# GROUND IMPROVEMENT ON STRIP-MINED SITES:
## Using Dynamic Compaction to Remediate Mine Spoil Sites

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## ABSTRACT

In what is becoming more and more common occurrence in the Eastern Coal Fields, a site that has been targeted for redevelopment is found to be covered with as much as 60 to 70 feet of uncontrolled mine spoil fills, placed at the conclusion of strip mining activities conducted during the past century. As such, they require deep foundations or a significant ground improvement effort to allow for shallow foundations to support vertical construction at the site. Today, many of these areas are being reused as part of infrastructure and site development associated with the shale gas industry.

The use of dynamic compaction to improve mine spoils can provide an economic form of ground improvement, provided the magnitude of loading proposed at a site is reasonably moderate, and modest bearing pressures are required. Dynamic compaction has become an increasingly viable and attractive ground improvement option for mine spoil sites, given the ease of implementation and degree of effectiveness over a wide variety of ground conditions. Based on the 80 case studies reviewed as part of this study, dynamic compaction was found to be highly effective at improving sites with low-rise structures, and where measured, increased SPT N-values in the upper 30 feet of mine spoil materials up to 40% on average.

## INTRODUCTION

In what is becoming more and more common occurrence along the East Coast of the United States, a site that has been targeted for redevelopment is found to require deep foundations or a significant ground improvement effort to allow for shallow foundations to support vertical construction at the site. Throughout what is known as the Eastern Coal Fields (which stretch primarily from Pennsylvania to Kentucky), this is virtually always the case; with sites being covered with as much as 100 feet of uncontrolled mine spoil fills, placed at the conclusion of strip mining activities conducted during the past century. Today, by virtue of the surficial coal seams being associated with the underlying Marcellus and Utica shale formations which underlie much of the northeastern United States, many of these areas are being reused as part of infrastructure and site development projects associated with the shale gas industry.

Originally discussed by Drumheller and Shaffer (1997), an effective method of limiting post-construction settlement for structures or site pads built over these types of thick deposits of coal spoils is dynamic compaction. In the past fifteen years, however, the number of projects constructed on former strip mine sites following the implementation of a dynamic compaction program has grown exponentially (particularly as a result of the booming shale gas industry in the northeastern united states), and as a result, so has the body of knowledge used to design and implement these programs. The results of these discussions, along with general conclusions as to recommended design parameters for a successful dynamic compaction program over mine spoil materials is discussed herein.

## GENERAL SUBSURFACE CONDITIONS

Similar to constructing a site on an unknown urban fill or non-engineered demolition site, the biggest issue associated with most strip mine sites is the uncontrolled nature in which these materials were placed at the completion of mining activities. Given the clayey nature of the parent shale bedrock with which the coal seams were extracted from, the makeup of coal spoils is generally a silty clay/clayey silt matrix with highly variable proportions of rock fragments, boulders, sand, and gravel. Groundwater is generally not of significant concern on these types of sites, given that most coal mine areas are at relatively high elevations.

Strip-mined sites are usually excavated just the way it sounds. The overburden soil and rock is removed along a strip to expose the underlying clay seam. The coal seam is that fully mined, and then the excavated overburden is then dumped back into the prior strip in an uncontrolled fashion. The process is then repeated along an adjacent strip, and so on, until the entire site is mined. Understanding this process, it is clear to see how the overburden bedrock (which is usually blasted prior to excavation) and the overlying residual soil becomes mixed prior to replacement in the excavation.

From a geotechnical perspective, the Standard Penetration Test N-values are typically all over the map for mine spoil material. A spoon driven through a clayey zone may have relatively low blow counts, while refusal is common in areas where the sampler encounters rock fragments. As a result, the density and makeup of mine spoil material is consistently inconsistent, with widely varying N-values throughout the soil mass.

## GEOTECHNICAL MITIGATION OPTIONS FOR MINE SPOILS

Once it has been determined that a site has mine spoil material to contend with, there becomes multiple options that are generally explored from a foundation support perspective. These options can vary from implementing a ground improvement program to allow for shallow foundation support and slab-on-grade construction, to installing deep foundations and structural floor slabs, to doing nothing. Generally, modern-day building codes prevent the third option, but the first two options are both very viable from a technical perspective.

Possible ground improvement options include dynamic compaction, surcharge, installation of rammed-aggregate piers, or grouting. However, given the extreme variability of mine spoils, and more importantly the potential for rock fragments and boulders throughout the layer, the more intrusive ground improvement options such as grouting or rammed aggregate piers can be somewhat challenging, albeit not impossible.

From a deep foundation perspective, there are multiple options, but for some of the same reasons mentioned above, some of these options are just as difficult to implement. Specifically, the idea behind deep foundations is to bypass the questionable soil layer. However, when the questionable soil layer is laden with boulders, cobbles, and other obstructions, installing pile foundations can be quite difficult. Alternative types of deep foundations such as drilled mini-piles, caissons, or auger cast piles are drilled-in elements that can sometimes get through the obstructions easier than driven piles. Regardless of the type of deep foundation chosen, a structural floor slab will almost always be required to transfer loads to the pile-supported columns; this is often the single biggest cost associated with this option.

As can be seen, there are several approaches that can be taken when it comes mitigating thick deposits of mine spoil material on a project site. Generally without exception, the implementation of a ground improvement program at a given site to allow for shallow foundations and slab-on-grade construction is going to provide a more cost-effective option that the installation of deep foundation elements constructed in conjunction with a structurally-supported floor slab. Further, of the ground improvement options available, dynamic compaction is almost always the most economical option and can generally be completed the fastest, which is of particular interest at sites where schedule constraints exist (which is especially commonplace within the energy sector).

## WHAT IS DYNAMIC COMPACTION?

Dynamic compaction consists of the introduction of multiple passes of high energy impacts at the ground surface by repeatedly dropping steel tampers ranging from 6 to 20 tons from drop heights ranging from 40 to 70 feet. The high energy impact creates a shock wave that densifies the soil at depth and reduces the void ratio; thus improving the consistency and overall engineering properties of the soil mass. In doing so, the need for off-site removal of the existing soils for replacement with compacted granular fill or the installation of deep foundations which bypass the loose soils can be eliminated.

The tamper used in the dynamic compaction process generally results in craters on the order of six feet in diameter and ranging in depth from two to six feet. Typically, following each pass, the craters are backfilled. If suitable, surrounding material can be pushed into the craters, resulting in an overall lowering of the site grade. If not, then imported granular material must be used to backfill the craters in between passes. In some instances, however, where the ground response is favorable or where shallow groundwater is not an issue, both passes can be completed simultaneously.

In addition to strengthening and compacting the existing fill or natural soils, dynamic compaction is similar to proof-rolling in that it exposes pockets of softer material or materials that are unsuitable to provide foundation support or to construct finished hardscape features upon. These areas, when identified during the compaction process, can be remediated in one of two ways; either additional pounding can be carried out until the soils are adequately densified, or granular soil can be used as backfill before conducting additional drops – this is often referred to as "dynamic replacement."

The degree and depth of soil improvement achieved with dynamic compaction depends upon the total amount of energy applied to the soil; i.e., the more energy imparted to the soil, the greater the degree of improvement. Depth of improvement is a function of the amount of weight being dropped and the drop height, with improvement depths of 20 to 30 feet commonly being achieved.

Dynamic compaction is typically performed over a predetermined grid pattern, with multiple passes being implemented on offsetting grids. The grid spacing, number of drops per impact point, drop height, and total number of passes is dependent on the site-specific soil conditions, the observed ground response, and the dissipation of pore water pressure subsequent to pounding.

Comprehensive monitoring of ground response is needed to control the work, and allow for modification to the program being implemented. The applied energy, impact grid, and the sequence and timing of the drops can all be adjusted, as needed, to achieve the desired results.

## DISCUSSION OF DYNAMICALLY-COMPACTED MINE SPOIL SITES

During the past 30 years, the level of confidence in dynamic compaction applications on strip-mined sites has increased tremendously. Based solely on the author's experience, at least 80 mine spoil sites within the Eastern Coal Fields have been improved utilizing dynamic compaction dating back to 1988. We also that expect that dozens of other sites have been completed by other dynamic compaction contractors as well.

As was previously mentioned, often times, the thickness of the mine spoil material in question is generally upwards of 40 to 70 feet thick, sometimes up to 100 feet. Separately, the general limits of improvement for a dynamic compaction program is on the order of 30 feet, using readily available commercial equipment in the United States. That being said, it is important to understand that the general approach when it comes to implementation of dynamic compaction at a mine spoil site is not to improve the entire fill mass, but rather created a densified crust of material about 20 to 25 feet thick, that will serve as a "soil mat" and generally iron around differential settlements that could occur as a result of consolidation of the fill at greater depths. This approach is important to keep in mind, as it is generally most applicable to low-rise type structures (say two to three stories) with relatively modest column loads that require modest bearing pressures (say 4,000 pounds per square foot or less).

More recently, the shale gas industry has started requiring pad sites to support compressors and other equipment associated with the shale gas industry, for both extraction processes and pipelines. Owing to the geology generally associated with the more near surface coal mining operations, there exists dozens of these types of sites where shale gas is in the process of being extracted from below previously strip-mined sites. While bearing capacity and settlement characteristics remain important on the types of sites, often times, the most import engineering property is the more near-surface slab-support moduli.

## Dynamic Compaction Project Summary

In preparing this paper, case studies from a total of 80 projects completed by the authors were reviewed. A summary of these projects is provided in Table 1, at the end of the text. The project type, as well as the specifics of the dynamic compaction program implemented (i.e. size of weight, height of drop, spacing of grid, etc.) are provided in detail.

The available data shows the majority of the projects by the authors completed utilized weights ranging from 10 to 16 tons, with drop heights ranging from 45 to 60 feet. Most programs implemented a two-pass system with grid spacings ranging from 10 to 15 feet, with 5 to 8 drops per point. When using the formula for estimating depth of improvement for dynamic compaction, as shown in Eq. 1 (Lukas, 1995), the range of improvement for these programs was between 20 to 30 feet below the ground surface.

$$D = n\sqrt{WH} \tag{1}$$

where: D = depth of influence (m)
n = empirical coefficient (0.4 to 0.5 for fill materials)
W = weight of tamper (Megagrams)
H = drop height (m)

Aside from evaluating the depth of influence of a program, the other major component to specifying a proper dynamic compaction program is the amount of treatment energy being imparted to the soil. This is generally noted in terms of kilojoules per cubic meter (kJ/m$^3$), and is a measure of the amount of energy put into the ground per unit volume. As can be seen in Eq. 2 (Lukas 1995), the amount of treatment energy is a function of the number of passes, number of drops, grid spacing, and energy per drop.

$$Applied\ Energy = \frac{(Tamper\ Weight) * (Tamper\ Height) * (\#\ of\ Drops) * (\#\ of\ Passes)}{(Grid\ Spacing) * (Grid\ Spacing) * (Depth)} \tag{2}$$

Looking at the range of weights and drop heights used on the 80 projects reviewed, the range of applied energies was generally found to be between 150 and 350 kJ/m$^3$, with some projects requiring close to 600 kJ/m$^3$ based on softer ground conditions at the site. This range of energy falls very reasonably within the industries standards given the general soil conditions at a mine spoil site. Specifically, the FHWA manual for dynamic compaction (Lukas 1995) suggests a range of 200 to 250 kJ/m$^3$ for granular fill materials and 250 to 350 kJ/m$^3$ for clay fill materials, the latter of which is more in line with mine spoil materials.

## RESULTS

There are a number of different ways to go about implementing and evaluating a dynamic compaction program; however, most projects fall into one of two categories. First, projects can be performed based on a method specification, whereas the geotechnical engineer specifies a certain amount of energy for the project to be met by the specialty contractor. Alternatively, projects can be performed on a performance specification, where the dynamic compaction contractor has a certain criteria to achieve (generally specified in terms of SPT N-value) and the post-improvement soils are then tested to verify that the criteria has been met. While the majority of the sites completed by the authors fall into the former, post-improvement data is available from some sites, and is summarized below.

### Ground Response During Dynamic Compaction

It is important to note, that regardless of which type of approach is taken, the most important aspect to the quality control and evaluation process of a project (particularly on highly heterogeneous mine spoil sites) is watching the ground response during the pounding process. That is to say, it is important to visually observe that the ground is densifying with each successive drop. In many instances, observing a certain level of penetration per drop is outlined at the acceptance criteria for the program. Alternatively, on sites with higher clay content, it is more advantageous to introduce more passes of less drops, and gradually densify the site by uniformly compressing the upper portion of the fill material. In areas where the material is soft to the point where densification is difficult, boney granular material can immediately be introduced to drive into and tighten up the subgrade, and achieve the penetration resistances that may be required.

### Post-Improvement SPT Results

In order to best evaluate the level of improvement achieved by a dynamic compaction program, it is best to have both pre- and post-improvement data to compare. SPT N-values taken both before and after the dynamic compaction program were available for six projects reviewed. A summary plot of the pre- and post-improvement average N-values for the projects reviewed is shown in Figure 1. As can be seen, a significant level of improvement was observed over about 30 feet, and particularly in the upper 20 feet. This is generally consistent with what is known as "Zone of Major Improvement", which is generally the upper 2/3 of the depth of influence being targeted.

It is important to note, however, that evaluating SPT N-values (or any other types of intrusive testing results for that matter) in mine spoil materials should be done cautiously and carefully. Specifically, on some sites where the minus 200 content of the spoils is considerably high, there is no appreciable increase in N-value following the completion of the program, even though every visual metric used suggest that a good level of improvement has occurred. In instances such as these, one must rely most on the ground response observations made during the implementation of the program, and ancillary data such as the elevation before and after compaction, to evaluate the overall effectiveness of the dynamic compaction program.

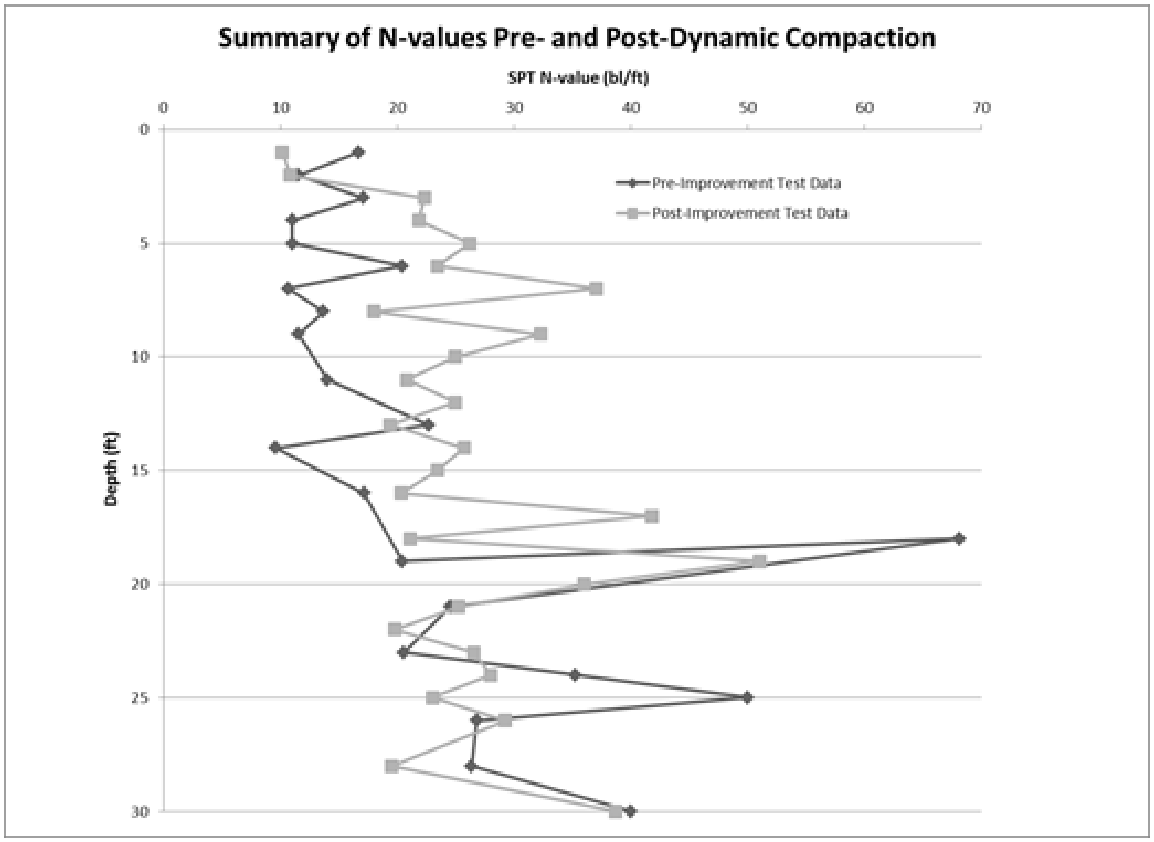

**Figure 1 – Summary of Pre- and Post-Improvement N-values for Six Projects Completed in Eastern Coal Fields**

## CONCLUSIONS

On disturbed sites, there are always several options for foundation support, some faster to implement than others, and some more economical than others. When it comes to foundation solutions on mine spoil sites, the body of data that has been collected over the past 30 years indicates that implementing a dynamic compaction program to improve mine spoil materials and allow for shallow foundations is a very viable and effective option. Based on a review of the author's 80 successfully completed projects, a number of lessons learned and conclusions can be drawn, and in no particular order, are as follows:

- Dynamic compaction of mine spoils offers an economic approach to ground improvement, provided that the column loads for the proposed vertical development are reasonably moderate in magnitude. Specifically, dynamic compaction programs are designed to improve the upper 20 to 25 feet of material, creating a "soil mat" which is designed to iron out differential settlements which could occur within the deeper fill materials.

- The amount of treatment energy for a successful dynamic compaction program within mine spoil materials should range from 150 to 350 $kJ/m^3$.

- It is possible to see an increase in SPT N-values of up to 40% following the completion of a dynamic compaction program; however, cautious should be used on sites with a significantly high percentage of minus 200 material in the mine spoil materials, as even though ground response during the program may have dictated a suitable level of improvement, the N-value may show little to no improvement.

- Viewing the ground response of a dynamic compaction program over mine spoil materials is vitally important to assessing how the passes should be conducted, how many drops are optimal, and whether more passes of less drops are needed.

## ACKNOWLEDGMENTS

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## KEYWORDS

Dynamic compaction, ground improvement, coal spoils, mine spoil, mining remediation, shale gas site development.

# Table No. 1 – Summary of Dynamic Compaction Projects on Mine Spoil Materials

| Year | State | City | Project Type | Max Fill Thickness | Area | Weight | Passes | Drops/Point | Drop Height | Grid | D.O.I. | AE/Volume |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (ft) | | (tons) | | | (ft) | (ft) | (ft) | (kJ/m$^3$) |
| 1988 | KY | Pikeville | School | n/a | Area | 18 | 1 | 8 | 60 | 20 | 26.8 | 77 |
| 1988 | KY | Meta | Coal Spoil Project | 10 | Area | 10 | 1 | 5 | 60 | 10 | 20.0 | 144 |
| 1988 | PA | Scranton | Residential | 30 | Area | 15-20 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1989 | KY | Vanceburg | Industrial | n/a | Area | 8 | 2 | 6 | 60 | 15 | 17.9 | 137 |
| 1990 | WV | Charleston | Commercial / Retail Centers | n/a | Area | 10 | 2 | 9 | 55 | 15 | 19.1 | 220 |
| 1991 | VA | Wise | Commercial / Retail Centers | n/a | Building | 10 | 1 | 7 | 60 | 10 | 20.0 | 202 |
| | | | | | Parking | 10 | 1 | 5 | 60 | 10 | 20.0 | 144 |
| 1994 | WV | Charleston | Energy | 100 | Crushing Plant | 11 | 2 | 7 | 70 | 9 | 22.6 | 564 |
| | | | | | Receiving Bins | 11 | 3 | 6 | 70 | 10 | 22.6 | 587 |
| 1995 | VA | Pardee | Energy | 55 | Area | 9 | 2 | 7 | 60 | 10 | 18.9 | 382 |
| 1995 | IN | Washington | Energy | 130 | Area | 9 | 4 | 5 | 55 | 10 | 18.1 | 523 |
| 1995 | KY | Pikeville | Office Complex | 20 | Area | 10 | 2 | 5 | 60 | 10 | 20.0 | 288 |
| 1995 | VA | Wise | Warehouse | 50 | Area | 15 | 2 | 7 | 70 | 15 | 26.4 | 237 |
| 1996 | KY | Hazard | Warehouse | 40 | Area | 10 | 2 | 6 | 60 | 13x19 | 20.0 | 140 |
| 1996 | KY | Hazard | Warehouse | 40 | Area | 13 | n/a | n/a | 60 | n/a | 22.8 | n/a |
| 1997 | KY | Hazard | Commercial / Retail Centers | n/a | Building | 12.5 | 2 | 6 | 60 | 11 | 22.3 | 319 |
| | | | | | Parking Lot | 11.5 | 2 | 4 | 60 | 10 | 21.4 | 247 |
| 1997 | PA | Wilkes-Barre | Commercial / Retail Centers | 20 | Area | 9 | 2 | 5 | 50 | 12 | 17.3 | 173 |
| 1997 | PA | Shanandoah | Supermarket | 18 | Area | 8 | 2 | 5 | 55 | 11 | 17.1 | 204 |
| 1998 | PA | Wilkes-Barre/Laflin | Warehouse | 29 | Column Locations | 8 | n/a | 6 | 50 | n/a | 16.3 | n/a |
| 1998 | KY | Harlan | Industrial | 10 | Area | 8 | 2 | 6 | 45 | 12 | 15.5 | 186 |
| 1999 | PA | Scranton | School | 58 | Area | 16 | 2 | 7 | 65 | 15 | 26.3 | 236 |
| 1999 | WV | Weirton | Warehouse | 15 | Area | 10 | 2 | 6 | 55 | 16 | 19.1 | 129 |
| 1999 | PA | Scranton | Commercial / Retail Centers | 50 | Area | 16 | 2 | 7 | 60 | 15 | 25.2 | 227 |
| 2000 | WV | Clarksburg | Warehouse | 40 | Area | 9 | 2 | 6 | 55 | 11 | 18.1 | 259 |
| 2001 | PA | Sommerset | Civil Structure | 40 | Area | 10 | 2 | 6 | 50 | 12 | 18.2 | 219 |
| 2001 | PA | Dickson City | Commercial / Retail Centers | 20 | Area | 10 | 2 | 5 | 55 | 15 | 19.1 | 122 |
| 2001 | VA | Wise | Warehouse | 44 | Area | 15.2 | 2 | 5 | 55 | 12 | 23.6 | 236 |
| 2001 | PA | Wilkes-Barre | Commercial / Retail Centers | 42 | Area | 10 | 2 | 6 | 60 | 12 | 20.0 | 240 |
| 2001 | OH | Stubenville | Commercial / Retail Centers | 70 | Area | 16.1 | 2 | 7 | 65 | 10 | 26.4 | 532 |
| 2002 | OH | Steubenville | Warehouse | 70 | Test Pads 1 & 2 | 15 | 2 | 5 | 60 | 13 | 24.4 | 209 |
| | | | | | Test Pad 3 | 15 | 2 | 5 | 60 | 12 | 24.4 | 245 |
| 2002 | OH | Steubenville | Warehouse | n/a | Area | 15 | 2 | 4 | 60 | 15 | 24.4 | 125 |
| | | | | 40 | Aprons | 10 | 2 | 6 | 60 | 13 | 20.0 | 204 |
| 2002 | PA | Scranton | Civil Structure | 24 | Area | 10 | 2 | 5 | 55 | 12 | 19.1 | 191 |
| 2003 | PA | Wilkes-Barre | Commercial / Retail Centers | 60 | Area | 15 | 2 | 5 | 50 | 15 | 22.3 | 143 |
| 2003 | VA | Wise | Commercial / Retail Centers | 60 | Area | 10 | 2 | 6 | 12 | 12 | 8.9 | 107 |
| 2003 | VA | Haysi | Prison / Jail | 34 | Area | 10 | 2 | 5 | 55 | 12 | 19.1 | 191 |
| 2003 | WV | Weirton | Commercial / Retail Centers | 30 | Area | 10 | 2 | 5 | 50 | 12 | 18.2 | 182 |
| 2004 | OH | Belmont | Civil Structure | 40 | Area | 10 | 2 | 9 | 60 | 12 | 20.0 | 360 |
| 2004 | PA | Shamokin | Industrial | 51 | Area | 16 | 2 | 6 | 65 | 13 | 26.3 | 269 |
| 2005 | WV | Wheeling | Commercial / Retail Centers | 18 | Area | 10 | 2 | 6 | 60 | 15 | 20.0 | 154 |
| 2005 | PA | Clearfield | Commercial / Retail Centers | 80 | Area | 15 | 2 | 5 | 60 | 12 | 24.4 | 245 |
| 2005 | PA | Dunmore | Civil Structure | 23 | Area | 10 | 2 | 8 | 55 | 12 | 19.1 | 306 |
| 2005 | OH | Petersburg | Energy | 60 | Area | 10 | n/a | n/a | 50 | n/a | 18.2 | NA |
| 2005 | VA | Wise | Residential | 75 | Area | 10 | 2 | 6 | 50 | 12 | 18.2 | 219 |
| 2006 | PA | Pittston | Residential | 40 | Area | 10 | 2 | 6 | 45 | 12 | 17.3 | 208 |
| 2006 | PA | Hanover | Warehouse | 41 | Int. Columns | 9 | 1 | 8 | 55 | 6 | 18.1 | 581 |
| | | | | | Individual Ftgs. | 9 | 1 | 7 | 55 | 6x12 | 18.1 | 254 |
| 2007 | PA | Hazelton | Industrial | n/a | Area | 10 | 2 | 6 | 55 | 12 | 19.1 | 230 |
| 2007 | WV | Mingo | Office Complex | 200 | Test | 10.5 | 2 | 8 | 55 | 10 | 19.6 | 452 |
| 2007 | PA | Wilkes-Barre | Commercial / Retail Centers | n/a | Transtion Zones | 10 | 1 | 5 | 50 | 12 | 18.2 | 91 |
| | | | | | Shallow Fill | 10 | 1 | 5 | 50 | 10 | 18.2 | 131 |
| | | | | | Deeper Fill | 16 | 2 | 5 | 70 | 12 | 27.3 | 273 |
| | | | | | Shallower Fill | 10 | 1 | 5 | 50 | 10 | 18.2 | 131 |
| 2007 | PA | Karthaus | Energy | 60 | A-1 & A-2, Pass 1 | 15.2 | 1 | 6 | 65 | 15 | 25.6 | 99 |
| | | | | | A-1&A-2 Pass 2&3 | 15.2 | 2 | 6 | 65 | 12 | 25.6 | 308 |
| | | | | | Total Energy | | | | | | | 406 |
| 2007 | PA | Humboldt | Warehouse | 20 | Area Pass 1 | 16.5 | 1 | 5 | 60 | 9 | 25.6 | 228 |
| | | | | | Area Pass 2 | 15 | 1 | 5 | 60 | 12 | 24.4 | 122 |
| | | | | | Total Energy | | | | | | | 351 |
| 2007 | PA | Taylor | Commercial / Retail Centers | n/a | Area | 15 | 1 | 6 | 50 | 10 | 22.3 | 193 |
| 2008 | VA | Jonesville | Commercial / Retail Centers | unknown | Area | 8 | 2 | 6 | 50 | 10 | 16.3 | 282 |
| 2008 | PA | Johnstown | Energy | 52 | Area | 25 | 2 | 6 | 65 | 15 | 32.8 | 253 |
| 2008 | WV | Morgantown | Energy | 40 | Area | 16 | 2 | 6 | 60 | 15 | 25.2 | 194 |
| 2008 | VA | Oakwood | Industrial | 60 | Area | 10 | 1 | 6 | 55 | 8 | 19.1 | 258 |
| 2009 | PA | Wilkes-Barre | Commercial / Retail Centers | 8 | Area | 10 | 2 | 8 | 50 | 12 | 18.2 | 292 |
| 2009 | WV | Varney | Commercial / Retail Centers | 20 | Area | 10 | 2 | 6 | 55 | 15 | 19.1 | 147 |
| 2009 | VA | Wise | Civil Structure | n/a | Area | 10 | 2 | 7 | 65 | 10 | 20.8 | 419 |
| 2011 | PA | Jessup | Civil Structure | 18 | Area Pass 1 | 16 | 1 | 6 | 65 | 25 | 26.3 | 36 |
| | | | | | Area Pass 2 | 16 | 1 | 6 | 65 | 10 | 26.3 | 227 |
| | | | | | Pass 3+ 2ft of stone | 16 | 1 | 6 | 65 | 10 | 26.3 | 227 |
| | | | | | Total All | | | | | | | 491 |
| 2010 | KY | Prestonsburg | Residential | 50 | Area | 10 | 1 | 6 | 50 | 10 | 18.2 | 158 |
| 2010 | PA | Humboldt | Warehouse | 53 | Area | 16 | 2 | 5 | 60 | 15 | 25.2 | 162 |
| 2010 | PA | Shanksville | Park | 35 | Area | 10 | 1 | 6 | 50 | 10 | 18.2 | 158 |
| 2011 | WV | Varney | Airport | 20 | Area | 10 | 2 | 6 | 55 | 15 | 19.1 | 147 |
| 2011 | PA | Johnstown | Civil Structure | 90 | Area | 16.5 | 2 | 6 | 60 | 12 | 25.6 | 308 |
| 2011 | WV | Williamson | School | 25 | Area Building | 10 | 1 | 8 | 50 | 8 | 18.2 | 328 |
| | | | | | Area Field | 10 | 1 | 5 | 50 | 8 | 18.2 | 205 |
| 2011 | PA | Ashley | Commercial / Retail Centers | 30 | Area | 16 | 1 | 5 | 55 | 15 | 24.2 | 77 |
| 2011 | WV | Wierton | Warehouse | 33 | Area | 10 | 1 | 6 | 60 | 8 | 20.0 | 270 |
| 2011 | PA | Hazelton | Warehouse | n/a | Area | 16 | 2 | 6 | 60 | 15 | 25.2 | 194 |
| 2012 | OH | Belmont | Office Complex | 57 | Area | 16 | 2 | 6 | 60 | 12 | 25.2 | 303 |
| 2012 | OH | Cadiz | Energy | 55 | Area | 16 | 2 | 6 | 60 | 15 | 25.2 | 194 |
| 2012 | PA | Wilkes-Barre | Commercial / Retail Centers | n/a | Area | 15 | 2 | 6 | 60 | 12 | 24.4 | 294 |
| 2012 | PA | Hanover Towwnship | Warehouse | n/a | Area | 10 | 2 | 6 | 50 | 12 | 18.2 | 219 |
| 2012 | OH | Steubenville | Civil Structure | 50 | Area | 16.5 | 2 | 7 | 50 | 12 | 23.4 | 328 |
| 2013 | PA | Clearfield | Office Complex | 25 | Area | 20 | 2 | 10 | 70 | 15 | 30.5 | 391 |
| 2013 | VA | Wise | School | 14 | Area | 9 | 2 | 5 | 50 | 12 | 17.3 | 173 |
| 2014 | WV | Mngo | Airport | >30 | Area | 10 | 2 | 5 | 50 | 12 | 18.2 | 221 |
| 2014 | WV | Logan | Civil Structure | >20 | Area | 10 | 2 | 5 | 50 | 12 | 18.2 | 193 |
| 2014 | PA | McKees Rocks | School | 30 | Area | 10 | 2 | 7 | 50 | 12 | 18.2 | 233 |
| 2014 | WV | Greenbrier | Energy | 60 | Area | 10 | 2 | 5 | 50 | 12 | 18.2 | 215 |
| 2015 | OH | Lafferty | Energy | 80 | Area | 15.2 | 2 | 5 | 60 | 15 | 20.0 | 186 |