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## **Low Mobility Grouting Applications in Karstic Gypsum**

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## **Low Mobility Grouting Applications in Karstic Gypsum**

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### **ABSTRACT**

Underneath the alluvial outwash deposits in much of Western Michigan lies sedimentary rock consisting of layers of limestone, sandstone, shale and gypsum. Karstic features have been found within the gypsum formations near the surface of the bedrock in Kent County and the surrounding areas. Excessive settlements from the voided gypsum have been observed on existing structures located along the Grand River in downtown Grand Rapids and some of the outer lying suburbs. A ground improvement method for remedying this type of karstic geology for both new and existing structures is to perform low mobility grouting (LMG) within the gypsum rock formation by installing vertical grout points over the questionable area. Micropiles can also be installed as deep foundation elements where there are higher structural design loads, utilizing the same drill hole as the LMG operation.

One of the advantages that LMG and micropiles have over other available foundation systems is their ability to be installed through difficult ground conditions not suitable for other techniques. Using specialized drilling methods, the drill casing can be advanced through man-made obstructions, cobbles, boulders, and deep into rock formations, which is typical of Western Michigan. Having this capability makes this technique an excellent choice for drilling in karstic formations where the casing can be advanced until conditions are encountered that confirms adequate bedrock. Where some projects may require the use of LMG to fill these voids, micropiles can serve a dual purpose by providing a structural deep foundation element as well as a mechanism for delivering ground treatment.

This paper will look at several case histories where LMG, with and without micropiles, was used in Western Michigan to treat the voided gypsum rock. The construction projects will cover both new and existing structures to include parking garages, buildings, schools, restaurants and bridges.

### **GEOLOGICAL SETTING**

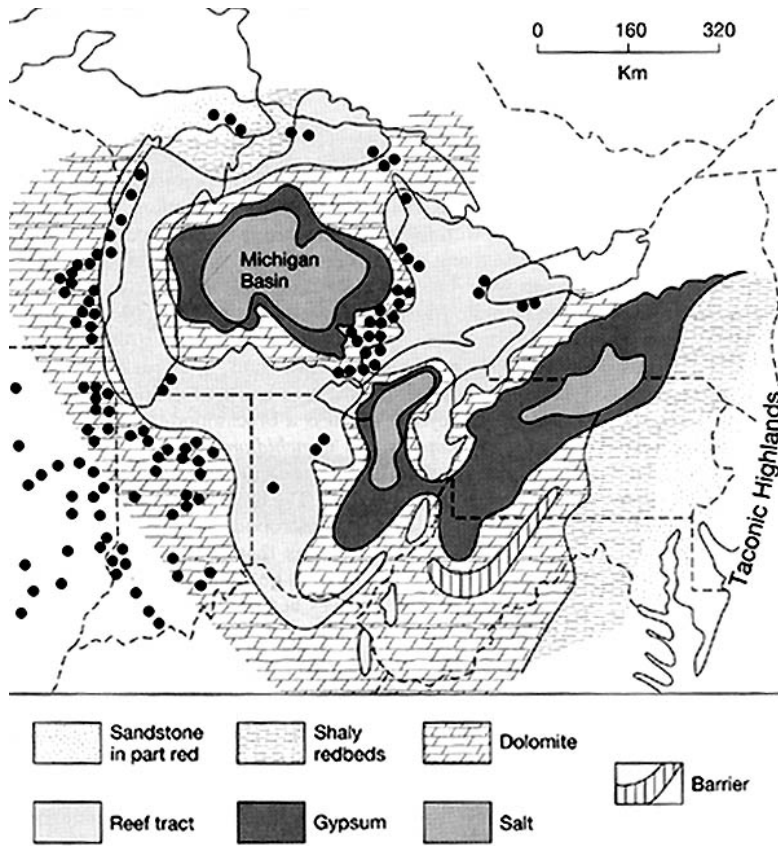
Overburden soils for Western Lower Michigan were predominantly deposited in glacial environments during the Pleistocene, the initial epoch of the Quaternary period. The upper soil strata consist mostly of stratified sand and gravel deposited from melt waters while the glaciers were retreating northward. Increased concentrations of gravel, cobbles and boulders are found within the outwash deposits near river valleys from the high water velocities. Occasionally, silt or clay layers will be found within the outwash deposits caused by periods of low flow from glacier melt waters.

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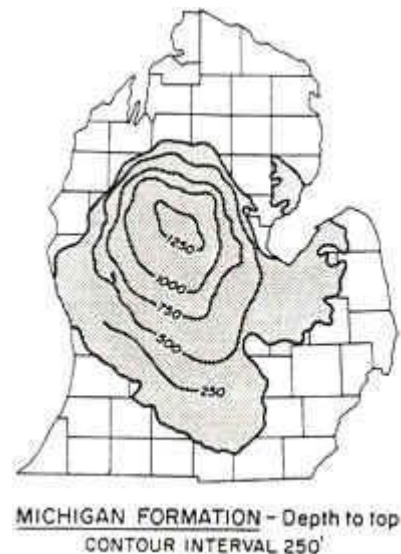
Glacial till is present beneath the majority of the glacial outwash deposits along the west side of the lower peninsula. The till was deposited by the glaciers as they advanced and retreated within the state. The majority of the till matrix is comprised of clay with varying amounts of sand, silt and gravel. Cobbles and boulders are also present within the till with random concentrations.



**Figure 1: Sedimentary Rock Deposits - Michigan Basin**

Gypsum deposits range in thickness from 4 to 20 feet throughout the Michigan Basin. Due to the concave geometry of the basin, the sedimentary rock of the Michigan Formation is closest to the ground surface near the perimeter of the basin and can be over 1,200 feet near the center. Figure 2 shows the approximate depth to the top of the Michigan Formation from existing ground surface. A high concentration of gypsum can be found near the bedrock surface in Kent County where gypsum mining operations have occurred since 1841. These deposits are susceptible to karstic solution cavities that could cause excessive settlements near the ground surface.

The upper bedrock layers were formed during the Paleozoic Era. These sedimentary rock strata consist primarily of limestone, sandstone, shale and gypsum. During the formation of these sedimentary rock deposits, the majority of the earth was flooded by sea water. Subsidence of the ground surface in the lower peninsula of Michigan formed an inland salt water lake known as the Michigan Basin. Over time the water evaporated causing the salt to precipitate into the underlying minerals and organic material. The varying degrees of minerals and organic matter created the stratified formations of limestone, sandstone, shale and gypsum, known as the Michigan Formation. Refer to Figure 1, which shows the Michigan Basin in relation to the surrounding states.



**Figure 2: Depth to Michigan Formation**

The solubility rate of gypsum in water is ten to twenty times more than limestone. The accelerated karstic features in gypsum require foundation solutions that quickly remedy the problem in existing structures or alleviate problems for new developments.

## **LOW MOBILITY GROUTING**

Low mobility grouting (LMG) is defined as pumping low slump grout, generally with a slump of 0 to 5 inches, to enhance the overburden soils (compaction grouting) or to fill voids (karstic bedrock). The rate of pumping and slump will define what type of low mobility grouting will be performed. Compaction grouting uses grout with a slump of 2 inches or less and is pumped at a rate of less than 2 cubic feet per minute. Void filling applications use a grout with a slump of up to 5 inches, pumped at a rate of greater than 2 cubic feet per minute. LMG for void filling prevents excessive grout volumes associated with filling cracks and fissures within the rock by using a low slump sand cement mix rather than a low viscosity neat cement grout. This paper describes LMG applications that were performed for void filling in karstic gypsum rock located in Western Michigan.



**Figure 3: Rotary Percussive Eccentric Drill Tooling**

Void filling LMG applications are usually determined by excessive settlements at the ground surface or by previous experience within the known regional geology. Soil borings are performed for the new construction or near the existing subsidence to confirm the presence of gypsum near the bedrock surface. It is important to note that the voids causing the subsidence of the existing structures or those that would be problematic after new construction are not always found prior to starting the LMG program.

LMG consists of drilling steel casing to either a known tip elevation within the bedrock based on previous geotechnical exploration or using the grout point itself to intersect the voided layer and find sound rock. Steel drill casing is advanced to the tip elevation using a rotary percussive eccentric duplex drilling system, a drilling technique that has come from the oil industry and reconfigured for specialty geotechnical construction. Low slump grout is then pumped through the steel casing to the tip until a cutoff pressure is reached or excessive ground heave is noted near the grout point. The steel casing is withdrawn in 2 foot intervals satisfying the refusal criteria at each stage. Refer to Figure 3,

which is a picture of the rotary percussive eccentric duplex drilling system.

## **MICROPILES**

Micropiles are drilled in deep foundation elements typically ranging in diameter from 5 to 12 inches. Traditionally in the United States, micropiles consist of a permanent steel casing, a central steel reinforcement bar and cement based grout. The drill casing is typically left in place

through the unsuitable overburden material shedding the axial load in friction to a competent soil or rock stratum below the casing. With the load shed in friction, micropiles can resist both axial compression and tension loads. Permanent steel casing left in the upper portion of the micropile can also be designed to resist lateral loads with limited lateral deflection.

Micropiles tend to be more economical than other deep foundation systems when there are one or more installation challenges on a project. These challenges can be separated into two major descriptions: physical and geotechnical. The following is a list of potential physical challenges encountered for deep foundation installation:

- Limited overhead clearance
- Vibration, settlement or noise sensitivity
- Limited plan access or the desire to work multiple operations
- Installation of foundation elements close to or through existing footings, walls or other structures

Geotechnical challenges that warrant micropile technology are:

- Variable weathered rock or karstic rock (voided or soil filled solution cavities)
- Cobbles, boulders or glacial till
- Uncontrolled fill containing natural or man-made obstructions
- Granular soils below the water table

In addition to the site challenges, potential downdrag forces on the micropiles can be eliminated when low mobility grouting has filled voided rock strata that could have collapsed within the cased length of the pile.

Codes and manuals for designing micropiles are beginning to be published from federal, state and international organizations. The following are a list of current publications with specific design guidelines for micropiles:

- FHWA-SA-97-070 - 2000
- Massachusetts Building Code 1998 – Section 1820.6 - Small Diameter Grouted Piles
- International Building Code - 2006

## **CASE HISTORIES**

Several case histories are available to describe the various low mobility grouting applications that have occurred in Western Michigan. These projects will be separated into new construction and existing structures.

## *NEW CONSTRUCTION*

### *Grand Rapids Convention Center*

The Convention Center is located along the east bank of the Grand River in downtown Grand Rapids. Construction of the original structure occurred in the early 1980s on a site that previously contained industrial facilities and the Welsh Auditorium. Excessive settlements of portions of the original structure were discovered in 1992. Geotechnical exploration near the subsidence area revealed voided gypsum approximately 40 feet below the ground surface. 1,700 cubic yards of low mobility grouting was used to fill the voided gypsum prohibiting further movement.

Expansion and renovations to the existing convention center in 2002 prompted the need for a deep foundation system due to the loose alluvial deposits within the overburden soils. Regardless of the deep foundation element selected, LMG was specified to a predetermined tip elevation in order to fill any potential voids within the karstic gypsum rock formation based on the previous settlements found on the site.

Construction for the expansion was separated into three phases. The first two phases were performed by other contractors consisting of a combination of drilled caissons and micropiles. The micropiles were installed in limited access situations while the caissons were installed in areas of unrestricted access and headroom. LMG was performed within each micropile and caisson.

The third phase of construction, performed by Nicholson, consisted of low mobility grouting and micropiles. The total number of LMG micropiles for this phase was 344, 100 ton piles at an average depth of 52 feet from ground surface. In addition sixteen LMG points were placed at the addition close to where the subsidence in 1992 occurred. LMG with micropiles was chosen for the third phase of construction over caissons due to the following factors:



**Grand Rapids Convention Center**

- Ability to penetrate man-made or natural obstructions without additional associated costs
- Drilling technique allowing for the installation of the micropile while simultaneously performing LMG
- Smaller installation equipment allowed for more operations onsite condensing the overall construction schedule
- Reduced spoils due to smaller hole sizes associated with contaminated soils

### *State Road M-78*

The Michigan Department of Transportation replaced the bridge over the Battle Creek River on state road M-78 just west of the city of Bellevue. The previous bridge was originally constructed in the 1970s and founded on shallow foundations. Geology at the project consisted of primarily sand and gravel glacial outwash deposits within the overburden and stratifications of limestone and karstic gypsum. Deep foundations were required for the bridge because it was a scour critical structure due to recent flood events on the Battle Creek River. A total of 77, 60 ton micropiles were installed in the three cofferdam structures after demolition of the existing bridge and foundations due to the karstic gypsum rock.



**State Road M-78**

### *Altacor Project & Grand Valley State University Parking Garage*

LMG and Micropiles were specified for both the Altacor Project and the Grand Valley State Parking Garage due to their geographical proximity to the Grand Rapids Convention Center. Geotechnical explorations for both projects verified the presence of gypsum rock near the bedrock surface, but were not as voided to the degree as the gypsum underneath the convention center. Due to the high solubility of the gypsum, micropiles were installed to protect the structures from future settlement if the rock were to become more severe.

The Altacor Project was located approximately 500 feet south of the Grand Rapids Convention Center on the same side of the Grand River. Construction for the Altacor Project was separated into three major structures: the main hotel, parking garage and plaza. A total of 729 LMG micropiles, with design loads ranging from 100 to 200 tons to depths up to 65 feet were installed for the Altacor Project.

Grand Valley State University decided to construct a parking garage at their downtown Grand Rapids location. The site was located near the convention center on the opposite side of the Grand River adjacent to railroad tracks. LMG with micropiles were originally designed for the stairwells, where higher concentrated loads were present over the gypsum rock. A cost analysis concluded that substituting LMG micropiles versus over excavation with shallow foundations on engineered fill would be more economical due to the temporary shoring that would have been required near the railroad tracks. The parking garage required the installation of 133, 100 ton LMG micropiles.

### *EXISTING STRUCTURES*

#### *Calvin Christian High School*

Calvin Christian High School was originally built in the 1960s in Grandville, a southwestern suburb of Grand Rapids. An addition on the southeast side of the building was built in 1998. Approximately five years after the addition was constructed, excessive settlements were noted in the new structure. Further geotechnical investigation confirmed the original geological profile consisting of silty sand within the overburden and sedimentary limestone, shale and gypsum within the exploratory depths of the bedrock. The settlement was thought to be within the granular overburden,



**Calvin Christian High School**

but did not rule out the possibility of voided gypsum rock. Helical pier foundations were connected into the existing shallow foundations within the addition to remedy the solution.

Settlement after the helical pier retrofit gradually continued over the next few years. The geotechnical consultant concluded that the settlements must be the result of voids within the gypsum rock underneath the building and preceded to layout a low mobility grouting program for the new addition. It was determined that micropiles would not be required due to low building loads from the addition as long as the voids were filled.

A total of 28 LMG points were installed within the disturbed area on an average rectangular spacing of 8 feet. Each grout point was extended to a depth of 50 feet, gradually removing the drill casing and pressurizing with low mobility grout for the bottom 35 feet of the hole until either the pressure criteria was met or heave was noted at the concrete floor. The upper 15 feet was simply tremied full to minimize the negative impacts that the helical piers may have had on

the structure. Continuous survey monitoring was performed throughout the grouting program to verify heave or excessive subsidence.

Voided gypsum was encountered in almost all of the LMG points. The grouting program filled all of the voids within the gypsum rock and consolidated the loosened granular material within the overburden. Settlement of the addition was impeded, with existing cracks in the brick mortar closed due to the slight heave created by the LMG grouting operation. Discussions with the school superintendent and maintenance department described an existing well that was within 50 feet of the building addition that was drawing water from rock formation. Periodic cleaning of the well screen produced rock chips, which may give some validation to the well promoting a higher solubility rate within the gypsum rock.

### *Arby's Restaurant*

Nicholson received a call from a local contractor requesting a price for performing low mobility grouting in the drive through lane at an Arby's Restaurant in Grandville. Geotechnical investigation of the existing structure concluded subsidence due to voided gypsum rock.

A total of five grout holes were drilled approximately 10 feet apart centered at the drive through window and following the drive up lane in either direction. Each grout point was extended to a depth of 40 feet, gradually removing the drill casing and pressurizing with low mobility grout until either the pressure criteria was met or heave was noted at the concrete pavement. All voids within the gypsum were filled during the LMG program and the settlement cracks within the existing structure tended to close due to the grout pressures that were recorded.

## **ACKNOWLEDGEMENTS**

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