

STORMWATER SYSTEM MANAGEMENT

BEST PRACTICES MANUAL



NPCC

Precast ... The Concrete Solution

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NPCA Stormwater Management Product Committee

This Best Practice Manual (BPM) is subject to revision at any time by the NPCA Stormwater Management Product Committee. This BPM is reviewed at least every three years. NPCA would like to thank members of the Stormwater Management Product Committee for their work in preparing this document.

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NOTES AND ACKNOWLEDGEMENTS

This manual does not claim or imply that it addresses all safety-related issues, if any, associated with its use. Manufacture of concrete products may involve the use of hazardous materials, operations and equipment. It is the user's responsibility to determine appropriate safety, health and environmental practices and applicable regulatory requirements associated with the use of this manual and the manufacture of concrete products.

Use of this manual does not guarantee the proper function or performance of any product manufactured in accordance with the requirements contained in the manual. Routine conformance to the requirements of this manual should result in products of an acceptable quality according to current industry standards.

WARNING: Lack of proper maintenance can result in poor performance of any wastewater system.

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INTRODUCTION

Stormwater structures are an important part of the manufactured concrete products industry, and every effort must be made to provide project owners and end users with the best possible products at competitive prices.

This manual is intended to guide manufacturers in quality production processes for manufacturing precast concrete stormwater structures. The manual is not intended to be all-inclusive and the recommendations are not intended to exclude any materials or techniques that would help achieve the goal of providing structurally sound, high-quality products. Attention to detail, quality materials, proper training and a workforce dedicated to safety and quality control will ensure that stormwater structures meet or exceed the expectations of engineers, contractors and end users.

Summary of Precast Concrete Benefits

Precast concrete is the ideal solution for stormwater management. Stormwater management systems must withstand some of the most powerful forces of nature, including high volumes of rushing water, extreme loading conditions and corrosive agents. A properly manufactured and installed precast concrete structure or system can last almost indefinitely. Precast concrete is inherently strong and durable, highly impermeable, corrosion-resistant and noncombustible.

Precast concrete is also a solid choice for underground

stormwater detention and retention. Precast concrete underground storage systems have many advantages over plastic and fiberglass alternatives. Stronger and more durable than other options, precast concrete actually gains compressive strength over time. Made of all-natural materials, concrete won't adversely affect water quality, an important consideration as environmental laws grow more stringent.

The precast concrete industry has responded to the Clean Water Act regulations by developing environmentally responsible products to control stormwater pollution, as well as precast systems used for erosion control, stormwater treatment, detention/retention, infiltration and bank stabilization.

Precast concrete products save time and on-site labor costs because they are delivered to the job site ready to install. Installation of precast concrete products is common practice in the construction industry. Precast products are readily available from thousands of manufacturers throughout North America.

Precast concrete ensures first-rate performance and quality that can be trusted. Precast is produced in a manufacturing environment that provides superior consistency, controlled conditions and quality control. Precast manufacturers can routinely achieve lower water-to-cement ratios, and therefore greater structural strength, than cast-in-place concrete



systems. And while other materials can deteriorate and lose strength over time, the strength of precast concrete gradually increases. The load-carrying capacity of precast concrete is derived from its own structural quality, not from adjacent soil or backfill.

Beside water, concrete is the most frequently used material on earth. Made of all-natural materials, it's safe for the environment. Modern cities around the world use precast

concrete stormwater management systems because concrete doesn't harm water quality or release pollutants into the potable water supply. Concrete can be recycled and can incorporate recycled materials in its production.

There is a growing demand for projects that incorporate green technology and are sustainable; precast concrete offers proven solutions for LEED certification (Leadership in Energy and Environmental Design, U.S. Green Building Council).

STRUCTURAL DESIGN

Precast concrete structures are built according to rigid standards adopted by nationally accredited organizations such as ASTM and ACI. The as-built structural integrity of precast concrete makes it capable of supporting heavy loads without relying on additional support from the soil envelope or compacted backfill. Other wastewater system materials may depend on supporting soils for installed load-bearing capacity.

Loading Conditions

A properly designed precast concrete stormwater structure must withstand a wide range of different loading conditions that vary considerably during manufacturing, installation, testing, and service.

Precast concrete structures are designed to withstand loading conditions determined by rational mathematical

design calculations and in accordance with ASTM C890, "Standard Practice for Minimum Structural Design Loading for Monolithic or Sectional Precast Concrete Water and Wastewater Structures."

The following forces must be considered in the proper design of any stormwater system:

- Surface surcharge loads
- Concentrated wheel and other heavy traffic loads
- Lateral loads (soil and groundwater)
- Presumptive soil bearing capacity
- Buoyancy forces
- Connection and penetration effects
- Point loads
- Seismic loads



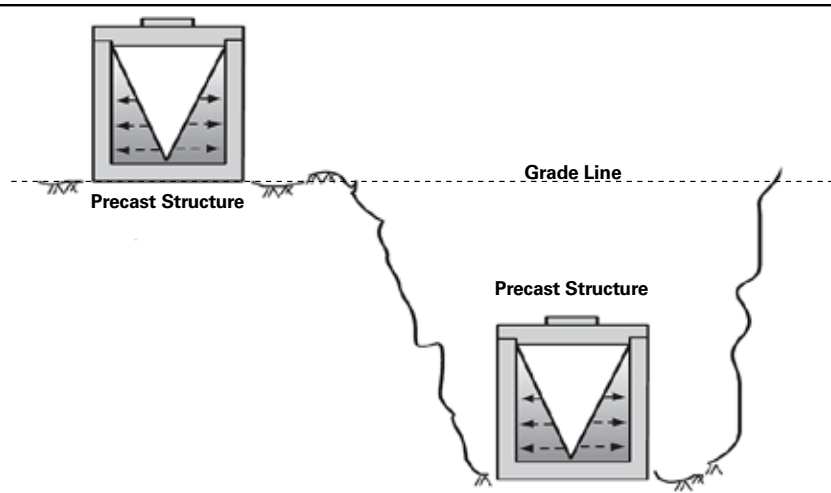
Precast concrete stormwater structures should be designed in compliance with one or more of the following applicable industry specifications, codes or standards, and as required by any regulatory entities having local jurisdiction:

- ASTM C361, "Standard Specification for Reinforced Concrete Low-Head Pressure Pipe"
- ASTM C443, "Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets"
- ASTM C478, "Standard Specification for Precast Reinforced Concrete Manhole Sections"
- ASTM C890, "Practice for Minimum Structural Design Loading for Monolithic or Sectional Precast Concrete Water and Wastewater Structures"
- ASTM C913, "Specification for Precast Concrete Water and Wastewater Structures"
- ASTM C923, "Standard Specification for Resilient Connectors Between Reinforced Concrete Manhole Structures, Pipes, and Laterals"
- ASTM C990, "Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants"
- ASTM C1433, "Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers"
- ASTM C1478, "Standard Specification for Storm Drain Resilient Connectors Between Reinforced Concrete Storm Sewer Structures, Pipes and Laterals"
- ASTM C1619, "Standard Specification for Elastomeric Seals for Joining Concrete Structures"
- ASTM C1677, "Standard Specification for Joints for Concrete Box, Using Rubber Gaskets"
- ACI 318, "Building Code Requirements for Structural Concrete and Commentary"
- IAPMO
- ANSI
- AWS
- CSA

The loading conditions illustrated in the diagrams should be analyzed and considered in the design of a stormwater structure.

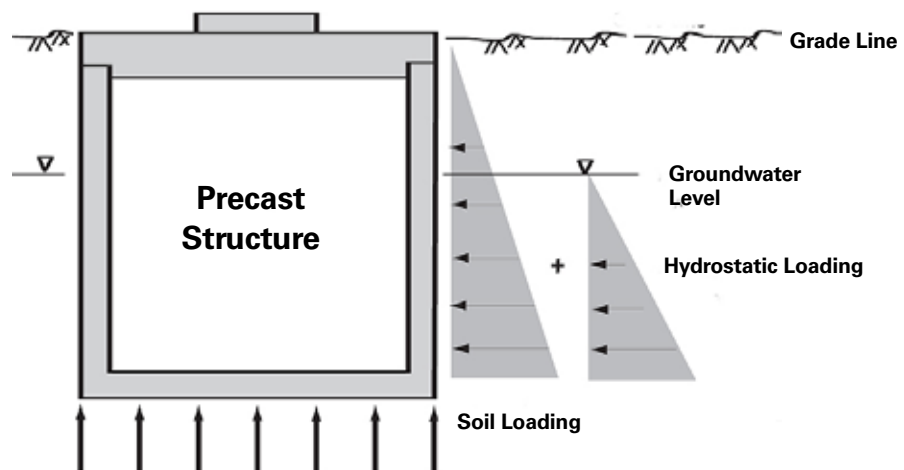
Internal Hydrostatic Loading

Structure Full
(on grade or
without backfill)



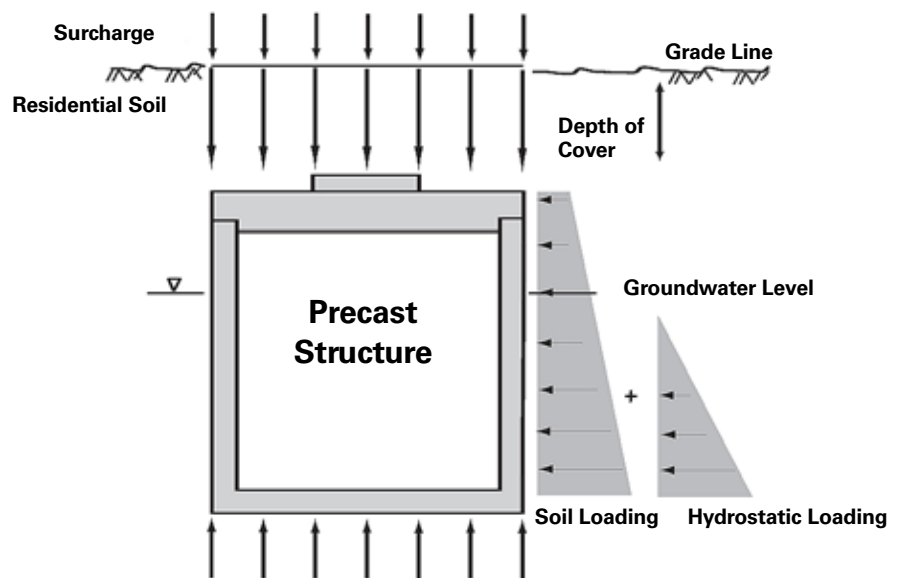
External Soil and Water Loading

Structure Empty



Optional Loading Where Appropriate

Manufacturer to specify
the maximum depth of
cover





The following design characteristics have a critical impact on the performance of stormwater structures:

Concrete Thickness

The concrete thickness must be sufficient to meet minimum reinforcement cover requirements and withstand design-loading conditions based on applicable industry specifications, codes or standards.

Concrete Mix Design

Concrete must have a minimum compressive strength of 4,000 psi at 28 days, according to the NPCA Quality Control Manual for Precast and Prestressed Plants. Consider mix design materials and methods to reduce concrete permeability, improve durability and increase strength. Maintain a low water-to-cementitious ratio ($w/c \leq 0.45$) (0.45

for freeze-thaw conditions; 0.48 for water-tight conditions, based on NPCA QC Manual standards.

Reinforcement

Proper design and placement are critical to withstand the significant loads applied to stormwater structures. Reinforcement must be adequate for required strength and service conditions, including temperature and shrinkage effects.

Any combination of steel bars, welded-wire and fiber that meet product specifications may be used as reinforcement, but careful attention should be paid to reinforcing design, location and specified concrete cover. Reinforcement placement inspection records (prior to casting) should be maintained in plant files. All reinforcement should meet applicable ASTM International specifications.

MATERIALS

The primary constituents of precast concrete, in addition to specified reinforcement, are cement, fine and coarse aggregates, water and admixtures. The following discussion covers relevant factors in the selection and use of these fundamental materials.

Cement

The majority of cement used in the manufactured concrete products industry is governed by ASTM C150, "Standard

Specification for Portland Cement," and ASTM C1157, "Standard Performance Specification for Hydraulic Cement."

ASTM C150 specifies eight different types of portland cements that are manufactured to meet the various normal chemical and physical requirements. The five types of portland cement typically used in the manufactured concrete products industry, as stated by ASTM C150, are:



- **Type I** Normal
- **Type II** Moderate Sulfate Resistant
- **Type III** High Early Strength
- **Type IV** Low Heat of Hydration
- **Type V** High Sulfate Resistance

Or as described in CSA A3000, the types of cement are:

- **Type GU** General Use Hydraulic Cement
- **Type MS** Moderate Sulfate-Resistant Hydraulic Cement
- **Type MH** Moderate Heat of Hydration Hydraulic Cement
- **Type HE** High Early-Strength Hydraulic Cement
- **Type LH** Low Heat of Hydration Hydraulic Cement
- **Type HS** High Sulfate-Resistant Hydraulic Cement

Cement type should be selected based on project specifications or individual characteristics that best fit the operation and regional conditions of each manufacturer. Note that specific types of cement may not be readily available in certain regions. For example, Type I Normal portland cement is a general-purpose cement used when the cement type is not specified; Type I cement is readily available. Type II Moderate Sulfate Resistant portland cement is typically used in regions where there is potential for moderate sulfate attack.

Type I and Type II portland cement make up nearly 90% of all portland cement produced. Type III High Early Strength portland cement is available in most large metropolitan areas. Type IV Low Heat of Hydration portland cement is typically manufactured only when required for massive concrete

projects (dams, piles, hydro projects), and therefore it is not as readily available. Type V High Sulfate Resistance portland cement is made available only in regions where there is potential for severe sulfate attack.

It is essential to store cement in a manner that will prevent exposure to moisture or other contamination. Bulk cement should be stored in watertight bins, silos or in other watertight storage facilities. If different types of cement are used at a facility, store each type in a separate bin or silo and clearly identify delivery locations.

On a short-term basis (less than 90 days), stack cement bags no more than 14 high or as prescribed by OSHA for worker safety. For long-term storage, do not exceed seven bags in height (or per the manufacturer's recommendations).

Design and maintain the cement bin and silo compartments so that they can discharge freely and independently into the weighing hopper. Cement in storage should be drawn down frequently to prevent undesirable caking. Use the oldest stock first. Discard any cement with lumps that cannot be reduced by finger pressure.



Aggregates

Using the correct type and quality of aggregates is essential in proper mix design as aggregates (fine and coarse) typically occupy 60 to 70% of the total concrete volume.

The NPCA “Quality Control Manual for Precast and Prestressed Concrete Plants” requires that any aggregates used in the concrete mix design conform to ASTM C33, “Standard Specification for Concrete Aggregates.”

It is also required that the proper personnel periodically evaluate the aggregates and maintain documentation at the plant for historical records as well as to check for permissible amounts of deleterious substances. Aggregate evaluation should include a check for potential deleterious expansion due to alkali reactivity, unless the aggregates come from a state DOT-approved source.

There are numerous reasons for specifying a nominal maximum aggregate size. Specifying a maximum aggregate size is desirable because size will affect cement proportions, durability, economy, porosity, pumpability, water proportions and the workability of the concrete mix (fresh and hardened state).

When determining the maximum size of the coarse aggregate, the maximum size should be as large as practical, but should not exceed 20% of the minimum thickness of the precast concrete element or 75% of the clear cover between reinforcement and the concrete surface. Larger maximum sizes of aggregate may be used if evidence shows that

satisfactory concrete products can be produced with larger stone.

Quality of Aggregates

It is important to specify a well-graded, sound, nonporous aggregate in accordance with ASTM C33. If quality of the aggregates does not meet specifications, the structural integrity of the entire precast concrete structure can be compromised.

Gradation of Aggregates

Aggregate gradation influences both the economy and strength of a finished precast concrete stormwater structure. The purpose of proper gradation is to produce concrete with a maximum density along with good workability to achieve sufficient strength.

Well-graded aggregates help improve workability, durability and strength of the concrete. Poorly graded or gap-graded aggregates rely on the use of excess cement mortar to fill voids between coarse aggregates, leading to potential durability problems.

Concrete mixes containing rounded coarse aggregates tend to be easier to place and consolidate. However, crushed aggregates clearly are acceptable. The use of elongated, flat and flaky aggregates is discouraged. Gap-graded aggregates lacking intermediate sizes are also discouraged.

Experience has shown that an excess of very fine or very

coarse sand/aggregates with significant intermediate-sized aggregate deficiencies is undesirable. Sand gradation should be uniform and have a fineness modulus in the range between 2.3 and 3.1. A variation in base fineness modulus greater than 0.2 may require a mix-design adjustment, as suggested in ASTM C33.

Aggregate Deleterious Substances

It is important to ensure all aggregates are free of deleterious substances. Deleterious substances are potentially harmful if they: react chemically with portland cement; interfere with the hydration process; or significantly change the volume of the aggregates, paste or both.

Deleterious substances include:

- Substances that cause an adverse chemical reaction in fresh or hardened concrete
- Clay, dust and other surface-coating contaminants
- Structurally soft or weak particles
- Coal, iron oxide, lignite, organic impurities, shale or silt

For good bond development between the cement paste and aggregates, ensure that aggregate surfaces are clean and free from excessive dust or clay particles. Excessive dust or clay particles typically are defined as material passing a #200 sieve, the limit of which should not exceed 3%. Friable aggregates may fracture in the mixing and placement process and thereby compromise the integrity of the hardened concrete product.

Moisture Content of Aggregate

The measurement of aggregate moisture content is important in the control of concrete workability, strength and quality. Fine aggregates (sands) can collect considerable amounts of moisture on their surfaces. Fine aggregates can hold up to 10% moisture by weight; coarse aggregates can hold up to 3% moisture by weight.

Water on the surface of an aggregate that is not accounted for in the mixture proportions will increase the water-to-cementitious ratio (w/c). The moisture content of aggregates will vary throughout a given stockpile and will be affected by changes in weather conditions.

Therefore, adjust mixture proportions as necessary throughout the production day to compensate for moisture content changes in the aggregate. Also, excessively dry aggregates can increase water demand by absorbing mix water during batching and placement. If the total water content in the mix design is inconsistent, the w/c will vary from batch to batch, causing variation in the workability and compressive strength.

The following methods will increase the likelihood of uniform aggregate moisture content:

- Enclosed storage of daily production quantities
- Store aggregates in horizontal layers
- Maintain at least two stockpiles
- Allow aggregate piles to drain before use
- Avoid the use of the bottom 12 in. of a stockpile
- Store entire stockpile indoors or under cover

Careful monitoring of aggregate moisture content during batching will reduce the need for additional cement to offset excess water in the mix; this practice will maintain high quality standards and save on expensive raw materials. The plant should have a program in place that manages aggregate surface-moisture content or accounts for moisture variation during batching.

Handling and Storage of Aggregate

Handle and store aggregates in a way that: prevents contamination (including cross-contamination between adjacent aggregate stock); minimizes segregation and degradation; and keeps gradations within specified limits. Aggregate handling is an important operation. Accurately graded coarse aggregates can segregate during a single improper stockpiling operation. Therefore, it is important to minimize unnecessary aggregate handling to reduce the risk of particle size segregation.

Minimize the number of handling operations and the material-drop heights to avoid product breakage.

The following methods can prevent aggregate segregation:

- Store aggregates on a clean, hard, well-drained base to prevent contamination. Bin separation walls should extend high enough to prevent overlapping and cross-contamination of different-sized aggregates.
- Avoid steep slopes (conical piles) in fine aggregate stockpiles. Fine aggregate stockpiles should not have slopes greater than the sand's angle of repose (natural slope, typically 1:1.5) to prevent unwanted segregation.
- Remove aggregates from a stockpile by working horizontally across the face of the pile. If possible, avoid taking aggregate from the exact same location each time.

Organic matter accumulation (especially leaves and twigs) or plant growth should be avoided in or around stockpiles in order to keep aggregates contamination-free.

Water

Water used in mixing concrete should be potable and meet the requirements of ASTM C 1602, "Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete." Avoid water containing deleterious amounts of oils, acids, alkalis, salts, organic material or other substances that may adversely affect the properties of fresh or hardened concrete.

Excessive deleterious impurities can adversely affect the concrete strength and setting time, and cause corrosion in reinforcement; water impurities can also cause staining, volume instability, efflorescence and reduced durability.

Chemical Admixtures

Chemical admixtures are ingredients other than water, portland cement and aggregates that are added to the concrete mix (before or during mixing) to help improve/modify the properties of fresh or hardened concrete. Admixtures are used to: improve concrete workability; entrain air; retard or accelerate set time; reduce permeability; reduce steel corrosion; and add integral color.

Commonly used chemical admixtures in precast manufacturing include:

- Accelerating admixtures (ASTM C494, "Specification for Chemical Admixtures for Concrete")
- Air-entrainment admixtures (ASTM C260, "Specification for Air-Entraining Admixtures for Concrete")
- Water-reducing admixtures (ASTM C494, "Specification for Chemical Admixtures for Concrete")
- High-range water-reducing admixtures or superplasticizers (ASTM C494, "Standard Specification for Chemical Admixtures for Concrete" and ASTM C1017, "Chemical Admixtures for Use in Producing Flowing Concrete")
- Specialty Admixtures such as corrosion inhibitors, shrinkage reducers and rheology modifiers (specific language is currently under development and review by ASTM C494, "Standard Specification for Chemical Admixtures for Concrete")

It is important to store admixtures in a manner that avoids contamination, evaporation and damage. Protect liquid admixtures from freezing and extreme temperature changes that could adversely affect their performance. Be sure to follow the manufacturer's storage recommendations if unsure of the proper storage procedure or if there are special storage procedures for the admixture. For optimum performance, protect admixtures from dust and temperature extremes.

Ensure admixtures are accessible for visual observation and periodic maintenance. Perform periodic recalibration of the batching system as recommended by the admixture manufacturer or as required by local regulations.

Chemical admixture performance can vary from manufacturer to manufacturer; exercise caution, especially when using new products. Conduct trial batches and document the results before using a new admixture for production. Follow the manufacturer's recommendations. Carefully check admixtures for compatibility with the cement and any other admixtures used. Do not mix similar admixtures from different manufacturers without the manufacturer's agreement or testing to verify performance compatibility.

Additional guidelines for the use of admixtures are included in ACI 212.3, "Guide for Use of Admixtures in Concrete."

Avoid accelerating admixtures that contain chlorides in order to prevent possible corrosion of reinforcing steel elements and other embedded metal objects.



Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs) are industrial byproducts used as an addition to or as a partial replacement for portland cement. SCMs consist of pozzolans (calcined shale, calcined clay and metakaolin), Class F fly ash, silica fume and blast-furnace slag. Primarily, SCMs are used to improve workability, durability, strength and other properties



in the concrete's fresh and hardened state. The recycling of industrial byproducts, reinforcing steel and concrete make precast a sustainable choice for stormwater system construction.

SCMs have the following classifications:

Cementitious materials – Ground Granulated blast furnace slag (ASTM C989, "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars" and ASTM C595, "Standard Specification for Blended Hydraulic Cements")

Pozzolanic materials – Class F fly ash, silica fume, metakaolin (ASTM C618, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete" and ASTM C1240, "Standard Specification for Silica Fume Used in Cementitious Mixtures")

Pozzolanic and cementitious materials – Class C fly ashes (ASTM C618)

Or, as described in CSA A3000: **Natural Pozzolan N; Fly ash F, CI, CH; Silica Fume SF; Slag S**

SCMs have a varying impact on the amount of water and air entrainment admixture required. Some SCMs, particularly fly ash, silica fume and ground granulated blast-furnace slag, could lead to significant improvements in permeability and resistance to sulfate attack.

Ready-Mixed Concrete

It is the precaster's responsibility to ensure that the ready-mix supplier is conforming to ASTM C94, "Standard Specification for Ready-Mixed Concrete." Ready-mixed concrete is manufactured and delivered to a purchaser in a freshly mixed and unhardened state.

Concrete testing is needed to ensure that the concrete used in manufacturing is in compliance with ASTM C94. It is essential to perform plastic concrete tests (slump, temperature, air content and density) at the plant prior to casting products.

Test records are required to verify that materials used in manufacturing precast concrete products conform to product specifications. Ready-mixed concrete manufacturers should record any added water on the delivery batch ticket for each truck and keep records of same.

CONCRETE MIXTURE PROPORTIONING & TESTING

Mix designs are selected based upon several necessary factors including permeability, consistency, workability, strength and durability (ACI 211, “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete”). The elements necessary to achieve high-quality precast concrete include:

- Low water-to-cementitious ratio ($w/c \leq 0.45$)
- Minimum compressive strength of 4,000 psi at 28 days
- Use of good quality and properly graded aggregate
- Proper concrete consistency (concrete that can be placed readily by traditional methods)

Water-to-Cementitious Ratio

High water-to-cementitious ratios (w/c) yield undesirable increased capillary porosity within the concrete. Capillary pores are voids resulting from the consumption and evaporation of water during the hydration or curing process. Enlarged and interconnected capillary voids serve as pathways that allow water and other contaminants to either infiltrate or exfiltrate through the concrete. Lower w/c values result in smaller and fewer pores, reducing the permeability of the concrete. ACI 318, “Building Code Requirements for Structural Concrete,” requires a maximum w/c of 0.45 for any concrete exposed to freezing and thawing, moist conditions or deicing chemicals.

Consistency

Proper consistency of fresh concrete is a critical element in producing high-quality, watertight concrete. Fresh concrete must be sufficiently plastic to be properly placed, consolidated and finished. The size, shape and grading of aggregates, cement content, w/c and admixtures affect the workability of a mix. When calculating w/c , it is important to consider the free moisture in the aggregates.

Workability

Water-reducing admixtures and superplasticizers can greatly increase the workability of fresh concrete without increasing the water-cementitious ratio. Experience has shown that concrete with a low water-to-cementitious ratio ($w/c \leq 0.45$) can be properly placed and consolidated with the aid and proper use of admixtures. Concrete should be air-



entrained in accordance with ACI 318 and ASTM C260. In certain circumstances, and where local regulations allow, a properly designed and tested self-consolidating concrete (SCC) mix can reduce the necessary effort to achieve proper consolidation of the concrete.

Air-Entrainment

Air-entraining admixtures are designed to disperse microscopic air bubbles throughout the concrete's matrix to function as small “shock absorbers” during freeze-thaw cycles. The required air content for frost-resistant concrete is determined by the maximum aggregate size and severity of in-service exposure conditions (ACI 318). In addition, air entrainment improves the workability and reduces bleeding and segregation of fresh concrete while greatly improving the durability of hardened concrete.

Testing

Perform all recommended plastic concrete tests (slump, temperature, air content and density) at the precast plant prior to casting products.

LIFTING DEVICES

Lifting devices and apparatuses used in precast concrete products shall be verified for capacity and shall have an adequate Factor of Safety (FS) for lifting and handling products, taking into account the various forces acting on the device including: form release suction; impact loads; and various positions of the product during handling, transportation and installation. The capacity of commercial lifting apparatuses shall be marked on the devices or posted in production areas. Lifting apparatus such as slings, lift bars, chains and hooks shall be verified for capacity and shall have an OSHA-compliant FS for lifting and handling precast concrete products.



COATINGS

Quality concrete with a $w/c \leq 0.45$ and a compressive strength equal to or greater than 4,000 psi is sufficient for stormwater structures. Under normal conditions, there is no need for additional applications of coatings. However, a protective exterior coating may be specified when a soil analysis indicates a potential for chemical attack.



PRODUCTION PRACTICES

Quality Control

Maintaining and using an updated plant-specific quality control manual ensures that a precast manufacturing facility produces the highest quality products for service. All plants must have a plant-specific quality control program and a quality control manual, that includes, but is not limited to, the following:

- Documented mix designs
- Pre-pour inspection reports
- Form maintenance logs
- Post-pour inspection reports
- Plant quality control procedures
- Raw materials used (material specifications)
- Production practices and procedures
- Reinforcement fabrication, placement and inspection records
- Concrete testing records
- Storage and handling procedures

Records of the above-listed items should be available for review by appropriate agencies upon request. It is strongly recommended that daily reports be documented and maintained on file by the precast plant for a minimum of three years.

Participation in the NPCA Plant Certification Program (and future programs) is recommended as an excellent way to ensure product quality. Use the NPCA "Quality Control Manual for Precast Concrete Plants" as the basis for developing a strong quality control program.

Quality control personnel should be adequately trained. Certification in NPCA's "Production Quality School Level 1" is required. Also, quality control personnel performing plastic concrete testing must hold certification as an "ACI Concrete Field Testing Technician, Grade 1."

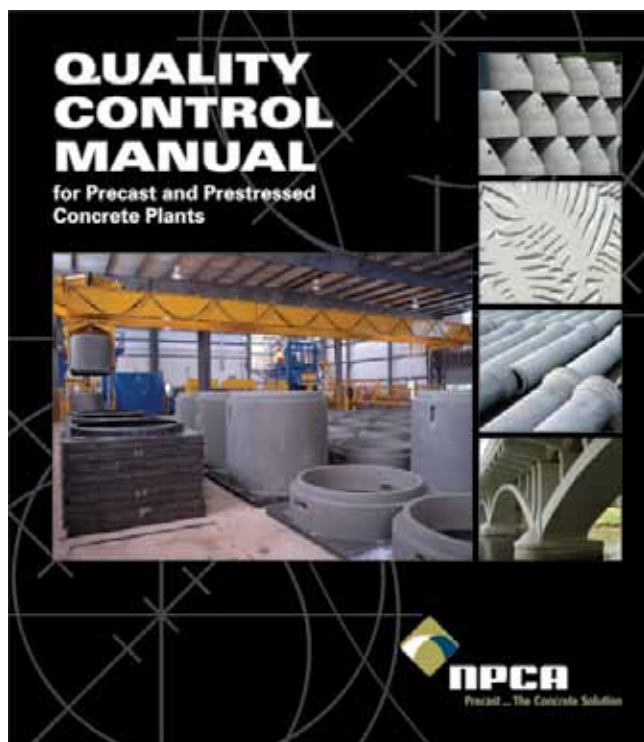
Forms

Forms for manufacturing precast concrete products shall be in good condition and of the type and design consistent with industry standards and practices. Forms should be capable of consistently providing uniform products and specified final dimensions.

Pre-Pour Operations

Conventional Reinforcement

Fabrication or specification drawings should provide reinforcing details, including size of reinforcing, placement,



spacing and minimum concrete cover.

Proper placement of reinforcing within the form is critical to the final strength and serviceability of the precast concrete product. The following specifications and standards apply to plain and deformed steel bars:

- Reinforcing Steel, Grade 60, deformed steel bars –ASTM A615, "Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement,"
- Reinforcing Steel, Low-Alloy – ASTM A706, "Standard Specification for Low-Alloy Steel Deformed Bars and Plain Bars for Concrete Reinforcement"
- Welded Steel Wire Fabric, Plain Type – ASTM A185, "Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete," If not stated, minimum bend diameters on reinforcement should meet the requirements set forth in ACI 318.
- If required, any coating for steel reinforcing bars or wires shall be specified by the Engineer-of-Record. Use of galvanizing or epoxy coating shall be at the option of the precaster.
- Weld reinforcement (including tack welding) shall be in accordance with AWS D1.4, "Structural Welding Code – Reinforcing Steel." The American Welding Society requires



either special preheat requirements (where applicable) or weldable-grade reinforcement as defined by ASTM A706 for any welding of reinforcing steel, including tack welds. Take special care while welding to avoid undercutting or burning through the reinforcing steel.

- Most conventional reinforcement (ASTM A615) produced today is made from recycled metals that have higher carbon contents and are more apt to become brittle if improperly welded. A brittle weld is a weak link, which can compromise the structural integrity of the finished product. ASTM A615 states: "Welding of material in this specification should be approached with caution since no specific provisions have been included to enhance the weldability. When the reinforcing steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used."
- Ensure lap splices for steel reinforcement (rebar and welded-wire reinforcement) meet the requirements of ACI 318. Adequate reinforcing bar development length is required to ensure specified design strength of the reinforcement at a critical section.
- Reinforcement steel should be free of loose rust, dirt and form-release agent. Cut, bend and splice reinforcing steel in accordance with fabrication drawings and applicable industry standards (CRSI and ACI). Inspect reinforcing cages for specified size, spacing, proper bends and development length.
- Secure the reinforcing cage in the form with an adequate number of chairs or supports so that rebar shifting will not occur during casting. It is important to place and hold

reinforcement in position as shown in the fabrication drawings.

Fiber Reinforcement

Data must be available to show conclusively that the type, brand, quality and quantity of fibers to be included in the concrete mix are not detrimental to the concrete or to the precast concrete product. Fiber-reinforced concrete must conform to ASTM C1116, "Standard Specification for Fiber-Reinforced Concrete and Shotcrete" (Type I or Type II). Fiber reinforcement may be used as secondary reinforcement in precast concrete stormwater systems.

Embedded Items

Embedded items such as plates, inserts, connectors and cast-in seals must be held rigidly in place during casting.

Pre-Pour Inspection Checklist

A typical pre-pour checklist, as illustrated on the next page, provides a means of documenting the required quality checks. A qualified individual should make inspections prior to each pour and correct any deviations prior to the start of placement activities. Pre-pour operations include:

- Cleaning, preparing and setting forms
- Positioning steel reinforcement according to structural design specifications
- Placing blockouts
- Positioning and securing embedded items

PRE-POUR INSPECTION REPORT

QUALITY CONTROL DEPARTMENT

PRODUCT							
Job #	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Casting Date							
Form Condition							
Form Cleanliness							
Form Joints							
Release Agent/Retarder							
Design Length (ft/in)							
Set-Up Length (ft/in)							
Design Width (ft/in)							
Set-Up Width (ft/in)							
Design Depth (ft/in)							
Set-Up Depth (ft/in)							
Blockouts							
Squareness							
End and Edge Details							
Reinforcing Steel							
Size of Reinforcing							
Spacing of Reinforcing							
Corrosion							
Reinf. Cleanliness							
Plates and Inserts							
Lifting Devices							
Top Finish (wet)							

* All applicable boxes should have a S=Satisfactory or
D=Deficiency

REMARKS: _____

QC Supervisor _____ Date _____ Inspector _____

CASTING CONCRETE

Transporting Concrete

When transporting concrete from mixer to form, use any method that does not contaminate the concrete, or cause delay in placing or segregation. One of the most preferred methods of pouring and placing concrete is discharging the concrete directly from the mixer into the forms. ACI 304R, "Guide for Measuring, Mixing, Transporting, and Placing," is a valuable reference.

Placing Concrete

Conventional Concrete

When placing any type of concrete it is important to keep the free fall of the concrete to a minimum and deposit the concrete as near to its final location as possible without objectionable segregation. Vibration equipment should not be used to move fresh concrete laterally in the forms; such practices result in segregation because mortar tends to flow faster than the more coarse aggregates.

Fiber Reinforced Concrete (FRC)

The same practices as described above for placing conventional concrete apply for placing FRC, but note that the workability of the FRC may be slightly reduced in comparison with conventional concrete.

Self-Consolidating Concrete (SCC)

Place SCC at a constant-pressure head from one end of the form, allowing air to escape as the concrete flows into and around steel reinforcement. Avoid placement practices that add additional energy to the mix and cause unwanted segregation such as excessive vibration, increased pour heights, or increased discharge rates.

Consolidating Concrete

Self-consolidating concrete (SCC) generally requires minimal consolidation effort, as it is able to flow and consolidate under its own weight. However, when using conventional concrete, consolidation operations are required to minimize segregation and honeycombing. Consolidation can be improved on particular molds by using vibrators with variable frequency



and amplitude. There are three types of vibration prevalent in the precast industry:

- Internal – stick vibrator
- External – vibrator mounted on forms or set on a vibrating table
- Surface – vibrator can be moved across the surface

The ideal vibrator would allow the operator to vary the amplitude (the effective distance of the vibration waves) and frequency (number of vibrations/min.).

Internal Vibrators

Internal or immersion-type vibrators are commonly used to consolidate concrete in walls, columns, beams or slabs. It is important to know proper vibration procedures for best results. Using proper vibration procedures will help make the concrete stronger and more durable because vibration helps consolidate the concrete mix and remove pockets of entrapped air.

When concrete is placed into the formwork, it should always be placed as near to its final location as possible and vibrated immediately after placed. The internal vibrator should be lowered vertically and systematically into the concrete without force until the tip of the vibrator reaches the bottom of the form.

When using internal vibrators, concrete should be placed in wall sections using lifts not exceeding 2 ft. Do not drag internal vibrators horizontally; this will cause the mix to separate and aggregates to pull away from the cement paste, reducing the quality of the product. Once consolidation is complete in one area, slowly remove the vibrator vertically and move the vibrator to the next insertion area. The process of vertically withdrawing the vibrator brings entrapped air to the surface. Ensure that the fields of vibration overlap with another insertion point to best consolidate the concrete and minimize defects.

External Vibrators

The most commonly used external vibrators in precast concrete manufacturing are vibrating tables. Vibrating tables are typically comprised of steel or reinforced concrete structures with external vibrators mounted to the supporting frame. Vibration is transmitted from the table to the mold and then to the concrete. Just as with internal vibrators, external vibrators should be positioned to allow for overlap of vibration areas. The vibration process should continue until the product is completely consolidated. Vibration is considered complete when large bubbles ($\geq 3/8$ -in. diameter) no longer appear at the surface. Also take care to not over-vibrate; segregation of the aggregate from the cement paste can result, lowering concrete quality and strength.

Surface Vibrators

A surface vibrator is used for consolidating concrete by application to the surface of a mass of freshly mixed concrete. There are four principal types of surface vibrators: vibrating screeds; pan vibrators; plate or grid vibratory tampers; and vibratory roller screeds.

Finishing Unformed Surfaces

Each precast concrete product is to be finished according to

its individual specifications. If finishing techniques are not specified, take care to avoid floating flat surfaces either too early or for too long. Premature finishing can trap bleed water below the finished surface, creating a weak layer of concrete that may become more susceptible to freeze-thaw cycles and chemical attack. Finishing with a wood or magnesium float is recommended. Do not finish until bleed water evaporates from the surface.





CURING PROCEDURES

Proper curing is significant for developing precast concrete's chemical resistance, strength and durability.

Note: Concrete temperature discussed in this manual refers to the temperature of the concrete itself, not the ambient temperature.

The nature of precast operations poses unique challenges to proper curing. To ensure cost-effective use of forms, precasters often strip the forms at the beginning of the next workday. That is an acceptable practice, according to ACI 308R, "Standard Practice for Curing Concrete." The time necessary to develop enough strength to strip the forms is highly dependent on the ambient temperature in the casting area.

The Portland Concrete Association (PCA) lists three methods of curing:

1. Maintaining water moisture by wetting (fogging, spraying and wet coverings)
2. Preventing the loss of water by sealing (plastic coverings or applying curing compounds according to ASTM C309, "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete")
3. Applying heat (often in conjunction with moisture, with heaters, or live steam)

Choose the method(s) that best suit the particular production operation; all three PCA methods are permissible for precast

systems. Maintaining moisture requires constant wetting, which is manpower-intensive. Alternating wetting and drying can lead to problems with cracking. Steam curing can also be effective and advantageous where early strength gain or additional heat for hydration is required. Concrete temperatures should never exceed 150 F (40 degrees maximum per hour increase). Both of these techniques are described in ACI 308R, "Standard Practice for Curing Concrete," and the PCA publication "Design and Control of Concrete Mixtures." <added PCA to Refs>

Plastic coverings or membrane-forming curing compounds require less intensive manpower and allow form-stripping the next day. There are some special considerations for both:

- Plastic sheeting must comply with ASTM C171, "Standard Specification for Sheet Materials for Curing Concrete," which specifies a minimum thickness of 4 mils and states that the sheet materials can be either white or opaque in color. PCA also states that other colors can be used depending on sun conditions and temperature. When using multiple sheets, overlap adjoining sheets by approximately 18 in. to prevent moisture loss.
- Curing compounds can be applied when bleed water is no longer present on the concrete surface. As with plastic, white-colored compounds might reflect sunlight better and limit temperature gain. Follow the manufacturer's recommendations.



Cold and Hot Weather Concreting

Cold-Weather Concreting

In cold weather conditions, concrete hydration rates are slower and therefore the need to retain heat from hydration becomes important. Concrete temperatures below 50 F are considered unfavorable for pouring due to the extended time required for strength gain and the possibility of freezing. However, once concrete reaches a minimum strength of 500 psi, usually within 24 hours, freezing has a limited impact. Ideally, precast concrete operations should be performed in heated enclosures that will provide uniform heat to the products until they reach 500 psi. If necessary, heating the mixing water and/or aggregates can increase the concrete temperature. Do not heat materials above 140 F, and do not use clumps of frozen aggregate and ice. ACI 306, "Cold Weather Concreting," contains additional recommendations on cold-weather concreting.

Hot-Weather Concreting

In hot weather conditions, hydration rates are accelerated and therefore the need to keep the concrete temperature regulated becomes increasingly important. It is crucial that the fresh concrete temperature not exceed 90 F at time of placement. The temperature of the concrete mix should be kept as low as possible using a variety of means, including:

- Shade the aggregate piles;
- Wet the aggregates (mix design must be adjusted to account for the additional water);
- Use chilled water; and
- Substitute ice for water

Note: During the curing process, ensure that the concrete temperature does not exceed 150 F. In all cases, protect freshly cast products from direct sunlight and drying wind. ACI 305R, "Guide for Hot Weather Concreting," contains further recommendations on hot-weather concreting.



POST-POUR OPERATIONS

Handling Equipment

Cranes, forklifts, hoists, chains, slings and other lifting equipment must be able to handle the weight of the product with ease and comply with federal and local safety requirements.

A routine inspection of all handling equipment is necessary. Qualified personnel should make periodic repairs and perform maintenance as warranted. Tag all chains and slings with individual load-capacity ratings. For U.S. plants, refer to the specific requirements of the Occupational Safety and Health Administration (OSHA). For Canadian plants, refer to the specific requirements of the Canadian Centre for Occupational Health and Safety (CCOHS).

Stripping and Handling Products

It is critical that concrete gain sufficient strength before stripping the forms. If the forms are stripped prematurely the concrete may never reach full design strength. Due to the nature of the precast business, the American Concrete Institute recognizes that forms will usually be stripped the next day. Under normal conditions (concrete temperatures > 50 F), properly designed concrete can reach the minimum compressive strength for stripping within this time period. Periodic compressive strength testing of one-day or stripping-

strength cylinders is required to confirm that proper concrete strength is attained.

It is important to handle recently poured and stripped products with care. Perform lifting and handling carefully and slowly to ensure that dynamic loads do not damage the product. Always follow recognized safety guidelines.

Post-Pour Inspection Checklist

A post-pour inspection checklist provides a method of identifying and communicating quality problems as they occur and valuable tool to identify any trends. After stripping a product from its form, inspect the product for conformance with the fabrication drawings. Clearly label all products with the date of manufacturing and mark products in accordance with project specifications and plans, unless marking the product will affect its aesthetics.

Cleaning

Clean dirt or blemishes from surface of exposed members.

POST-POUR INSPECTION REPORT

QUALITY CONTROL DEPARTMENT

PRODUCT							
Job #	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Casting Date							
Inspection Date							
Mark Number							
Shipping Strength							
Top Finish							
Bottom Finish							
Surface Texture							
As Cast Length							
As Cast Width							
As Cast Depth							
Cracks							
Spalls							
Squareness							
Chamfers							
Honeycomb/Grout Leak							
Bowing							
Exposed Reinforcing							
Exposed Chairs							
Plates and Inserts							
Chamfer & Radius Quality							
Openings/Blockouts							
Lifting Devices							

REMARKS: _____

QC Supervisor _____ Date _____ Inspector _____

FINISHING & REPAIRING CONCRETE

Repairing Concrete

Repairing Minor Defects – Defects that do not impair the use or service life of the product are considered minor or cosmetic and may be repaired in any manner that does not impair the product.

Repairing Honeycombed Areas – The proper procedure for repairing honeycombed areas is as follows:

1. Remove all loose material from the damaged area.
2. Cut back the damaged zone in horizontal or vertical planes deep enough to remove the damaged concrete.
3. Use only materials that are specifically developed for concrete repair, and make repairs according to the manufacturer's specifications.
4. Coarse aggregate particles should break rather than merely dislodge when chipped.

Repairing Major Defects – Major defects are defined as those that impair the intended use or structural integrity of

the product. If possible, repair products with major defects by using established repair and curing procedures only after a qualified person evaluates the feasibility of the repair. Refer to ACI 546,"Guide to Concrete Repair," for further guidance.

Secondary Pours

For products that require secondary pours, establish procedures to assure that the new concrete bonds adequately to the product and becomes an integral part of it as per ASTM C1059, "Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete."

The surfaces of the product against which the secondary pour is to be made should be free of laitance, dirt, dust, grease or any other material that will tend to weaken the bond between the original and new concrete. If the surface is very smooth, roughen it to help promote a good bond. As a minimum, use a high-quality water stop, keyway and continuation of reinforcing between pours to ensure a watertight joint.

DELIVERY, STORAGE & HANDLING

Handle precast members in position consistent with their shape and design. Lift and support only from support points. Protection installed precast from damage caused by erection operations

Storage of Products

Storage areas must be flat and strong enough to support the product without causing damage. Store the product in a manner that will not damage it in any way while stacking, moving or handling. Organize storage areas in a manner that will facilitate rotation of inventory.

Marking of Products

Unless otherwise specified by project specifications or authority having jurisdiction, products should be marked in accordance with project specifications and plans.

Final Product Inspection Check

Inspect the product visually at the plant prior to shipping,





preferably after being loaded and secured on the delivery vehicle. If there are any product defects or areas of concern, are observed, this condition should be noted, filed and fixed before leaving the plant.

Product Shipment

All vehicles used to transport products should be in good condition and capable of handling the product without

causing damage. Allow products to adequately cure prior to shipment to a job site or distant storage areas. Secure all products properly with appropriate blockage and nylon straps (other other approved securing devices) in order to avoid product damage during shipment. NPCA's publication "Cargo Securement for the Precast Concrete Industry" outlines proper methods for securing product. The final inspection should include a check of these items.

SEALS, FITTINGS & JOINTS

Careful attention to joint details, sealing materials and pipe connections are important to ensure quality stormwater structures. Systems in areas of high water tables may require special methods for joint and penetration seal designs.

Joint Designs

Joint designs commonly used include; single off-set, confined groove, tongue-and-groove or lap joints. For the manufacture of stormwater structures, it is recommended that only interlocking joints be used.

Sealing Materials

Refer to the following ASTM specifications for installing seals, fittings and joints:

- ASTM C990, "Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants"

- ASTM C443, "Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets"
- ASTM C1677, "Standard Specification for Joints for Concrete Box, Using Rubber Gaskets"

Consult your sealant and gasket supplier for manufacture's sizing and installation instructions.

Access, Risers and Manholes

All access risers and manholes must be structurally sound and watertight.



INSTALLATION

Proper installation of stormwater management systems is critical for maintaining structural integrity. The modular nature and simple joint connections of precast concrete components enable fast assembly and installation once onsite. Correct installation procedures will result in a properly installed structure or stormwater system while maintaining a safe work environment

Site Conditions

The installation site must be safe and accessible to trucks and installation equipment. The construction area should be free of trees, branches, overhead wires or parts of existing buildings that could interfere with the delivery and installation of the stormwater management system.

Bedding

Use a minimum of 4 in. of approved bedding material compacted to a minimum 90% (by Proctor Test) in an area not less than the base area of the precast units and preferably 6 in. beyond the outside of the structure's base footprint. The bedding of incoming and outgoing pipes should be consistent with the bedding/compaction of the stormwater structure to prevent differential settling. Local ground conditions may require additional bedding depth for adequate support; follow the engineer's recommendations. The site's soil bearing pressure must be sufficient to support anticipated live and

dead loads applied to the precast concrete stormwater system.

Placement

Setting the Base: Set the base on graded bedding according to job specifications, making sure connectors or pipe openings match design elevations. Level the top of the base along both horizontal axes.

Joint Installation

Butyl Gasket – Use only manufacturer-recommended sizes for specific diameters. Clean and inspect tongue-and-groove surfaces. Surfaces should be free of contaminants.

Confined O-Ring – Follow these installation steps:

- Clean and inspect joint surfaces.
- Lubricate the bell and O-Ring groove.
- Lubricate O-Ring gasket thoroughly before placing into confined groove space provided.
- Run a smooth round object between the gasket and the tongue several times around the entire circumference.
- Lower the lubricated end of the next section making sure steps are aligned into final position.
- Keep sections level/plumb to prevent rolling the gasket or breaking the bell.



Profile and Pre-lubricated Gaskets – Install according to manufacturer’s specifications.

Pipe Connections and Inverts – Install according to manufacturer’s recommendations.

Flexible Boot Connections – Follow these installation steps:

- Clean the pipe surface and the inside of the boot.
- Insert the end of the pipe flush with the inside of structure’s wall or as allowed by jurisdiction, keeping the pipe centered within the connector.
- Install all take-up clamps in grooves, if provided, at the receiving end of the connector.
- Tighten the clamp to the manufacturer’s recommended torque before deflection of the pipe.
- Pipe should be supported during connection and after installation until proper backfill/compaction around the pipe has been completed.
- Any grouting that will inhibit the design/flexibility of the connector should be avoided; follow connector-manufacturer’s instructions.

Compression Type Connector – Follow these installation steps:

- Cut $\frac{3}{4}$ -in. bevel on the end of the pipe to be inserted into the stormwater structure.
- Clean the pipe surface and inside area of connector.
- Lubricate the inside of the connector and the exterior area of pipe being inserted.

- Center the beveled end of the pipe into the connector.
- Keeping the pipe level, push the pipe into connector until pipe is flush with inside of the wall (or as required by local specifications).

Mortar Joint – Locate the pipe into the opening to meet specified elevations. Use a non-stick (non-binding) mortar to completely fill voids around pipe. Allow proper grout/mortar curing time before backfilling.

Pipe Stubs – Any pipe stubs installed in the stormwater management structure must be restrained from movement to prevent blowout resulting from groundwater loading or any testing pressures. A minimum length of 5 ft may be required

Lift Hole Sealing (full penetration) – Lifting holes should be sealed by inserting a rubber plug or other approved material into the hole (if supplied) and/or filling with non-shrink mortar, applied from both the inside and the outside of the precast wall.

Backfill Procedure

If vacuum testing is required, do the test before backfilling. Detecting leaks and making repairs is safer, easier and simpler prior to backfilling. Compact fill-in lifts using the same procedure as with a standard trench construction. Backfill material should be clean and free of large rocks (> 3 in. in diameter) and placed in uniform lifts less than 24-in. deep to prevent tipping of the structure.

MAINTENANCE

Maintenance is an important component for ensuring the specified service life of a precast concrete stormwater system.

The specifying engineer is responsible for providing proper maintenance schedules and Best Management Practices (BMP) to the system owner(s) to ensure the long service life of precast concrete stormwater systems. While precast components are inherently low-maintenance, recommended minimum maintenance schedule for the overall stormwater system includes:

- Solids removal
- Floatable debris removal
- Routine inspections for structural adequacy and durability of components

Wastewater system design should accommodate ease of

access for scheduled inspection and maintenance. Precast concrete stormwater designs should include ease of access for inspectors as follows:

1. Ease of access for visual inspections to identify service needs;
2. Adequate room for inspectors and service equipment access;
3. Properly sized and located manhole access, whether using cast iron or aluminum hatches;
4. Adequate access and accommodation for standard vacuum trucks to perform scheduled sediment-storage cleanout; and
5. Global unit configuration and access for the most cost-efficient long-term inspection and maintenance operations.

REFERENCES

CODES

Occupational Safety and Health Administration (OSHA)

29 CFR 1910.184 (Slings)

29 CFR 1926.650-652 (Excavation)

MANUALS & GUIDES

National Precast Concrete Association (NPCA)

NPCA, "Quality Control Manual for the Precast and Prestressed Concrete Plants"

NPCA, "Guide to Implementing SCC"

NPCA, "Cargo Securement for the Precast Concrete Industry"

SPECIFICATIONS & STANDARDS

American Concrete Institute (ACI)

ACI 116R, "Cement and Concrete Terminology"

ACI 211.1, "Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete"

ACI 211.3, "Standard Practice for Selecting Proportions for No-Slump Concrete"

ACI 212.3, "Chemical Admixtures for Concrete"

ACI 237, "Self-Consolidating Concrete"

ACI 304R, "Guide for Measuring, Mixing, Transporting and Placing Concrete"

ACI 305R, "Guide for Hot Weather Concreting"

ACI 306R, "Guide for Cold Weather Concreting"

ACI 308R, "Guide to Curing Concrete"

ACI 318, "Building Code Requirements for Structural Concrete and Commentary"

ACI 350R, "Code Requirements for Environmental Engineering Concrete Structures and Commentary"

ACI 544, "State-of-the-Art Report on Fiber Reinforced Concrete"

ACI 546, "Guide to Concrete Repair"

ASTM International

ASTM A36, "Standard Specification for Carbon Structural Steel"

ASTM A82, "Standard Specification for Steel Wire, Plain, for Concrete Reinforcement"

ASTM A185, "Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete Reinforcement"

ASTM C443, "Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets"

ASTM A496, "Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement"

ASTM A497, "Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete Reinforcement"

ASTM C595, "Standard Specification for Blended Hydraulic Cements"

ASTM A615, "Standard Specification for Deformed and Plain Carbon Steel-Bars for Concrete Reinforcement"

ASTM A706, "Standard Specification for Low-Alloy Steel Deformed Bars and Plain Bars for Concrete Reinforcement"

ASTM A820, "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete"

ASTM C33, "Standard specification for Concrete Aggregates"

ASTM C94, "Standard specification for Ready-Mixed Concrete"

ASTM C125, "Standard Terminology Relating to Concrete and Concrete Aggregates"

ASTM C136, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates"

ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete"

ASTM C150, "Standard Specification for Portland Cement"

ASTM C171, "Standard Specification for Sheet Materials for Curing Concrete"

ASTM A185, "Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete"

ASTM C260, "Standard Specification for Air-Entraining Admixtures for Concrete"

ASTM C309, "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete"

ASTM C494, "Standard specification for Chemical Admixtures for Concrete"

ASTM C496, "Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement"

ASTM C443, "Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets"

ASTM C595, "Standard Specification for Blended Hydraulic Cements"

ASTM C618, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete"

ASTM C857, "Standard Practice for Minimum Structural Design Loading for Underground Precast Concrete Utility Structures"

ASTM C890, "Standard Practice for Minimum Structural Design Loading for Monolithic or Sectional Precast Concrete Water and Wastewater Structures"

ASTM C913, "Standard Specification for Precast Concrete Water and Wastewater Structures"

ASTM C989, "Standard Specification for Ground Granulated Blast Furnace Slag"

ASTM C990, "Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants"

ASTM C1017, "Chemical Admixtures for Use in Producing Flowing Concrete"

ASTM C1059, "Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete"

ASTM C1116, "Standard Specification for Fiber Reinforced Concrete"

ASTM C1157, "Standard Performance Specifications for Hydraulic Cement"

ASTM C1240, "Standard Specification for Silica Fume Used in Cementitious Mixtures"

ASTM C1602, "Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete"

ASTM C1677, "Standard Specification for Joints for Concrete Box, Using Rubber Gaskets"

American National Standards Institute (ANSI)

ANSI A10.9, "Safety Requirements for Masonry and Concrete Work"

ANSI 46-2007, "Evaluation of Components and Devices Used in Wastewater Treatment Systems"

American Welding Society (AWS)

AWS D1.4, "Structural Welding Code – Reinforcing Steel"

Canadian Standards Association (CSA)

CSA A3000, "Cementitious Materials"

Canadian Centre for Occupational Health and Safety (CCOHA)

Occupational Health & Safety Guides

Portland Cement Association (PCA)

PCA, "Design and Control of Concrete Mixtures"

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GLOSSARY

AASHTO – American Association of State and Highway Transportation Officials; The AASHTO standard specifications for highway bridges have information relevant to retaining wall design.

Abutment – a retaining wall that provides structural support for the deck of a bridge or overcrossing.

Active pressure – soil pressure on a retaining wall after slight deflection which relieves some of the lateral soil load.

Admixture – a material other than water, aggregates, cement and fiber reinforcement used as an ingredient of concrete and added to the batch immediately before or during its mixing.

Admixture, accelerating – an admixture that accelerates the setting and early strength development of concrete.

admixture, air-entraining – an admixture that causes the development of a system of microscopic air bubbles in concrete, mortar or cement paste during mixing.

Admixture, water-reducing – admixture that either increases the slump of freshly mixed concrete without increasing the water content or that maintains the slump with a reduced amount of water due to factors other than air entrainment.

Aggregate – granular material, such as sand, gravel, crushed stone or iron blast-furnace slag used with a cement medium to form hydraulic-cement concrete or mortar. Aggregates are typically inorganic, natural (e.g., gravel), processed (e.g., crushed rock) or man-made (e.g., air cooled blast furnace slag and expanded shale).

Aggregate, coarse – generally pea-sized to 2 inches; aggregate of sufficient size to be predominately retained on a No. 4 sieve (4.75 mm).

Aggregate, fine – generally coarse sand to very fine; aggregate passing the 3/8 inch sieve (9.5 mm) and almost entirely passing a No. 4 sieve (4.75 mm) and predominately retained on the No. 200 sieve (0.75 mm).

Air content – the volume of air voids in cement paste, mortar or concrete, exclusive of pore space in aggregate particles; usually expressed as a percentage of total volume of the paste, mortar or concrete.

ASTM – ASTM International is a not-for-profit organization that provides a forum for producers, users, ultimate consumers and those having a general interest (government and academia) to meet and write standards for materials, products, systems and services.

Backfill – earth or other material placed between a retaining wall and existing ground.

Backslope – the non-horizontal finish grade of soils behind a wall; typically expressed as horizontal distance to vertical height (H:V backslope); used in engineering calculations, backslope increases the design on a wall.

Base course – the first course to be installed. It may be totally or partially buried.

Base material – a base pad of free draining granular material, compacted and leveled to receive a base course.

Batter – as applied to walls, the difference between the wall face alignment and vertical to horizontal. A lean of the wall face toward the retained fill is considered a positive batter, while an outward lean is considered a negative batter. Batter is often built into a wall by off-setting (setting back) successive courses of a wall by a specified amount. The batter adds a stabilizing factor to the wall.

Bearing capacity – the pressure that a soil can sustain without failing.

Bedding material – gravel, soil, sand or other material that serves as a bearing surface on which a structure rests and which carries the load transmitted to it.

Bleeding – the separation of mixing water or its emergence from the surface of newly placed concrete caused by the settlement of the solid materials.

Bonding agent – a substance applied to a suitable substrate to create a bond between it and a succeeding layer, such as between a layer of hardened concrete and a layer of fresh concrete.

Boundary conditions – a term used to describe what is happening above the wall (parking lot, road, fence, slope).

Buried block – the block below grade.

Cement, hydraulic – cement that sets and hardens by chemical interaction with water and is capable of doing so under water.

Cementitious material – an inorganic material or mixture of inorganic materials that set and develop strength by chemical reaction with water by formation of hydrates.

Cohesive soil – a cohesive soil is one that sticks together and includes the clays, clay shale, silty clay, sandy clay, loams, etc. Primarily it resists load in direct proportion to its cohesive strength.

Cold joint – a joint or discontinuity formed when a concrete surface hardens before the next batch is placed against it.

Concrete – a composite material that consists essentially of a binding medium within which are embedded particles of aggregate fragments, usually a combination of fine aggregate and coarse aggregate; in portland cement concrete, the binder is a mixture of portland cement and water.

concrete, fresh – concrete that possesses enough of its original workability so that it can be placed and consolidated by the intended methods.

Compressive strength – measured maximum resistance of a concrete or mortar specimen to axial compressive loading; expressed as a force per unit cross-sectional area; or the specified resistance used in design calculations.

Consistency – the relative mobility or ability of freshly mixed concrete to flow; it is usually measured by the slump test.

Consolidation – the process of inducing a closer arrangement of the solid particles in freshly mixed concrete during placement by the reduction of voids, usually accomplished by vibration, centrifugation, rodding, tamping or some combination of these actions. Consolidation facilitates the release of entrapped air; as concrete subsides, large air voids between coarse aggregate particles are filled with mortar.

Coulomb earth pressure theory – a method for calculating simple earth pressure. The coulomb theory was developed in the 1780s and remains the basis for present day earth pressure.

Critical zone – the critical zone refers to either increased loading exerted on the wall by the mass of a building or the like, or movement of the ground which can cause movement of a building or the like.

Curing – action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and, if applicable, pozzolanic reactions to occur so that the potential properties of the mixture may develop.

Curing compound – a liquid that can be applied as a coating to the surface of newly placed concrete to retard the loss of water or to reflect heat in order to provide an opportunity for the concrete to develop its properties in a favorable temperature and moisture environment.

Dead load – an inert, inactive load.

Detention – the storage and slow release of stormwater following a precipitation event by means of an excavated pond, enclosed depression, or precast concrete system.

Design Manual for Segmental Retaining Walls – published by the National Concrete Masonry Association (NCMA). This manual is used in modular retaining wall design.

Deleterious substances – materials present within or on aggregates that are harmful to fresh or hardened concrete, often in a subtle or unexpected way. More specifically, this may refer to one or more of the following: materials that may be detrimentally reactive with the alkalis in the cement (see alkali aggregate reactivity) clay lumps and friable particles, coal and lignite, etc.

DOT – Department of Transportation

Drainage material (unit fill) – free draining granular material used in the block cores and just behind the wall to collect and disperse water. A coarse, clean aggregate is used to reduce loss of material through the block joints.

Dry-cast (no-slump concrete) – concrete of stiff or extremely dry consistency showing no measurable slump after removal of the slump cone.

Differential settlement – the uneven sinking of material (usually gravel or sand) after placement.

Elongated aggregate – a particle of aggregate where its length is significantly greater than its width.

Embedment – the depth a wall is buried below finished grade. The minimum practical embedment for a wall structure is the level toe slope 6 inches below finish grade. As a wall gets taller or is placed in less stable sloping conditions, the embedment must be increased to satisfy stability requirements. Embedments are included in the total wall weight.

Entrained air – see air void; microscopic air bubbles intentionally incorporated into mortar or concrete during mixing, typically between 10 μm and 1,000 μm (1 mm) in diameter and spherical or nearly so.

Exfiltration – to cause (as a liquid) to flow outward through something by penetrating its pores or interstices. exposed wall

Face – the portion of the retaining wall that is above grade.

Factor of Safety (FS) – with respect to sliding and overturning, a minimum desirable FS = 1.5 for sliding and F.S. = 1.5 to 2.0 for overturning.

Fiber reinforcement – discontinuous tensile filaments of steel or synthetic materials designed to provide secondary reinforcement of concrete structures and to help mitigate the formation of plastic shrinkage cracks.

Float – a tool, usually of wood, aluminum or magnesium, used in finishing operations to impart a relatively even but still open texture to an unformed fresh concrete surface.

Floating – the operation of finishing a fresh concrete or mortar surface by use of a float, preceding troweling when that is to be the final finish.

Fly ash – the finely divided residue transported by flue gases from the combustion of ground or powdered coal; often used as a supplementary cementitious material in concrete.

Footing – the soils, gravel and/or engineered materials used directly below a retaining wall to distribute the weight/load of the wall to the underlying soil.

Forms (molds) – a structure for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.
foundation soil – soil zone immediately beneath the retaining wall units, wall leveling pad and the reinforced soil zone. It is important that it is sufficiently strong and that it will not consolidate. Any fill in the foundation soil must be compacted as structural fill.

Freeboard – the vertical distance between the design water surface elevation and the elevation of the precast concrete structure that contains the water.

Friable – easily crumbled or pulverized, as it refers to aggregates.

Friction angle – is the maximum angle of a stable slope determined by friction. The higher the friction angle the more stable the slope. The friction angle is the maximum is expressed in degrees and for a typical clay soil it is 26 degrees. Granular soils generally have higher friction angles.

Frost heave – an upward thrust of ground or pavement caused by the freezing (water-to-ice expansion) of water in moist soil.

Gap grading – aggregate graded so that certain intermediate sizes are substantially absent (i.e., aggregate containing large and small particles with medium-size particles missing).

Geogrid – a geosynthetic material manufactured with high-tensile strength materials specifically for the purpose of reinforcing and creating a structural soil mass.

Global stability analysis – looks at a rotational or compound failure mechanism that is significantly different than simple sliding and overturning analysis. Global stability analysis is required for more complex structures involving slopes, poor soils and/or tiered wall sections. Global failures occur well behind or below the wall systems.

Gravity retaining wall – a free-standing retaining wall that does not require any soil reinforcement behind the wall. Modular gravity walls rely on weight, depth, wall batter and inter-unit shear strength to achieve stability. Larger units with more depth provide greater stability and can achieve greater wall heights.

Gradation – the particle-size distribution as determined by a sieve analysis (ASTM C 136, etc.); usually expressed in terms of cumulative percentages larger or smaller than each of a series of sizes (sieve openings) or the percentages between certain ranges of sizes (sieve openings).

Granular unit fill – free-draining aggregate material which is small enough (3/4 to 1-1/2 inches, not including material) to easily fill unit cores and the gaps between units while containing minimal fine material (sands, silts) that could pipe through wall joints from occasional water flow.

Height, total wall – the vertically measured height of a retaining wall; includes the portion of the wall extending below the ground surface in front of the wall (subgrade).

Hydration – formation of a compound by the combining of water with some other substance; in concrete, the chemical process between hydraulic cement and water.

hydrostatic pressure – the water pressure behind the wall; this lateral force can also lead to wall failure if not accounted for in the wall design.

IAPMO – The International Association of Plumbing and Mechanical Officials

Impervious – the property of a material that prevents the penetration of water under ordinary hydrostatic pressure.

Infiltration – to cause (as a liquid) to permeate something by penetrating its pores or interstices.

Lateral earth pressure – soil pressures that are exerted laterally (horizontally). These may be active, at-rest or passive. Precast modular walls are generally designed to support active earth pressure due to their flexibility.

Leveling pad – a gravel or concrete pad installed to create a level, horizontal surface for wall construction.

live load – the weight of all non-permanent objects in a structure; live loads generally do not include the special cases of wind or seismic loading.

Load – (see surcharge)

Non-cohesive soil – a non-cohesive soil is one in which soil grains do not stick together (e.g., sand, gravel); it resists loads by its internal friction since its resistance increases with increasing weight from above. Generally, non-cohesive soils tend to have more uniform strength than cohesive soils.

Ordinary High Water (OHW) – an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape; OHW is typically the level where natural vegetation changes from predominantly aquatic to predominantly terrestrial.

organic impurities (re: aggregate) – extraneous and unwanted organic materials (twigs, soil, leaves and other debris) that are mixed in aggregates; these materials may have detrimental effects on concrete produced from such aggregates.

OSHA – Occupational Safety and Health Administration, U.S. Department of Labor.

Overturning – the tendency to tip or rotate outward around the toe of the wall due to the moment resulting from the earth pressure force as well as other lateral forces.

Passive pressure – pressure acting to counteract active pressure. Passive pressures occur as a structure is forced against the soil, creating very high resisting pressures. Passive pressures are normally neglected in the design of precast modular walls due to the modest embedment.

Pervious – the property of a material that permits movement of water through it under ordinary hydrostatic pressure.

Plastic concrete – see concrete, fresh.

Portland cement – hydraulic cement produced by pulverizing portland cement clinker, usually in combination with calcium sulfate.

Pozzolan – a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

precast modular block wall (PMB) - the generic name for walls made up of large block modular units formed of precast concrete.

PSI – pounds per square inch; units used to measure of concrete compressive strength.

Reinforced fill – retaining wall backfill that contains reinforcing material to create the structural mass.

Retained soil – soil that is held back by the wall.

Retention – the process of collecting and holding surface and stormwater runoff with no surface outflow.

Rotational failure or slide – a failure of a slope that involves slipping of the earth on a curved surface (see global stability).

Scour – erosion caused by rapid flow of water.

Secondary pour – a situation when a succeeding layer of concrete is placed on previously placed hardened concrete.

Segregation – the unintentional separation of the constituents of concrete or particles of an aggregate, resulting in non-uniform proportions in the mass.

Seismic design standards – standards that are contained in the AASHTO standard specifications for highway bridges which describe a pseudo-static method of analysis based on Mononobe-Obake Theory application of conventional earth-pressure theory.

Set – the condition reached by a cement paste, mortar or concrete when it has lost plasticity to an arbitrary degree, usually measured in terms of resistance to penetration or deformation; initial set refers to first stiffening; final set refers to attainment of significant rigidity.

Shear strength – a measure of the ability of a soil to resist forces that tend to separate it from its position on a slope and cause it to move. Shear strength includes both cohesion and internal friction.

Shop drawings – approved final plan for construction prepared and stamped by the wall design engineer licensed to practice in the state where the product is installed.

Silica fume – very fine non-crystalline silica produced in electric arc furnaces as a byproduct of the production of elemental silicon or alloys containing silicon; also known as condensed silica fume and micro-silica. It is often used as an additive to concrete and can greatly increase the strength of a concrete mix.

Sliding – the lateral movement away from the backfill surface due to horizontal forces resulting from the soil backfill and other forces such as surcharge.

Slope – the face of an embankment or cut-earth section; any ground whose surface makes an angle with the horizontal plane. Toe slope is in front of the wall and the back slope is behind the wall.

slope stability – consideration of a slope's propensity to fail (become unstable or slide) as a result of several potential failure mechanisms including rotational slips, compound slips and translational slides (see global stability).

Slump – a measurement indicative of the consistency of fresh concrete. A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete is allowed to subside. The distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture and thus to be inversely related to concrete strength (unless water-reducing admixtures are used). Under field conditions, however, such a strength relationship is not clearly and consistently shown. Therefore, care should be taken when relating slump results obtained under field conditions to strength (ASTM C 143).

Soil compaction – the method of mechanically increasing the density of soil. The proctor test (standard for modified proctor) determines the maximum density of a soil needed for a specific job site. The test first determines the maximum density achievable with a given compactive energy for the materials and uses this figure as a reference. Secondly, it tests the effects of moisture on soil density. The soil reference value is expressed as a percentage of density. Proper placement and compaction of soils are essential to the successful performance of the retaining wall structure. Post-construction settlement is an obvious concern with poorly compacted materials as well as excessive lateral wall movement and/or insufficient shear strength to perform as intended. Soils must be compacted in lifts to achieve maximum soil shear strength and validate the design.

Soil conditions – the on-site conditions of the soil for the footing and the backfill materials.

Soil reinforcement – tensile reinforcing elements usually placed in horizontal layers in soil so that the resulting composite soil is stronger than the original unreinforced soil (see geogrid).

Soil stabilization – the act of improving soil properties by inclusion of reinforcing elements, chemical substances, compaction or other methods.

Specification – an explicit set of requirements to be satisfied by a material, product, system or service that also indicates the procedures for determining whether each of the requirements is satisfied.

SRWall software – design software for geogrid reinforced retaining walls.

Standard – as defined by ASTM, a document that has been developed and established within the consensus principles of the Society.

Superplasticizer – see admixture, water-reducing. Superplasticizers are also known as high-range water-reducing admixtures. supplementary cementitious materials (SCMs) – finely divided, powdered or pulverized materials added to concrete to improve or alter the properties of the plastic or hardened concrete.

Surcharges – a surcharge load resulting from forces that are applied along the surface of the backfill behind the wall. This extra load can be in the form of a sloping backfill surface, often referred to as the “surcharge angle” temporary or moving loads (e.g., a vehicle, building, parking lot, roadway or other retaining walls stepped one above the other). Surcharge loads must be included in the design and engineering of retaining walls.

Tensile load – a pulling force or stress.

Tensile strength – the ability of a material to withstand tension forces or loading. A term used as an abbreviation for ultimate tensile stress.

Tiered walls – two or more walls set above or below each other, rather than building one very tall wall. The tiered walls can create more useable space, and can provide a more aesthetically pleasing appearance.

Troweling – smoothing and compacting the unformed surface of fresh concrete by strokes of a trowel.

Water-to-cementitious ratio (w/c) – the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of portland cement in concrete, mortar or grout; stated as a decimal.

Water table – the upper limit of the portion of the ground wholly saturated with water.