CEDERGREN, H. R.
Consulting Engineer, Sacramento, California, USA

Overcoming Psychological Hang-Ups is Biggest Drainage Challenge
Vaincre les préjugés est le problème prioritaire du drainage

Drainage systems, often incorporating synthetic textiles, are helping to make Civil Engineering projects safe from damaging actions of water. Great progress has been made in recent years, but several archaic and unrealistic negative beliefs and attitudes are hampering progress. Overcoming these "hang-ups" is a bigger challenge than designing good drainage systems. Upmost examples are the following: (a) The belief that drainage itself is not necessary, not practical, or too expensive, (b) The belief that nearly every drainage problem can be solved by the use of blends of sand and gravel containing moderate amounts of fines, and (c) A general reluctance on the part of specialists to try any new idea or product that does not have a long experience record. Until these psychological hang-ups can be overcome, the potential benefits of drainage and synthetic textile products in them cannot be fully realized. Meetings such as the 1st International Conference on the Use of Fabrics in Geotechnics and the present one can do a lot to open the eyes of people designing engineering works needing good drainage systems.

Les systèmes de drainage, qui comportent souvent des textiles synthétiques, contribuent à protéger les ouvrages de génie civil des effets destructeurs de l'eau. De grands progrès ont été faits ces dernières années, mais un certain nombre de préjugés archaïques, inexacts et négatifs font encore obstacle au progrès. Surmonter ces idées préconçues est une tâche plus considérable que de calculer de bons systèmes de drainage. Les exemples les plus criants sont les suivants: a) l'idée selon laquelle le drainage lui-même n'est pas nécessaire, pas efficace, ou trop cher; b) la notion selon laquelle tout problème de drainage ou presque peut être résolu au moyen de mélanges de sable et de gravier contenant une fraction modérée de fines; c) la réticence généralisée de la part des spécialistes à essayer toute idée nouvelle et tout produit qui n'a pas des références nombreuses et anciennes. Tant que ces préjugés ne seront pas éliminés, les avantages potentiels de l'emploi des textiles synthétiques dans le drainage ne pourront pas être pleinement reconnus. Des manifestations comme le 1er colloque international sur l'emploi des textiles en géotechnique et comme le présent congrès peuvent faire beaucoup pour ouvrir les yeux de ceux qui établissent les projets des ouvrages de génie civil où un bon drainage est nécessaire.

INTRODUCTION

Drainage, often with the aid of synthetic textiles, is doing a great deal to make Civil Engineering projects safe from detrimental actions of water. Significant progress has been made in the past few years, but a number of unfounded negative beliefs and attitudes (hang-ups) are greatly interfering with progress, with the result that many engineering works create unnecessary hazards to the public, and deteriorate prematurely from the effects of water. Several prime examples discussed in this paper are the following:

(1) The belief that drainage itself is not necessary, is not practical, or is too expensive is a prime hang-up. This attitude has resulted in widespread practices that eliminate drainage as a design consideration in some important areas of engineering. Two areas are discussed here: (a) One example is the thousands of miles of dikes and thousands of small dams which have been built without drains. All of these structures would be safer with good drains. Upgrading existing structures and providing drains in the ones built in the future would be of great benefit to people in virtually every part of the world. (b) The second example is the common practice of designing pavements as "strong" but undrained systems. In this area alone, a lack of drainage is causing premature damage that is costing taxpayers throughout the world countless billions of dollars a year.

(2) The belief that nearly every drainage problem can be solved by the use of drains constructed of blends of sand and gravel containing not more than 5% of fines (material finer than 0.074 mm (No. 200 sieve) is a hang-up of major proportions. This widespread fallacy is a major obstacle to the use of the textiles in engineering projects requiring drainage, as it implies that they are seldom needed. Single-layer (and even some multiple-layer) drains constructed with sand and gravel blends seldom have the conductivity ($\underline{k}$ x thickness) needed to accommodate all of the water entering drains and thus protect Civil Engineering works from damaging actions of water. Quantities of water needing to be removed by drains for engineering works should always be estimated by appropriate calculations with Darcy's law and flow nets, or other suitable methods. Such calculations nearly always show the need for a layer of open-graded (narrow size-range) aggregate in the conducting part of a drain. And this mandates the use of some kind of filter--either specially processed good quality aggregate or a suitable textile--to prevent clogging of the open-graded layer.

(3) A general reluctance on the part of specialists of all kinds to try any new idea or product that does not have a long track record has impeded progress in all fields of technical and medical work. It has kept the textiles out of many projects where they might have been of significant benefit. A coordinated educational program is needed to overcome negative attitudes about textiles in drainage systems.

FIRST HANG-UP:

The belief that drainage is not necessary, is not practical, or is too expensive.

Drains are routinely designed for large earth dams, concrete dams, drydocks, large retaining walls, basements for large buildings, and many other major Civil

Engineering works needing protection from water. But they are almost never provided for many small, "unimportant" structures or to remove surface water entering pavements. An unwillingness to even consider drainage systems for many facilities is a hang-up of major size that can be blamed for huge economic losses and the existence of greater hazards to the public than would exist if the majority of these works were well drained. Examples are:

(a) Levees and Small Dams. Any water-impounding dam or levee that is not provided with a drainage system is susceptible to the development of concentrations of seepage on the downstream slope and beneath the downstream toe, as shown in Fig. 1. Any such structure is

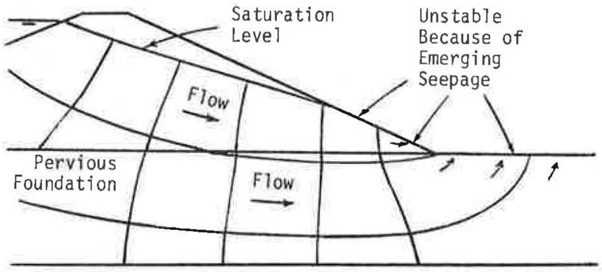

Fig. 1 Cross section through a typical dam or levee having no drainage system.

potentially likely to fail from seepage at some time. Although any dam or levee designer will probably admit that good drainage is a nice idea, he may say it isn't worth the cost for the countless small dams and thousands of miles of small levees around the world. Hopefully as more and more people become aware of the fact that the probability of failure of any dam or levee can be substantially reduced by a drainage system constructed at its landside toe, funds will be made available to upgrade the safety of many of these structures not having drains.

Dams and levees that have not been provided with good drainage systems can fail from seepage with little or no advance warning, because undermining ("piping") from seepage can be occurring without much external evidence. One such small irrigation dam in a Western State had been given its regular annual safety inspection and reported "safe for continued use". That night it failed by piping, culminating years of undermining by seepage that had gone unnoticed. Seepage exit areas that are not covered with good filters and drainage layers can loose significant amounts of materials that are washed away and not even noticed, as was the case with this project, until a break-through occurs and a rapid failure ensues. When all important seepage exits are protected with good filters and surcharged with clean drainage aggregate and gravel fill, failures of this kind can be virtually eliminated because the soil particles are trapped by the filters, and the piping actions are not allowed to start.

Figure 2(a) and (b) shows two applications of geotextiles in drains for levees and small dams. Figure 2(a) shows a substantial toe drain that controls seepage in both the dam and the foundation. A suitable synthetic cloth or filter fabric protects an open-graded drainage layer from clogging, and another fabric keeps dirt out of its upper sides. To insure adequate permeability the open-graded layer should contain no material finer than about 1 cm. size. A pipe at the bottom conducts the seepage to gravity outlets or to sumps for removal by pumps. Most of the volume of the trench can be any stable earth fill, suitably compacted. A drain of this kind can be used for upgrading the seepage safety of countless miles of levees, and thousands of small dams with seepage problems. It is also a good type for new dams or levees to be constructed on permeable foundations.

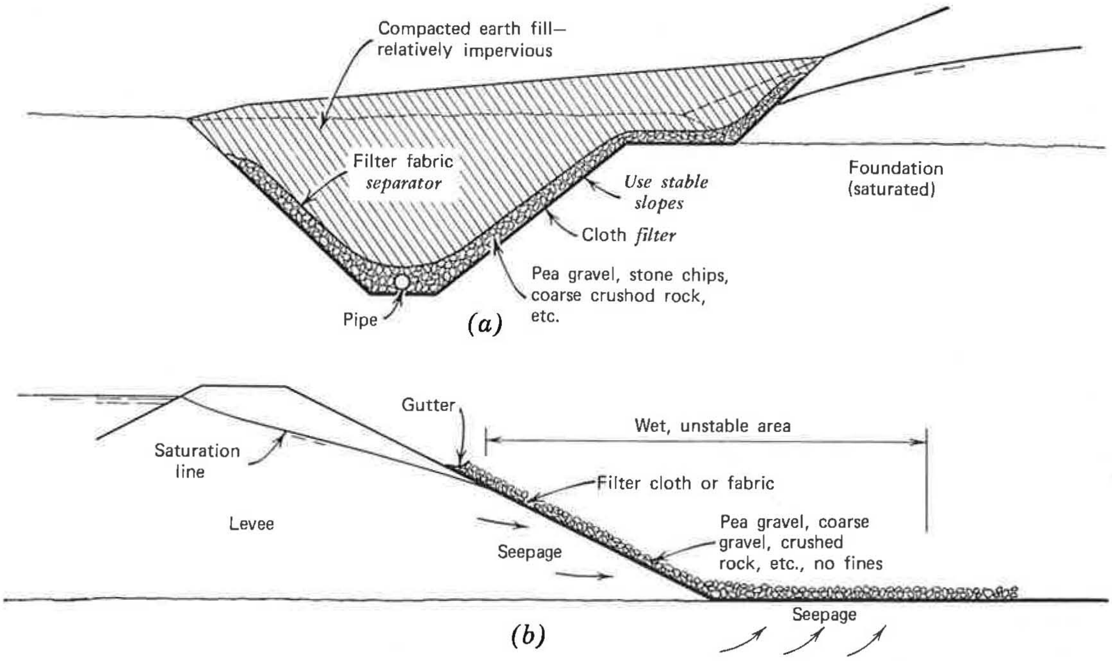

Fig. 2 Illustration of two potential uses for fabrics in drains for dams and levees. (a) A toe drain controlling seepage through dam and foundation, (b) A temporary measure for preventing imminent failure. (After Fig. 5.16 of "Seepage, Drainage, and Flow Nets," 2nd Ed., H. R. Cedergren, Copyright © 1977, John Wiley & Sons, Inc. N. Y. Reprinted by permission of John Wiley & Sons, Inc.)

Figure 2(b) shows a type of filter blanket that can be used to provide protection to levees and small dams with shallow seepage problems, such as minor sloughing, pin boils, and other shallow instability problems caused by seepage. If stockpiles of suitable porous aggregates and suitable fabric filters are kept on jobsites, and shallow seepage conditions should develop under high water stages, protective blankets of this kind can be quickly placed on troublesome areas. The fabric should have sufficient permeability to allow free flow of seepage into the aggregate layer which should be coarse gravel, crushed stone, railroad ballast, or comparable good-quality, highly permeable material. If additional weight is needed, any stable granular material can be placed over the drainage layer, provided a filter layer is placed where necessary to keep fine soils out of the coarse layer. This is not a recommended treatment for deep-seated instability problems, unless it is heavily ballasted.

Before the development of the synthetic fabrics, drains of the kinds shown in Fig. 2 would have been constructed as graded filters (1), with a fine aggregate filter layer being placed against the soil surfaces on which the drains were to be constructed, and one or more coarser layers to provide for water removal and weight (2), (3). Many water-impounding structures have been provided with drains constructed of durable, natural mineral grains; however it can be difficult to obtain filter aggregates fine enough to provide filter protection, yet permeable enough to freely remove all of the incoming water without the build-up of excessive head. Also, if the filter aggregates are placed on wet, soft ground, as for the levee in Fig. 2(b), the filter material tends to mingle with the wet soil, and its permeability is greatly reduced. Under such conditions, if a selected filter fabric is carefully rolled out over the surface needing protection, it serves as a separator, holding the soil in place, and preventing it from entering into the open-graded drainage layer and reducing its permeability.

The use of filter fabrics had a great deal of impetus in regions in which problems developed with sand and gravel filters that did not meet specification needs, and in cases where a lack of space made it difficult to place graded filters. In places where strong currents and heavy wave action would physically remove filter aggregates under large rock used for riprap and breakwaters, the synthetic fabrics have been particularly helpful. Barrett (4), Dunham and Barrett (5), and other workers describe early shore-erosion protection structures such as stone seawalls and jetties that used the fabrics to hold fine soils in place and thus prevent undermining of these works. Seemel (6) presents a good summary of the development and use of the fabrics. Numerous papers in the First International Conference on the Use of Fabrics in Geotechnics describe usages of fabrics in projects around the world.

In both of the examples given in Fig. 2, the drains are in exterior parts of the structures, and are accessible for removal and replacement if problems should develop over the life of a project.

If the belief that drains are not needed in many small structures such as levees and small dams can be overcome, drainage systems--often with the incorporation of fabrics-can be of great benefit in upgrading the seepage safety of countless structures around the world. An outstanding example of the use of fabrics to help upgrade seepage safety of existing structures is the dike for the Florida Power & Light Company's cooling water reservoir in Florida, where 1.5 million square yards (1,250,000 m^2) of nonwoven fabric was used in constructing a drain of the general type shown in Fig. 2(a) (7).

(b) Pavements. The modern belief of most pavement designers that internal drainage is not needed is a psychological hang-up of gigantic proportions, and one that defies explanation, as it cannot be justified on any engineering or economic basis. Because of it pavements deteriorate 3 to 4 times faster (annually) than if they were well drained.

Historically, road builders have believed in good drainage; however hardly any modern road designers do. As a consequence, nearly all of the important pavements that have been built in the past several decades have failure mechanisms built right into them. During the periods of time that structural sections are filled with water, the rates of damage (per traffic impact) can be hundreds to thousands of times greater than when there is little or no free water to be acted upon by traffic and climate. For centuries road builders have known that coping with the water that gets into pavements and the soils under them is the biggest obstacle to having long-lasting, trouble-free pavements. Even the Ancient Romans built their famous road system above the surrounding terrain to help eliminate water damage. In 1820 John L. McAdam (8) said that ". . . if water pass through a road and fill up the native soil, the road whatever may be its thickness loses support and goes to pieces." And, "The erroneous opinion . . . that (by) placing a large quantity of stone under the roads, a remedy will be found for the sinking into wet clay or other soft soils . . . (so) that a road may be made sufficiently strong artificially to carry heavy carriages though the subsoil be in a wet state . . . has produced most of the defects of the roads of Great Britain." His complaint is valid today.

Shortly after enactment of the U.S. Federal Aid Act of 1916, pavements were designed on the basis of the Soil Classification (A-1, A-2, etc.) and a designers experience and judgment. With the advent of modern Soil Mechanics methods, pavement designs have been based almost entirely on strength factors obtained by making tests on saturated samples of base and subgrade materials. Designers have tended to believe that these methods guarantee that any and all problems with water are automatically eliminated. Build pavements sufficiently "stout" and there is no need for drainage, is the idea. Since the loads applied in the tests are generally "static" and traffic impacts are "dynamic" one might expect shortcomings in the designs using these methods. Much of the damage to pavements is caused by the pore pressures and actions in the water impacted by heavy vehicles; other severe damage is caused by climatic actions on the trapped water, such as freezing, "D"-cracking, blow-up, shrinkage cracking, premature oxidation, and the break-out of chunks of pavement to create the well-known "pot holes". Most of these actions do not occur at all in well drained pavements.

In the period from about 1950 to 1962 several highly instrumented and documented "road tests" were made to determine what makes pavements break up and what can be done about it. The primary (but almost totally ignored) finding in these tests was that during periods when free water was trapped in the test pavements, each traffic impact produced up to hundreds and thousands of times more damage than when there was no free water in their sections. In the WASHO road test (9), damage rates were up to 70,000 times greater (per impact) with free water than with no free water present; in the AASHO road test (10), the wet damage rates were 10 to 40 times greater than the dry; in the Univ. of Ill. Circular Test Track experiments (11) they were 100 to 200 times greater with free water than without.

Those planning the Road Tests were thinking only in terms of finding the strongest combinations of pavement and base materials to resist damage, not at all in terms of eliminating the free water with good drainage. As a consequence, not a single one of the hundreds of combinations tested was well drained! And so the prevailing practice of pavement designers continued to be to design pavements "stout", but not even think of drainage as a viable design concept.

Confidence in the "un-drainage" philosophy has been so high that many designers look with disfavor on anyone who dares to question this approach, and deeply resent any suggestion that drainage is a better concept. As part of the work carried out to develop the FHWA's "Guidelines for the Design of Subsurface Drainage Systems for Pavement Structural Sections," (12) field interviews were conducted with State Highway engineers throughout the U.S. in the 1971-72 period. Comments made by persons interviewed probably represent a good cross-section of the opinions of pavement designers everywhere. One of those interviewed said, "I have nothing but contempt for anyone who thinks pavements can be drained." In a major Western state, a top pavement designer said, "But, of course, it is neither necessary, practical, nor economical to drain pavements." In all of these states, pavements were breaking up prematurely from traffic and undrained water.

An engineer in one state interviewed said, "Anyone who thinks pavements can be drained is a fool." He said they had tried drainage and it just doesn't work. They had meticulously compared hundreds of miles of "drained" pavements with many miles of similar, but "undrained" pavements and couldn't detect any difference in performance. On inquiry, we found that a "drained" pavement was a stretch of road (on their standard low-permeability sand base) with a narrow cross drain every 300 to 400 feet (91 to 122 m) with a drain pipe in a trench backfilled with concrete sand. Such a drain could not have had much influence in draining water out of more than a strip 2 or 3 feet (0.6 to 0.9 m) wide above each one of the drains; therefore there should have been no noticeable difference between "drained" and "undrained" pavements. Yet, these engineers were so firm in their convictions they were almost willing to come to blows with anyone disagreeing with them. What a hang-up they had!

In 1977 the U.S. Department of Transportation (DOT) released a report of a major study of the condition of our Nation's highways (13). That report said that out of a $450 billion total outlay expected for American roads between 1976 and 1990, $329 billion will be needed just to keep our roads in their 1975 condition. Applying information I have gathered in investigations of deteriorating highway and airfield pavements across the United States (12), (14), I estimate that the modern belief that pavements don't need to be drained can be blamed for about 2/3 of the repair and replacement costs facing our nation, which represents an unnecessary and avoidable loss of at least $15 billion a year (15) to American taxpayers, and on a world-wide basis, at least a trillion dollars over a 40 year period (16). Even though it is not possible to pin-point the exact losses caused by this hang-up, it must be evident that they represent a severe drain on already overburdened taxpayers.

Taxpayers, public officials, and members of the public media have become alarmed at the rapid deterioration of our "Magnificant Pavement System" that was supposed to represent the best thinking and modern technology, and consumed vast sums of materials, energy, and money. With over 116 million potholes jarring American drivers, and their cars and trucks, an emergency pothole filling bill by Congress was decried as "A Poor Choice of Patchwork" by Engineering News-Record (17). A U.S. News & World Report feature (18) says that Congress' increase in the allowable loads on federally-aided roads in 1974 from 73,280-lb. to 80,000-lb. was an "unwise" act by our legislators. It says that American roads--the most expensive public works undertaking of all time--are being battered to pieces. Numerous other national publications have expressed concern over the deteriorating pavements. Though the increase in loads voted by Congress has been a large factor in the accelerated damage to our undrained system, it would have had a great deal less impact had these pavements been well drained.

Many things contribute to pavement failure; however water is by far the greatest contributing factor (other than traffic impacts). The antiquated "un-drainage" philosophy is a hang-up that must be overcome, before significant improvement in the pavement deterioration dilema can be expected.

SECOND HANG-UP:

The belief that blends of sand and gravel containing a few percent of fines are suitable for all drainage needs.

This ill-conceived belief is a hang-up of major proportions, and one that is an obstacle to the use of the fabrics in drains as it implies they are seldom needed.

Human actions are often a matter of simply following a "popular" practice, no matter how rational or how irrational it may be. Popular practices, like a pendulum, often swing from one extreme to another. Beliefs about what kinds of aggregates are good drainage materials have gone through pendulum-like cycles over the years. After about 1750 there was a period when designers of roads and other engineering works believed that the coarse rock and boulders employed in "French Drains" were ideal materials. Under favorable conditions these drains often served their purpose, at least in part. But, when the large head-size boulders and rocks were placed in trench drains in erodible silts, fine sands, and the like, the drains often became clogged the first time the adjacent soils became saturated. So this kind of material fell in bad repute because of the piping and clogging it produced.

As engineers became concerned over the need to prevent piping, there developed a tendency to use blends of sand and gravel in drains without determining if the blends were permeable enough to remove the water without excessive build-up of head in the drains. They began to believe that concrete sand and other materials containing less than about 5% of fines (silt and clay) were satisfactory for virtually every drainage need. This widespread belief (hang-up) has led to the design and construction of many dams, levees, roads, and other Civil Engineering works that are poorly drained. It persists in spite of world-wide experience proving that this belief belongs in the fairy-tale world.

If errors in thinking about drainage requirements are to be eliminated, we must not forget that every seepage and drainage situation follows specific laws of Nature, and depends on physical factors such as coefficient of permeability, hydraulic gradient, and area of cross-section in which water is flowing. Seepage and drainage are quantitative problems, not qualitative. Each problem has its own specific solution. To ensure that drains will be able to remove the water reaching them, the inflows must be estimated with seepage principles and the required permeabilities and dimensions of drainage layers must also be calculated using the same fundamentals (3), (19), and (20).

Even the simplest "thumb-nail" calculation that uses reasonable values for permeabilities, gradients, and dimensions will almost always show the need for a layer of highly permeable, open-graded aggregate in drains for Civil Engineering works. And this dictates the use of filters--either special aggregates meeting accepted filter criteria, or suitable textiles--to prevent piping and clogging actions, together with a layer or zone of highly permeable aggregate that removes the water.

The filter requirements of drains have been described in many books and publications (21), (22), (23), etc., and the desired properties of fabric filters are discussed in recent publications (24), (25), etc.. Although the discharge needs of drains have had hardly any attention at all until recently, the principles that can be used in making these determinations (largely Darcy's law and flow

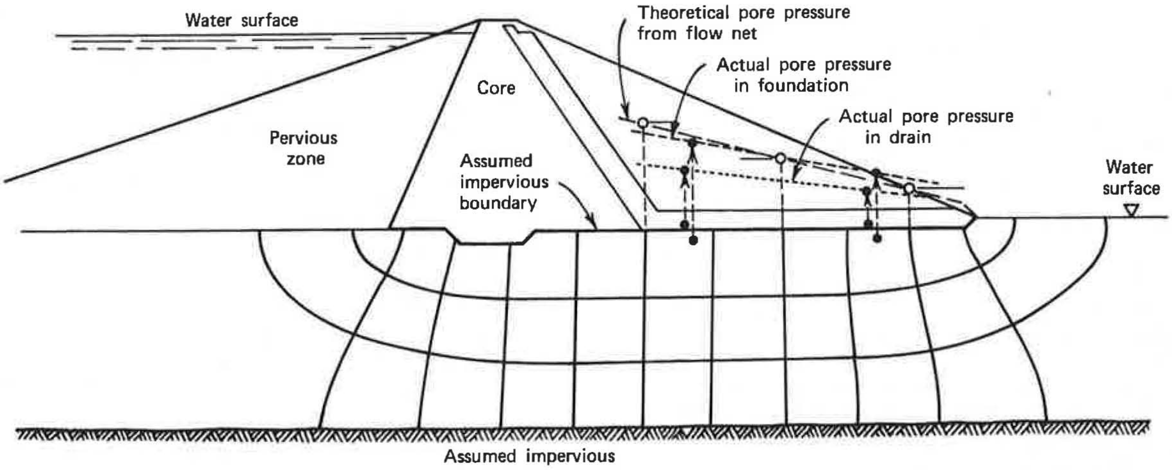

Fig. 3 Uplift pressures that built up under an earth dam with an expensive but ineffective drain were not measurably influenced by the drain (From Embankment-Dam Engineering, Casagrande Volume; 2nd Chapter, by H. R. Cedergren, "Seepage Control in Earth Dams." Copyright © 1973, John Wiley & Sons, Inc. New York. Reprinted by permission of John Wiley & Sons.

nets) have been described in many publications over the past 40 years or so (26), (27), etc.

The dam illustrated in Fig. 3 epitomizes the extremes to which the sand and gravel blend idea has been used in drains. Here, a 60 m high earth dam was built in 1965 in a Western state of the U.S. Designed and built by a major dam design firm, it has a very costly and complex drain system that provided no discernible benefits in controlling uplift pressures under the dam. All drain zones were constructed in three layers, with outer "fine filters" on both sides of an inner "coarse filter". All zones were allowed to contain up to 5% of fines, on the presumption that this amount of fines is satisfactory in drains. After water had stood in the reservoir for several months near the position shown, pore pressures in the drain and in the foundation built up to the levels shown. In order to better understand the problem I constructed the flow net shown, on the assumption that the drain was completely impervious (accepting no foundation seepage). Piezometric heads obtained from the flow net are also shown in Fig. 3. It can be seen that they agree almost exactly with those measured, showing that the drain in fact has no effect on uplift pressures. This dam is a remarkable illustration of the invalidity of the premise that blended aggregates containing not more than about 5% of fines are suitable drainage aggregates.

A great many of the dams I have been asked to investigate because of seepage problems, have had problems caused because drains were either not used, or those that were contained too many fines and did not have the levels of permeability needed to remove the water without excessive head build-up. Only when the discharge needs of drains are properly estimated, and the drains are designed to carry these amounts of water can such deficiencies be eliminated.

Not being willing to analyze drains as conveyors of water, while being willing to follow a misguided concept is a major psychological hang-up that needs to be combated by extensive educational and promotional programs.

THIRD HANG-UP:

The unwillingness to try a new material or idea that does not have a long track record.

Progress in all areas of technology (and medecine) has been hampered by this kind of hang-up. Ideas that happen to be popular remain in vogue for years while eminently superior ideas remain untried, largely because of psychological hang-ups and a "fear of the unknown."

Specialists in all fields have a reluctance to try new ideas that have not been accepted by their peers. A person who follows a practice used by his predecessors or fellow workers (no matter how bad) is generally not blamed if something goes wrong. But let him try something new or innovative (no matter how fundamentally superior it may be) and if problems develop he is usually called "reckless", "irresponsible", or at the minimum "careless". There is often a tendency to be extremely critical about something new and to look "through rose-colored glasses" at the conventional, no matter how poor its record.

This kind of behavior has gone on throughout recorded history. When Galileo furnished evidence that proved the earth revolves around the sun and is not the center of the universe as was believed in his time, he was forced to spend the last years of his life under house arrest after being tried by the Inquisition in Rome for suggesting such a radical idea. Engineers, doctors, and other specialists have stubbornly ignored new ideas that later proved vastly superior to ideas that had been popular at a given time. The potential benefits of open-graded aggregates and synthetic fabrics in drains for engineering works are not being fully realized because of mental or psychological hang-ups such as are discussed in this paper.

Ideas eminently superior to prevailing ideas and practices have been rejected, even ridiculed. When Dr. Simmeliveis in Vienna suggested in 1880 that simple sanitation (washing hands, etc.) could reduce Streptococal infections he was scoffed at and not allowed to operate. Not until 1920 were his cleanliness ideas accepted by the medical profession. In about 1780, Dr. Benjamin Rush of Philadelphia said Cholera and Typhoid were spread by contaminated well water and bottled water. He was ridiculed and his idea lay unaccepted for more than 150 years! Even in the 1920's many children were dying from infantile diarrhea because of inaction and refusal to accept a concept that was very sound. Examples of this kind of human behavior can be found in all major fields.

Why do experts in all fields resist new ideas? Largely because it is "safe" to stay with an accepted procedure--no matter how poor its record. "Don't rock the boat" is an expression that aptly expresses the general attitude about making changes or trying something new. It is very hard to overcome.

One of the problems that needs to be overcome with the synthetic fabrics is the fact that people generally have come to look upon the synthetic products as being rather fragile and of limited life expectancy. Many of the synthetic products such as water hoses and black plastic sheeting become brittle and badly deteriorated in just a few years. Even though much of the deterioration is caused by exposure to sun light, and the fabrics in engineering will be protected from such exposure, there is a tendency to look upon the fabrics skeptically in relation to long-time performance.

Engineers in decision-making administrative positions sometimes don't keep themselves informed about new products or ideas, and reject an idea simply because it is new to them. In 1974 I reviewed a near-failure of a dam in California, caused by an ineffective internal drainage system containing aggregates with 6% of fines. Seepage had caused the near collapse of this dam when its reservoir was quickly filled. I recommended a new toe drain of the general design shown in Fig. 2(a), and such a drain was designed. Just before the opening of bids, an engineer with an agency having control over part of the funds said he would not permit any plastic materials to be used. A redesigned drain with vertical walls was subsequently built with no fabrics used. Severe caving problems had to be fought and the redesigned drain cost substantially more than my original design with fabrics. Unfortunately, this kind of reactionary attitude is altogether too common. It is a handicap to progress.

SUMMARY COMMENTS:

Only part of the potential benefits of good drainage systems and good drainage products is being realized because of some unrealistic and unfounded beliefs (hang-ups). Examples of three major areas where psychological hang-ups are impeding progress as discussed in this paper are:

(1) The belief that drainage itself is unnecessary, impractical, or too costly,

(2) The belief that aggregate blends of sand and gravel materials that provide good filter protection will automatically provide good drainage, and

(3) A general reluctance to try any new idea or product before it has a long experience record.

Collectively these misguided concepts are restricting progress in drainage and the use of new products in drainage systems. Major educational and promotional programs are needed to overcome these hang-ups.

REFERENCES:

(1) Terzaghi, K. & Ralph B. Peck, Soil Mechanics in Engineering Practice, John Wiley & Sons, Inc. (New York, 1948).

(2) Bertram, G.E., "An Experimental Investigation of Protective Filters," Harvard Publication 267, (Cambridge, Mass., 1940).

(3) Cedergren, H. R., Seepage, Drainage, and Flow Nets, 2nd Ed., John Wiley & Sons, Inc. (New York, 1977), 175-220.

(4) Barrett, Robert J., "Use of Plastic Filters in Coastal Structures," Proceedings, 10th International Conference on Coastal Engineering, (Tokyo, 1966), 1048-1067.

(5) Dunham, James W. & Robert J. Barrett, "Woven Plastic Cloth Filters for Stone Seawalls," Journal, Waterways, Harbors, and Coastal Engineering, Div. ASCE, Vol. 100, No. WWI (New York, 1974).

(6) Seemel, Richard N., "Filter Fabrics," Civil Engineering, ASCE, (New York, April, 1976), 57-59.

(7) "Dike Safety Upgraded with Millions of Square Feet of Fabrics," Civil Engineering, ASCE (New York, Jan. 1981), 46-47.

(8) McAdam, John L., "Report to the London Board of Agriculture," (London, 1820).

(9) Highway Research Board, "Special Report 22", (Wash. D.C., 1955).

(10) Highway Research Board, "Summary Report (Report 7), the AASHO Road Test, National Advisory Committee," Special Report 617, Publication No. 1061, (Wash. D.C., 1962).

(11) Barenberg, E. J. & Owen O. Thompson, "Behavior and Performance of Flexible Pavements Evaluated in the U. of Ill. Test Track," Highway Engineering Series No. 36, Illinois Research Series 108 (Urbana, Ill., January, 1970).

(12) Federal Highway Admin. (FHWA), "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections," prepared by Joint Venture of Ken O'Brien & Assoc., L. A., and H. R. Cedergren, (Wash. D.C., 1973).

(13) "Nation's Roads Deteriorating Rapidly," Engineering News-Record, (New York, Nov. 10, 1977), 14.

(14) U. S. Army Corps of Engineers, "Methodology and Effectiveness of Drainage Systems for Airfield Pavements," prepared by H. R. Cedergren for Construction Engineering Research Lab. (CERL), (Ill. 1974).

(15) Cedergren, H. R., "Poor Pavement Drainage Could Cost $15 Billion Yearly," Engineering News-Record, (New York, June 8, 1978), 21.

(16) Cedergren, H. R., "How to Save Highway Dollars," Sacramento Union, (Sacramento, Calif., Dec. 16, 1978).

(17) "A Poor Choice of Patchwork," Editorial, Engineering News-Record, (New York, March 2, 1978).

(18) "America's Highways Going to Pot," U.S. News & World Report, (Wash. D.C., July 24, 1978), 36-38.

(19) Cedergren, H. R., "Seepage Control in Earth Dams," Chap. 2, Embankment-Dam Engineering--Casagrande Vol. John Wiley & Sons, Inc. (New York, 1973, 21-45.

(20) Cedergren, H. R., Drainage of Highway and Airfield Pavements, John Wiley & Sons, Inc. (New York, 1974).

(21) Taylor, D. W., Fundamentals of Soil Mechanics, John Wiley & Sons, Inc., (New York, 1948).

(22) Terzaghi, K., Theoretical Soil Mechanics, John Wiley & Sons, Inc., (New York, 1943).

(23) Tschebotarioff, G. P., Soil Mechanics, Foundations, and Earth Structures, McGraw-Hill, (New York, 1951).

(24) Oregon State University, "Test Methods and Use Criteria for Filter Fabrics," prepared for the FHWA, U.S.D.O.T., by Dept. of Civil Engr. & Transportation, O.S.U., (Corvallis, Oregon, 1978).

(25) Cedergren, H. R., Seepage, Drainage, and Flow Nets, 2nd Ed., John Wiley & Sons, Inc.(N. Y., 1977),207-16.

(26) Muskat, M., The Flow of Homogeneous Fluids Through Porous Media, McGraw-Hill (New York, 1937). reprinted by J. W. Edwards, Pub., Inc. (Ann Arbor, 1946).

(27) Casagrande, Arthur, "Seepage Through Dams," Journal of the New England Water Works Association, (Boston, 1937).