by means of clips and fasteners. However the line posts do not experience the same tension from the fabric as the end, corner, and pull posts. Since line posts do not experience the large tension while stretching the fabric the minimum bending strength must be the maximum environmental load.

Line Post:	Used every 10 ft as an intermediate post
------------	--

Post Installation

Several schedule 40 (steel) posts were purchased for the experiment that satisfied the ASTM recommendations shown in Table 3.⁹ All of them had the same length of 8' 8", the 8'

8" height was based on a 6 foot height requirement, and 32 inch buried under the ground for the footing.⁸

Table 3 ASTM post recommendations.⁹

PIPE (schedule 40) (steel) Min. yield strength not applicable Line post: Outside Diameter 2.375 in Thickness 0.154 in Weight 3.65 lb/ft End Corner and Pull Posts: Outside Diameter 2.875 in Thickness 0.203 in Weight 5.97 lb/ft	PIPE (cold rolled or welded pipe) (steel) Min. yield strength 50,000 psi Line post: Outside Diameter 2.375 in Thickness 0.130 in Weight 3.12 lb/ft End Corner and Pull Posts: Outside Diameter 2.875 in Thickness 0.160 in Weight 4.64 lb/ft
---	--

The posts selected for the tests were schedule 40 steel posts as indicated above in Table 3. As per industry standard for the remainder of this report the 2.375 and the 2.875 inch diameter posts will be referred to as 2.5 and 3 inch diameter posts respectively. The yield strength of the posts is 25,800 lb/in² for both and the section modulus is 0.5606 in³ for the 2.5 inch post and 1.064 in³ for the 3 inch post.^{5,8}

For the concrete anchor systems, the concrete used was a rapid-set type C concrete. Appendix 2 gives the guidelines for fence post installation for the NJDOT as well as several surrounding states. The NJDOT specifications require that the concrete must set for 72 hours before applying a load to the post. The posts were allowed to set for 168 hours or seven days, more than double the minimum time specified, before they were loaded.¹⁰

Breaking Loads of Fence Fabric

The breaking load of the fence fabric or mesh is a useful piece of information for the post design. The breaking load of the mesh points toward a minimum required load for the end posts. In Table 4 for a typical strand of Type II Number 9 mesh the breaking load is 1290 pounds, however this is not the net breaking load of the mesh system itself. In the PennDOT research study it was found that a load, applied to a stretcher bar inserted into the fence fabric, pulled perpendicular to the height of 5 feet of fence fabric stretched between two posts caused the fabric to fail at loads between 2,400 and 2,700 pounds.¹ According to their results the foundations did not fail and can be considered rigid, therefore this system can be analyzed using statics. Also, assuming that the load transfer from the mesh to the post is uniform, this produces the worst case scenario in which the loading can be considered homogeneously distributed over the height of the post. By assuming the load to be equally distributed this produces the most conservative estimate. In reality the post will bend or tilt, thus reducing the loading at the top of the post and in turn decreasing the moment at the base of the post. Using the maximum load of 2,700 pounds the distributed load on the post is [Distributed Load = Direct Load / (Length x 2)] calculated to be 270 lbs/ft on each post. (Please note that in the previous calculation the division by two, is the result of the load being applied to a stretcher bar inserted into the mesh between two rigid posts.) This equates to a

moment about the base of each post [$\text{Moment} = (\text{Distributed Load} \times \text{Length}^2) / 2$] equal to 3,375 ft-lbs. Hence any loading, which causes a moment in excess of 3,375 ft-lbs at the base of the post, will cause the mesh to fail.

Table 4 Fence fabric breaking loads.¹¹

Size Coated Wire Gage	Nominal Diameter of Coated Wire	BREAKING LOADS			
		Type I and II	Type III	Type IV	
				Bonded	Extruded
	in.	lb	lb	lb	lb
6	0.192	2170	1560	1800	1290
9	0.148	1290	930	1200	850
11	0.12	850	610	800	515

NOTE: The shaded boxes are the No. 9 fabric used in NJDOT fence installations

EXPERIMENT

The experimental portion of the research consisted of two parts. The first part was a finite element modeling analysis of the post systems. This data would be used to design the experiment and give projected experimental field results. The second portion consisted of actual field-testing. Since the loading was going to be in the thousands of pounds range and it was going to be conducted in a field environment where it is sometimes difficult to maintain controlled conditions it was crucial that the testing system be well-built and safe. With the results in hand from the analytical portion, a testing apparatus was specified to withstand the projected loads to be exerted in the field. Once the experimental field results were obtained, they were then compared back to the original analytical model.

Background for Pullouts

The procedure was roughly based on the original PennDOT fence post testing that occurred in the 1970's, and is provided as background information in Appendix 2. The procedure for the PennDOT test applied a loading at the top of the pole. Their testing concluded that the footings did not fail before the material failure of the post. However, their height of pull or moment arm was at 4'6" from the ground surface. The report has indicated that conclusive research is required, based on the lack of failure of the footings.¹

In this research study, a loading was applied to the post at 24 inches above the ground, the bumper height of an average car. Of course a car would provide a dynamic loading to the fence post; however, the concern of this study is on the comparison between the failure of the concrete footing posts and the anchor footing posts in a static test.

Finite Element Modeling

A finite element model (FEM) was generated to compare the two fence post systems in a mathematical method. The results generated from the modeling are discussed later in this

report in Appendix 1. The posts that were modeled were based on the ASTM post recommendations set forth in Table 3.^{8,9} The modeling demonstrated the use of constant soil parameters as well as uniformity of the concrete. The results and differences will be discussed within the data and analysis section as a comparison to the results from the field research.

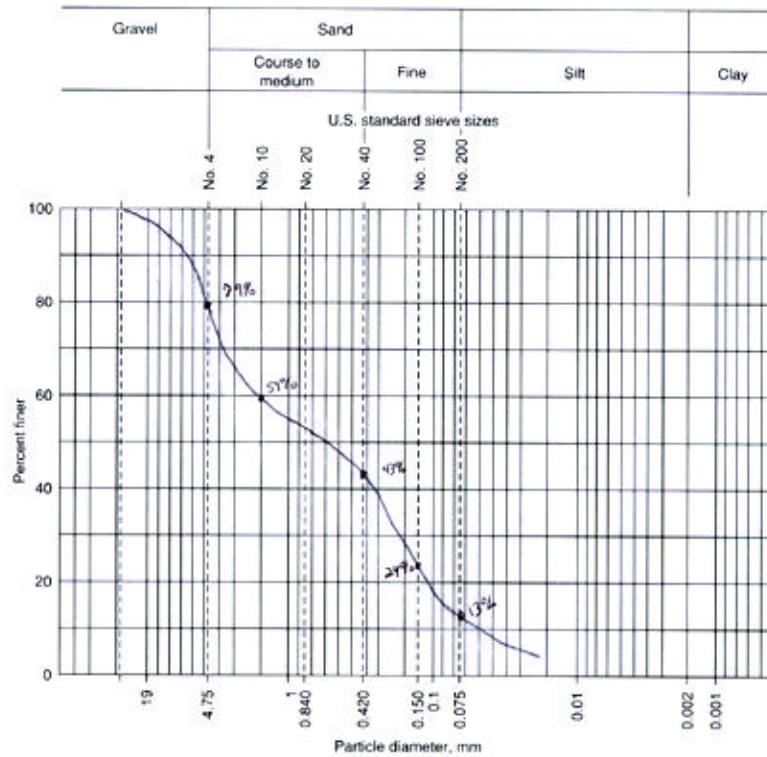
Site Selection

Site selection became a problematical issue for this project. There were several dilemmas. One was the need for a dead load to anchor the loading mechanism. There was concern over using dump trucks and rubber tire backhoes because of the potential for rolling. If the vehicle rolled the load would be inconsistent making the results from test to test incompatible. A track bulldozer was selected for its shear weight as well as its ability to remain motionless. At one point, it was expected to conduct the testing on an actual field installation along Route 55 in Cumberland County, NJ. However, this offered its own tribulations. If the testing was conducted on Route 55 it would require traffic closures which are rather costly and bothersome to motorists. Also someone would have had to repair the fence after testing occurred, another cost that would have to be incurred. On top of that the actual testing would have taken several days of set-up as well as to carry out and complete, thus making the roadside work rather cumbersome.¹² The final problem was getting a bulldozer onsite, as the NJDOT does not maintain bulldozers as part of its normal maintenance fleet. This was enough incentive to select a non-roadside site, sufficiently withdrawn from the road to avoid lane closure, but available enough to move the machinery into place and provide an adequate spacing between the posts. Selection of the site also required avoiding of shallow underground utilities. Thus the complications involved with site selection provided a strenuous effort to overcome these obstacles. A secondary site was selected near the construction of the Metro-Mall Complex in Newark, NJ. Being an active construction site, they maintained a number of large earth moving machines, including several bulldozers. We made arrangements with the property owners, however we were unable to mobilize before the harsh winter months, after which time the site was no longer available to be used for our testing. Another site was selected after that in Bayonne, NJ this site also had a bulldozer on-site for maintenance reasons. Unfortunately, when we went to install the posts it was discovered that below the top six (6) inches of soil there was several feet of roofing shingles used as fill. This site was also abandoned due to the lack of natural soil material. Finally we contacted a construction contractor who owns a bulldozer and requested permission to install the posts in their maintenance yard. We were granted permission and immediately installed the posts. Soil samples were obtained from the site prior to installation. A soil gradation can be seen in Figure 6, which shows the material to be a natural gap-graded gravelly-sand. The material was acceptable and the site was free of underground utilities. The site was also sufficiently large to allow for adequate spacing between the posts.

GRAIN SIZE DISTRIBUTION

Data Sheet 5b

Project Fence Post Project Job No. 2000-07
 Location of Project Rutgers Boring No. _____ Sample No. _____
 Tested By Judson Wible Date of Testing _____



Visual soil description Gravelly - Sand with Organics
 Soil classification A-1-a Soil
 System _____

Figure 6 Soil gradation analysis for site location.

Installation of Fence Posts

The selected area was cleared of debris, rocks, and other obstructions. All of the necessary materials and tools were set up on a large tarp including the concrete, posts, anchors, shovels, tape measures, and all other necessary materials.

The initial site set up was planned on paper. In accordance with typical installation procedures, the spacing of the posts needed to be at least ten feet apart. The area of the site was large enough to satisfy these requirements. Therefore it was decided to minimize potential interaction effects between post tests, and space them out at least ten feet apart.



Figure 7 First hole dug on-site for a 2.5 inch line post set in a concrete footing.

The hole shown in Figure 7 took approximately 50 minutes to dig by hand. The digging began for this hole (Concrete Post #1) in the rear right location of the site. See Figure 8 for the location of each individual installation. Since there were only two posts being set in concrete, the concrete was mixed by hand. Mixing was performed in a mix barrel, and three cylinders were prepared to verify compressive strength. This hole shown in Figure 7 was used for the 2.5 inch diameter line post. After completion of the pouring, a plastic covering was placed around the post, over the cement and secured in place. The plastic covering was used to secure the moisture within the concrete to prevent the mixture from drying out before it cured. This was done in accordance with specifications shown in Appendix 2.

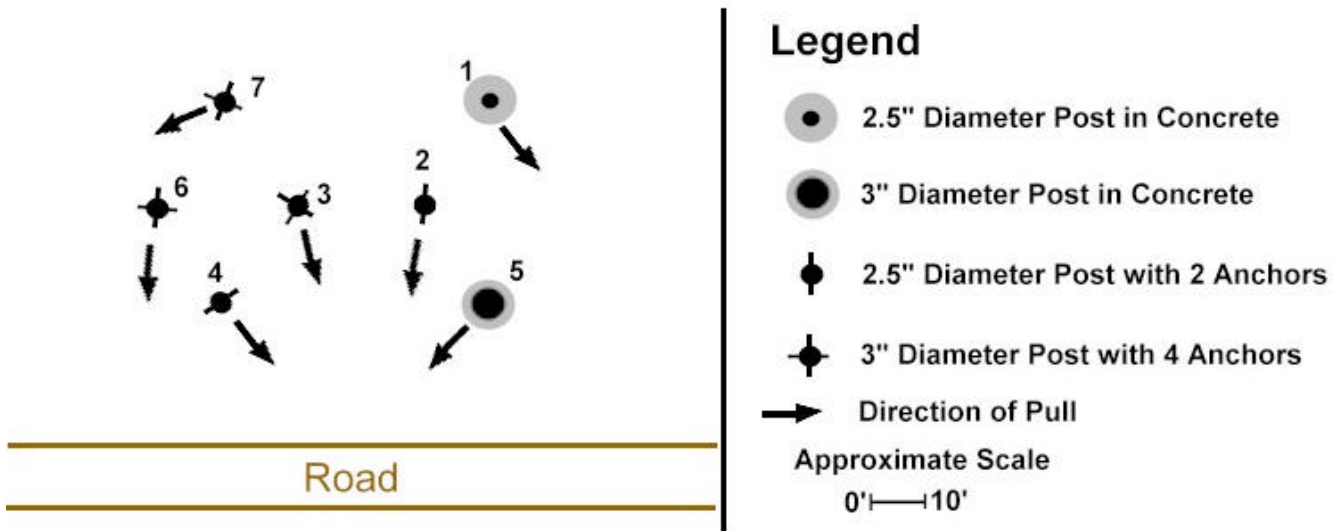


Figure 8 A diagram of the hole locations, indicating size of post, anchor mechanism, and identification number.

The second post set in concrete (Concrete Post #5) was completed, with the correct width and depth, in one hour. This hole was used to install a three inch diameter end post. The concrete was mixed and placed in the same fashion as the previous concrete installation. As with the other post the concrete was covered with plastic when it was finished.

The total installation time of a line post set with a drive anchor (Anchor Post #2) was roughly 25 minutes. The total manual installation time of an end post set with a drive anchor (Anchor Post #3) was roughly 35 minutes. A hand held post driver, a heavy round pipe with an end cap and side handles, was used to drive the post straight down into the soil. This took approximately 15 minutes. Then the anchor shoe and blades were positioned as shown in Figure 9. The blades were driven by hand with a sledgehammer as shown in Figure 10. These each took an additional 5 minutes to drive. The final line post installation ready to be tested is shown in Figure 11.



Figure 9 Photograph of driven 2.5 inch line post with one set of anchor blades positioned for installation.



Figure 10 Photograph of driven 2.5 inch line post with one of the anchor blades driven via a sledgehammer into position.



Figure 11 Photograph of fully installed 2.5 inch line post and anchor blades ready to be tested.

Post Pull-out Set-up

If the testing had been done in a laboratory environment, a piston load cell combination would have been used. However, the goal of the project was to conduct field tests to simulate actual right-of-way conditions. A track bulldozer was selected as a dead load for the pull-out system for its weight as well as its ability to remain stationary. Dump trucks and rubber tire backhoes could not be used because if they rolled even slightly the load would be inconsistent making the results from individual pull-outs incompatible.



Figure 12 The testing apparatus consisting of a ratchet mechanism, load cell, and bulldozer are shown.

The overall pull-out testing apparatus is shown in Figure 12. Attached to the bulldozer was a wire rope capable of withstanding five thousand pounds. A shackle capable of withstanding six thousand pounds attached the wire rope to a specially constructed lifting ring. Two lifting rings were purchased each capable of withstanding ten thousand pounds. The lifting rings were manufactured to screw connect into the ten thousand pound load cell, but still allow rotation to avoid any torque in the testing system. The opposite side of the load cell consisted of another swivel hook and shackle connecting to a ratchet. The four thousand pound ratchet or “come-along” was used to apply the loading to the fence posts. The load cell monitored the ratchet loading and recorded the information on a data acquisition unit. It also provided a real-time graphical display of the loading, as shown in Figure 13.¹³



Figure 13 The data acquisition unit. The monitor shows the graphical representation of the ratchet loading.

Manual readings of the deflection were measured by a dial gauge deflectometer. Ideally, the unit would have been located 24 inches above the ground surface, exactly where the pear ring was pulling on the post thus matching the FEM analysis. However, the actual placement of the deflection measuring equipment was at 21 inches above the ground surface, to avoid damage. It was determined that even when excessive horizontal deflections occur, the effect of 3 inches vertical was negligible. The placement of the deflectometer was consistent for all of the posts such that the displacement data could be compared, the deflectometer is shown in Figure 14.



Figure 14 The deflectometer was attached to a stationary pole that was driven in the ground nearby so the deflection could be measured at the pull height.



Figure 15 The pull-out system is shown just after beginning a pull-out test.

In Figure 15 the entire testing apparatus is shown, ready to begin a pull-out test. The load cell and ratchet connect the bulldozer to the fence post to be tested. The van in the background contains the data acquisition system and monitoring equipment. In the front portion of the photo the deflectometer can be seen in the zero position. Also in the background of the image, on either side of the front of the van, can be seen two posts that are ready to be tested.

Testing

Both the load cell and the ratchet were placed on crates so that their load wouldn't initially be a factor in the calibration of the load cell and deflectometer. A picture of the two devices on the crates is shown in Figure 16. The load cell and the deflectometer were zeroed. The data acquisition unit was started, to measure the load being applied to the pole. The ratchet was

used to incrementally load the post system, and manual measurements of the dial gage readings were taken every two ratchet pulls. This deflection measurement was recorded along with the load value at that point. The deflection measurements were manually recorded while the data acquisition unit was taking load measurements automatically.



Figure 16 This figure shows a before and after picture of the ratchet and load cell. The before picture, on the left, shows the devices lying on the crates ready for testing, the after picture shows the system in tension.

DATA AND ANALYSIS

Field Testing Results

Fence Post #1

A concrete line post with a 2.5 inch diameter was installed. The loading was applied to a maximum force of 937 lbs. at which point there was a deflection of 4.6 inches. This failure caused a strain concentration in the post, causing it to permanently bend, which is representative of the development of a plastic hinge.

Fence Post #2

An anchor line post with a 2.5 inch diameter was installed. The direction of loading was parallel to the line of the single set of anchor blades. Thus, simulating loading directly on the line post or mesh. The loading was applied to a maximum force of 1123 lbs. at which point there was 4.7 inches of deformation. The post itself experienced little or no bending. There was some minor upheaval of the soil around the base of the post. The movement of the post was due to the deformation of the soil.

Fence Post #3

An anchor end post with a 3 inch diameter was installed. The loading was applied at a 45 degree angle to either line of the four anchor blades. Thus, simulating a scenario of an end post that is loaded at an angle, caddy corner to the anchors. The post withheld a maximum force of 1873 lbs. at which point there was 5.5 inches of deformation. The post itself experienced little or no bending. There was no upheaval of the soil around the base of the post. The movement of the post was due to the deformation of the soil below the grade.

Fence Post #4

An anchor line post with a 2.5 inch diameter was installed. The direction of loading was perpendicular to the line of the single set of anchor blades. Thus, simulating loading directly on an incorrectly installed line post. During our literature review it was found that on occasion a contractor did not understand the correct orientation of line post anchors and installed the blades parallel to the mesh. The post withheld 1170 lbs of force at a deflection of 4.6 inches. The failure with this post loading was due to upheaval of the soil and partial removal of the anchor post from the ground. The post itself experienced little or no bending. There was no upheaval of the soil around the base of the post. The movement of the post was due to the deformation of the soil below the grade.

Fence Post #5

A concrete end fence post with a 3 inch diameter was installed. The loading was applied to a maximum force of 2700 lbs of force. At the point of maximum loading, the post experienced a deflection of 5.9 inches. The failure of the system was due to the creation of a plastic hinge at the base of the steel post and the subsequent bending of the post without failure in the concrete. There was no movement of the soil around the base of the footing. The movement of the post was due to the deformation of the post itself.

Fence Post #6

An anchor end post with a 3 inch diameter was installed. The loading was applied in line with one of the two sets of anchor blades. The post withheld a maximum force of 1790 lbs of force, at the point the deflection was at 5.6 inches. Thus simulating loading directly on an end post or mesh. The post itself experienced little or no bending. There was no upheaval of the soil around the base of the post. The movement of the post was due to the deformation of the soil below the grade.

Fence Post #7

An anchor end post with a 3 inch diameter was installed. The loading was applied at a 45 degree angle to either line of the four anchor blades. Thus, simulating a scenario of an end post that is loaded at an angle, caddy corner to the anchors. This test was done to duplicate the testing on Fence Post 3 to verify the test results. The post withheld a maximum force of 1678 lbs. at which point there was 5.4 inches of deformation. The post itself experienced little or no bending. There was no upheaval of the soil around the base of the post. The movement of the post was due to the deformation of the soil below the grade.

The data obtained from the field pull-out testing is provided in Appendix 3.

Analysis of 2.5 inch diameter posts

In Figure 17 photographs of field-testing of a line post installed with drive anchors is shown. It can be seen that there is little to no bending of the post itself but the soil has deformed to allow the post to tilt. In Figure 18, a comparison is made between the deflection and the loading of the 2.5 inch diameter fence posts. The graph shows strong similarities between the post systems. None of the 2.5 inch diameter post pull-outs exceeded 1,200 lbs. of force. However, the graph shows that the Anchor Post #4 was marginally stronger than the other two installations. For a graphical representation of what the Anchor Post #4 test set-up looked like, refer to Figure 8. The concrete footing was slightly weaker than the other two

systems. The data presented in Figure 18 shows that all of the posts experienced roughly the same deflection versus the loading. This signifies that none of the 2.5 inch diameter fence post installations are clearly superior, based on these field testing results. These results indicate that for line posts, a concrete post is not a better choice than an anchor post. Henceforth, these systems can be considered roughly equivalent, based on these specific testing conditions.



Figure 17 Testing results Anchor Post #2 of a 2.5 inch diameter line post installed with drive anchors. Shows deformation of the soil resulting in post inclination.

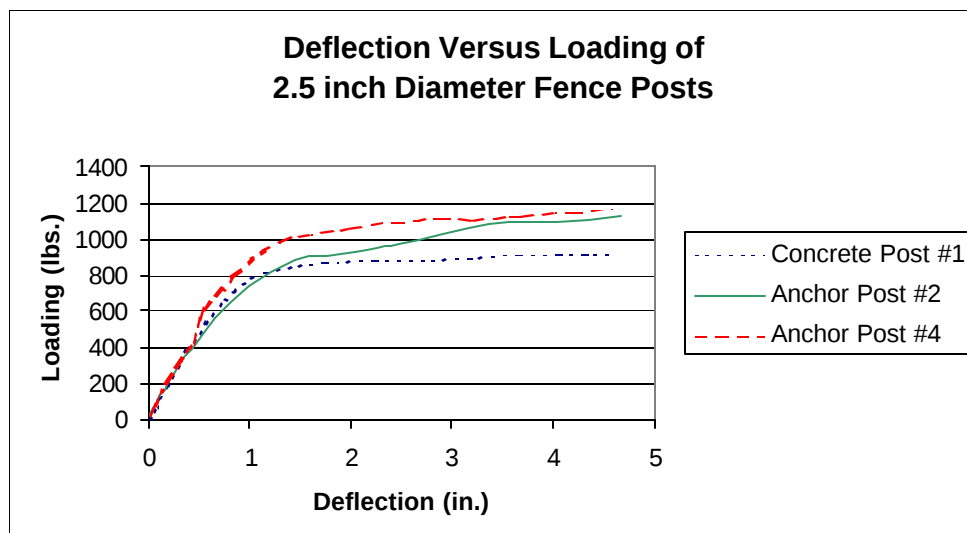


Figure 18 The Deflection versus loading of the 2.5 inch diameter fence posts.

Analysis of 3 inch diameter posts

In Figure 19 a photograph of a test of a 3 inch diameter post installed with drive anchors is shown. It can be seen that there is little to no bending of the post itself, but the soil has deformed to allow the post to tilt. In Figure 20 a photograph of a test of a 3 inch diameter post installed in concrete is shown. It can be clearly seen that the post has bent indicative of the formation of a plastic hinge. Figure 21 shows the deflection versus the loading graph of the 3 inch diameter fence posts. The graph shows that the concrete post obtained a significantly higher loading with less deflection. All of the other anchor fence posts performed similarly obtaining roughly the same deflection under the loading applied. Thus, indicating that regardless of installation orientation of the anchors their overall performance is hardly affected. The graph of the deflection of the concrete appears to be reminiscent to a typical yield strength curve of steel. This was not surprising considering from visual observations the post developed a plastic hinge at its base and began to bend. The concrete was undamaged, however the post deformed as the loading was increased. The anchor posts experienced compression of the soil substructure, thus allowing rotation of the post about the anchor shoe. The posts did not deform, but there was excessive post leaning. This signifies that of the 3 inch diameter fence post installations the concrete footing is clearly stronger based on these field testing results.



Figure 19 Testing results of Anchor Post #6 a 3 inch diameter post installed with drive anchors. Shows deformation of soil resulting in post inclination.



Figure 20 Testing results of Anchor Post #5 a 3 inch diameter post installed with concrete. Shows the formation of a plastic hinge in the post.

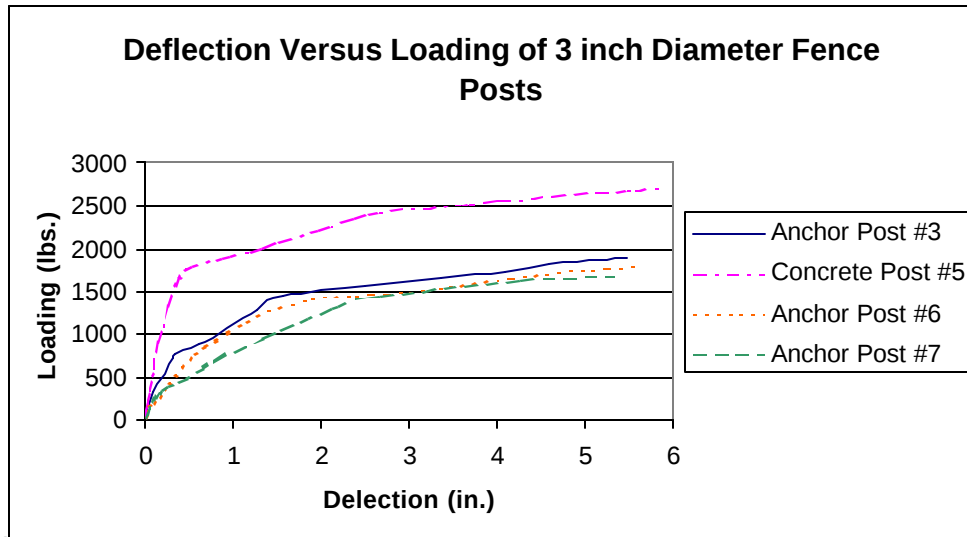


Figure 21 Deflection versus loading of the 3 inch diameter posts, a comparison between a concrete footing and anchor posts.

During installation, pull loads when stretching fabric are rarely over 1,000 pounds. These pull loads are applied directly to a stretcher bar, which therefore distributes the load over the height of the end posts. The 1,000 pound direct load distributed over a 6 foot height, produced a distributed load [$\text{Distributed Load} = \text{Direct Load} / (\text{Height})$] of 166.6 lbs/ft. Conservatively this equates to the same moment [$\text{Moment} = (\text{Distributed Load} \times \text{Length}^2) / 2$] (3000 ft-lbs) of a direct 1,500 pound load at 2 feet from the surface. Loading at 2 feet above the surface is what was done in the field tests, the results can be seen in Figure 21. Each of the posts withstood the force, albeit with varying degrees of deflection.

Even though both systems were able to withstand the loading, this does not make the systems equivalent. In fact, the systems are not equivalent. However, they may both be sufficient to be used, therefore we established a failure criterion. Developed earlier in this report, from the analysis of the PennDOT research study it was found that loading, which causes a moment in excess of 3,375 ft-lbs, will cause the mesh to fail.¹ Therefore based on our test at 2 feet above ground level the direct load [$\text{Direct Load} = \text{Moment} / \text{Height}$] of 1,688 pounds is needed to produce mesh failure. It is reasonable that the posts must at least be able to sustain this level of loading to be sufficient in field applications. Thus, they must withstand at least 1,688 pounds without excessive deflections. The 1,688 pound loading is our failure criterion for sufficient performance in field applications. From Figure 21 we can see that all the posts reached this loading level. Consequently for these site conditions and testing setup, even though the concrete installation is stronger than the anchor system, they both performed within tolerable limits established in this study. It is possible that under different conditions, such as impact loading, the systems may react completely dissimilar, however this was not part of the study.

An interesting comparison is evident in the graph between the concrete post footings. Figure 22 shows similarities in the loading versus deflection data of the 3 inch and 2.5 inch posts in concrete footings. Both posts experienced permanent deformation in the field tests, and both tests experienced a point where their material curves level out significantly. This is the

approximate yield point of the steel posts. In both cases the lateral loading on the posts in concrete formed a plastic hinge, the strain concentrated in the post at the interface between the post and the concrete. All the deformations of the system are a result of the properties of the steel and not the concrete. There is little, if any, soil deformation and the concrete remained undamaged.

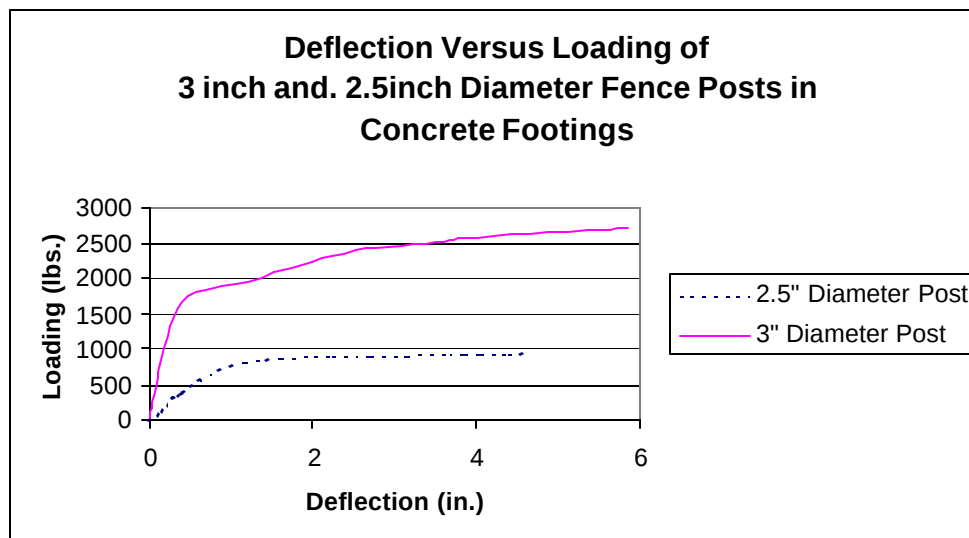


Figure 22 The deflection versus loading comparison of 3 inch versus 2.5 inch diameter concrete posts.

Yielding verification in concrete footing

In the concrete footings, steel yielding apparently occurred based on visual observations during the field tests. To verify that yielding did indeed occur, the bending strength must be calculated. The 2.5 inch post had a yield strength of 25,800 psi and a section modulus of 0.5606 in^3 .^{5,14} Thus the bending moment (yield strength times section modulus) is equal to 1,200 ft-lbs. Therefore, calculating out the corresponding equivalent direct load at 2 feet above grade is 600 pounds. The 3 inch post had a yield strength of 25,800 lb/in² and a section modulus of 1.064 in^3 . Hence, the bending moment (yield strength times section modulus) is equal to 2,290 ft-lbs. Therefore, calculating out the corresponding equivalent direct load at 2 feet above grade is 1,145 pounds. Cross-referencing the 600 pounds for the 2.5 inch and 1,145 pounds for the 3 inch posts in concrete to Figure 22 it is clear that the posts did indeed exceed their yield strength. A similar analysis cannot be conducted on the anchor posts because the posts tilted about the shoe, producing plastic strains in the surrounding soil. By distributing the stress throughout the foundation, the anchor posts prevented yield failure of the steel.

Material and Labor Costs

The economic savings can be analyzed with the costs of materials and labor for each of the installation processes. Regardless of the installation process, the cost of the posts remains the equal. For a steel post that is 2.5 inches in diameter and 104 inch long schedule 40 galvanized the cost is \$26.26 each. For a steel post that is 3 inches in diameter and 104 inches long schedule 40 galvanized the cost is \$41.21 each.

Based on interviews with NJDOT approved fence contractors, approximately 100 anchors or concrete posts can be installed per day.⁵ However, this estimate is very subjective due to experience of the contractor, crew size, as well as the method of installation used; i.e. manual labor-intensive versus mechanical assisted installations.

From actual field measurements, utilizing a manual method for the drive anchor posts the installation time was approximately 25 minutes for one laborer. For a manual method for the concrete posts installation the installation time was approximately 60 minutes for one laborer. The soil gradation for the site in Figure 6, shows the subsurface material to be a natural gap-graded gravelly-sand. For this type of gravelly material it was not unexpected that manually digging a hole was a difficult task. Clearly demonstrating that manual installation times will be highly dependant upon the soil properties of the site. Thus under these conditions for every one concrete post that is set two drive anchor posts can be installed.

Table 5 Breakdown of material costs for fence post installations.¹⁵

Installation Type 104 inch long	Post	Anchor Shoe \$3.89 each	Anchor Blades \$4.30 each	Concrete \$113.08/yd ³	Total Cost
Line Post with Anchor	\$26.26	\$3.89	\$8.60	X	\$38.75
End Post with Anchor	\$41.21	\$7.78	\$17.20	X	\$66.19
Line Post with Concrete	\$26.26	X	X	\$11.31	\$37.57
End Post with Concrete	\$41.21	X	X	\$11.31	\$52.52

In respect to the economic savings, the analysis is based on cost of expendable supplies and fence materials as shown in Table 5. All costs shown are for reference purposes only and were based upon actual quotes received from NJDOT approved fence contractors. These costs may not accurately reflect the “going rate” from the manufacturer; in fact further research has found that the drive anchors may be significantly cheaper.¹⁶ For the anchor blades and shoes the cost is \$4.30 per blade and \$3.89 per shoe. For the line anchor posts, with one shoe and two blades the cost is \$12.49 for the drive anchor footing system. For the end anchor posts, with two shoes and four blades the cost is \$24.98 for the drive anchor footing system. For the concrete footing system hand mixed concrete is \$113.08 per cubic yard or \$4.19 per cubic foot. The volume of an average end post hole is approximately 2.4 cubic feet, hence with the concrete at \$4.19 per cubic feet the net concrete cost is estimated to be \$10.06 per hole. According to at least one contractor, a post set in hand mixed concrete is \$11.31 per hole, hole sizes are approximately the same for line and end posts therefore, this amount covers both posts installations.⁵ This is very close to the calculated estimate, for the purposes of analysis the contractors’ amount will be utilized. For the line posts, the expendable supplies and fence materials the concrete posts are slightly more economical. However, for the end posts, the economic savings are clearly in favor of the concrete. A graphical representation of the breakdown of material costs is revealed in Figure 23, a summary net cost per installation type is shown in Figure 24.

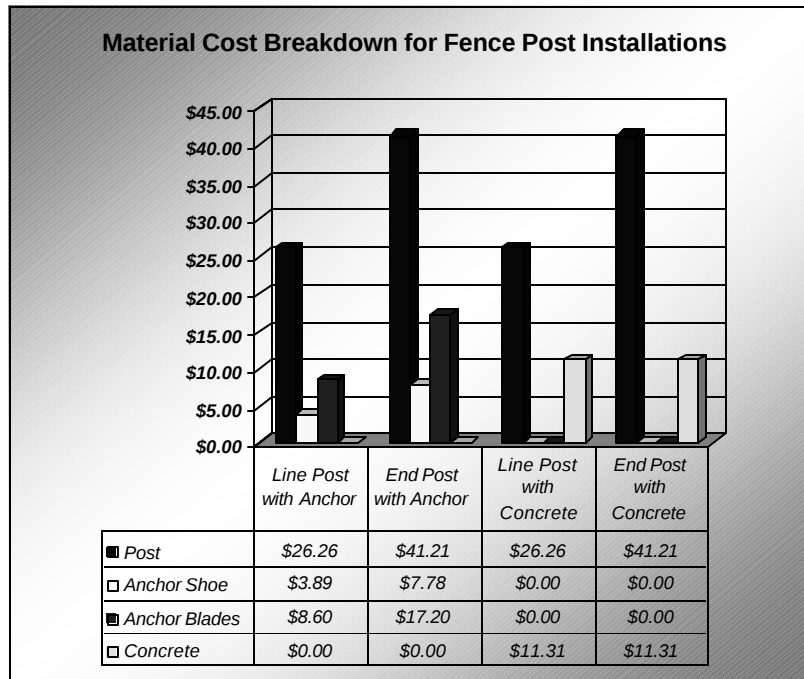


Figure 23 Material cost breakdown for fence post installations.

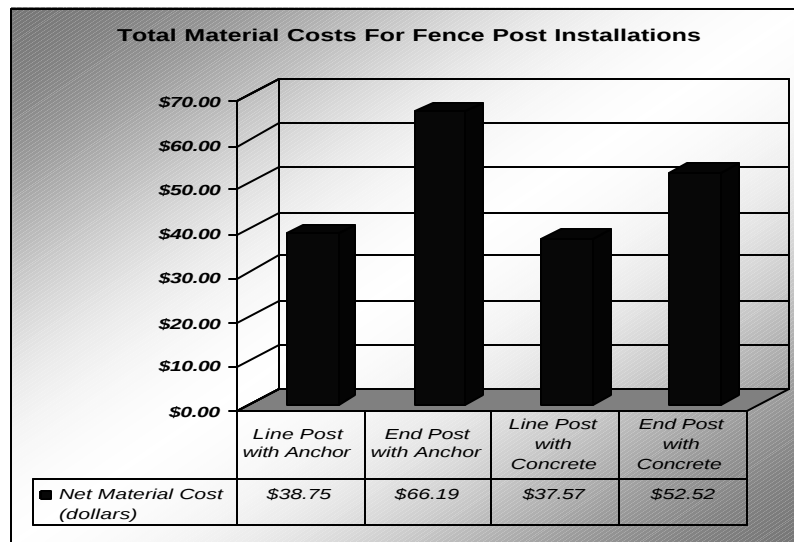


Figure 24 Total net material cost for fence post installations.

The above analysis does not take into account the capital costs associated with a cement truck or a mechanical hole digger. The analysis only covers material costs of the manual installation of the fence posts. The only major equipment needed for a manual installation is a shovel, a post hole driver, a wheelbarrow, and sledgehammer. Mechanical equipment could be used to speed up installation time, however based on contractors comments the increase in efficiency would be about the same. Therefore, should the contractor decide to use a mechanical method of driving the posts, there would most likely still be a cost savings

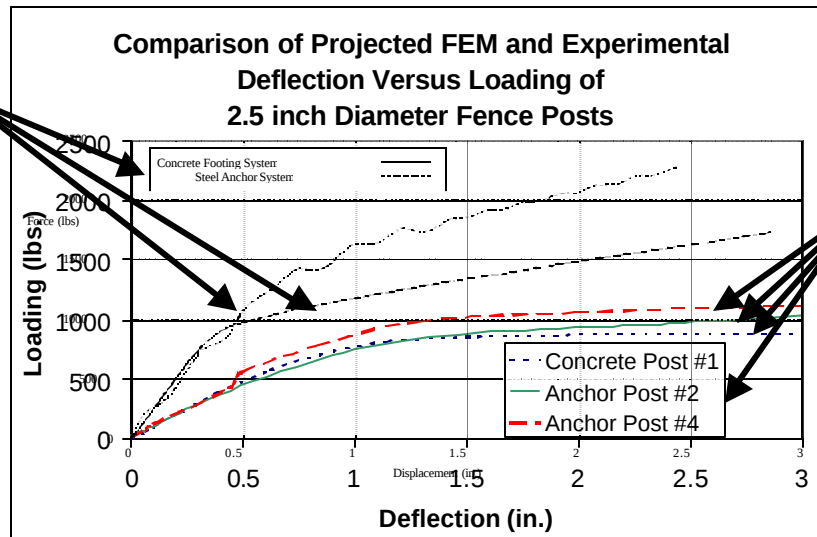
over a mechanical hole digger. In conclusion, the anchor posts are less expensive to install than the concrete posts based on labor time, however the material costs are larger.

FEM VERIFICATION OF RESULTS

The Finite Element Modeling of the fence posts provided a predication of what might transpire in the field. From the FEM analysis a load-displacement curve was generated Figure 37, which indicated that the steel anchor system would carry more lateral load than the concrete footing system for a “2.5 inch thick wall diameter post”. Due to the large amounts of processing time it was not possible to analyze all of the posts scenarios tested in the field. Instead a set of post dimensions that represented an *average-intermediate* post was selected and used for both the concrete footing and steel anchor models. This representative intermediate post has the diameter of a line post but the wall thickness of a terminal post. Thus, the flexural stiffness of the representative post lies between the extreme values of a terminal post and a line post. The analysis showed that the concrete footing was rigid, and that the lateral loading would create plastic strain concentrations at the base of the post. The resultant was the formation of a plastic hinge causing permanent deformation in the post. However, the drive anchor system model showed that it could distribute the strains over a larger region, better than the concrete footing.

For the 2.5 inch post, the FEM model accurately depicted that the anchor posts would outperform the concrete posts, in comparison to field tests. However, the model projected overall better performance of both systems than experienced in the experimental field tests. As was expected the soil conditions of the model and the test site were different. The difference in the soil properties, as well as the flexural stiffness, was the most likely causes of the discrepancy between the FEM and real world results. An overlay of the results of the FEM analysis and the experimental test data is shown in Figure 25. It can clearly be seen that the systems followed similar trends.

FEM
analysis
results

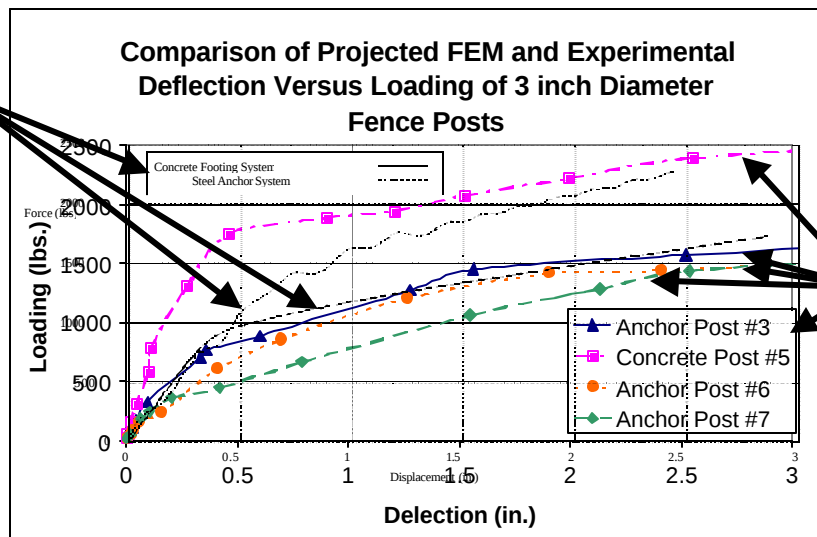


Field /
experimental
results

Figure 25 Comparison of projected FEM deflections to the actual experimental deflections for a 2.5 inch post.

Based on the outcome of these simulations and the experiment, the 2.5 inch diameter anchor system out-performed the concrete, even if only marginally. Unlike the 2.5 inch diameter posts the 3 inch diameter post installed in concrete out-performed the drive anchor posts. The FEM model did not accurately depict what would happen in field tests. The 3 inch post in concrete experienced smaller deflections than the anchor post for any given load. As previously stated, the soil properties as well as the flexural stiffness most likely contributed to this inconsistency between the FEM and real world results. There is an overlay of the results of the FEM analysis and the experimental test data shown in Figure 26.

FEM
analysis
results



Field /
experimental
results

Figure 26 Comparison of projected FEM deflections to the actual experimental deflections for a 3 inch post.

CONCLUSIONS

The goal of the analytical simulation and field experimentation was to both quantitatively and qualitatively compare the performance of the concrete fence footing system versus the drive anchor fence footing system under static loading. The focus of the experiment was to compare and evaluate the viability of the two fence post systems by comparing performance and cost of materials. Field testing and an FEM analysis was conducted to evaluate the deflection performance when a static load was applied to each post system at two feet above grade on the posts installed in “concrete” versus “drive anchors.”

The two post types had different mechanisms of failure. When the post in concrete failed, the plastic strains caused an above grade material failure of the post. When the drive anchor post failed, the plastic strains caused a below grade deformation failure of the soil. The FEM analysis predicted that most of the deformation of the drive anchor system would be a result of soil deformation, rather than post deformation. This hypothesis was confirmed by the experimental tests. The tests revealed that the drive anchor system posts tilted with little to no failure in the post material, indicating that the majority of the failure occurred in the soil. The drive anchor system is capable of distributing the lateral loads better throughout the post, anchors, and soil. However, the concrete utilizes the elastic properties of steel to bounce back from minor loading and is thus more forgiving.

The orientation of the drive anchors for both the line and the end posts seemed to make little difference. The main factor affecting the strength of the drive anchors appears to be the number of blades installed (two versus four) and the strength of the soil. Though various soil conditions were not tested, it was expected that stiffer soil materials would result in better performance of the posts with drive anchors. Likewise, larger deflections are expected with a looser soil. The test results revealed that the effectiveness of drive anchor systems is largely dependant on soil interaction, while concrete was less reliant upon soil conditions.

Based on the field-testing results for the 2.5-inch diameter fence post installation, the experiment revealed that all of the posts experienced roughly the same deflection versus loading. Thus, these systems can be considered roughly equivalent.

For the 3-inch diameter systems a failure criteria, based upon mesh failure, was established at 1,688 pounds for the experiment’s specific testing setup. All the post installations were able to withstand the test loading. However, the results did reveal that the concrete posts obtain a significantly higher loading with less deflection than the drive anchors. Nonetheless, since they both performed within tolerable limits established in this study it appears that these systems can be used interchangeably.

In respect to cost benefit, where neither a concrete truck nor any other form of mechanical device can be used, there are the labor and the material costs to consider. For one laborer utilizing a manual installation method, it was found that it took just under 30 minutes to install the drive anchors and approximately 60 minutes for concrete. For the line anchor posts, with one shoe and two blades the cost is \$12.49 and for the end anchor posts, with two shoes and four blades the cost is \$24.98 for the drive anchor footing system. Consequently, for the concrete footing system utilizing hand mixed concrete the cost is \$11.31 per hole, hole sizes are approximately the same for line and end posts therefore this amount covers both posts

installations. Hence for the line posts, the expendable supplies and fence materials for the concrete posts are slightly more economical; and for the end posts, the economic savings are clearly in favor of the concrete. Since in an installation there are relatively few end posts installed, and the material cost for the line posts are so similar; the difference in labor costs becomes the critical factor. Hence, based on labor costs it can be roughly estimated that drive anchor systems are half as expensive as concrete systems. It should be noted though that, from interviews with contractors it was determined that if a concrete truck or mechanical devices are utilized then the labor costs are almost equal.

From the field tests and the FEM analysis, the drive anchors and the concrete systems both performed within tolerable limits established in this study. In regards to the financial viability in areas where only manual means of installation could be used there was a significant cost savings in favor of the drive anchors. Hence, the results indicate that the drive anchor and the concrete systems can be used interchangeably.

APPENDIX 1 FINITE ELEMENT MODELING AND ANALYSIS OF POST ANCHORAGE SYSTEMS

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Introduction

As a component of the fence post study being conducted for NJDOT, analytical investigations were performed to evaluate the effectiveness of alternatives to poured concrete footings for fence posts. One standard procedure employed for setting posts involves the use of a concrete footings. An alternative system, in which steel angles are attached to the post is being evaluated in this study. The two systems in question are illustrated in Figure 27 below.

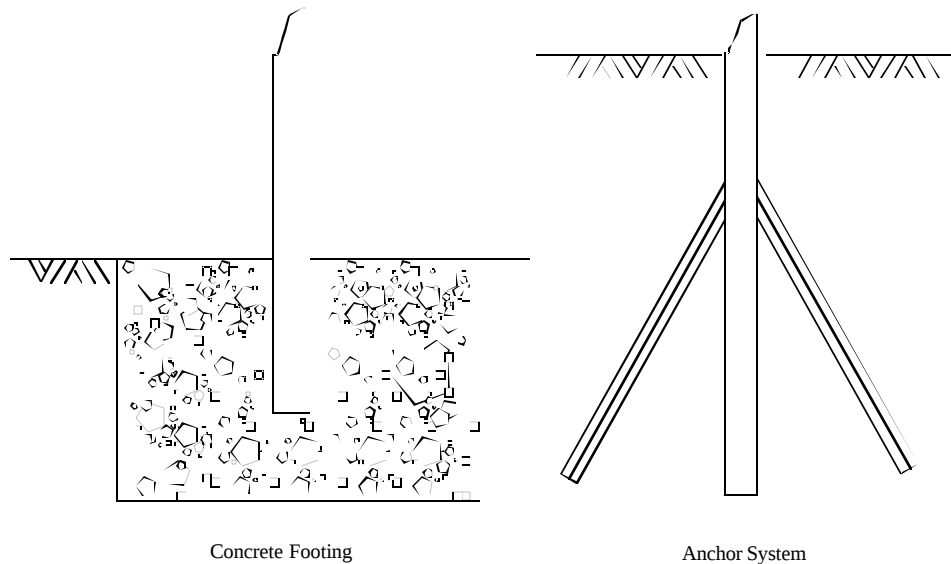


Figure 27 Post Systems

While these systems will ultimately be field tested as part of this study, preliminary analytical work was considered to be prudent preparation for the field testing. The goal of the analytical simulation work was to determine whether or not the steel anchor system would produce similar displacements when lateral load is applied to the post to those that would occur using a traditional footing

Since the simulations were performed *in preparation* of the field testing, field soil data was not available for use in the simulations. Instead, a representative soil model was adopted (which is described later in this document) for use in the simulations. By using the same soil model for both simulations involving the concrete footing system and the steel anchor system, conclusions can be drawn regarding the *relative performance* of the two systems for a single soil type. However, there should be no expectation that the displacements

predicted by the simulations performed will necessarily match displacements measured in the field when the field testing is ultimately performed. If the soil conditions at the field test site match those used in the simulations, then the results should be comparable. However, if the field conditions differ from those assumed, the results will also differ.

Qualitative conclusions can still be drawn from the simulation work based on differences in the ways the two systems behave in the assumed soil. The aspect of primary concern is the magnitude of post displacements that will occur when the post is laterally loaded. What is of interest is to determine if displacements in the steel anchor system will be substantially larger than those in the footing system. This is the question that the analytical simulation attempted to answer.

Analysis Software Chosen

Finite element analysis (FEA) was used as the simulation tool for this study. There are many FEA codes (software programs) available in the marketplace, however only a few of those codes have the requisite features needed to model the post-soil problem. Initially the Abaqus code was chosen for the analytical modeling work. Some preliminary software was written to generate a mathematical “mesh” of the system in question. At a later date it became apparent that one of the crucial features needed for both fence post models would be the modeling of interaction between various parts of the anchor system and the soil. It is the contact between the footing and the soil that provides support to the post in the footing system. Likewise, contact between the steel angles and the soil provides support to the post in the steel anchor system. Thus, being able to model interactions (contacts) between the various post components and the soil was found to be very important and the FEA software chosen had to be able to account for such interactions.

For this reason, it was decided that the LS-DYNA3D code would be used instead of Abaqus. One of the strengths of LS-DYNA3D is that it has some of the most advanced contact algorithms available in any FEA software package available at this time. Contact algorithms are the mathematical features of a FEA code that allow the code to model interactions between parts of the model. For example, contact between the outer surface of the footing and the soil is needed to model posts with concrete footings. In the steel anchor system, the steel angles come into contact with various soil elements in the model. Also, the use of contact algorithms allows the separation of components (i.e. lack of contact) to be modeled also. For example, as load is applied to a post in one direction, the post will cause compression on the soil on one side of the post but the soil on the opposite side of the post may cease to be in contact with the post (or at least have an essentially zero stress level) .

For these reasons, LS-DYNA3D was used as the FEA code for the simulations reported on herein. The mesh generation program LS-INGRID was used to build the FEA meshes (shown later in this document) that were analyzed using LS-DYNA3D. The use of LS-INGRID turned out to be absolutely critical in the case of the steel anchor system due to the very complex 3D geometry of the steel angle legs. In the following sections, descriptions of the models analyzed in this study are presented along with results from the analyses.

Constitutive Models for Materials

Soil

The LS-DYNA3D soil model used in the simulation was a modified Drucker-Prager cap plasticity model that models pressure dependent yield for the soil material under consideration. (This material model is called *MAT_GEOLOGIC_CAP_MODEL in LS-DYNA3D terminology).

The model has two major parts: a shear failure surface, indicating shearing flow, and a “cap”, intersecting the equivalent hydrostatic pressure stress axis.

The major advantage of this cap model over other pressure-dependent soil models is that the amount of volumetric deformation of soil under shear loading is controlled. Based upon the assumption of normality of plastic flow to the yield surface, the plastic strain rate vector has a component in the volumetric (hydrostatic) direction. In other soil models such as the Drucker-Prager and Mohr-Coulomb, this hydrostatic strain continues as shear loading is increasing and produces much more dilatency than what is observed in experiments.

However, in the cap model used, dilatency is predicted within the range that the hardening law permits. In other words, the cap expands until the cap intersects the failure envelope at the stress state and remains at that point. The rate of the cap expansion in the model permits experimentally observed amounts of volumetric deformation to be modeled and thus produces a better representation of the behavior of soil.

Since field soil data was not available at the time that these simulations took place, a soil condition had to be *assumed*. The parameters used in the geologic cap material model of the present LS-DYNA3D simulations were selected to be representative of a granular type of soil. Selected soil parameters from “Evaluation of Viscoplastic Cap Model” by M. G. Katona (ASCE *Journal of Geotechnical Engineering*, Vol. 110, No. 8, August 1984) were used in this study.

The failure envelope surface in the geologic cap material model of LS-DYNA3D can be written in the form:

$$h_f = \sqrt{J_2} - \min(F_f(I_1), T_{mises}) = 0 \quad (1)$$

where

$$F_f(I_1) = a - g e^{(-b I_1)} + q I_1 \quad (2)$$

and

$$T_{mises} = |X(k) - L(k)|. \quad (3)$$

The cap surface is defined in the following form:

$$h_c = \sqrt{J_2} - F_c(I_1, k) = 0 \quad (4)$$

where

$$F_c(I_1, k) = \frac{1}{R} \sqrt{[(X(k) - L(k))]^2 - [I_1 - L(k)]^2}, \quad (5)$$

$$X(k) = k + RF_f(k), \quad (6)$$

and

$$L(k) = \begin{cases} k & \text{if } k > 0 \\ 0 & \text{if } k = 0 \end{cases}. \quad (7)$$

The complete set of soil model parameters used in this study are shown in the following table:

Table 6 Soil model parameters.

Material Constant	Numerical Value	Unit	Numerical Value	Unit
K (Bulk Modulus)	460.0	Mpa	66.7	ksi
G (Shear Modulus)	275.8	MPa	40.0	ksi
a	1.72375	Mpa	0.25	ksi
b	0.09717	Mpa ⁻¹	0.66999	ksi ⁻¹
g	1.2411	Mpa	0.18	ksi
q	0.137	-	0.137	-
D	0.09717	-	0.09717	-
W	0.066	-	0.066	-
X_o	-1.303155	-	-1.303155	-
R(Cap axis ratio)	2.5	-	2.5	-
Φ (Friction angle)	30	degree	30	degree
r (Mass density)	1800.0	Kg/m ³	112.4	lb/ft ³

Post Steel

The constitutive model for the steel post was chosen as an isotropic hardening plasticity model with yield stress $s_y = 40 \text{ ksi}$, and failure plastic strain, $e_{pf} = 0.036$. The modulus of elasticity, E , was 30000 ksi.

Concrete

Based upon the modified Hognestad's stress-strain relationship for concrete,

$$s_{comp} = s_{peak} \left[\frac{2e_{comp}}{e_o} - \left(\frac{e_{comp}}{e_o} \right)^2 \right],$$

the material behavior of the concrete footing under static loading was approximated with an isotropic hardening plasticity model. The key assumptions made in the model are listed below.

1. The compressive strength of plain concrete is approximately 6000 psi.
2. Modulus of elasticity considered is for static loading rather than dynamic rates of loading.
3. For normal-weight concrete with a density of 145 lb/ft^3 the initial modulus of elasticity can be evaluated as $E_{initial} = 57000 \sqrt{s_{peak}}$.

The parameters used in the LS-DYNA3D concrete model are given in the following table:
 Table 7 Parameters for the LS-DYNA3D concrete model.

Parameter	Description	Value	Unit	Value	Unit
E	modulus of elasticity	30442.8	Mpa	4,415.2	ksi
s_y	yield stress	41.37	Mpa	6.00	ksi
r	density	2348.0	Kg/m ³	146.6	lb/ft ³
E_t	tangential stiffness after yielding	2000	Mpa	290	ksi
n	poisson's ratio	0.2	-	0.2	-

Analysis Models

Dimensions of the Steel Post

The dimensions of various line and terminal posts are listed below based on data that was provided by NJDOT. Since the steel anchor model used in this study required *very large* amounts of time to analyze (as is discussed in the following sections), it was not possible to analyze all of the posts listed in the table below. Instead a set of post dimensions that represented an *average-intermediate* post was selected and used for both the concrete footing and steel anchor models. This representative intermediate post has the diameter of a line post but the wall thickness of a terminal post as is indicated below. Thus, the flexural stiffness of the representative post lies between the extreme values of a terminal post and a line post.

Table 8 Post dimension parameters.

Post Type	Outer Diameter(inch)	Thickness(inch)
Terminal Post A	2.875	0.160
Terminal Post B	2.875	0.203
Line Post A	2.375	0.130
Line Post B	2.375	0.154
Post Selected for FEA Simulation	2.375	0.203

Model I : Concrete Footing System

A sketch of the physical dimensions of the concrete footing system analyzed in this study is given in Figure 28. The model includes a steel post, a concrete footing, and a large soil mass surrounding the footing. The finite element (FE) mesh was generated in a cylindrical coordinate system. Nonreflecting boundary conditions were used to eliminate erroneous bouncing of body waves, which might be induced by the loading condition, along the system boundary. Since LS-DYNA3D is 3-dimensional nonlinear *dynamic* finite element code, the static loading condition desired had to be simulated with a very low rate of loading. Gravitational acceleration in the vertical direction was also included in the analysis.

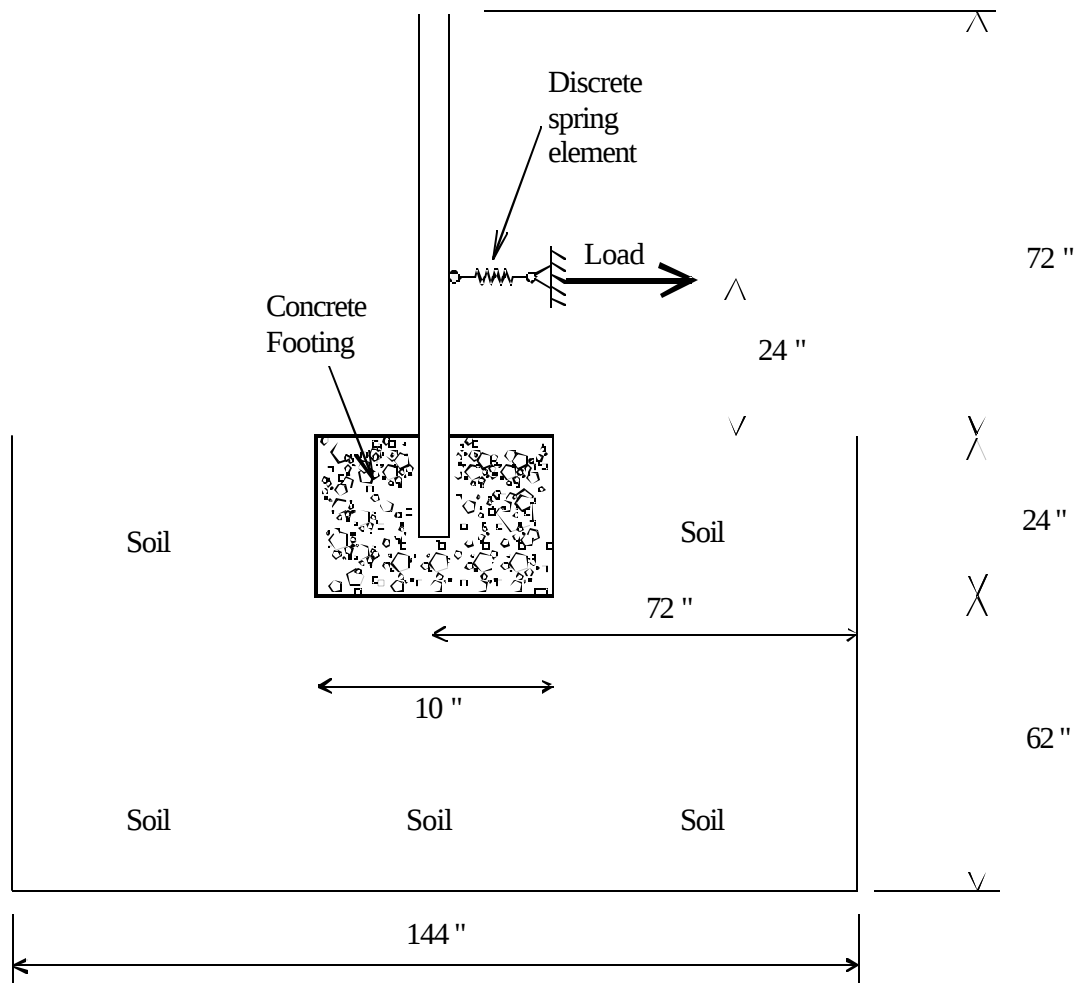


Figure 28 Physical Dimensions of Concrete Footing System

An externally applied loading condition was modeled by prescribing the movement of a node at the end of a discrete spring element. The opposite end of the spring was attached to a nodal rigid body formed from selected nodes in the steel post. The load application point was located at 2 feet (610 mm) from ground level. The spring was used to load the system rather than a simple force so that displacement control could be accomplished rather than using load control.

Two possible failure mechanisms, including material failure of the steel post due to large deformation and system failure by slip between the concrete footing and soil, were studied in this model. In particular, in the study of slip failure, an accurate contact modeling between the concrete footing and soil was very important for accurate simulation.

To estimate the contact force (friction) as accurately as possible, the classic laws of friction were employed, which can be summarized as follows.

1. Friction forces are proportional to applied loads.

2. Coefficient of friction is independent of nominal contact area.
3. Due to the very slow motion of the footing with the loading, the static coefficient of friction takes a main role in determining the contact forces. In other words, relative velocities between the footing and the soil are negligible.
4. Coefficient of friction is independent of sliding speed.

A static friction coefficient of 0.65 for contact between masonry concrete and sand soil was assumed on the basis of analogy made from *Mechanical Engineer's Handbook* (edited by Marks, L.S., 1951). Bond failure of the steel post from the concrete footing is very unlikely to happen and was not considered in the analysis. Therefore it was assumed that the post is rigidly bonded to the footing.

Since the footing model was symmetric, a symmetry model in which only one half of the model is analyzed was used to reduce the simulation time required. Various views of the final mesh that was constructed and analyzed are shown in Figure 29 and Figure 30. Note that the steel tube was modeled using shell elements while the concrete footing and the soil mass were modeled using solid elements. The mesh was generated using the LS-INGRID preprocessor.

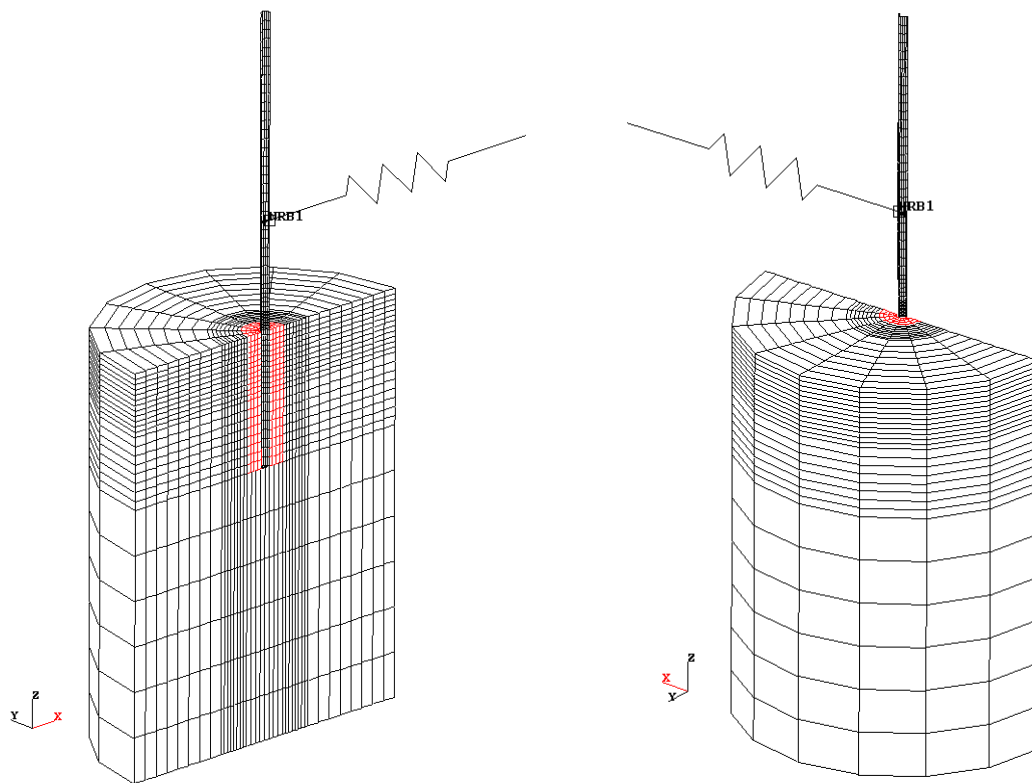


Figure 29 Concrete Footing FEA Model

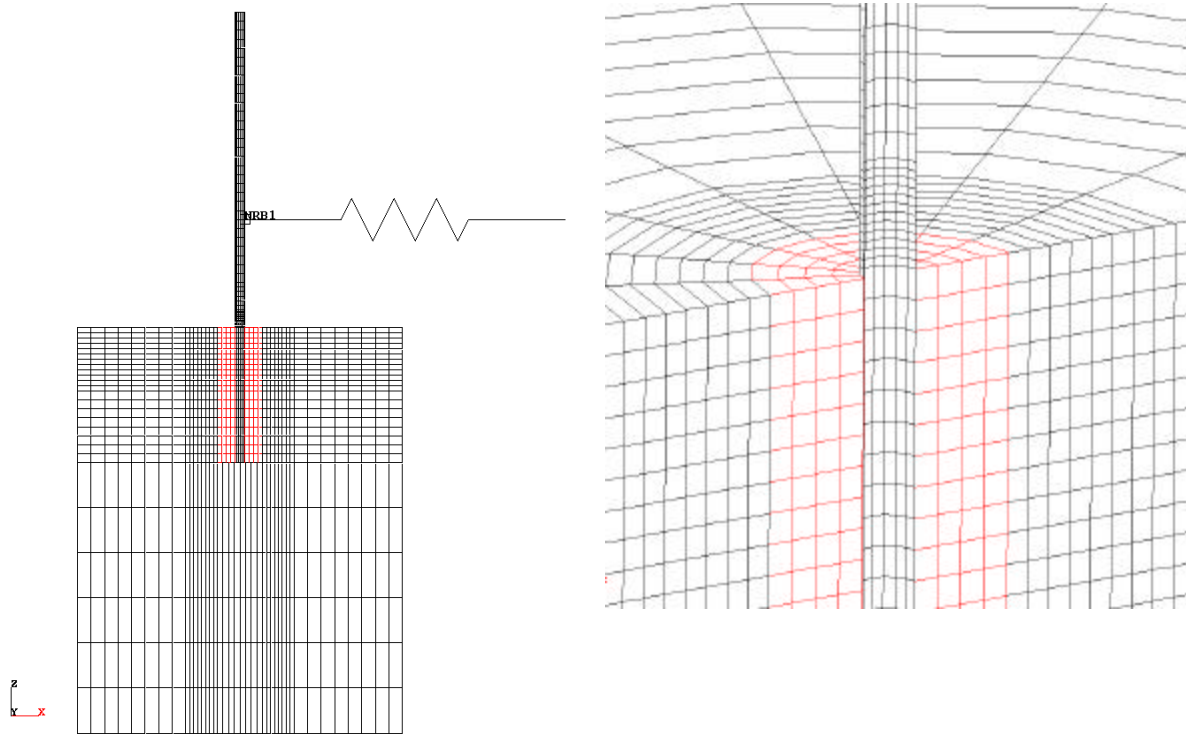


Figure 30 Concrete Footing FEA Model Details

Model II : Steel anchor System

A sketch of the physical dimensions of the steel anchor system analyzed in this study is given in Figure 31. The model includes a steel post, steel anchor legs (made from steel angles), and a large soil mass surrounding the steel post and the anchors legs. The finite element (FE) mesh was generated in a Cartesian coordinate system with nonreflecting boundary conditions to eliminate erroneous bouncing of body waves. Gravitational acceleration in the vertical direction was included in the analysis.

Due to the complexity of the geometry of the steel anchor system, the level of mesh refinement used in this model was fairly high. The three-dimensional *nonsymmetrical* orientations of the L-shaped steel-angle anchors in the surrounding soil made it very difficult to generate the exact configuration of the system in 3-dimensional space. However a very close approximation was achieved. As an simplification, the connections of the steel anchors to the post were assumed to be rigid attachments without any bolts. However, except for this simplification, the mesh generated using LS-INGRID successfully matches the actual geometry of the anchor system very closely. Figures illustrating various aspects of this complex 3D model are given in Figure 32, Figure 33, and Figure 34.

Due to the non-symmetrical three-dimensional nature of this model, a symmetry model of reduced size could not be used. Also note in Figure 34 the level of mesh refinement that was used to model the soil adjacent to the steel anchors. Such mesh refinement resulted in a

very large model which required a great deal of time to analyze. The table below compares the “computational size” (number of elements in the model and analysis time required) of the footing model versus the steel anchor model.

Table 9 Model computational size.

Model	Total Number of elements	Quadrature Rule	Computational Time(days)
Concrete Footing Model	4704	One point rule for all elements	1
Steel Anchor Model	13064	Two point rule for shell elements in anchors	90

In the steel anchor model, all soil elements were modeled using solid finite elements. The steel post was modeled using shell elements and the steel anchors were also modeled using shell elements. In terms of the soil, there is a large soil block with a hole in the middle and an inner soil core that fits into this “hole” and matches very tightly with the geometry of the steel anchor legs.

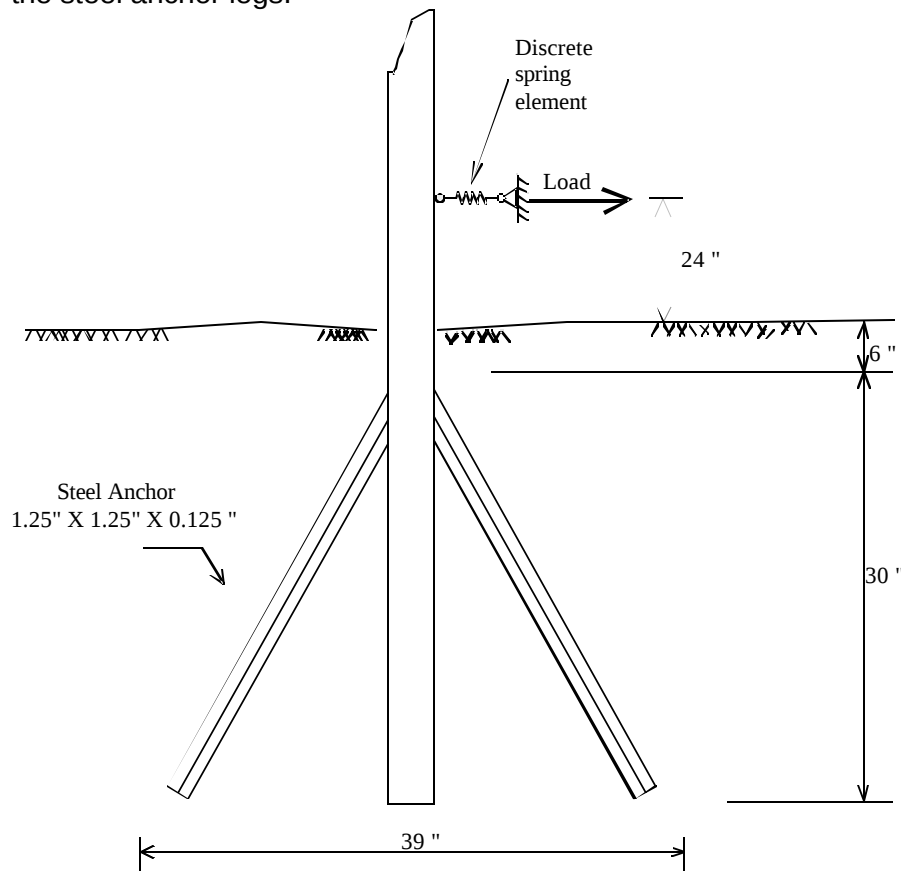


Figure 31 Physical Dimensions of Steel anchor Footing System

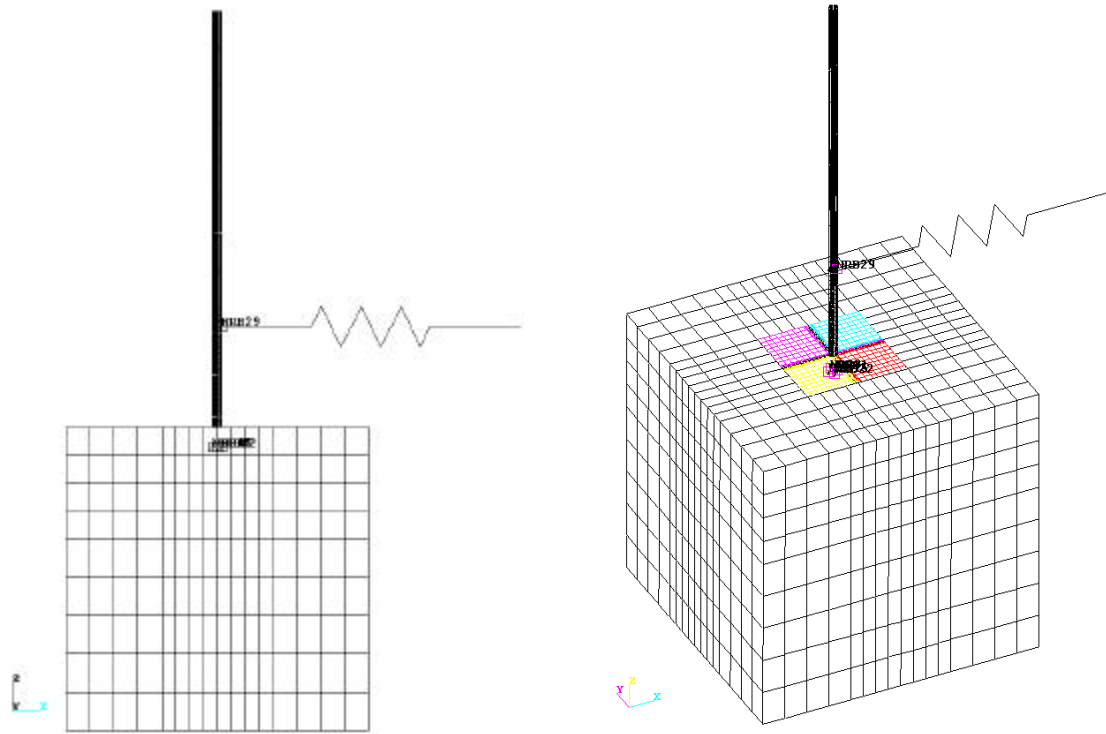


Figure 32 Overall Steel Anchor FEA Model

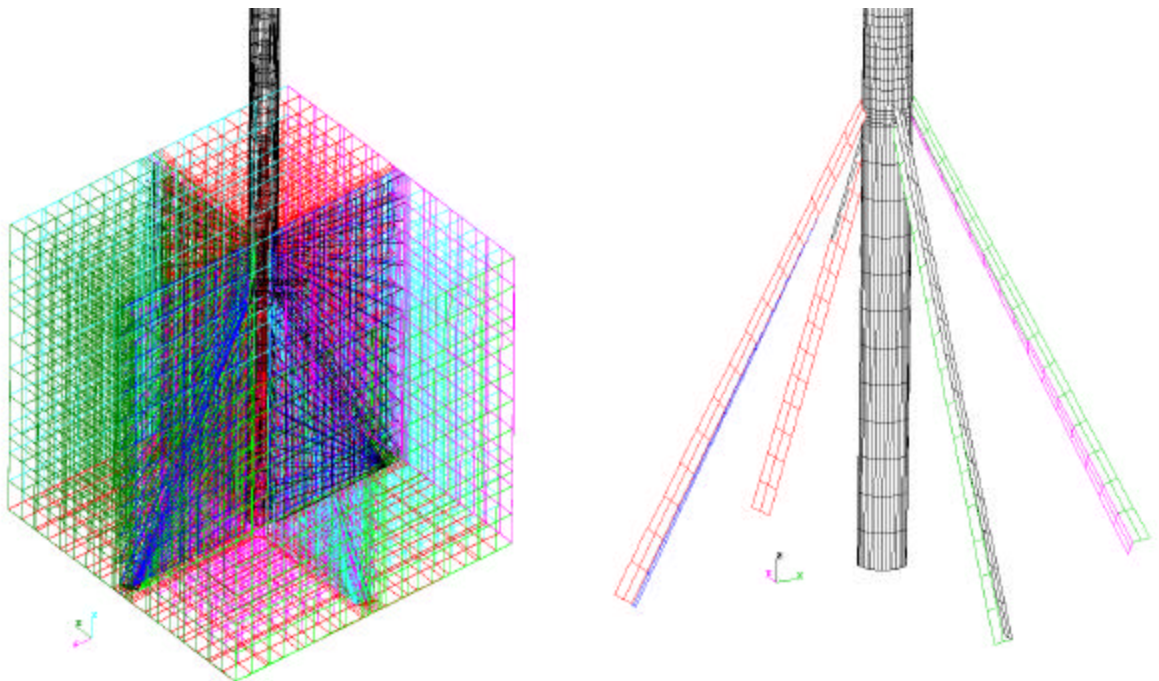


Figure 33 Central Core of Soil Immediately Adjacent to Steel Anchors

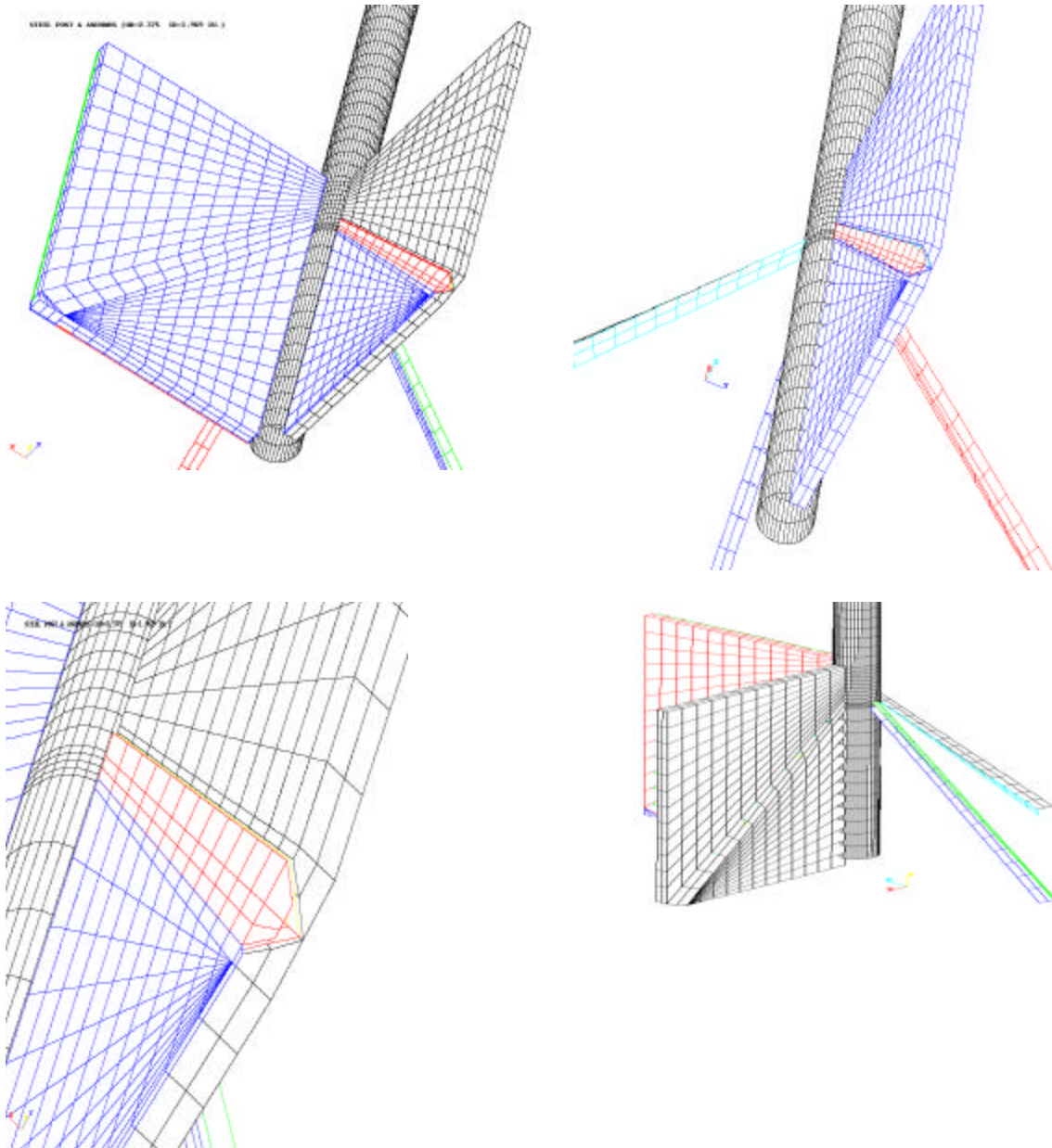


Figure 34 Details of Soil Slices and Soil Wedges Near the Steel Angle Anchors

The mesh refinement and size of elements in the steel anchor mesh tremendously increased the computational time compared to that of the concrete footing simulation. This is due to the nature of the explicit time integration method employed in LS-DYNA3D. Due to the combination of very small soil elements and small time steps, the steel anchor analysis took 90 days to run on a Silicon Graphics Origin 2000 server. This analysis time could be drastically reduced if an implicit time stepping scheme were available in LS-DYNA3D. At present, LSTC (Livermore Software Technology Corporation; the makers of the LS-DYNA3D

code) has released version 950 of LS-DYNA3D. Version 950 has an implicit time stepping solver, however, the soil model used in this study has not yet been implemented in that implicit solver. Thus, at present, the analysis must be run in explicit time-stepping mode which takes a great deal of time. In the future, the analysis time required should be reduced drastically once the material model *MAT_GEOLOGIC_CAP_MODEL has been converted for use with the implicit solver in LS-DYNA3D.

An additional numerical difficulty that arose in the steel anchor model was *hourglassing*. When element matrices are formed by numeric integration, they contain only information at the integration sampling points (quadrature points). If strains evaluated at the sampling points are zero for certain modes of nodal displacements, then strain energy will vanish for that mode at the integration points and instabilities in the FEA mesh will arise. Instabilities may be present in cases where reduced integration rules are used unless the mesh is well refined. Since computational time was a primary consideration in the present study, the one point integration rule (the default in LS-DYNA3D) was used but a very fine mesh resolution was also used to prevent excessive hourglassing.

Results

Analysis results for the case of lateral loading on the concrete footing system are shown in Figure 35 and Figure 37. Analysis results for the case of lateral loading on the steel anchor system are shown in Figure 36 and Figure 37. Figure 35 illustrates the formation of a plastic hinge in the steel post at the point where the post emerges from the concrete footing. There is very little soil deformation in this particular simulation. Initially the soil deformations from the analysis seemed to be too small, however, an alternate check using a nonlinear pile program and approximately the same soil parameters as those used in the present study predicted very similar displacement results. It was concluded that the relatively small soil displacements are attributable to the strength of the assumed soil type and the relatively small loads imposed on the overall system.

The concrete footing model was also subjected to a primarily vertical load to verify that the model was in fact capable of predicting *pullout* of the footing from the soil. For a nearly vertical load, the footing did indeed pull vertically out of the soil mass. Thus, the modeling of sliding contact between the concrete footing and the soil were found to be correct and can indeed model sliding of the footing against the soil. For the lateral load case, however, where the load is only 2 feet above the soil level, the post forms a plastic hinge before any vertical motion of the footing occurs. This may change given a weaker soil however for the granular soil assumed in the simulations, the behavior of the concrete footing system is that indicated in Figure 35 and Figure 37.

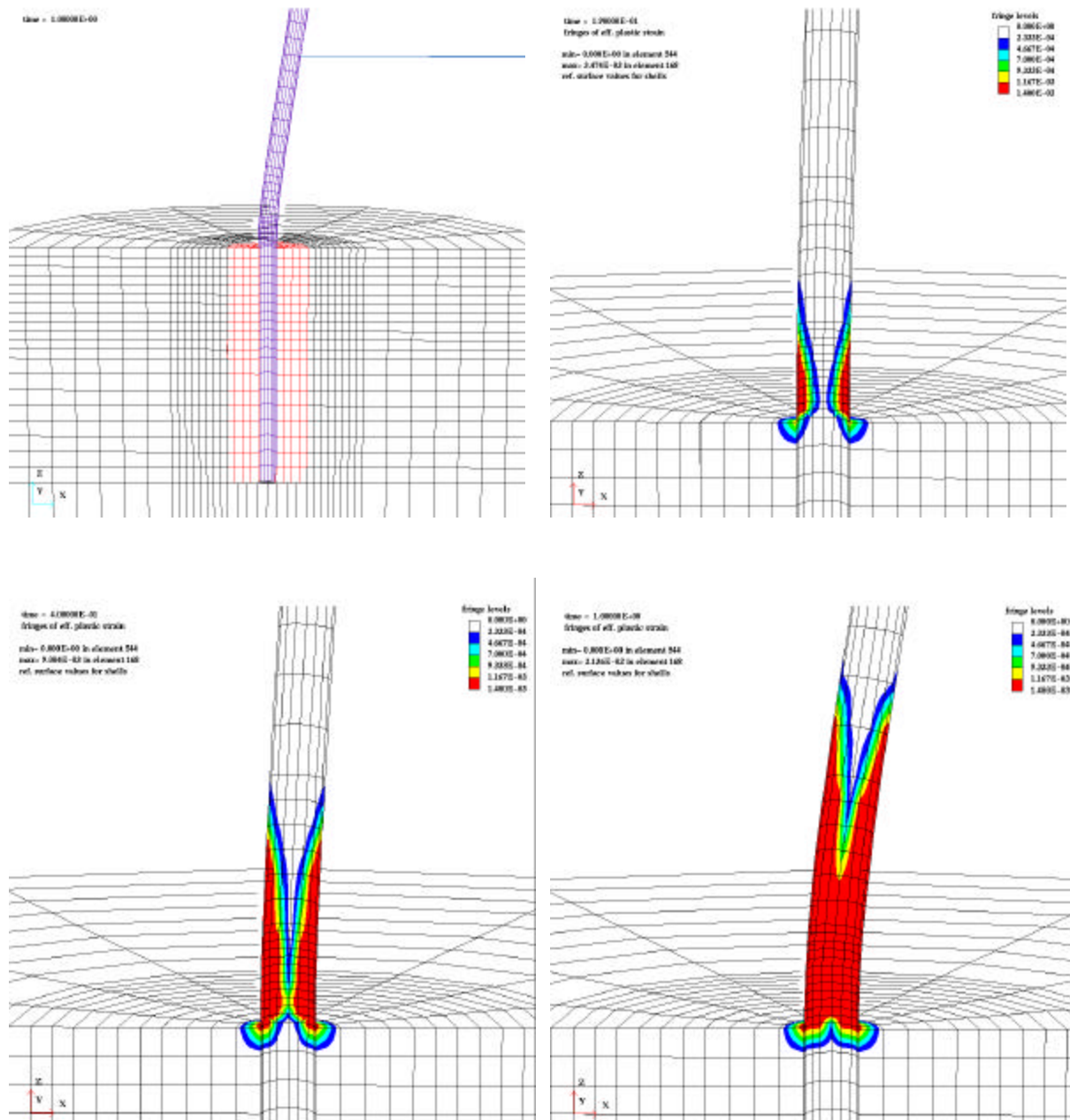


Figure 35 Deformed Shape and Plastic Strains for Footing System
(Expanding Zone of Plastic Strains in Steel Post Indicates Formation of a Plastic Hinge)

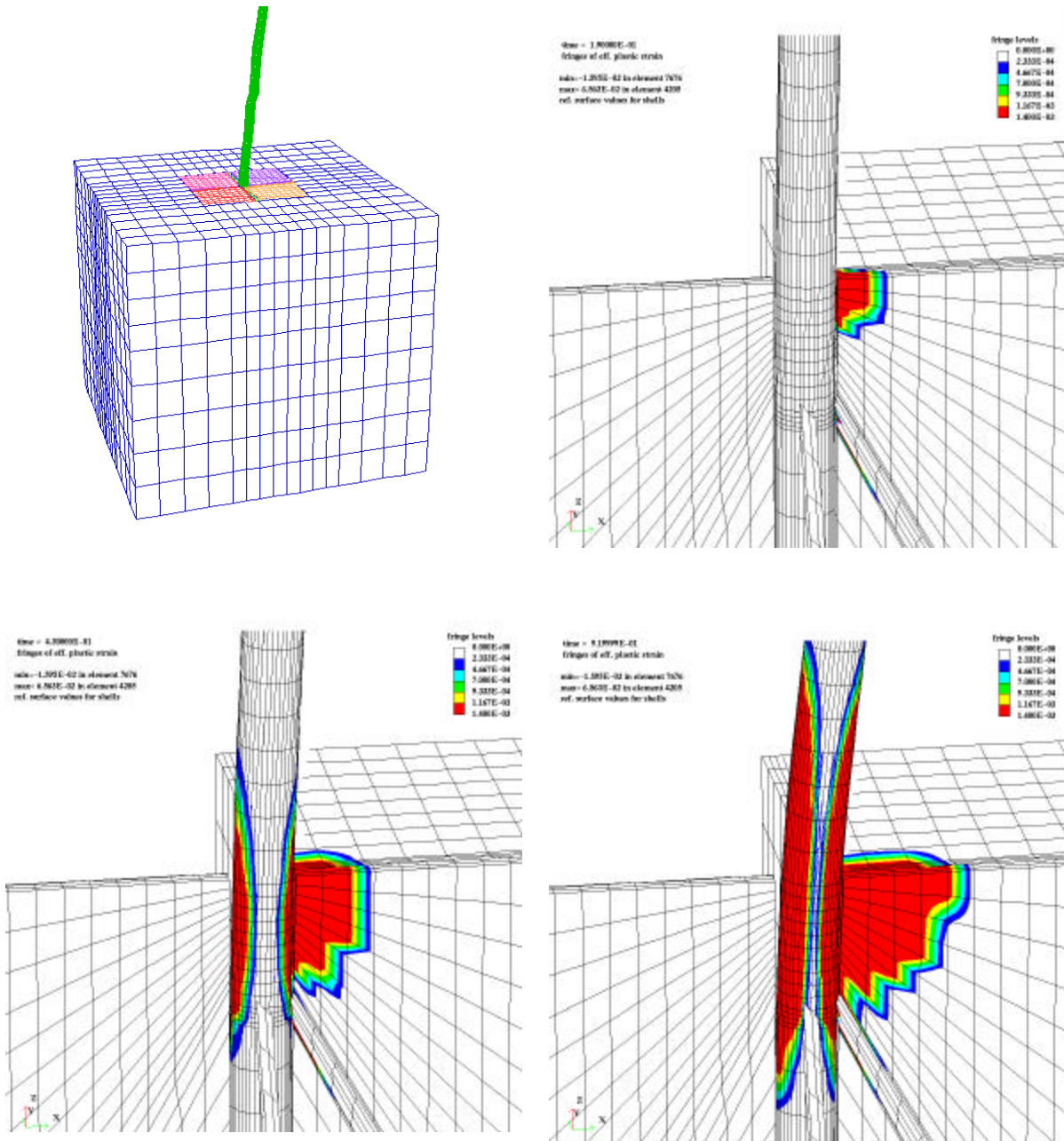
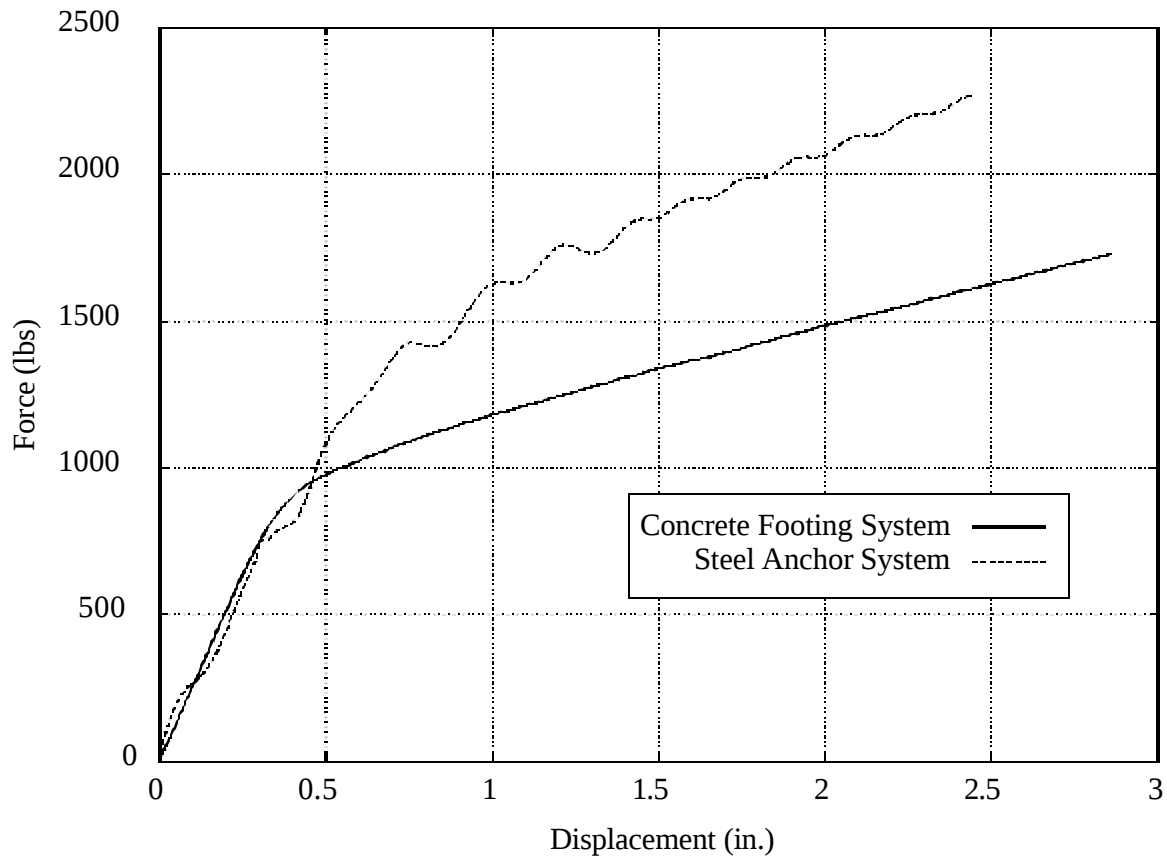


Figure 36 Deformed Shape and Plastic Strains for Anchor System
(Expanding Zone of Plastic Strains in Steel Post Indicates Formation of a Plastic Hinge)



(Note: The displacements indicated above are displacements of the post at the load application point 2 feet above the soil surface)

Figure 37 Load-Displacement Curves for the two Post Systems Analyzed

Figure 37 illustrates the formation of a plastic hinge in the steel post for the steel anchor system. The three plots in Figure 36 illustrating plastic strain distributions also include selected portions of the soil mass (soil slices and wedges) so that strain levels in the soil can also be seen. Unlike the concrete footing system, the plastic strains in the steel post for the steel anchor system are much more widely distributed vertically along the length of the post. In Figure 35, it was observed that the plastic strains in the post do not extend far below the elevation of the flooring surface. In Figure 36, plastic strains in the post extend several inches below the surface elevation. This is due to the fact that the steel anchor system is much more flexible than the concrete footing system. The increased flexibility of the anchor system permits stresses and strains in the post to be distributed over a larger zone. In contrast, the high stiffness of the concrete footing system forces a hinge formation in a very localized area.

Also of importance in Figure 36 is the fact that plastic strains do not develop in the soil sections to the left of the post. Since the lateral load on the post is pulling it toward the right, one would expect that soil on the left side of the post would remain largely unstressed and unstrained near the surface. The use of contact definitions between the post and the soil in

this analysis has permitted the post to separate from the soil (forming a small gap) on the tension side. This prevents non-physical tension stresses from developing in the soil on the left side of the post. Using other analysis programs, soil elements in this condition are often forced into a non-physical (fictitious) tensile stress state. However the use of the contact algorithms in LS-DYNA3D in the present study has avoided such problems.

Conclusion

The load-displacement curve shown in Figure 37 indicates that the steel anchor system can carry more lateral load than the concrete footing system for the soil conditions assumed in this study. This is due to the fact that the more flexible steel anchor system can distribute the stresses in the post and soil over a larger region. The concrete footing, being much more rigid, concentrates stress and strain at the top of the concrete footing and causes the formation of a plastic hinge at a lower load level than that of the steel anchor system.

If the soil conditions in which these systems are installed differs dramatically from the soil conditions assumed herein, the performance of the systems could potentially change. It appears however, that based on the results of these simulations, the steel anchor system has a very good chance of performing as well as or better than a concrete footing system. The goal of the analytical simulation component of this project was to qualitatively compare the performance of the two systems for an assumed soil condition. That goal has been achieved and the results seem to indicate that the anchor system could perform more than adequately in the field. However, field tests need to be conducted in various soil conditions to positively confirm the performance of the steel anchor system.

APPENDIX 2 DEPARTMENT OF TRANSPORTATION SPECIFICATIONS

A comprehensive search for chain link fence specifications was conducted of multiple East Coast Departments of Transportation. The New Jersey DOT, New Jersey Turnpike Authority, Maryland DOT, New York DOT, Massachusetts Highway Department, Connecticut DOT, and Pennsylvania DOT were included in this search. Summaries of these DOT specifications detailing the fence post foundation installation is attached as Addendum #1.

Pennsylvania Department of Transportation Research

The Pennsylvania DOT performed a research project in the mid 1970's entitled "The Pull Resistance of Right-of-Way Fence Posts in Concrete Footings Versus Drive Anchors." The research was performed with the cooperation of Anchor Post Products, Inc. and The PennDOT. According to PennDOT this research was the basis for their current fence installation specification. The final conclusions and recommendations are detailed in Table 10.

Description of PENNDOT Testing

"...The soil conditions were also tested as far as density, clay content, sand content, rock content, etc. and the Design and Testing Department decided to use poor quality soil. All posts and concrete footings were per the Department of Transportation's specification and were tested as follows:

Using a bulldozer as a dead weight, a chain was attached 4'6" from grade on the post and using a pulljack, force was applied and this force registered on the deflection meter. The deflection reading was then calculated into pounds.
..."

Source PennDOT report entitled "The Pull Resistance of Right-of-Way Fence Posts in Concrete Footings Versus Drive Anchors."

Their main objective was "the primary evaluation of the drive anchor system versus concrete footings, the adequacy of PennDOT's current line post specification and the forces on the fence fabric during erection were to be evaluated." However the PennDOT testing mainly utilized "H" section posts, did not take into account any economic impacts, and didn't conduct any computer modeling. Their tests performed indicated that the drive anchors are stronger than concrete footings in certain situations.

Table 10 Results of PENNDOT testing.

SIZE	MATERIAL	TYPE	FOUNDATION	ORIENTATION	FAILURE lbs	
inches					Post	Fndtn.
2.25	Aluminum	H-beam	Anchor 0.25"x0.25x"30"		350	
1.875	Aluminum	H-beam	Anchor 1"x1x"30"		200	
2.25	Galvanized	H-beam	Anchor 1.25"x1.25x"30"		1000	
2.25	Galvanized	H-beam	Anchor 1.25"x1.25x"36"		1000	
2.25	Aluminum	H-beam	Anchor 1.25"x1.25x"30"	Parallel to fence	500	
2.25	G. Steel	H-beam	Anchor 1.25"x1.25x"30"	Parallel to fence	700	
2.25	Aluminum	H-beam	Anchor 1.25"x1.25x"36"		425	
2.25	Aluminum	H-beam	Concrete 9" diam. 42" deep		425	
2.25	G. Steel	H-beam	Standard concrete footing			1000
1.875	Aluminum	H-beam	Standard concrete footing		300	
3	Steel	Sch 40	Anchor 1.5"x1.5x"30"	2 sets of blades, fabric failed at 2700 lbs		
3	Steel	Sch 40	Standard concrete footing	Footing moved at 1600 lbs, fabric failed at 2400 lbs		

Explanation and Summation of PennDOT Testing Results

The only test where the foundation actually failed was in the 2.25 inch Galvanized Steel H-beam. However since the tests performed under the same conditions except for anchors showed that H-beam failed at the same load, nothing can be surmised about the footing itself. The other test with the 3 inch diameter schedule 40 Terminal Post yielded results that demonstrate the superiority of the drive anchors over concrete. This second test was not repeated to verify the results, also the required force to cause failure in the drive anchor has not been determined.

Conclusions and Recommendations of PENNDOT

- 1) Drive anchors be approved as an Alternate to concrete footings for all types of right-of-way fencing currently specified.
- 2) Additional testing be conducted to determine the suitability of both 6061-T6 and 6063-T6 Aluminum Junior section posts as line posts. *
- 3) Design end, corner, and pull post sections in a similar manner to the current Type I line post specification using a 1000 pound minimum design pull at the top of each section. **
- 4) The current specification for Type I line post be adopted for all line post sections.
- 5) The 30" drive anchors be used solely since there is no appreciable advantage to using 36" blades.
- 6) The drive anchors be placed parallel to direction of the test pull (perpendicular to the fabric) for consistency and because the maximum loading will be

applied in that direction; hence the maximum resistance is required for that direction.¹

Source PennDOT report entitled "The Pull Resistance of Right-of-Way Fence Posts in Concrete Footings Versus Drive Anchors."

- * Probably should avoid aluminum post due to past numerous DOT and Transit Auth. previous problem with theft of Aluminum posts.
- ** 1000 Pound minimum used due to common construction practice of 925 lbs. stretched fence fabric value.¹

Other Department of Transportation Specifications

NEW JERSEY DOT 1989¹⁷

FENCES

Chain-link Fence

Fence and gates shall be erected in accordance with the construction requirements recommended by the manufacturer and the following:

- Terminal posts shall be set at the beginning and end of each continuous length of fence, at abrupt changes in vertical and horizontal alignment, and on each side of gate locations.
- Aluminum surfaces to be placed in contact with concrete shall be given a coat of zinc chromate primer.
- Posts to be set in concrete shall be installed in dug or drilled holes. Posts not requiring concrete foundations may be driven to the required depth if ground conditions permit or the posts shall be installed in holes dug or drilled to allow sufficient room for proper backfilling. When solid rock is encountered, any posts not required to be set in concrete shall be installed by drilling the rock to the required depth and grouting the post therein with grout composed of one part cement to two parts sand.
- Post holes for posts not requiring concrete foundations shall be backfilled with suitable material. Backfill shall be placed in layers not exceeding 4 inches and each layer shall be thoroughly tamped. When backfilling and tamping are complete, the posts and anchors shall be held securely in proper position.
- Pull shall not be applied to posts set in concrete foundations until the concrete has cured a minimum of 72 hours.
- Gates shall be equipped with locks and two sets of keys.

FENCES

Chain-Link Fence

Chain link fence shall conform to AASHTO M 181 and the following:

- Carriage bolts with elastic stop nuts shall be zinc coated by electroplating process and shall be Type RS conforming to ASTM A 164.
- Bonded-type PVC-coated fabric shall also be zinc coated with the weight as specified for extruded type.
- Gate fabric shall be the same material used in the adjacent fence.
- Gate locking devices, stops and keepers may be galvanized malleable iron or steel except plunger bars may be tubular or bar steel.
- Posts, rails, wire fabric ties, stretcher bars and railing and post sleeves for chain-link fence on bridges shall be Alloy 6061T6.¹⁰

NEW JERSEY TURNPIKE AUTHORITY

FENCING

Description.

This work also consists of furnishing and installing new “C” section steel line posts with all required connections to the existing 84” high, type II, chain link fence fabric.

Methods of Construction.

(A) Right of Way and Perimeter Fencing.

Drive anchors and “C” section line posts shall be used for this contract. “C” section line posts shall be driven on 10 foot centers at a minimum of 36 inches into the ground.

FENCE

Chain Link Fence.

(H) Drive Anchors for “C” section line posts shall be cast, galvanized, steel shoes with 2 - 1.5” x 1.5” x 30” galvanized steel blades as manufactured by The Anchor Group, Baltimore, Maryland; or an approved equal.

(K) “C” Section Line Posts shall be roll formed steel shapes conforming to the requirements of ASTM 669 Group II with a minimum yield strength of 45000 psi. Line posts shall be galvanized, 1 - 7/8” standard “C” post as manufactured by The Anchor Group, Baltimore, Maryland; or an approved equal.

NEW YORK DOT Jan 1995

FENCES

CONSTRUCTION DETAILS

General

...

All end, corner, and intermediate posts shall be set plumb in concrete bases of the depth and diameter shown on the plans or standard sheets. The Contractor shall have the option of setting the line posts in concrete or using methods of driving and anchoring specified by the fence manufacturer and approved by the Engineer.¹⁸

MASSACHUSETTS HIGHWAY DEPT. 1988

CHAIN LINK FENCE AND GATES

General

The posts shall be set true to the line and grade of the proposed fence.

End, Corner and Intermediate Brace Posts shall be set in concrete bases as shown in the Construction Standards.

The posts in masonry walls shall be set in pipe sleeves or sockets.

All line posts, except those that are unstable due to soil conditions as described hereinafter, shall have drive anchor assemblies as shown in the Construction Standards.

CONNECTICUT DOT 1995

CHAIN LINK FENCE

Construction Methods

The posts shall be spaced in line of fence not further than 10 feet on centers. Intermediate or line posts, except where indicated on the plans, may be driven by mechanical means. A suitable driving cap shall be used to insure that no damage is caused to the post, galvanization or polyvinyl chloride coating. Posts not driven, and all other type posts shall be set in Class "A" Concrete conforming to Section 6.01.

MARYLAND DOT Jan 1988

FENCES

Construction Requirements.

Concrete.

Concrete footings shall be constructed in accordance with dimensions as shown on the Standards. Posts shall be centered in cylindrical concrete footings. The concrete shall be thoroughly compacted around the post by tamping or vibrating. The finish top surface shall be a troweled smooth finish, slightly above the ground line uniformly sloped to drain away from the post. The post shall not be disturbed in any manner within 72 hours after the individual post footing is complete.

Hand mixed concrete shall not be used without written permission of the Engineer. If permitted, the hand mixed batch shall not exceed 1/2 yd 3 .

Where rock is encountered at a depth less than the specified footing depth, a hole 1 in. larger than the greatest dimension of the post shall be drilled a depth of 12 in. or to the planned footing depth, whichever is less. After the post has been set, the remainder of the drilled hole shall be filled with grout, composed of one part Portland cement and two parts mortar sand by dry loose volume. The space above the rock shall be filled with concrete in the normal manner for posts set in concrete as described above. In rock areas all posts shall be set in concrete.

Anchorage for Line Posts and Terminal Posts (End, Pull and Corner Posts) .

A. The following alternate will be allowed in case of line posts only. After being driven in the ground, the line post shall be held rigidly upright by means of two galvanized steel angle bar anchors. When utilizing the galvanized steel HBeam the size of the angle bar anchor shall be 1 x 1 x 30 in. For all other line posts the size of the angle bar anchor shall be 1 1/2 anchors shall be driven diagonally through galvanized steel fittings attached to opposite sides of the post. The approximate spread of the anchors at their full depth shall be 39 in. The device and procedure must have prior approval of the Engineer.

B. The following alternate will be allowed for terminal posts (end, pull & corner posts). After being driven into the ground the terminal post shall be held rigidly upright by means of two anchor units spaced approximately 6 in. apart along the terminal post, and each anchor unit driven in a direction to offset the stresses caused by the tension of the fence wire. Each anchor unit shall be composed of two 1 1/2 x 1 1/2 x 30 in. Galvanized Steel angle bar anchors which are driven through galvanized steel fittings attached to opposite sides of the post. The approximate spread of the anchors at their full depth shall be 39 in. The device and procedure must have prior approval of the Engineer.¹⁹

PENNSYLVANIA DOT

RIGHT-OF-WAY FENCE

End Posts, Corner, and Pull Posts, Line Posts, Braces, Stretcher Bars, Truss Rods, Fittings, and Hardware - As shown on the Standard Drawings and as follows:

(a) Type 1 Right-of-Way Fence

1. End Posts. Round, rectangular, or square tubular sections meeting the requirements of Table A; if acceptable, other posts sections, meeting the requirements of Table A.

Table 11 Minimum section modulus about major and minor axis.

TABLE A						
Minimum Section Modulus About Major & Minor Axis-in ³						
Fabric	Minimum Yield Point Stress-ksi					
	45 or greater		45 to 35		35 to 25	
Height	Major	Minor	Major	Minor	Major	Minor
4'	0.304	0.110	0.392	0.141	0.548	0.197
5'	0.381	0.171	0.489	0.220	0.686	0.308
6'	0.457	0.247	0.588	0.317	0.823	0.444
7'	0.533	0.336	0.685	0.432	0.960	0.605
8'	0.609	0.439	0.784	0.564	1.097	0.790

2. Corner and Pull Posts. Section 1110.02(a)1., except finish brace clamps or attaching devices, adjustable to various horizontal and vertical angles.

3. Line Posts. Tubular, H-column, or I-beam sections, meeting the requirements of Table B; if acceptable, other post sections, meeting the requirements of Table B.

Table 12 Minimum section modulus about major axis..

TABLE B				
Minimum Section Modulus About Major Axis-in ³				
	Minimum Yield Point Stress-ksi			Test
Fabric Height	45 or greater	45 to 35	35 to 25	Load Kips
4'	0.267	0.343	0.480	1.6
5'	0.333	0.429	0.600	2.0
6'	0.400	0.514	0.720	2.4
7'	0.466	0.600	0.840	2.8
8'	0.533	0.686	0.960	3.2

(b) Type 2 and Type 5 Right-of-Way Fence.

1. End, Corner, and Pull Posts. Tubular, angle, or other acceptable section, meeting the requirements of Table A.

2. Line Posts. Tubular, ribbed tee, Ushaped angle, or other acceptable section, meeting the requirement of Table B.

Attach an acceptable plate or other device to the post to hold plumb and to keep properly aligned. Fasten the plate or device by welding or riveting (not less than 2 rivets), or by another acceptable method.

DRIVE ANCHOR

Acceptable anchors, from a manufacturer listed in Bulletin 15.

APPENDIX 3 RAW DATA FOR POST PULL-OUTS

Table 13 Results from 2.5 inch diameter post pull-outs

Concrete Post #1		Anchor Post #2		Anchor Post #4	
Deflection (in.)	Load (lbs.)	Deflection (in.)	Load (lbs.)	Deflection (in.)	Load (lbs.)
0.000	0.000	0.000	24.000	0.000	20.000
0.067	67.000	0.046	60.000	0.061	78.000
0.113	112.000	0.079	92.000	0.098	126.000
0.186	190.000	0.269	264.000	0.440	424.000
0.286	288.000	0.444	405.000	0.491	556.000
0.386	390.000	0.672	566.000	0.825	781.000
0.623	576.000	0.999	747.000	1.281	991.000
0.843	708.000	1.463	878.000	1.981	1064.000
1.150	820.000	2.048	938.000	2.852	1113.000
1.600	864.000	2.479	976.000	3.203	1103.000
2.237	881.000	3.363	1079.000	3.567	1127.000
2.697	884.000	4.038	1093.000	4.164	1147.000
3.163	895.000	4.672	1123.000	4.609	1170.000
3.667	909.000				
4.393	923.000				
4.614	937.000				

Table 14 Results from 3 inch diameter post pull-outs.

Anchor Post #3		Concrete Post #5		Anchor Post #6		Anchor Post #7	
Deflection (in.)	Load (lbs.)	Deflection (in.)	Load (lbs.)	Deflection (in.)	Load (lbs.)	Deflection (in.)	Load (lbs.)
0.000	19.530	0.000	27.000	0.000	19.530	0.000	19.530
0.024	107.420	0.004	63.000	0.018	54.000	0.016	50.500
0.046	175.000	0.017	161.000	0.028	93.000	0.064	190.500
0.092	332.000	0.042	312.000	0.053	161.000	0.103	241.500
0.335	708.000	0.095	590.000	0.159	244.000	0.199	362.000
0.359	766.000	0.110	791.000	0.411	610.000	0.417	446.000
0.600	884.000	0.270	1313.000	0.694	859.000	0.790	665.000
1.276	1274.000	0.461	1748.000	1.267	1210.000	1.548	1062.000
1.562	1450.000	0.898	1884.000	1.902	1416.000	2.130	1288.000
2.518	1572.000	1.208	1943.000	2.409	1445.000	2.532	1436.000
3.362	1660.000	1.518	2075.000	3.215	1533.000	4.266	1635.000
4.097	1714.000	1.994	2221.000	4.687	1733.000	5.356	1678.000
4.608	1806.000	2.547	2392.000	5.381	1773.000		
5.162	1854.000	3.609	2514.000	5.622	1790.000		
5.468	1873.000	3.870	2558.000				
		4.657	2612.000				
		5.563	2680.000				
		5.858	2700.000				

References

- ¹ “The Pull Resistance of Right-Of-Way Fence Posts in Concrete Footings Versus Drive Anchors”, Gerald J. Malasheskie, Commonwealth of Pennsylvania Department of Transportation – Bureau of Materials, Testing and Research, June 1976
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- ⁴ New Jersey Turnpike Authority, memo from R. Bruce Noel Construction Engineer June 24, 1982
- ⁵ Interview with contracting manager John DeRosa Consolidated Fence Inc., August 11, 2000.
- ⁶ Interviews with NJDOT approved fence contractors, ongoing interviews were conducted between May and September 1997
- ⁷ “Right-Of-Way Fence”, Standard Specifications For Construction & Materials received from PennDOT Bureau of Design, August 1997.
- ⁸ “Selected ASTM Standards for Fence Materials and Products”, ASTM, 1988. Designations: F567-84
- ⁹ “Selected ASTM Standards for Fence Materials and Products”, ASTM, 1995. Designations: F1043-95
- ¹⁰ Standard Specifications for Chain-Link Fence – NJDOT: Section 614 – Fences
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- ¹² Online Documentation found at <http://www.state.nj.us/transportation>.
- ¹³ McMaster-Carr Product Data Sheets, McMaster-Carr Technical Department August 1999
- ¹⁴ Century Fence Company Technical Department Fence Specifications June 1997
- ¹⁵ Consolidated Steel & Aluminum Fence Co., Inc Kenilworth, NJ price quotation for material costs January 2001
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- ¹⁷ Standard Specifications Construction & Materials, New Jersey State Department of Transportation, 1989
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