WATER OPERATION AND MAINTENANCE BULLETIN

No. 191 March 2000

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- Shaking Table 2-D Models of Concrete Gravity Dam for Computer Code Validation

UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photograph*:** The first Koyna model before being mounted in the shake table.

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PIPELINE INLET SCREENING IN EID

One of the most persistent problems that irrigation districts face each year during irrigation is how to screen their irrigation water before it enters their closed pipeline systems.

Southern Alberta has relatively clean water, but nevertheless a considerable amount of debris, vegetative matter and trash is generated within the irrigation distribution system itself.

View of self-cleaning screen.

The Eastern Irrigation District's divisional superintendent Kevin Tebo needed a self-cleaning screen to prevent weeds from clogging up the inlet structure to Lateral G, North Bantry, a closed gravity pipeline system. "This pipeline draws approximately 3.03 m^3/s at full capacity and it was imperative that we kept the pipeline inlet structure free of weeds," says Tebo. The North Bantry canal which supplies water to Lateral G, will lose approximately 1/3 of its capacity throughout the irrigation season due to vegetation growth. "We clean that canal once a year, which uproots a lot of weeds, which compounds our weed problem at that pipeline inlet structure," states Tebo.

A Duperon self-cleaning trashrack made from lightweight, corrosion resistant steel was installed. A 1/8 HP motor powers, through a gear box, a continuous chain of urethane rakes that travel up a bar screen. As the loaded rake travels over the top, the weeds fall into a cast-in-place enclosure which is easily accessible by a front end loader. The urethane scrapers can vary in width and style depending upon the debris and intake requirements.

"We run the self-cleaning screen continuously through the peak irrigation season, and it worked very well in keeping the weeds clear of the pipeline inlet structure," says Tebo.

SAFETY CONSIDERATIONS

by Steve Engelman

The Bureau of Reclamation's (Reclamation) safety motto is, "Safety first, every job, every time!" This article includes information on confined space entry, lockout/tagout procedures, and personal and equipment safety. The following material on confined space entry is provided for your information.

Confined Space Entry Program

The Occupational Safety and Health Administration (OSHA) issued a general industry standard on permit-required confined spaces (permit spaces) on January 14, 1993, which became effective on April 15, 1993. This standard was promulgated in order to address instances of death and injury to employees who entered confined spaces to conduct work activities or attempt rescue of others.

Reclamation power and water facilities have areas which may be classified as confined spaces. Reclamation and irrigation district employees routinely enter these areas in order to conduct operation and maintenance activities.

In order to address the OSHA standard, Reclamation management has issued a directive (SAF 01-02) which states that all provisions of 29 CFR 1910 will be followed. The standards which Reclamation is committed to comply with in this respect are 29 CFR 1910.146 and 29 CFR 1910.269. Reclamation provides guidance documents through the Safety and Health Services/Management Services Office at the Reclamation Service Center in Denver. These documents suggest a means to comply with these standards.

The OSHA standard regulates entry into confined spaces which are classified as permit spaces. Permit spaces are spaces which meet the definition of a confined space and also have an additional hazard potential of an atmospheric or physical nature.

OSHA defines confined spaces as a space which has limited or restricted means of entry or exit. It is large enough for an employee to enter and perform assigned work, but it is not designed for continuous occupancy by the employee. In 29 CFR 1910.120, OSHA identifies spaces such as tanks, vessels, silos, storage bins, hoppers, vaults, and pits as examples of confined spaces. Incidents reported and classified as confined space accidents include spaces such as mixers, sewers, trenches, drums, boilers, crushers, furnaces, presses, drains, and traps.

Reclamation facilities, including utility manholes, pipelines, penstocks, scroll cases, tunnels, shafts, and siphons, are some of the spaces for which consideration must be given for applicability of the OSHA standard.

In order for a confined space to be classified as a permit space, it must also have **one** of the following hazards associated with the space or introduced by an operation to be conducted in the space.

Atmospheric Hazard

The space has, or has the potential to have, an atmospheric hazard which exposes entrants to risk of death, injury, acute illness, or impairment of the entrant to exit the space unaided.

Conditions which would constitute a hazardous atmosphere would include an atmospheric concentration of:

- A substance exceeding its permissible exposure limit or an Immediately Dangerous to Life or Health (IDLH) value which could cause at least one of the risks stated

- A flammable gas, vapor, or mist in excess of 10 percent of its lower flammable limit (LFL)

- An airborne flammable dust in excess of its LFL

- An oxygen concentration below 19.5 percent or above 23.4 percent

Engulfment Hazard

The space has, or has the potential to have, a means of surrounding and capturing the entrant by a liquid or flowing solid substance that can cause death by strangulation, constriction, or crushing.

Entrapment Hazard

The space's internal physical configuration can trap or asphyxiate an entrant.

The first order of business for management is to determine whether there are confined spaces in Reclamation facilities or in facilities controlled by others (i.e., irrigation districts) which Reclamation employees are requested to enter. Once confined spaces are identified, each confined space and the activities to be conducted within the space must be assessed for inherent, as well as introduced, hazards. This assessment process is best documented through the establishment of a confined space inventory system which describes the space, location, space and operational hazards, and the classification of the space.

Any facility which contains permit spaces must have a system of notification to restrict unauthorized entry. When facilities have permit spaces, the regulations require that all entries must be controlled, and if nonfacility personnel are requested or required to enter, facility management must notify the entry personnel of the status and hazards of the space. Confined spaces must be analyzed for inherent and introduced hazards based upon the operations to be conducted in the confined space in order to determine whether they are "permit-required" confined spaces.

Once a space has been determined to be "permit-required," the requirements of 29 CFR 1910.146 and 269 must be implemented. Reclamation guidance suggests that the management requirements of the standard are best met by establishing administrative assignments which authorize specific individuals within specific organizational units to perform the necessary functions necessary to efficiently manage the program.

These assignments include a position (program coordinator) which is authorized to oversee the entire program within a facility or organization. This program coordination position would be responsible for establishing program procedures as well as monitoring the status of implementing the confined space entry program.

Assignments within the facility or organizational personnel office should be made in order to meet efficiently the training and medical qualification provisions of the standards. Management is required to provide training to all entry personnel which provides the understanding, knowledge, and skills necessary to safely perform each individual's assigned duties. In addition, all entry personnel will be provided appropriate medical evaluations and clearances determined necessary to protect the safety and health of the employee. If entrants will be required to use respiratory protection, a medical evaluation and respirator fit test must be provided. Also, if entrants are expected to perform duties of a stressful nature, it is suggested that management assess the entrant's health status through a medical evaluation of the employee's capability to conduct the assigned duties safely. The training and medical evaluation provided must be documented.

A permit system must be established for entries into "permit-required" confined spaces. All entries are conducted under the direction of an entry supervisor who has specific responsibilities required by the regulations. The system or program establishes the means for preparing, issuing, using, and canceling detailed written entry procedures. A management-level review must be conducted annually to evaluate the adequacy of implementing the program and the efficiency of each entry permit.

Each entry into a permit-required space requires a separate written permit which identifies the hazards and controls for conducting the operation. The written permit establishes the procedures to be followed, the equipment to be used, and the responsibilities of all involved individuals. The permit also details the communication and emergency procedures which are to be in place for the entry. Each permit must be signed by management officials given entry supervisory responsibilities to attest to the adequacy of the entry procedures and that preparatory entry conditions have been met.

Entries into spaces with potential atmospheric hazards require testing for oxygen, combustibles, and toxic contaminants to ensure that contaminant concentrations do not exceed established limits. Testing is conducted as often as necessary to ensure that conditions are suitable for work within the space. Proper selection and use of the monitoring instrumentation, as well as knowledge of exposure limits of the contaminants, are critical for safe entry into spaces with atmospheric hazards. Air monitoring instruments must be intrinsically safe, portable, reliable, and easy to use. The instruments must be properly maintained and calibrated. Calibrations must be performed prior to and after entry in order to verify the accuracy of the instrument. It is important that adequate calibration records be maintained.

Knowing the capabilities and limitations of the instruments used is important. The person conducting the monitoring should be aware of the various factors which may affect instrument readings, such as response time and possible chemical interferences. The monitoring sequence must be appropriate. OSHA specifies that oxygen, combustibles, and toxic testing are sequentially sampled in order to ensure accurate readings. A user must know what conditions may cause instruments to go into an alarm mode and what may cause false alarms, such as discharged batteries or use in excessive humidity. The majority of these instrument types are sensitive to abuse which can cause instrument error.

Based upon accident data, OSHA has determined that asphyxiation is the leading cause of death in confined spaces. Several conditions and activities can cause an oxygen-deficient (less than 19.5 percent) atmosphere. An oxygen-deficient atmosphere can be caused by displacement by other atmospheric contaminants such as recirculated diesel exhaust, vaporized solvents, leaking gas cylinders, decomposition of organic materials, combustion, or other chemical reactions. Atmospheric hazards can also be created in the space by welding and grinding operations which introduce toxic substances from the metals or fluxes used.

A recent incident in Alaska involved a confined space with an operations-based atmospheric hazard. An individual died from asphyxiation upon entering a 30-inch stainless steel pipe which was being installed at Prudhoe Bay. The individual entered to adjust an argon dam constructed of styrofoam and wood. The argon gas is used to displace oxygen around the pipe’s seam to allow welding of the stainless steel. According to an expert witness at the trial against the company, argon apparently leaked outside the dam, displacing the oxygen in the space where the individual entered. The company provided no confined space training, had no entry procedures, and no had harnessing despite the pipe's laying at a sharp angle. The company was charged and convicted under the State’s penal statutes.

Atmospheric hazards in the confined space might require the use of respiratory protective equipment. The required equipment could range from an air-purifying respirator to a self-contained breathing apparatus. The proper respiratory protection must be selected on the basis of atmospheric oxygen and contaminant concentrations and characteristics with consideration given to the limitations created by the space to be entered and the operations to be conducted. Selecting respirators should be conducted with the assistance of an industrial hygienist. Personnel using respiratory protection must be provided medical clearance for respirator use and a respirator fit test.

Depending upon the hazards of the confined space, safe entry can be a very complex procedure. The importance of comprehensive hazard assessment of confined spaces and the operations to be conducted in the space cannot be overemphasized. It is essential that persons entering all confined spaces, especially permit spaces, exercise caution. Maintaining communication with personnel outside the permit-required confined space is critical in order to ensure timely response or rescue required because of an entrant's inability for self exit. Remember: SAFETY FIRST, EVERY JOB, EVERY TIME.

INTRODUCTION TO EROSION CONTROL PRODUCTS AND GEOTEXTILES

by Jay Swihart and Alice Comer

Erosion Control Products

The International Erosion Control Association's 1992 Winter Report estimates that $6 billion to $13 billion are spent annually in the United States to mitigate the offsite impacts of erosion and sediment. Sediment accounts for more than two-thirds of all pollutants entering U.S. waterways (Theisen, 1992). Geosynthetic component systems have been developed to help restrain the gradual or sudden wearing away of soils. We will discuss products ranging from temporary products, such as hydraulic-mulch geofibers, plastic erosion-control meshes and nettings, erosion-control blankets and silt fences, to the high-performance, turf-reinforcement mats, geocellular confinement systems, erosion-control geotextiles, fabric-formed revetments, and concrete-block systems. The type of erosion control system specified depends on a number of factors (e.g., slope angle, climate, runoff, soil profile, and ultimate land use). The specifier must select a technique that will perform up to expectations at the lowest cost.

The first group of erosion control products that we will discuss is materials of a temporary nature which facilitate vegetative establishment and then degrade. These short-term materials or temporary erosion and revegetation materials (TERMs) degrade, leaving only vegetation for long-term low to medium flow resistance.

TERM techniques include straw, hay, and hydraulic mulches; tackifiers and soil stabilizers; hydraulic mulch geofibers; erosion-control meshes and nets; erosion-control blankets; and fiber-roving systems.

Biaxially Oriented Process Nets

Biaxially oriented process (BPO) nets are typically manufactured from polypropylene or polyethylene resins. They can be designed for site-specific requirements for composition, strength, elongation, aperture size and shape, color, and ultraviolet stability.

Because they do not absorb moisture, they do not shrink and swell like paper nets and jute blankets. They are adaptable and have been used alone to anchor loose fiber mulches, such as straw, hay, and wood chips.

Lightweight nettings placed over mulches come in rolls that are 3 to 4-1/2 meters in width, weigh about 55 kilograms, and will cover 0.4 hectares (one acre) or more. Installation of these products is less labor-intensive than traditional netting products.

Erosion-Control Meshes

A step above BPO nets are woven polypropylene geotextile erosion-control meshes. The newer twisted-fiber, erosion-control meshes can provide comparable performance to natural-fiber erosion-control blankets.

These photodegradable, natural-looking, high-strength polypropylene meshes protect the soil surface from water and wind erosion and accelerate vegetative development. Light rolls, 4 meters wide, facilitate installation on slopes and channels.

Erosion-control meshes may be used alone, with dry mulches, or as a stabilizing underlay for sod reinforcement. They also show promise as an open-weave geotextile facing for fostering vegetation on geosynthetically reinforced steepened slopes of bioengineering installations where establishment of woodyplant species is desired.

Displaying rapid photodegradation in one direction, these meshes allow woody vegetation to freely sprout and emerge through the installation with little potential of girdling.

Erosion-Control Blankets

BOP nettings or woven meshes of varying characteristics are placed on one or both sides of finely tuned, erosion-control blankets adapted to anticipated site conditions. These 1- to 2-meter-wide biodegradable fiber erosion-control blankets are composed of straw, excelsior, cotton, coconut, polypropylene, or blends.

Nettings or meshes may contain ultraviolet (UV) stabilizers for controlled degradation or long chain interrupters to accelerate photodegradation. Colors vary from clear, tan, or green to black.

Methods of holding the fibers in place range from glues and glue strips to more superior parallel lock stitching with cotton, polyester, or polyolefin threads.

Applications for the wide variety of blankets range from protection of gradual to steep slopes to low or moderately flowing channels. The top-of-the-line blankets may provide temporary resistance to short-duration flow velocities of up to nearly 3 meters per second.

Perhaps most advantageous to the environment, these meshes and nettings may ultimately become biodegradable. As photodegradation progresses, the plastic chains break into shorter and shorter segments down to a plastic "sand" which becomes part of the soil. These short segments become biologically degradable and are attacked by soil microorganisms and converted to carbon dioxide and water.

TERMS Versus PERMS

The second group of erosion control products is more permanent. These materials are utilized where site conditions require the higher performance of reinforced vegetation or revetment systems. The permanent erosion and revegetation materials (PERMs) may be divided into subcategories of those having reinforced-vegetation (biotechnical composites) or hard-armor systems.

Biotechnical composites are composed of nondegradable materials which furnish temporary erosion protection, accelerate vegetative growth, and ultimately become synergistically entangled with living plant tissue to extend the performance limits of vegetation. These materials provide permanent, medium to high flow resistance when they are protected from sunlight by shading from vegetation and soil cover.

Examples of biotechnical composites (PERMs) include UV-stabilized fiber-roving systems, erosion-control revegetation mats, soil and sports turf geofibers, vegetated geocellular containment systems, and vegetated concrete-block systems.

The hard-armor systems (PERMs) generally employ inert materials used to provide high to maximum flow resistance where conditions exceed performance limits of reinforced vegetation systems. Hard-armor systems are used to provide permanent erosion protection of areas subject to high flows, wave action, and/or scour attack. Examples include geocellular containment systems, fabric-formed revetments, concrete-block systems, gabions, riprap, composites, and hybrids.

Fiber-roving systems are another geosynthetic system providing moderate erosion protection. Developed in the late 1960s, rovings are applied in a continuous strand for protection of drainage swales and slopes.

Fiberglass roving is a material formed from fibers drawn from molten glass and gathered into strands to form a single ribbon. Polypropylene roving is formed from continuous strands of fibrillated yarns wound onto cylindrical packages so the material can be fed continuously from the outside of the package.

Use of fiberglass roving has been declining because of its carcinogenic properties and is being displaced by more versatile, environmentally friendly polypropylene roving.

Erosion-control roving is unusual because of the flexibility of application, allowing for any width of thickness of material to be applied (Agnew, 1991). Other erosion-control materials, such as blankets or mats, require the user to apply the width or thickness of material supplied.

Fiber rovings may be viewed as an *in-situ* erosion-control geosynthetic with reduced labor and material costs over traditional blanket materials. Installation is easier, with minimal waste factors from overlap. Using compressed air, roving is rapidly applied through a nozzle over the seeded surface and then anchored in place using emulsified asphalt or other natural or synthetic soil stabilizers.

Photodegradable polypropylene roving may be used for temporary applications (TERMs) or when UV stabilizers are added for extended use situations (PERMs). In addition, these polypropylene roving systems may be colored to match substrates or improve visual aesthetics.

The use of fiber-roving systems (FRSs) is rapidly expanding. Key markets include highways, surface mines, and landfills. The future in FRSs lies in the development of a one-step application apparatus to further accelerate installation efficiency. The concept of developing an on-site mat or blanket is appealing and extremely cost effective.

Geosynthetic Mattings

Geosynthetic mattings generally fall into two categories: turf reinforcement mats (TRMs) or erosion-control revegetation mats (ECRMs).

Turf reinforcement is a method by which the natural ability of plants to protect soil from erosion is enhanced through the use of geosynthetic materials. A flexible three-dimensional matrix retains seeds and soil, stimulates seed germination, accelerates seedling development, and, most importantly, synergistically meshes with developing plant roots and shoots.

In laboratory and field analyses, biotechnically reinforced systems have resisted flow rates in excess of 4 meters per second for durations of up to 2 days, providing twice the erosion protection of unreinforced vegetation (Carroll, Rodencal, and Theisen, 1991).

Such performance has resulted in the widespread practice of turf reinforcement as an alternative to concrete, riprap, and other armor systems in the protection of open channels, drainage ditches, detention basins, and steepened slopes. Permanent geosynthetic mattings are composed of durable synthetic materials stabilized against UV degradation and inert to chemicals normally encountered in a natural soil environment. These mattings consist of a lofty web of mechanically or melt-bonded polymer nettings, monofilaments, or strong and dimensionally stable matrix. Polymers include polypropylene, polyethylene, nylon, and polyvinyl chloride.

High-strength TRMs provide sufficient thickness and void space to permit soil filling/retention and the development of vegetation within the matrix. TRMs are installed first, then seeded and filled with soil. By their nature of installation, TRMs can be expected to provide more vegetative entanglement and long-term performance than ECRMs.

Geocellular Containment Systems

Geocellular containment systems (GCSs) work in a unique fashion; their strength or stabilization by confinement is achieved by a series of three-dimensional cells up to 20 centimeters deep. When expanded into position, the polyethylene or polyester cells have the appearance of a large honeycomb, one of nature's most efficient structures. The cells are then backfilled with soil, sand or gravel, or concrete depending upon application.

Vegetated GCSs are limited to flow velocities of 2 to 3 meters because of the tendency of the cells to sustain scouring under high-flow velocities of shear conditions. For high-flow conditions, GCSs may act as an easy-to-install form that is filled with concrete or grout to create a hard-armored system. Typically, a geotextile will be placed beneath the expanded web to provide separation and/or filtration.

GCS applications include erosion control for steep slope revegetation, channel liners, shoreline revetments, retaining walls, boat ramps, and low-flow stream crossings.

Fabric-Formed Revetments

Fabric-formed revetment systems (FFRs) are mattresses typically constructed of water permeable, double-layer woven geotextiles that are positioned on the area to be protected and filled with a pumpable fine aggregate concrete (structural grout). The two layers of geotextile are joined at discrete points to create a form which, when filled with grout, will conform to most subsoil conditions. Thickness and geometry are determined by internal spacer threads woven into the upper and lower sheets of fabric.

Installation of FFRs consists of four basic steps:

- Site preparation
- Geotextile and panel placement/field assembly
- Structural grout pumping
- Inspection of field seams, zipper connectors, and lap joints

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Agnew, William, *Erosion-Control Product Selection*. Geotechnical Fabrics Report vol. 9, No. 3, pp. 24-27, St. Paul, Minnesota. USA, April 1991.

Carroll, Robert G., Jr., Jeff Rodencal, and Marc S. Theisen, *Evaluation of Turf-Reinforcement Mats and Erosion-Control and Revegetation Mats under High Velocity Flows*. Proceeding of the XXII Annual Conference of the International Erosion Control Association, Orlando, Florida. USA, 1991.

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Geotextiles

Introduction

Geotextiles are the most versatile and widely used of the geosynthetic products. They were first used in the 1950's for erosion-control applications as an alternative to cumbersome granular soil filters. Today, they have a long list of uses, and new applications are developed daily.

Types

Geotextiles go by a number of names dating back to their early use including filter fabric, construction cloth, and road rug. They come in two basic types: woven and nonwoven. The woven products are generally stronger, but the nonwovens are generally less expensive for light-duty applications. The individual fibers that make up geotextiles are synthetic polymers providing excellent strength and durability.

Design by Function

Geotextiles have numerous civil engineering applications, but all applications break down into four basic functions:

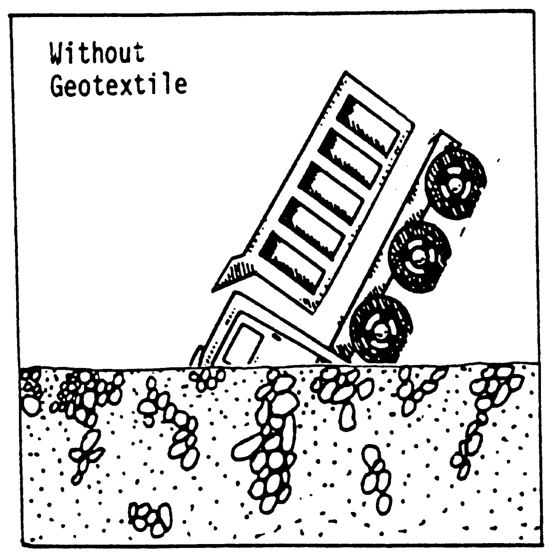
Separation — Geotextile used between dissimilar materials to maintain or improve the function and integrity of both.

Reinforcement	Geotextile (good in tension) used to improve the strength of a soil (poor in tension but good in compression).
Filtration	The flow of liquid (but no soil loss) across the plane of the geotextile.
Drainage	The flow of liquid or gas (but no soil loss) along the plane of the geotextile.

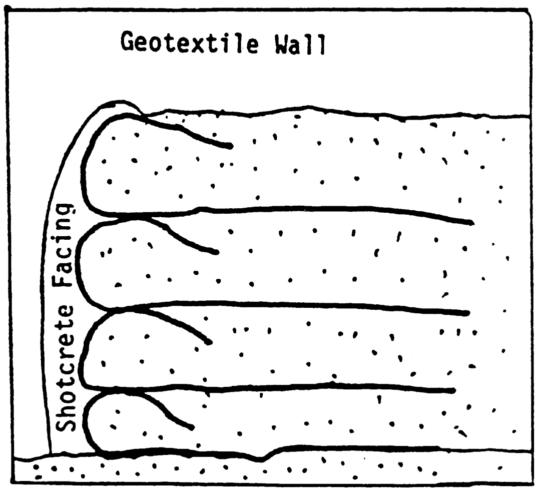
In many applications, a geotextile performs more than one of these functions simultaneously.

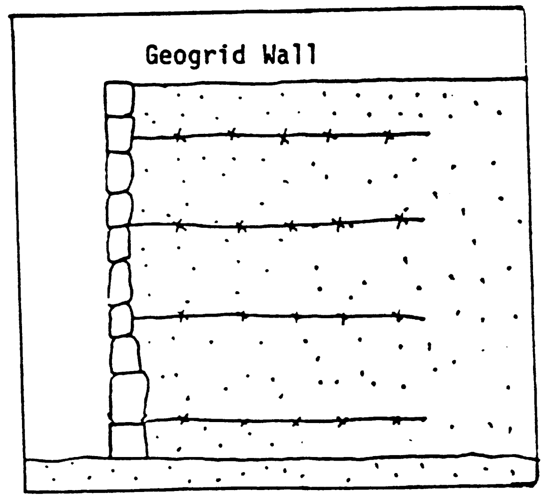
Geotextile Applications

Separation—Geotextiles are often used on unpaved roads because of the old engineering adage: "10 pounds of stone placed over 10 pounds of mud yields 20 pounds of mud!"

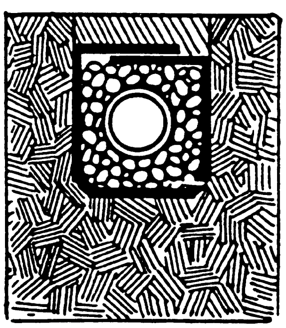


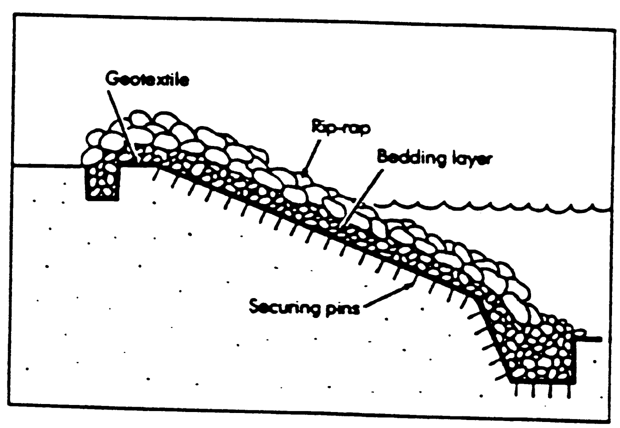
Reinforcement—Geotextiles can increase the bearing capacity of soft soils and allow the construction of steep embankments. For high-strength reinforcement, geogrids often prove more economical than geotextiles. Facing options include stone, masonry block, railroad ties, treated timber, shotcrete, concrete, etc.



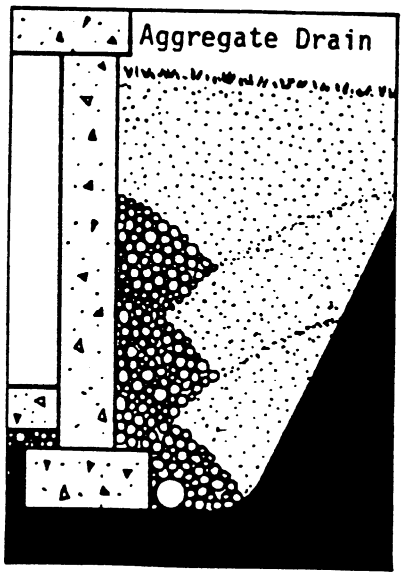


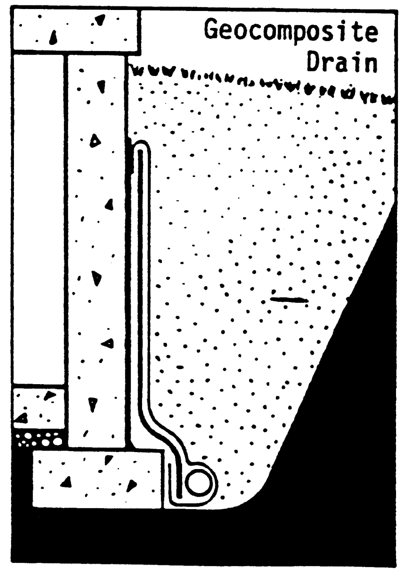
Filtration—Geotextiles are an alternative to thick, graded-soil filters and are routinely used with trench drains and for erosion control.





Drainage—Gases (air, methane, etc.) are often vented through a geotextile drainage layer. Liquids usually require a thicker drainage layer, such as an aggregate drain, leading to the use of geocomposites such as geonets, wick drains, or sheet drains.





SHAKING TABLE 2-D MODELS OF A CONCRETE GRAVITY DAM

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Summary

One of the most famous and studied cases of dams subjected to earthquake loading is the Koyna Dam in India. In this study, a 2-dimensional model of Koyna Dam at 1/50 scale was used on a shake table to simulate effects and serve as data for nonlinear computer model calibration. A new concrete mix was designed for the nonlinear similitude modeling. This new mix provided the correct kinematic failure of concrete at scale. Two models were tested to failure—one with an initial shrinkage crack and one monolith. Reservoir effects were not modeled. The results of both models are discussed and compared. The ability to model nonlinear effects is discussed.

Introduction

One of the most famous and studied cases of dams subjected to earthquake loading is the Koyna Dam in India. This 338-foot (103-meter) high concrete gravity dam suffered cracking during a magnitude 6.5 earthquake in 1967.[1] During this earthquake, the ground acceleration in the stream direction reached 0.49 gram, with a total duration of strong shaking lasting about 4 seconds. At the time of the event, the reservoir was 37 feet (11 meters) below the crest.

Following the Northridge earthquake on January 17, 1994, and the earthquake in Kobe, Japan, 1 year later on January 17, 1995, new information about vertical acceleration magnitudes was available. Continuing concerns about the performance of concrete dams subjected to severe earthquakes has stimulated research to find new approaches to analyze and predict this performance using nonlinear numerical analysis techniques.[2] In some cases, linear dynamic analyses indicate high stresses which can only be studied using nonlinear models.

Several studies have been conducted on gravity dam monoliths.[2,3,4,5] In references 2 and 3, attention was given to developing a modeling material which maintained similitude with the prototype. In reference 2, test results were compared to linear elastic analysis results. More recent studies have been completed using models tested in centrifuges.[6,7] This more recent work was developed to provide data which can be used for comparison to numerical models.

The purpose of this investigation was to produce results that could be compared to nonlinear computer models. The geometry of the model was scaled from the Koyna Dam and followed previous work.[2,3] The models were designed, to the extent possible, to maintain similitude relationships and yet be simple enough for direct comparison with computer-predicted results. To this end, unlike the previous studies,[2,3] similitude with reservoir effects is not attempted, thereby eliminating the need to model coupling effects. Two models were tested—a model with a natural pre-existing crack and a monolithic model failed during testing.

Experiment Set-Up and Procedure

The scale chosen for this model was a 1/50 geometric scale. Similitude requirements for models have been summarized in other references,[8] and estimated properties of Koyna Dam have also been suggested.[2,3] These properties are summarized in table 1.

Table 1.—Estimated concrete properties, the associated scale factors, and the model material target values

Property	Prototype estimate	Scale factor	Target value
E	27,940,000 kPa (4,000,000 lb/in^2)	50	558,800 kPa (80,000 lb/in^2)
f_c'	27,940 kPa (4,000 lb/in^2)	50	558.8 kPa (80 lb/in^2)
f_t	2,794 kPa (400 lb/in^2)	50	55.9 kPa (8 lb/in^2)
Density	2,403 kg/m^3 (150 lb/ft^3)	1	2,403 kg/m^3 (150 lb/ft^3)
ε_u^c	0.0025	1	0.0025
ε_u^t	0.00012	1	0.00012

Concrete Mix Design and Material Properties

For this study, a new low strength concrete mix was designed. Considerable work had been accomplished in previous studies[2,3,9] to produce an appropriate similitude concrete mix. As suggested, curing and the associated shrinkage cracking can be problematic when using concrete mixes having highly reduced properties. In addition, the use of any lead product to meet density requirements needs to be analyzed to assure that requirements for handling, storage, and disposal of hazardous wastes are met. This latter problem, in particular, limits the ability to have the material commercially produced and complicates the disposal of such materials. In addition, when modeling nonlinear failure, consideration must be given to reproducing the correct failure mechanism at model scale.

The concrete mix for this study used bentonite pellets as a component to reduce strength. The use of bentonite pellets poses a problem logistically since saturation of the pellets is required prior to mixing.

The trial mix was initially made in the laboratory with bentonite hydration accomplished overnight. Based on the apparent success of this mix, both shake table models were made using this bentonite-concrete mix design. Due to the volume required for the shake table models (6 cubic yards, including test cylinders), the actual model mix was ordered and supplied commercially. For the commercial mix, hydration was attempted in the mixer drum during transit. At the batch plant, the water was reduced from the original design to decrease sloshing in transit. On-site water was added to achieve a slump of approximately 7.5 inches which was believed would indicate a mix similar to the laboratory mix. The resulting water content for the model mix was lower than the original laboratory mix due to incomplete hydration of the bentonite during transit. The incomplete hydration of bentonite resulted in a higher free-moisture content and, thus, higher slump for a given water content. Properties for the models were reasonably close to requirements.

Laboratory testing was done in support of each experiment. Standard 6" x 12" cylinders of the bentonite concrete were made from each batch. Stress-strain data for a typical compression test are shown in figure 1. Of particular significance, typical of normal concrete, breaks for all compressive cylinder tests failed in a classic shear plane of approximately 65 degrees.

Model Construction and Instrumentation

Tests were completed in the Bureau of Reclamation's (Reclamation) Materials Engineering and Research Laboratory. The Vibration Laboratory for large-scale tests has been in existence at Reclamation since 1969.[10] For these experiments, the models were constructed on a shake table and excited in a single axis corresponding to a horizontal motion along the upstream-downstream axis. A sinusoidal excitation of 14 Hz, the predicted first mode of the structure, was selected for practical reasons associated with the table and for simplicity in numerical model calibration.

The first Koyna model is shown in figure 2; the second Koyna model is shown mounted on the shake table in figure 3. The 1/50 scale chosen results in an 8.5-foot (2.6-meter) tall model weighing 7,850 pounds. A slab representing the foundation was poured monolithically with the model to provide a fixed lower boundary at the base of the dam. All-thread rods were imbedded in the foundation to provide a means of anchoring the model to the shake table. Instrumentation was designed to measure displacements and accelerations on the model and from the input actuator.

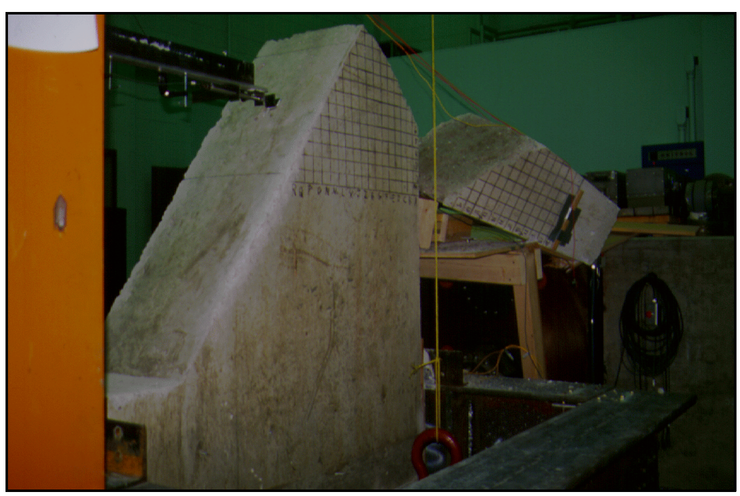

Figure 2.—The first Koyna model before being mounted in the shake table.

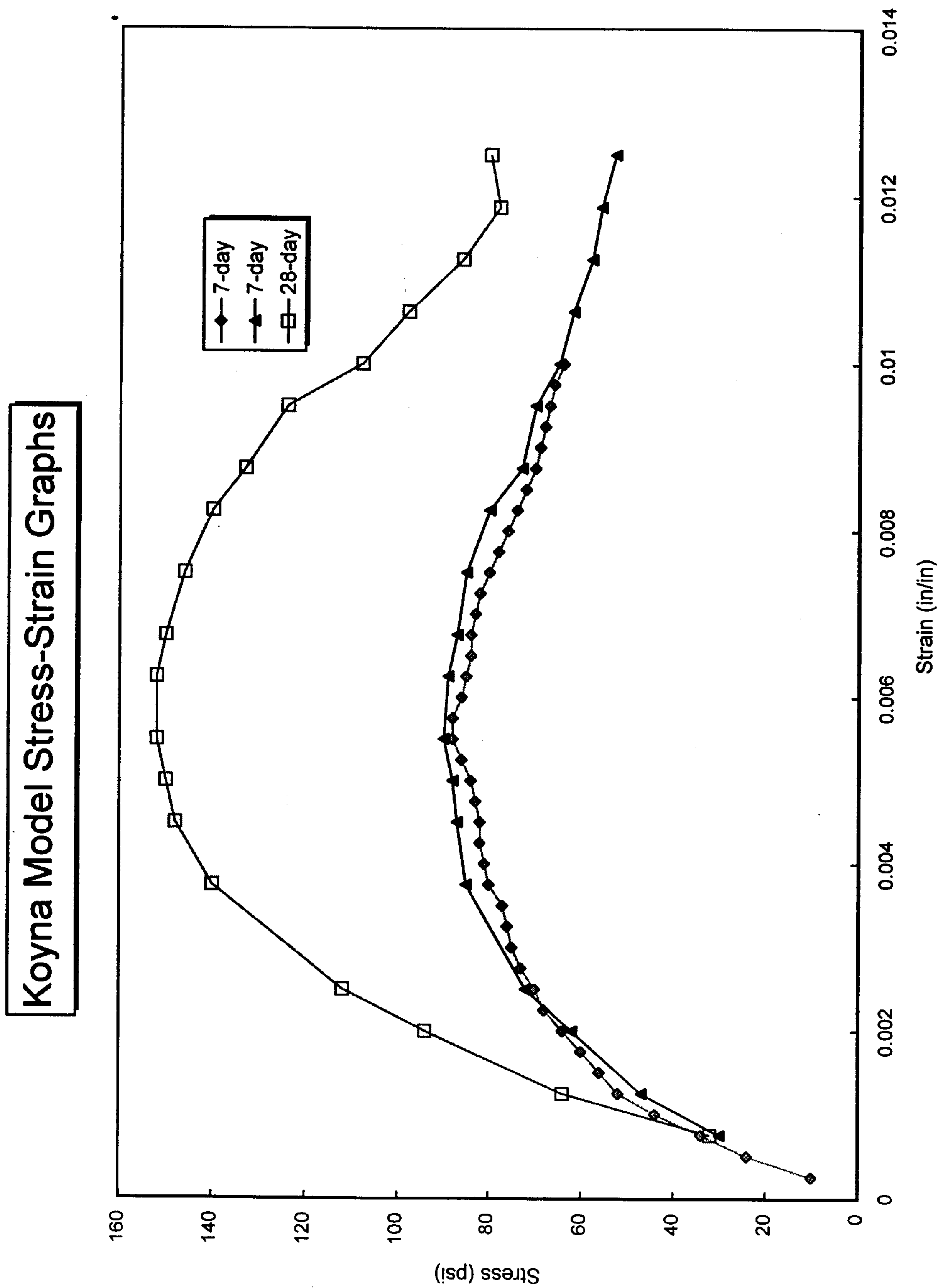

Figure 1.—Stress-strain graphs.

Figure 3.—The second Koyna model mounted on shake table.

The first model was cast laying down on its side adjacent to the shake table. In this position, forming and placing was much easier, having an entire face for access and only a 1-foot, 9-inch depth of material. After a period of approximately 20 days, a small shrinkage crack appeared on the exposed face. At this time, tension tests were run which may be useful in modeling the onset of shrinkage. At approximately 28 days, the model was lifted onto the shake table, and the forms were removed. The shrinkage crack was evident on the side of the model and on the sloped face and was assumed to extend through the model to the other two adjacent faces. The plane of the crack had an inclination of approximately 20 degrees from horizontal towards the side of the model. After approximately 1 additional week, the surface had dried sufficiently to apply instrumentation, and the test was run.

The second model was cast upright in the shake table and was tested at 15 days to avoid the shrinkage cracking experienced in the first model. By casting upright and testing earlier, the onset of shrinkage cracking was avoided, and the second model produced a material failure under dynamic loading. Another benefit of testing the model earlier was the lower strength of the material. A complete suite of laboratory tests was performed on the material immediately following the testing of the model.

Summary conclusions from the tests are as follows:

1. A new concrete mix design is proposed which shows promise for use in similitude testing. The mix uses bentonite to reduce strength properties of the concrete and can be readily adjusted to simulate various scales. The components may be mixed in mass and can be provided by commercial producers because no hazardous materials are used. Disposal is also easily accomplished by conventional methods.

2. The new mix produces strength and stiffness characteristics which nearly match the similitude requirements. More importantly, for nonlinear modeling of the failure mechanism, the mix fails in a shear plane almost identical to conventional concrete.

3. The initially cracked model (model 1) and the monolithic model (model 2) showed general modal characteristics which were similar for small accelerations.

4. Model 1 is characterized as a kinematically nonlinear model because its initially cracked top section failed in a sliding mode. This model demonstrated that there was some initial bond on a typical shrinkage crack. This model showed that even a crack visible to the eye on multiple faces must overcome some bonding before sliding can occur.

5. When sliding of a failed section initiates, the nonlinear effect creates very large changes in the dynamic response under a constant sinusoidal input motion. The amplitude above the crack in this model actually becomes less than the base, and the response is phase shifted. Put simply, the base can move back and forth beneath the top with the motion being only loosely coupled.

6. The monolithic model (model 2) failed with a material failure which was characteristic of previous models and is believed to be characteristic of cracks in actual cases.

7. During the monolithic test, a change in the base boundary condition created a highly nonlinear and indeterminate boundary condition. This nonlinear change also showed large changes in the dynamic response of the model which are easily seen in comparison to the constant motion input. Unfortunately, this same boundary condition change makes exact time history matching with numerical models impractical.

8. Both models failed at approximately 2.2 g's of acceleration. In the kinematic model (model 1), sliding created a slow progressive sliding during the cyclic motion. In the materially nonlinear model (model 2), a crack was initiated in less than 1/30 of a second, and sliding occurred for a number of cycles before the top of the model toppled. The toppling is inconsistent with previous models and is believed to be related to vertical accelerations produced by the boundary condition change.

9. Laboratory tests were performed on the material used to construct the shake table models to provide parameters typically needed in nonlinear numerical models.

10. Results in the kinematic failure model (model 1, sliding) can conceivably be time-step matched to verify nonlinear models. Results from the materially nonlinear model (model 2) can be verified in a general manner to verify cracking pattern and acceleration required for failure.

Acknowledgments

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Mission

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