

Best Practices Manual

Precast Concrete Retaining Wall Systems



**Dedicated to expanding the use
of quality precast concrete**

INTRODUCTION

This manual provides guidance on material selection, manufacturing techniques, testing and installation to attain structurally sound, precast retaining wall systems and related components for precast retaining wall systems. It is not intended for use as a regulatory code or minimum design standard, but rather as an aid to manufacturers, engineers, contractors and owners.

This manual will be most effective when used in conjunction with a complete review of local codes and design considerations before designing or manufacturing any precast retaining wall system.

It is impossible for a manual of this type to be all inclusive, and the recommendations are not intended to exclude any materials or techniques that will help achieve the goal of producing structurally sound precast retaining wall systems. Attention to detail, appropriate materials, proper training of workers and quality control throughout a repeatable process will ensure that the precast

retaining wall systems meet the needs of specifiers, contractors and owners while protecting the environment.

Precast concrete retaining wall systems, when manufactured and installed properly, will outperform and outlast systems consisting of competing materials. With the increasing regulatory demands for structurally sound precast retaining wall systems, it is critical for precast manufacturers to continually raise the bar on quality. It is with this in mind that many industry specialists have come together to create this manual.

The quality of precast retaining wall systems will be dependent on a number of interrelated factors. Those factors include the quality of: (a) the precast retaining wall system, (b) the up-front planning and design of the wall, (c) the engineering behind the wall, (d) wall construction, and (e) the component manufacture. In general, a precaster that produces precast retaining wall systems will find that they are selling solutions as opposed to selling retaining wall systems. The precaster should take care to align itself with a team that can deliver the full scope of services necessary to build a wall that will stand the test of time.

Precast Retaining Wall Systems Best Practices Manual

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NOTES

1. 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.

2. 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.

CONCRETE MIX DESIGN

Properly proportioned concrete mixes should contain adequate strength, durability, uniform appearance and acceptable workability, and should be economically feasible. If a precast concrete manufacturing plant is to obtain a quality mix design; appropriate selection of materials, processes and proportioning needs to be obtainable, repeatable and consistent.

Most concrete used in precast concrete manufacturing has a compressive strength between 3,000 and 6,000 psi, (20 to 41 MPa), but a 4,000 psi (28 MPa) 28 day minimum compressive strength is strongly recommended. Most precast concrete manufacturers furnish their products with strengths in excess of 4,000 psi (28 MPa) in order to avoid damage that lower strength concrete may experience while being handled. The structural integrity of a concrete product designed with a compressive strength less than 4,000 psi (28 MPa) could be jeopardized if excessive loading is sustained by the member.

In order to increase the overall quality and integrity of a precast concrete product, added considerations must be taken into account. A quality precast concrete product should emphasize methods to reduce permeability, improve durability and increase strength.

Permeability refers to measuring the rate at which water can percolate through concrete when the water is under pressure or the ability of concrete to oppose infiltration of liquids or gases. Permeability can be reduced with a low water-cement ratio (0.45 or below) and an adequate moist-curing period.

Durability of concrete refers to the ability of concrete to withstand weathering action, chemical attack, abrasion, or any process of deterioration while maintaining its desired engineered properties. Durability and life of the concrete depend on several variables such as the mix design proportioning, ingredients used in the mix design, placing and curing procedures, and the interactions between the ingredients used in the mix design.

Reinforcement

A typical precast concrete structural member has a high resistance to compressive stresses but lacks the sufficient resistance to elevated tensile forces. To improve precast concrete's structural properties and to prevent cracking, reinforcement is incorporated into the concrete. Reinforcement may also be used to help resist compressive forces or to improve the dynamic properties of the structure.

In order to provide adequate structural support during early-age handling, installation and service, the sufficient amount of reinforcement must be provided. All reinforcement should meet applicable ASTM International Specifications and Manufacturer's guidelines. Reinforcement may not be required where engineering analysis shows that the cover section has sufficient strength without reinforcement.

Materials

The primary constituents of precast concrete 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 C 150, "Standard Specification for Portland Cement" and ASTM C 1157, "Standard Performance Specification for Hydraulic Cement."

ASTM C 150 specifies eight different types of portland cement 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 C 150, are:

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

Or as per 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 on project specifications or individual characteristics that best fit the operation and regional conditions of each manufacturer. It is also imperative to recog-



nize that specific types of cement may not be readily available in certain regions.

Type I portland cement is general-purpose cement that is used when the cement type is not specified. Type I cement is readily available.

Type II 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 percent of all portland cement produced.

Type III portland cement is typically available in larger metropolitan areas.

Type IV portland cement is typically manufactured only when required in massive projects (dams, piles, etc.), therefore it's not as readily available.

Type V portland cement is made available only in regions where there is potential for severe sulfate attacks.

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 the bags no more than 14 high. For long-term storage, do not exceed seven bags in height (or per manufacturer's recommendations).

Proper personnel should also design and maintain the bin and silo compartments so that they are able to discharge freely and independently into the weighing hopper. Cement that is 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 since aggregates (fine and coarse) typically occupy 60 percent to 70 percent of the total concrete volume. The NPCA Quality Control Manual for Precast and Prestressed Concrete Plants recommends that any aggregates used in the concrete mix design conform to ASTM C33, "Standard Specification for Concrete Aggregates."

It is also recommended that the trained 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. Personnel should also check for potential deleterious expansion due to alkali reactivity, unless the aggregates come from a state department of transportation-approved source.

There are numerous reasons for specifying a nominal maximum aggregate size. Specifying a maximum aggregate size is desirable since this 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 percent of the minimum thickness of the precast concrete element or 75 percent of the clear cover between reinforcement and the surface of the retaining wall. Larger maximum sizes of aggregate may be used if evidence shows that satisfactory concrete products can be produced.

Quality of Aggregates

It is important to specify a well-graded, sound, nonporous aggregate in accordance with ASTM C33. If quality of the aggregates is subpar, the structural integrity of the entire precast concrete member can be compromised.

Gradation of Aggregates

Aggregate gradation influences both the economy and strength of a finished precast retaining wall system. 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 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 having an excess of very fine or very coarse sand/aggregates with large 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 call for an adjustment to the mix design 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 or if they interfere with the hydration process of cement and 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, silt

For good bond development between the cement paste and aggregates, ensure 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 is no more than 3 percent. Friable aggregates may fracture

in the mixing and placement process, compromising 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 percent moisture by weight; coarse aggregates can hold up to 3 percent.

Water on the surface of an aggregate that is not accounted for in the mixture proportions will increase the water-cementitious ratio. The moisture content of aggregates will vary throughout a 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 water-cement ratio will vary from batch to batch causing variation in the workability and compressive strength.

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

- Enclose storage of daily production quantities
- Store aggregates in horizontal layers
- Have at least two stockpiles
- Allow aggregate piles to drain before use
- Avoid the use of the bottom 12 inches (300 mm) 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. This will maintain high quality standards and save on expensive raw materials. The plant should have a program in place that manages 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 handling to reduce the risk of particle size segregation. Also, minimize the number of handling operations and material drop heights to avoid breakage.

The following methods can prevent 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 (i.e., 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 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 affect the concrete strength and setting time, and cause reinforcement corrosion, 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 workability, entrain air, retard or accelerate set time, reduce permeability and reduce steel corrosion, and to add 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 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, which 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. It is also important to protect admixture batching components 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 manufacturer or as required by local regulations.

Chemical admixture performance can vary; exercise caution, especially when using new products. Test some trial batches and document the results before using a new admixture for production. Follow manufacturer's recommendations exactly. 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 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 (SCMs)

Supplementary cementitious materials are industrial byproducts used as an addition to or as a partial replacement to portland cement. Supplementary cementitious materials consist of pozzolans (calcined shale, calcined clay and metakaolin), fly ash, slag and silica fume. Primarily supplementary cementitious materials are used to improve workability, durability, strength and other properties in the concrete's fresh and hardened state.

SCMs have three classifications:

1. Cementitious materials – blast furnace slag (ASTM C595, "Standard Specification for Blended Cements")
2. 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")
3. Pozzolanic and cementitious materials – Class C fly ashes (ASTM C618)

Or as per 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 blast furnace slag, could lead to significant improvements in permeability and resistance to sulfate attack, which are important considerations in precast retaining wall system design and performance.

Ready-Mixed Concrete

Ready-mixed concrete is manufactured and delivered to a purchaser in a freshly mixed and unhardened state. It is important to verify that the ready-mixed concrete supplier is operating in accordance with ASTM C94, "Standard Specification for Ready-Mixed Concrete."

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 useful in verifying that materials used in manufacturing precast concrete products conformed to the product specifications. Ready-mixed concrete manufacturing also should record any added water on the delivery batch ticket for each truck and keep it on file.

MIXTURE PROPORTIONING

Mix designs are selected based upon several necessary factors including permeability, consistency, workability, strength and durability (Ref 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-cementitious ratio (less than 0.45)
- Minimum compressive strength of 4,000 psi (28 MPa) at 28 days
- Use of good quality and properly graded aggregate
- Proper concrete consistency (concrete that can be placed readily by traditional methods).



Water-Cementitious Ratio

High water-cementitious ratios 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 water-cementitious ratios result in smaller and fewer pores, reducing the permeability of the concrete. ACI 318, "Building Code

Requirements for Structural Concrete,” recommends a maximum water-cementitious ratio 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 (flowable or deformable) to be properly placed, consolidated and finished. The size, shape and grading of aggregates, cement content, water-cementitious ratio and admixtures affect the workability of a mix. When calculating the water-cement ratio, 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 low water-cementitious ratios (less than 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. In certain circumstances, and where local regulations allow it, 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 workability and reduces bleeding and segregation of fresh concrete while greatly improving the durability and permeability of hardened concrete.

Testing

Perform plastic concrete tests (slump, temperature, air content and density) at the plant prior to casting products. Record any added water on the delivery batch ticket for each truck and keep it on file.

LIFTING INSERTS

Commercially manufactured lifting devices come furnished with documented and tested load ratings. Use the devices as prescribed by the manufacturer’s specification sheets.

All lifting devices and apparatus should meet OSHA requirements or other applicable codes and standards. Inserts embedded in the concrete shall be designed for an ultimate load that is four times the working load (Factor of Safety = 4). (Refer to OSHA 29 CFR 1926.704)

PRODUCTION PRACTICES

Quality Control

Having a quality control manual in place outlines the basic requirements a precast concrete plant needs to abide by to assure the production of quality precast concrete products. All plants must have a quality control program and manual, including but 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
- Production practices
- Reinforcement fabrication and placement
- Concrete testing
- Storage and handling

Records of the above listed items should be available for review by appropriate agencies upon request. It is strongly recommended that daily reports are 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 the Production Quality School Level 1 is recommended.



Also, quality control personnel performing plastic concrete testing must hold certification as an ACI Concrete Field Testing Technician Grade 1.

Forms

In order to manufacture accurate (within dimensional tolerances) and surface defect-free products, precast concrete forms need

to be in good condition. Frequent inspection intervals and regular maintenance ensures that forms are free of any damage that could cause concrete placement difficulties or dimensional problems with the finished product. Uniform concrete surfaces are less permeable and enhance the installation and aesthetics of the completed project.

Use forms that prevent leakage of cement paste and are sufficiently rigid to withstand the vibrations encountered in the production process. Maintain forms properly, including cleaning after each use and inspection prior to each use, to ensure uniform concrete surfaces. Ensure forms are level and on a solid base. Apply form release agents in a thin, uniform layer on clean forms. Do not apply form release agents to reinforcing steel or other embedded items, as it can compromise the bond between the steel and the concrete. Do not allow the form release agent to puddle in the bottom of forms. Remove excess form release agent prior to casting.

A number of precast companies have their own shops where skilled workers create forms for the many specialty precast products available. Each form must be designed to meet individual product specifications. Select forming materials, configuration, hardware and accessories that help the stripping process and minimize stripping damage. Inspect and maintain joint areas to ensure proper tolerances on concrete joints and keyways.

PRE-POUR OPERATIONS

Pre-Pour Inspection

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
- Placing blockouts
- Positioning embedded items

(Pre-Pour Checklist, Table)

CASTING CONCRETE

Transporting Concrete

When transporting concrete from mixer to form, use any method that does not contaminate the concrete, cause delay in placing, or segregate. One of the most preferred methods of pouring and placing concrete is discharging the concrete directly from the mixer into the forms. ACI 304, "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 ahead of the more coarse materials.

Fiber Reinforced Concrete (FRC)

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

Self-Consolidating Concrete (SCC)

Place self-consolidating concrete 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 efforts since 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.



Three types of vibration are 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 you to vary its amplitude (how far away from the vibrator each vibration can be felt) and frequency (how many times the equipment vibrates each minute).

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 it 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 feet (600 mm). Do not drag internal vibrators horizontally; this will cause the mix to separate, aggregates to pull away from the cement paste and reduce the quality of the product. Once consolidation is complete in one area, slowly remove the vibrator vertically and move the vibrator to the next area. The process of withdrawing the vibrator brings entrapped air to the surface. Insure that the fields of vibration overlap with another insertion to best consolidate the concrete and minimize defects.

External Vibrators

The most commonly used external vibrators used in precast concrete manufacturing are vibrating tables. Vibrating tables normally consist of a steel or reinforced concrete table with external vibrators mounted to the supporting frame. Vibration is transmitted from the table to the mold and then to the concrete. The 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 (3/8" (10 mm) diameter or greater) 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. Four principal types exist: vibrating screeds, pan vibrators, plate or grid vibratory tampers, and vibratory roller screeds.

Finishing Unformed Surfaces

Each product is to be finished according to its individual specifications. If finishing techniques are not specified, take care to avoid floating either too early or for too long. Premature finishing can trap bleed water below the finished surface, creating a weak layer of concrete 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 surface.

CURING PROCEDURES

Proper curing is significant in developing 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 standard, according to ACI 308, "Standard Practice for Curing Concrete." The time necessary to develop enough strength to strip the forms is highly dependent on ambient temperature in the casting area.

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

1. Maintaining water moisture by wetting (fogging, spraying, wet coverings, etc.)
2. Preventing the loss of water by sealing (plastic coverings or applying curing compounds)
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 are permissible for precast retaining wall systems. Maintaining moisture requires constant wetting, which is manpower-intensive. Alternate 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 (65 C). Both of these techniques are described in ACI 308, "Standard Practice for Curing Concrete," and the PCA publication "Design and Control of Concrete Mixtures."



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

1. 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 them by approximately 18 inches (450 mm) to prevent moisture loss.

2. Curing compounds can be applied when bleed water is no longer present on the 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

In cold weather conditions, hydration rates are slower and therefore the need to retain heat from hydration becomes important. Concrete temperatures below 50 F (10 C) 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 (3.5 MPa) (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 (3.5 MPa). If necessary, heating the mixing water and/or aggregates can increase the concrete temperature. Do not heat above 140 F (60 C), and do not use clumps of frozen aggregate and ice. ACI 306, "Cold Weather Concreting," contains further recommendations on cold-weather concreting.

Hot Weather

In hot weather conditions, hydration rates are accelerated and therefore the need to keep the temperature regulated becomes increasingly important. It is crucial that the fresh concrete temperature not exceed 90 F (32 C) at time of placement. The temperature of the concrete mix should be kept as low as possible using a variety of means, including:

- Shading the aggregate piles
- Wetting the aggregates (mix design must be adjusted to account for the additional water)
- Using chilled water
- Substituting ice for water

Note: During the curing process, ensure that the concrete temperature does not exceed 150 F (65 C). In all cases, protect freshly cast products from direct sunlight and drying wind. ACI 305, "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

Minimum Strength Requirement

It is critical that concrete gain sufficient strength before stripping from 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 workday. Under normal conditions (concrete temperatures greater than 50 F (10 C)), 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 recommended 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.

Product Damage During Stripping – Inspect the product immediately after stripping to check for damage.

POST-POUR INSPECTIONS

A post-pour inspection checklist, as illustrated on the following page, provides a method of identifying and communicating quality problems as they occur and 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 these in accordance with project specifications and plans.

Finishing and Repairing Concrete

Repairing Minor Defects

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

PLANNING AND DESIGN

Repairing Honeycombed Areas

The proper procedure for repairing honeycombed areas is as follows: Remove all loose material from the damaged area. Cut back the damaged zone in horizontal or vertical planes deep enough to remove the damaged concrete. Use only materials that are specifically developed for concrete repair, and make repairs according to the manufacturers' specifications. 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.

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 concretes. 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.

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 and in a manner that will facilitate rotation of inventory.

Marking of Products

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

Final Product Inspection

Check the product visually at the plant prior to shipping, preferably after being loaded and secured on the delivery vehicle. If there are any defects or areas of concern, this should be noted and filed.

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 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.

This portion of this Best Practice Manual is designed to cover items that a precaster should be prepared to deliver to its customers from a retaining wall design and engineering perspective.

Testing

A number of products currently exists in the marketplace with more likely to follow. In order to support the proper engineering of a precast retaining wall system, the product needs to have completed a number of tests that will assist the design engineer in modeling performance of the precast retaining wall. Those tests include:

1. A sliding test, which establishes the resistance to sliding of the precast retaining wall when placed on varying bearing surfaces. Generally sliding tests are run on crushed stone and lean concrete surfaces.
2. A shear test, which establishes the resistance that one precast retaining wall unit, will have against any locking mechanism within a second precast retaining wall unit. Also with reinforcement?
3. A connection test for walls that involve reinforcement. These connection tests should be specific to the type of reinforcement used in a wall.

Specifications

Each precast retaining wall system should provide a comprehensive guide specification in CSI Master Format for the use by architects, engineers and specifiers. Such specifications should at a minimum address; (a) submittals, (b) delivery, storage and handling (c) quality assurance, (d) material characteristics, (e)



execution/installation. One "material characteristic" that can be of particular importance to retaining walls is the "product height tolerance" of the wall unit. Each manufacturer will have its own recommendation regarding acceptable plus or minus maximum height tolerance. In general, height dimensions should not vary more than a maximum of $\pm 1/8$ inch (3 mm) for every 4 feet (122 cm) of the unit.

Wall Design and Construction Manual

Each product should provide a comprehensive design and construction manual. Although the design of a precast retaining wall system may be fairly straightforward, it may also be quite complex and involve a high degree of geotechnical and/or civil engineering expertise. A design and construction manual will provide wall designers, installers and others with the information useful in the design, the construction and cost estimation of a precast retaining wall system that will remain attractive and structurally stable for the duration of its intended life.

A checklist of items that should be addressed in a design and construction manual include:

1. Shapes Catalog
2. Architectural Finish Options
3. Unit Characteristics
4. General overview of Design Parameters
 - a. Wall geometry
 - b. Soils information
 - c. Water/Drainage
 - d. Surcharges
 - e. Terraced Walls
5. Wall Construction
6. Typical Wall Details for corners, curves, base step ups, top of wall treatments, railing, geo-grid placement, etc.
7. Wall Charts

Wall Design Software

Each precast retaining wall system company should provide engineering tools to support the design of its product. Those tools can be specific to the precast retaining wall system company or generic to a broader class of retaining wall systems. If generic, then the precast retaining wall company should be able to provide data templates specific to its product that are compatible with the generic design software.

Wall Design and Upfront Planning

A precaster that is producing precast retaining wall systems should consider that it is selling a solution to a site-specific challenge, not merely a precast retaining wall system. As such, it may be important that a precaster work closely with an architect, engineer, contractor or customer in the upfront planning stages of a project. The old axiom – measure twice, cut once – could never be truer than when planning a precast retaining wall. Time can be saved, costs reduced and value added if the supplier of the precast retaining wall system also participates in the up-front planning of the wall. This opportunity often eludes the precaster, but for those who want to add value in a category of retaining wall products that is promoting itself as a “value added product,” the informed precaster has much to contribute.

By way of example, on most new construction sites (commercial sites), soil borings and tests will have been taken where the building is to be built. However, seldom are soil borings taken where the retaining wall is to be built. Since soil characteristics are critical to the proper design of a precast retaining wall, working with the civil engineer to obtain borings at the wall locations is adding value.

Data Gathering

If involved in the planning and engineering of a precast retaining wall, data regarding a specific site must be gathered. A good checklist should be developed, which could include:

1. Wall Geometry Grading Plan
 - a. Back slope
 - b. Toe slope
 - c. Surcharges
2. Soils
 - a. Does a soils report from a geotechnical engineer exist?
 - b. Determine the soil characteristics for the foundation, reinforced and retained soil zones.

ENGINEERING

Precast retaining wall systems must be designed for specific site conditions. This takes into account, by way of example, wall geometry, soils conditions, slopes and surcharges. Precast retaining wall systems must be designed to withstand these unique site conditions. Each design should be performed by a qualified professional engineer who is experienced in the design of retaining walls. Each precast retaining wall should be accompanied by a stamped set of plans, such plans setting forth the design methodology used and the key assumptions upon which the design is based. The plan shall also serve as the “road map” for the wall installer. As such, the plan should clearly label the block types, elevations, embedment, grid lengths, drainage details, etc. An easily understandable stamped plan will greatly increase the probability that the job foreman constructing the wall will be able to comply with the design requirements.



Wall Installation

The final and critical step to the completion of a precast retaining wall is proper wall installation. Each precast retaining wall system will / should have its own unique recommendations for proper wall component installation. It is essential that the precaster make available to the wall contractor wall construction guidelines. Such guidelines will generally cover site preparation, excavation, leveling pad preparation, base course installation, backfilling and compaction, drainage considerations, placement of additional courses and geogrid placement.

REFERENCES

Manuals

NPCA Quality Control Manual for the Precast and Prestressed Concrete Plants

Specifications

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 544, "State-of-the-Art Report on Fiber Reinforced Concrete"
ASTM International
ASTM A185, "Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete Reinforcement"
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 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 for Concrete Reinforcement"
ASTM A820, "Specification for Steel Fibers for 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 C260, "Standard Specification for Air-Entraining Admixtures for Concrete"
ASTM C494, "Standard Specification for Chemical Admixtures for Concrete"
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 C1017, "Chemical Admixtures for Use in Producing Flowing Concrete"
ASTM C1116, "Standard Specification for Fiber Reinforced Concrete and Shotcrete"

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

American Welding Society (AWS)

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

Occupational Safety and Health Administration (OSHA)

29 CFR 1910.184 (Slings)
29 CFR 1926.650-652 (Excavation)

Canadian Standards Association

CSA A3000 "Cementitious Materials Compendium"

Periodicals and Textbooks

Gowripalan, N., et al, "Effect of Curing on Durability," ACI, Durable Concrete, 1994
Hunter, L.E., "Concrete Waterproofing," Pitman & Sons, London, 1947
Kosmatka, Steven H. and Panarese, William C., "Design and Control of Concrete Mixtures," 13th edition, Portland Cement Association, Skokie, Illinois, 1988
Levett, M., "Precast Concrete," Applied Science Publishers, London, 1982
Mindess, Sidney and Young, Francis T., "Concrete," Prentice Hall, Englewood Cliffs, N.J. 1981
Neville, A.M., "Properties of Concrete," 4th edition, Wiley & Sons, New York, 1996
U.S. Department of Interior, "Concrete Manual," 8th edition, Denver, 1981
Portland Cement Association, "Design and Control of Concrete Mixtures," Fourteenth Edition, 2002
U.S. Department of Interior, "Concrete Manual," 8th edition, Denver, 1981
Waddell, Joseph, "Fundamentals of Quality Precast Concrete," National Precast Concrete Association, Indianapolis, IN

GLOSSARY

AASHTO- American Association of State Highways and 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 shales, 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.

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.

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 – - with respect to sliding and overturning, a minimum desirable factor of safety is 1.5 for sliding and 1.5-2.0 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.

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 upthrust of ground or pavement caused by the freezing of 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 by high tensile 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.

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.

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.

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

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

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 nonuniform 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-okabe 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 retaining wall is located.

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 because of the horizontal forces resulting from the soil backfill and other forces such as surcharge.

slope – the face of an embankment or cut 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 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, take care 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 is 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. 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 give a more aesthetic look.

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

water-cementitious ratio – 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 and abbreviated as w/c.

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

workability of concrete – that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated and finished to a homogenous condition.

This Best Practices Manual is subject to revision at any time by the NPCA Retaining and & Sound wall Product Committee, which must review it at least every three years.

Special thanks are given to the Retaining Wall Task Group for updating/compiling this manual:

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