Freeze-Thaw Resistance of Pervious Concrete

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A considerably severe exposure condition on portland cement concrete elements is exposure to cycles of freezing and thawing. Since the 1930s, air entrainment has been used to enhance the freeze-thaw resistance of portland cement concrete exposed to an external environment. The typical deterioration of concrete exposed to freeze-thaw conditions is random cracking, surface scaling and joint deterioration due to D-cracking. The first two are primarily due to lack of adequately entrained air in the concrete mass or the surface layer, respectively, and the latter phenomenon is primarily related to non-durable aggregate.

The general mechanism by which air entrainment improves concrete durability in freezing and thawing exposures is as follows: When water in the concrete (generally resulting from precipitation or from contact with moist sub grade) freezes, it expands and this movement of water generates pressures that, when in excess of the tensile strength of concrete or mortar layer at a surface, can cause cracking and scaling. Concrete has to be critically saturated (>91%), which is generally true for concrete surfaces. Entrained air bubbles are microscopic in size (0.01 inches or less), evenly distributed in the paste fraction, and take on water during the freezing cycle to relieve pressure buildup. Generally, an air entrainment of 4 to 8% and, more importantly, an air bubble spacing factor of less than 0.01 inch provides satisfactory freeze-thaw performance under most conditions.

As opposed to conventional concrete, pervious concrete typically has a large volume of 15 to 35% of interconnected voids. This void structure is not the same as the entrained air in regular portland cement concrete. In properly designed and installed pervious concrete pavements, water drains through it to an underlying draining layer and/or soil and will not be retained in its void structure. However, if the pervious concrete is completely saturated and is subjected to freezing, the water has no place to go. This can result in pressure on the thin cement paste that coats the aggregates and cause deterioration of pervious concrete installations. Some laboratory research studies have indicated that pervious concrete has poor freeze-thaw resistance when tested under fully saturated conditions (Procedure A of the ASTM C 666 test). However, this is a significantly severe test used to test conventional concrete and is not representative of the potential field exposure conditions of properly designed and constructed pervious concrete pavements. It is possible to an add air-entraining admixtures to pervious concrete mixtures to protect the coating paste, but the entrainment of air cannot be verified or quantified by normal standard test methods.

Pervious concrete that is partially saturated should have sufficient voids for the movement of water and thus demonstrate good-freeze thaw resistance. Can the pervious concrete be in a fully saturated condition? We believe it is possible under the following conditions:

1. If there is severe clogging of the void structure in pervious concrete its ability to drain is compromised. Precipitation on severely clogged pervious concrete will cause its void structure to become fully saturated. However, if there is severe clogging then the whole

objective of using pervious concrete is lost, let alone the issue of freeze-thaw resistance. It is imperative that the design detail of pervious concrete pavement ensures that water flow around the project site is adequately diverted so as to preclude and minimize clogging of the pervious concrete layer. Some amount of clogging is not expected to affect the freeze-thaw resistance very much. Maintenance of pervious concrete to periodically flush or vacuum clogged sections may be necessary in some cases and is generally recommended.

2. In certain areas of the country (Midwest and Northeast) the average daily temperature (average of minimum and maximum daily temperatures) stays below freezing point for a long period during the year. For example, in Minneapolis, MN, the average daily temperature stays below freezing from mid-November to mid-March. Precipitation during winter months will permeate pervious concrete pavements and underlying drain courses and may cause it to reach a saturation level.

3. When the ground water table comes up to less than three feet from the top of the surface or if there is substantial moisture flow from higher ground it may possibly saturate the pervious concrete.

Recommendations

Dry Freeze and Hard Dry Freeze
Dry freeze are areas of the country that undergo a number of freeze-thaw cycles (15+) annually but there is little precipitation during the winter. If the ground stays frozen as a result of a long continuous period of average daily temperatures below freezing, then the area is referred to as hard dry freeze area. Since pervious concrete is unlikely to be fully saturated in this environment, no special precaution is necessary for successful performance of pervious concrete. However, a 4– to 8–in. thick layer of clean aggregate base below the pervious concrete is recommended as an additional storage for the water. Many parts of the Western USA at higher elevations come under this category.

Wet Freeze
This includes areas of the country that undergo a number of freeze-thaw cycles annually (15+) and there is precipitation during the winter. Since the ground does not stay frozen for long periods it is unlikely that the pervious concrete will be fully saturated. No special precaution is necessary for successful performance of pervious concrete but a 4 to 8-in. thick layer of clean aggregate base below the pervious concrete is recommended. Many parts of the middle part of the Eastern United States come under this category.

Hard Wet Freeze
Certain wet freeze areas where the ground stays frozen as a result of a long continuous period of average daily temperatures below freezing are referred to as hard wet freeze areas. These

areas may have situations where the pervious concrete becomes fully saturated. The following precautions are recommended to enhance the freeze-thaw resistance of pervious concrete: 1. Use an 8- to 24-in. thick layer of clean aggregate base below the pervious concrete; 2. Attempt to protect the paste by incorporating air-entraining admixture in the pervious mixture; 3. Place a perforated PVC pipe in the aggregate base to capture all the water and let it drain. Not every situation warrants all the 3 safeguards. The safeguards are organized in the order of preference.

For example, a pervious concrete sidewalk at Pennsylvania State University in State College, PA, which is a hard wet freeze area, has shown good performance over five winters while it has only an 8–in. thick layer of aggregate base underneath the pervious concrete.

High Ground Water Table

Pervious concrete is not recommended in freeze-thaw environments where the ground water table rises to a level less than three-feet from the top of the surface or where substantial moisture can flow from higher ground.

Summary

There have been several pervious concrete pavement projects in dry and wet freeze areas demonstrating good field performance over several years. Recommendations for successful performance of pervious concrete pavements under the various freeze-thaw conditions have been provided. There is limited experience of performance of pervious concrete pavements in hard wet freeze areas. Therefore, in such areas utmost care must be taken. Pervious pavements should be placed by an experienced installer and the pavement structure and surrounding details should be designed to accommodate the anticipated water flow and drainage requirements.

Send any suggestions or corrections to NRMCA, 900 Spring Street, Silver Spring, MD 20910, USA. Attn: Pervious Concrete

Projects in Freeze Thaw Conditions

Name	Application	Year	Location	Freeze Thaw Information
Western Carolina Retinal Associates	parking lot	2002	Asheville, NC	Wet freeze, 90 cycles/year
Penn State/ Centre County Visitor Center	sidewalk (heavily used)	1999	State College, PA	Hard wet freeze, 120 cycles/year, average below freezing for 90 days
Athens Regional Park	walking path and a parking area	2003	Athens, TN	Wet freeze, 90 cycles/year
Finley Stadium	parking lot extension	1997	Chattanooga, TN	Wet freeze, 50 cycles/year
University of North Carolina Estes Drive Commuter Lot and Friday Center Commuter Lot	parking lot	2002	Chapel Hill, NC	Wet freeze, 90 cycles/year
Kozeliski's Law Office, now DePauli engineering	parking lot	1991	Gallup, NM	Hard dry freeze, 210 cycles/year, average below freezing for 60 days
Milligan's Drive Way	driveway	1993	Gallup, NM	Hard dry freeze, 210 cycles/year, average below freezing for 60 days
Residential home	alley and side Yard.	1994	Gallup, NM	Hard dry freeze, 210 cycles/year, average below freezing for 60 days
Hennessy Porsche	parking lot	2003	Roswell, GA	Wet freeze, 50 cycles/year
Brashers Auto Auction	parking lot (~15 acres)	1985	Salt Lake City, UT	Wet freeze, 90 cycles/year

Project Name:	Western Carolina Retinal Associates
Engineer:	McGill Associates
Contractor:	Petrus UTR, Savannah, Georgia (Subcontractor)
Ready Mixed Concrete Supplier:	Asheville Concrete
Project Location	Regional Medical Park, Asheville, NC
Year Completed:	2002

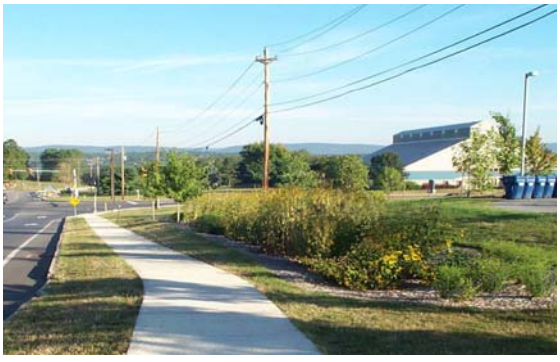
The project is a 22,000 sf parking lot for a busy medical practice. The pervious concrete is 6" thick placed over 4"-7" of #57 stone. The location undergoes an average of about 90 cycles/year. However, the climate is not a hard freeze, as the average daily temperature does not drop below freezing point very often. There is precipitation during winter so the location is considered a wet freeze. The pavement is vacuumed quarterly, no pressure washing. The current performance is good. Mix design details were 2,445 lbs. #87 stone-washed gravel, 611 lbs. portland cement, 20+/- gal. water, 6 oz. retarder, 4% air entrainment, 12-15% voids using ASTM C140. The subgrade is sandy/clay with a slow, but passable infiltration rate. There are no truck loads on the parking lot.

Contact: G. Carroll Hughes

Project Name:	Penn State/ Centre County Visitor Center
Engineer:	Cahill Associates, Inc.
Contractor:	
Ready Mixed Concrete Supplier:	
Project Location	State College, PA
Year Completed:	1999

The project is a heavily used sidewalk approximately 300 feet long. There is very heavy foot traffic as it is next to a football stadium. The pervious concrete is 4" thick with an 8" large, clean-washed aggregate base on un-compacted sub grade. The location undergoes an average of about 121 cycles/year. The average daily temperature stays below freezing for 90 consecutive days (on average) and there is winter precipitation. So the climate is considered as a hard wet freeze. There is very little maintenance. The current performance is good. Mix design is based on Florida concrete association w/ cold weather additive.

Contact: Andrew Potts, Cahill



Project Name:	Athens Regional Park
Engineer:	Lentz & Associates, Nashville, TN
Contractor:	East Tennessee Construction, Athens, TN
Ready Mixed Concrete Supplier:	Cleveland Ready Mix, Cleveland, TN
Project Location	Athens, TN
Year Completed:	2003

The project involves a walking path and a parking area. The walking path has 5" of pervious concrete over a 5" stone base, on top of underlying clay soil. The parking area has 6" of pervious concrete over a 5" stone base; it includes some drainpipes. There are about 1200-1300 cubic yards in the parking area, while the walking path is 1/3 mile long. The location undergoes an average of about 90 cycles/year. However, the climate is not a hard freeze, as the average daily temperature does not drop below freezing point very often. There is precipitation during winter so the location is considered as a wet freeze. There was some vacuum sweeping after a heavy rainstorm deposited mud on the pathway. The current performance is good and there is no clogging or raveling.

Contact: Frank Lennox

Project Name:	Finley Stadium
Engineer:	Betz Engineering, Chattanooga, TN
Contractor:	Kitsmiller Paving, Chattanooga, TN
Ready Mixed Concrete Supplier:	Vulcan Materials
Project Location	Chattanooga, TN
Year Completed:	1997

This project is a municipal parking in which the pervious concrete was placed adjacent to conventional pavement to extend an existing parking area. The lot is in daily use, with occasional weekend use for football games and special events. The pervious concrete is 4" thick and has a total volume of 2,000 cubic yards. It was placed over a #57 gravel base, which had a perforated PVC pipe in the subgrade to capture all water and divert to storage and use in watering the football field. The gravel base was placed over a geo-textile fabric, which rested on top of dirt. The location undergoes on an average about 50 cycles/year. However, the climate is not a hard freeze, as the average daily temperature does not drop below the freezing point very often. There is precipitation during winter so the location is considered a wet freeze. There is no annual maintenance and the current performance is good with minimal if any clogging, minimal raveling. The pavement is still sound and in good condition. The mix design involved 400 lbs of cement, 2700 lbs of #67 stone and a w/cm of 0.43 with a retarder of 28 oz/yd3.

Contact: Frank Lennox

Project Name:	University of North Carolina Estes Drive Commuter Lot and Friday Center Commuter Lot
Engineer:	Cahill Associates, Inc.
Contractor:	Barnhill and CC Mangum
Ready Mixed Concrete Supplier:	Ready Mixed Concrete Company
Project Location	UNC, Chapel Hill, NC
Year Completed:	2002

This project is a heavily used commuter parking lot – 150 spaces @ Friday Ctr. and 75 spaces @ Estes. The pervious concrete is 5" thick, over an 18" large, clean-washed aggregate base on un-compacted sub grade. The project involved 1,500 cubic yards of pervious concrete and won the American Council of Engineering Companies (ACEC) – Grand Conceptor Award. The location undergoes on an average about 90 cycles/year. However, the climate is not a hard freeze, as the average daily temperature does not drop below freezing point very often. There is precipitation during winter so the location is considered as a wet freeze. There is very little maintenance. After two winters of above average freeze thaw cycles, the current performance is good. The mixture design is proprietary.

Contact: Godwin, RMC or Andy, Cahill

Project Name:	Kozeliski's Law Office, now DePauli engineering First project of pervious in Gallup
Engineer:	Frank A. Kozeliski, P.E.,F.A.C.I.
Contractor:	Ray Armendariz's first project, under the direction of Frank and George Kozeliski
Ready Mixed Concrete Supplier:	Gallup Sand and Gravel Co. Gallup, New Mexico
Project Location	102 West Hill Ave. Gallup, New Mexico N 35 – 31.560 W 108-44.465 elevation 6503 ±`
Year Completed:	July, 1991

The project is a parking lot for a small company. The lot is about 600 sq. yards and the traffic is pickups, SUVs and cars (all four-wheelers). The material was placed 4" to 6" thick and leveled with a regular garden rake. No drainpipes or curbs and gutters. It was compacted with a walk-behind flat plate compactor. The material was cheaper than concrete but more expensive than gravel base. The location undergoes an average of about 212 cycles/year. The average daily temperature stays below freezing for 62 consecutive days (on average) but there is very little precipitation during this period and only about 10 inches of rain throughout the year. So the climate is considered a hard dry freeze with very high freeze thaw cycling. There is no annual maintenance on this project and, after 13 years, the performance has been good. Over the past 13 years the parking lot has filled with mud that drops off the vehicles when parked. Two years ago, after a 4" rain caused flooding of the town, the parking lot had no ponded water. There are still voids to drain the water. There is some raveling of the coarse aggregate and clogging due to the mud. The parking lot has been through many snows and it has not turned into a pile of loose rock. When it was a new parking lot, the snow was pushed off and the sun came out and there was no ice build up on surface. The snow tends to melt quickly. Mixture design was cement = 300 lbs / cu.yd; coarse aggregate # 57 – 1 " minus size 2570 lbs / cu.yd; water about 20 gals / cu.yd. Plastic unit was about 106 pcf, no entrained air or water reducer or fly ash. % void based on ASTM C-138 20 to 24 %. When filling a 4"x8" cylinder with pervious and then adding water 2" of water can be placed into the cylinder. And it

will fill the voids. Compressive strength after 28 days about 1000 psi. No special curing of the pervious. Just placed and opened for traffic.

Project Name:	Milligan's Driveway.
Engineer:	Frank A. Kozeliski, P.E.,F.A.C.I.
Contractor:	John Milligan and Family's Project, under the direction of Frank Kozeliski
Ready Mixed Concrete Supplier:	Gallup Sand and Gravel Co. Gallup, New Mexico
Project Location	1326 Country Club Drive. Gallup, New Mexico
(City, State):	N 35Degrees – 31.051' W 108D-43.780' elevation 6560 ±`
Year Completed:	October, 1993

The pervious concrete was placed as a driveway surface to keep a rustic look. The driveway is about 400 feet long and 10' wide. The traffic is pickups, SUVs, and cars (all four-wheelers), which have traveled up and down the hill every day for 11 years. The material was placed 4' to 6" thick and leveled with a regular garden rake. It was compacted with a walk-behind flat plate compactor. There are no drainpipes or curbs and gutters. The location undergoes an average of about 212 cycles/year. The average daily temperature stays below freezing for 62 consecutive days (on average) but there is very little precipitation during this period and only about 10 inches of rain throughout the year. So the climate is considered a hard dry freeze with very high freeze thaw cycling. There is no annual maintenance on this project and, after 11 years, the performance has been good. There is loose rock on the edge and some clogging where rai has caused soil to run onto the pervious. We placed a yellow color in the pervious when installed but it is not there now. The owner has a science background and is pleased with the results. The neighbors have placed base gravel twice and it continues to go down into the mud. The material was cheaper than concrete but more expensive than gravel base. Mixture design was cement = 300 lbs / cu.yd; coarse aggregate # 57 – 1" minus size 2570 lbs / cu.yd; water about 20 gals / cu.yd. Plastic unit was about 106 pcf, no entrained air or water reducer or fly ash. % void based on ASTM C-138 20 to 24 % . When filling a 4"x8" cylinder with pervious and then adding water 2" of water, can be placed into the cylinder. And it will fill the voids. Compressive strength after 28 days about 1000 psi. No special curing of the pervious. Just placed and opened for traffic.

The pervious fell apart on an incline of 10% where it was about 2” thick and cars and trucks would spin going up the hill.

Project Name:	Residential Home, George Kozeliski's Alley and Side Yard
Engineer:	Frank A. Kozeliski, P.E.,F.A.C.I.
Contractor:	Gallup Fence's first project, under the direction of George Kozeliski
Ready Mixed Concrete Supplier:	Gallup Sand and Gravel Co. Gallup, New Mexico
Project Location	1105 Ridgecrest Drive Gallup, New Mexico N 35 Degrees – 31.141 W 108-43.367 elevation 6514 ±`
Year Completed:	July, 1994

The pervious concrete is about 400 sq. yards. The traffic is a garage truck pickup, an SUV and a dog (all four-wheelers). The material was placed 4" to 6" thick and leveled with a regular garden rake. It was compacted with a walk-behind flat plate compactor. No drainpipes or curbs and gutters. The location undergoes an average of about 212 cycles/year. The average daily temperature stays below freezing for 62 consecutive days (on average) but there is very little precipitation during this period and only about 10 inches of rain throughout the year. So the climate is considered a hard dry freeze with very high freeze thaw cycling. There is no annual maintenance on this project and, after 10 years, the performance has been good. There is more ground cover to keep the mud down and vehicles park but do not fall into the mud. Part of the pavement is on a hill and it slid some. There is one crack that we have noted. The pervious lot has been through many snows and it has not turned in to a pile of loose rock. Mixture design was cement = 300 lbs / cu.yd; coarse aggregate # 57 – 1" minus size 2570 lbs / cu.yd; water about 20 gals / cu.yd; plastic unit we about 106 pcf. No entrained air or water reducer or fly ash. % void based on ASTM C-138 20 to 24 % . When filling a 4"x8" cylinder with pervious and then adding water, 2" of water can be placed into the cylinder. And it will fill the voids. Compressive strength after 28 days about 1000 psi. No special curing of the pervious. Just placed and opened for traffic.

Project Name:	Hennessy Porsche
Engineer:	Steven L. Rowe, ASLA
Contractor:	PCI Systems, LLC
Ready Mixed Concrete Supplier:	Fulton Concrete
Project Location	Roswell, Georgia
Year Completed:	2003

The pervious concrete project is a Porsche dealership parking lot with a total area of 12,000 square feet. It involves 5" thick pervious concrete over 4" thick layer of #57 stone over geotextile. Curb and gutter with flush curb separating asphalt. The parking lot is in good condition and there is no annual maintenance. The location undergoes an average of about 50 cycles/year. However, the climate is not a hard freeze, as the average daily temperature does not drop below the freezing point very often. There is precipitation during winter so the location is considered as a wet freeze. There is no annual maintenance and the parking lot is in good condition. The concrete mixture design is 89 stone, no air, and 119 lb per CF.