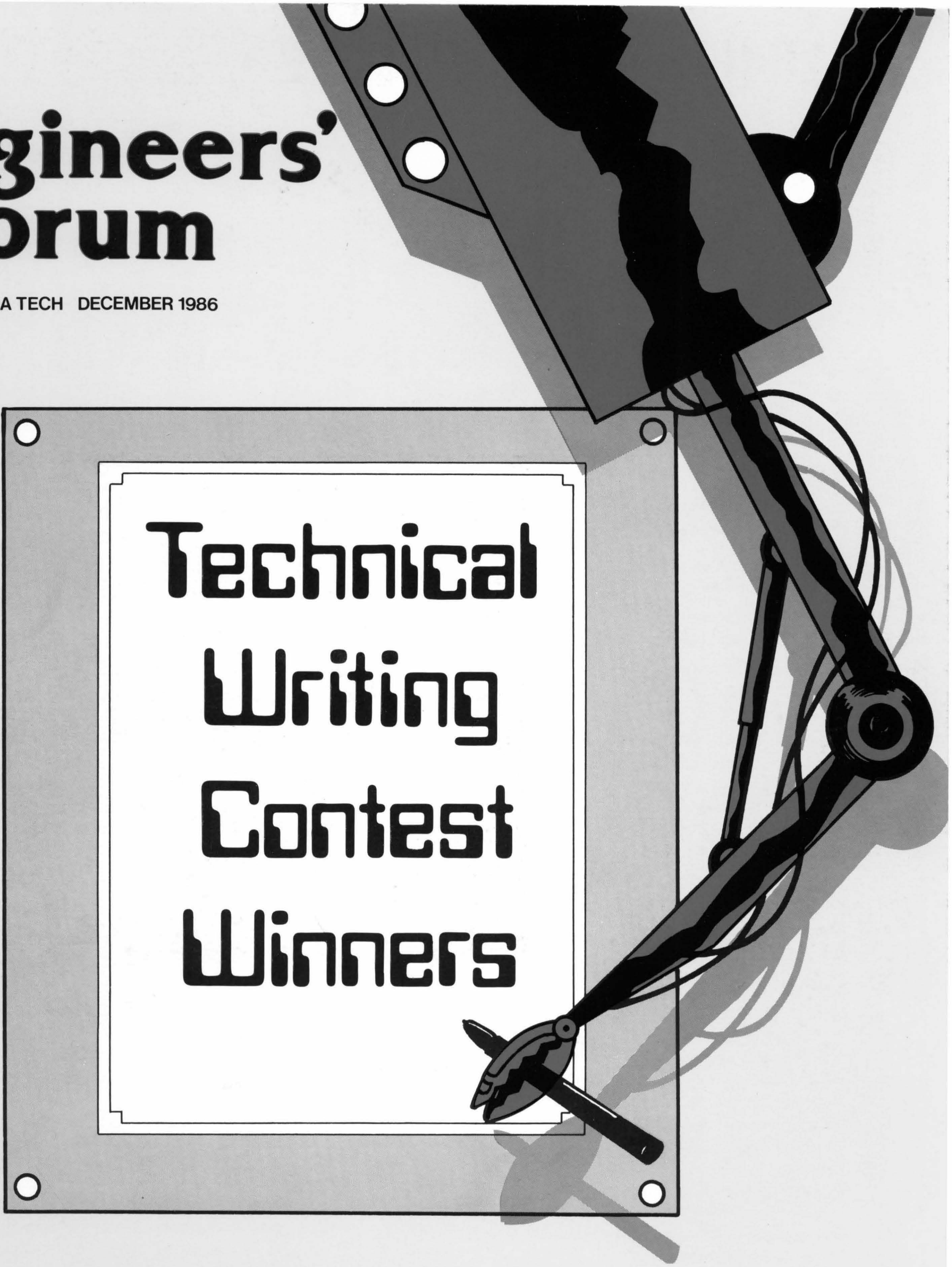
Engineers' Forum

VIRGINIA TECH DECEMBER 1986



SPECIAL EDITION

Editor's Page

Let Your Imagination Run Away With You

If you're an engineer — or studying to be one — chances are non-engineers have at some point accused you of not being able to let your imagination run away with you. Perhaps those of us who are not engineers tend to separate too quickly the creativities required by the arts and by engineering. If your innovation potential is insulted by a non-engineer, you can counter by mentioning some of the avant garde research being conducted at Tech.

For example, three seniors in ESM are working on streamlined spokeless wheels for racing bicycles. This research is being prompted by regulations prohibiting any bicycle part whose sole purpose is to reduce wind resistance. Solid disks, if used to replace spokes, could not be classified as optional wind cheaters. In addition to being an innovative solution to a problem, these devices will turn out to be aesthetically pleasing.

With the plethora of fascinating findings at Tech, it's surprising that more technical reports are not entered in our contest each year. The main restrictions put on the entries simply pertain to the paper's length (1500 to 2000 words) and authorship (Tech student upon entry).

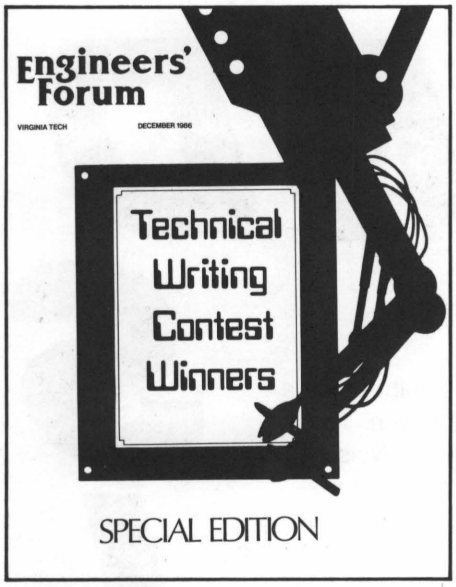
Starting in the next issue, the *Engineers' Forum* will feature a column to recognize students' creative research. Also featured will be brief profiles of the students and their reasons for conducting the research. We are depending on you, our readers, to keep us up to date on what you find interesting.

We encourage you to give us a call if you know someone who is studying something exciting or is simply excited about his study. Any questions regarding the technical writing contest are welcome, too. Our office number is 961-7738.

Susan L. Talbot

Editor's Note:

In early November, a fire in the steam tunnels wiped out our computer cables. Without this link which we use for typesetting, *Engineers' Forum* could not come out in November as originally planned. We hope that this delay has not caused any inconvenience.



Cover design by Matthew Dawson.
Matt is a freshman architect from OZ.

Engineers' Forum

Special Edition
Volume 5, Number 2
December, 1986

Editor's Note: *Contained in this issue are the winners of our Technical Writing Contest held last spring.*

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Engineers' Forum is Virginia Tech's student engineering magazine. *Engineers' Forum* magazine is published four times during the academic year. Editorial and business office is located at 112 Femoyer Hall, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. Phone (703) 961-7738. Member of Engineering College Magazines Associated, Carolee Stark, Chairperson.

Printed by University Press, Roanoke, VA

MICHAEL F. RIEMER

Stability of the Narrows, Virginia

LANDSLIDE

ABSTRACT

A stability study of the Narrows landslide was performed in order to estimate the likelihood of a rapid slope failure, and to determine an efficient means of slope stabilization for this site. The study included research of the slope conditions, a site inspection, and a computer analysis of the data gathered using STABR, a slope stability computer program. The study revealed two independent failure mechanisms: limited surface slumping of the shale formations, and a large circular slip failure extending beneath U.S. Route 460. Neither failure mode is likely to cause a catastrophic failure at this site. The shale slumping can best be contained by the construction of a retaining wall on the slope, which would prevent sliding material from reaching the highway. The rotational movement can be alleviated by installing a system of horizontal drains in the slope, since the driving force of this movement is the added weight of excess groundwater in the slope.

INTRODUCTION

Small movements of the slopes along rural highways are common, and can usually be accepted as inevitable consequences of road construction. At certain sites, however, such as the northern side of U.S. Route 460 near Narrows, adverse geological conditions can combine with destabilizing construction to create landsliding of major proportions. One section of this slope has become particularly troublesome: the state has already spent over one million dollars attempting to control it, spending $8,000 each year on maintenance[1], and the possibility of large, rapid movement endangers both the highway and a nearby railroad line.

This paper culminates a slope stability analysis of the Narrows landslide. The analysis has two primary objectives: 1) To describe the actual sliding mechanism, including the location of the slip surface and an identification of the factors which control the movement, and 2) To determine an effective means of stabilizing this slope in order to reduce future movement.

The following stability analysis consists of three parts: research of the site to establish the slope conditions and failure surface, a computer analysis to identify the critical slope condition, and a computer simulation of the effect of drainage on the slope stability.

BACKGROUND

Movement at the Narrows landslide was first reported in 1916, when the Virginian Railroad noted that sections of the track were shifted by considerable earth movement. Since then, the entire slope has shifted a total of about thirty feet. Rather than creeping continuously the slope moves intermittently, with the periods of greatest movement coinciding with either prolonged heavy rains or major construction work on the highway. In repeated efforts to halt the slide, the state constructed two retaining walls at the toe, or lower boundary of the slide. The first was a concrete beam wall, which was replaced in 1971 by a sturdier metal bin wall. At the same time, nearly 250,000 cubic yards of soil were removed in an effort to unload the slope. In spite of these measures, the landslide has continued moving. While there have been no large scale failures of the slope, repeated minor movements indicate that the slope has not reached a position of long-term stability.[2]

DESCRIPTION OF SLOPE

The particular section of the slope in question lies on the northern side of U.S. Route 460, approximately two miles east of the town of Narrows, Virginia. The area affected by the slide is roughly triangular, with the toe of the landslide extending some 1500 feet along the highway, and the upper scarp reaching over 700 feet up the slope (Fig. 1). Route 460 runs across the toe of the slide, whose lower boundary is marked by the bin wall to the south of the highway. This wall has failed at several sections, while the corrugated metal panels have been completely sheared off their original supports.

SURFACE

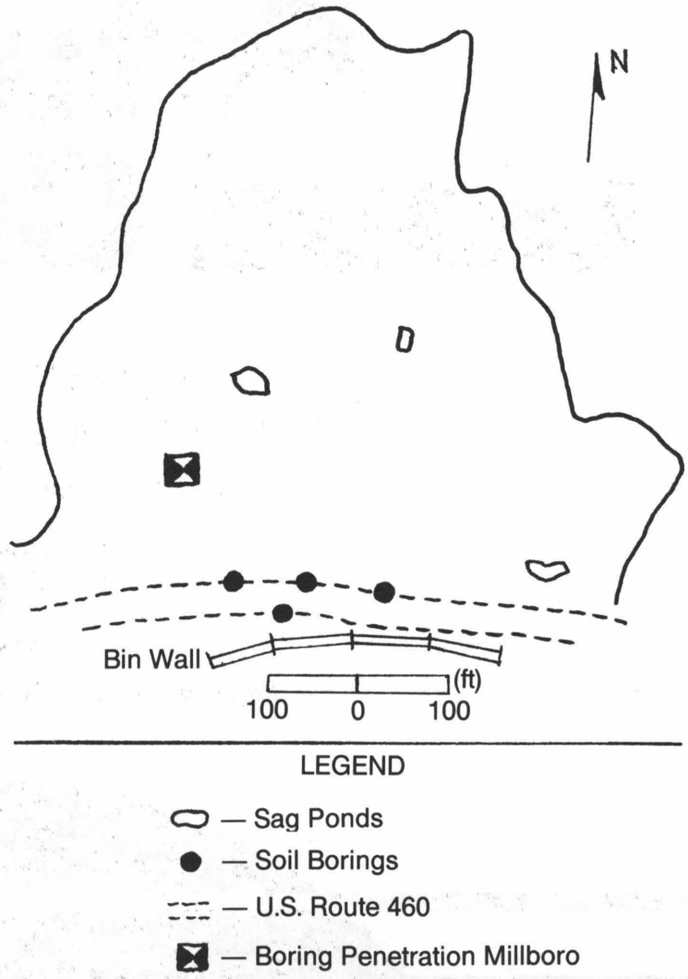
The surface of the slide is highly irregular but the average slope angle at the location of the slide is twenty degrees. Weathered outcroppings of crumbling shale dot the lower region, and open fissures up to six inches wide characterize the eastern and central section of the slide. Relatively stable sections of the slope are covered by annual vegetation, while other sections consist entirely of loose sand and soil that have recently been deposited. Perhaps the most striking characteristic of the slide surface, however, is the large number of "sag ponds" scattered across the face of the slide. Sag ponds are minor depressions in the slope left by the sliding process which fill with rainwater. Though these depressions may occur near the top of a steep slope, they can contain standing water almost continuously. Some of the sag ponds at this site support a population of cattails, a plant usually associated with marshes, which testify to the high availability of water at these points.

SUBSURFACE

The geology of the slope is complex, and relatively little data about the underlying soil strata is available. In 1967, the Virginia Department of Highways took a series of soil borings along the northern shoulder of Route 460. Using these limited sources, a representative cross-section of the landslide has been developed (Fig. 2). This profile is extremely sketchy, and the lack of more detailed subsurface data makes the profile a limiting factor for the sophistication of this analysis.

The upper eighteen to twenty feet consists primarily of clay and silt, though local outcroppings of shale and sandstone exist at the surface. The clay layer is highly impermeable, and is therefore the primary cause of the slope's poor drainage characteristics. Beneath this clay lies a layer of weathered, sandy shale, which extends to a depth of 65 feet. This sandy shale is more permeable and stronger in shear than the clay above it. Below this depth, the entire slope is underlain by a layer of black shale, which has been identified as the Millboro shale formation. This formation is exposed in other locations near the slide, and is over 300 feet thick.

Figure 1: Location and Extent of the Landslide



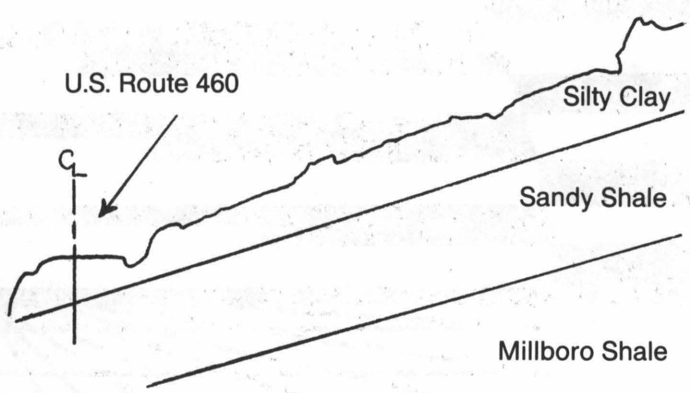


Figure 2: Soil Profile of the Slope

PRESENT STABILITY

From the feature of the landslide described earlier, it seems clear that there is more than one mechanism of sliding occurring at this site. The repeated movements of surface soil down the slope and onto the highway suggest slumping of the surface shale, while the pronounced upper scarp and bin wall failure at the toe suggest a circular slip failure. [A review of these failure mechanisms is presented in the Appendix.]

The properties of the shale in the surface outcrops support the idea that the slumping is seated in these formations. The well-bonded shales commonly found in the Allegheny region are subject to extreme weathering, or deterioration. Thus, when a formation of this type is subjected to intermittent saturation and drying, or freezing and thawing, the shale often literally disintegrates into fine, planar particles.[3] Consequently, the shear strength decreases, and a section of the slope which was previously secure becomes unstable, sending both the weakened shale and adjoining clay down the slope. The construction associated with the widening of Route 460 in 1970 has undoubtedly accelerated the rate of slumping: by removing material at the toe of the slope, the evacuation has reduced the support of soil farther up the slope.

The large scale movement of the slope is almost certain due to a circular slip type of failure. The location of the slip surface is known at three points: the toe of the slide at the bin wall, the upper scarp, and a point located during the 1967 borings, which lies 20 feet under the northern shoulder of the highway. Taken together, these points define a unique circle, whose center lies more than 900 feet above the slope. This circle represents the idealized failure surface about which the stability calculations are performed. The computer analysis was carried out using a slope stability program, STABR, which calculates the factor of safety for a given situation using Bishop's Modified Method.[4] The coordinate system used by the program, the simplified slope conditions, and the critical slip circle are shown in Figure 3.

In order to calculate the stability of any slope, width and strength parameters for each type of soil present must be given. For the upper two layers this presents no problem, since accurate estimates based on similar soil deposits can be made. The strength of the Millboro shale, however, does pose a problem: its strength depends on its level of deterioration, which in turn depends on the history and drainage characteristics of this particular slope. Fortunately, one of the soil properties can be back-calculated, because the stability is known for the present condition. Since the slope is currently unstable, the factor of safety must be 1.0. Thus the strength of the Millboro shale can be determined by trial and error, by finding out what strength is required to bring the current slope conditions to a position of marginal stability. For the soil properties and slip surface of this analysis, the friction angle of the shale was calculated to be 23 degrees.

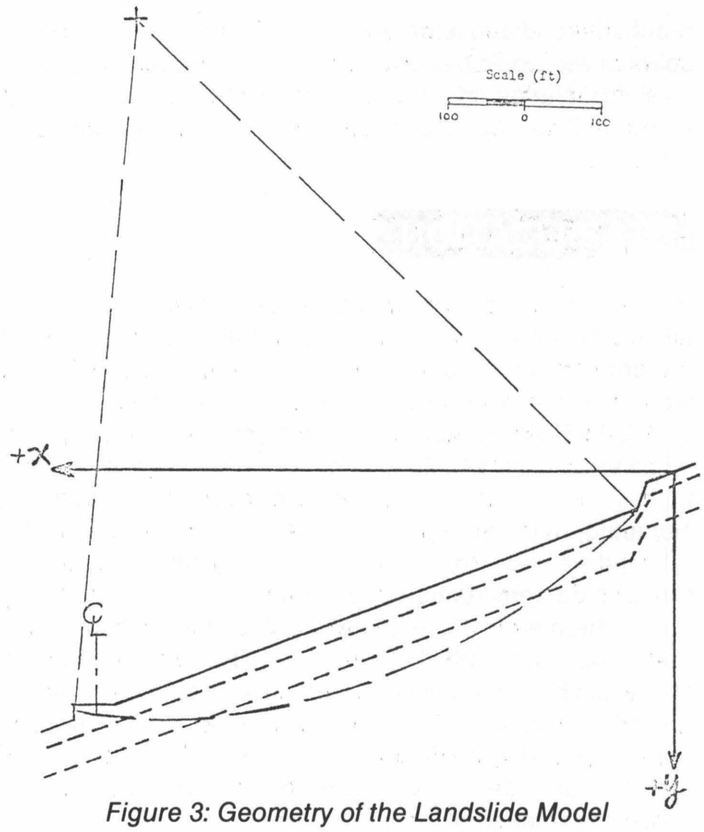


Figure 3: Geometry of the Landslide Model

Although the theoretical slip surface defined by the circle in Figure 3 cuts into the lowest layer, it is far more likely that the actual slip surface departs from the circular model to follow the soil boundary at a depth of 65 feet. This would occur for two reasons. Most importantly, the black shale is virtually impermeable compared to the broken, sandy shale above it. As a result, water which drained through the upper layer is stopped at this boundary, and the pore pressure rises accordingly. This reduces the effective stress at the soil interface and consequently reduces the soil strength. In addition, the outer surface of the black shale is subject to weathering by the stagnant water. As a very thick surface layer of the black shale deteriorates, its resistance to shear drops and it virtually acts as a lubricant between the remaining black shale and the sandy shale above it.

Although an exact determination of the failure surface is necessary for a complete understanding of the landslide, a more crucial concern centers on identifying the cause of the instability. Since the movements occur intermittently, the key factor must vary over time. For this slope, as for may other unstable slopes, the amount of groundwater present is the critical factor. While the groundwater has little effect on the shear strength of the soil, it increases the moments created by the soil mass by effectively raising the weight of the soil. Since the volume of soil tending to cause rotation is greater than the volume resisting it, the net effect of an increase in groundwater is a decrease in the relative stability of the slope. At the Narrows landslide, the clay layer near the surface is pierced by a number of fractures, through which rainwater can infiltrate the sandy shale which forms the bulk of the unstable soil mass.

Given these slip mechanisms, there is virtually no possibility of rapid, catastrophic slide. While the slumping soil could reach the road and temporarily block traffic, the amount of soil involved would be relatively small. In contrast, the circular slide includes virtually the entire slope, but its movement is self-limiting since the soil mass becomes more stable as it moves.

STABILIZATION

Since there is little or no chance of a catastrophic slope failure, the short term goal of a stabilization plan should be the prevention of surface slumping onto Route 460. This would considerably reduce the annual maintenance costs of $6,000-8,000, which are currently spent in keeping the highway and its shoulder clear of debris. Unfortunately, there is no economical means of preventing this surface slumping, since the exposed shale will continue to deteriorate and weaken. However, the slumping can be contained through the construction of a modest retaining wall along the northern edge of the highway to keep the sliding material on the slope and off the highway. The wall required for this would be small since the surface slumping is limited to a small volume of soil. This measure would have an additional benefit: by holding the slumping soil near the toe of the circular slide, it would contribute to the moment resisting the rotation of the larger slide.

While movements of the circular slide pose no immediate danger or expense, over a long period of time any differential movements across the width of the slope could effectively tear the highway apart. Physical retention of slide this massive is not feasible, as the shear bin wall attests. The unstable portion of the slope includes nearly one million tons of soil. Rather than trying to restrain the sliding material a more realistic alternative would be to prevent the movement by providing adequate drainage. Lowering the water table would remove the cause of the instability by reducing the net moment due to the soil weight, while also reducing the destabilizing pore pressures at the slip surface.

The computer program STABR was used to determine the relative stability that could be attained by a uniform lowering of the water table, such as might be accomplished using horizontal drains. The analysis predicts that a drainage program which would lower the water table to a depth midway into the sandy shale layer would increase the factor of safety from its current value of 1.0 to approximately 1.5.

CONCLUSION

The geology, surface features, and history of the Narrows landslide indicate that there are two mechanisms of slope failure at this site. The gradual obstruction of U. S. Route 460 with slope debris results from surface slumping of the weathered shale formations seated in the clay layer, while the shear failure of the metal bin wall and the net displacement of the entire slope are caused by a massive circular slip failure. Neither of these mechanisms are capable of causing a rapid, catastrophic failure for the slope.

While the surface slumping can only be contained, stability calculations indicate that the much larger circular slip movement can probably be eliminated by significantly lowering the water table through the implementation of a drainage program.

APPENDIX

BASIC SLIDING THEORY

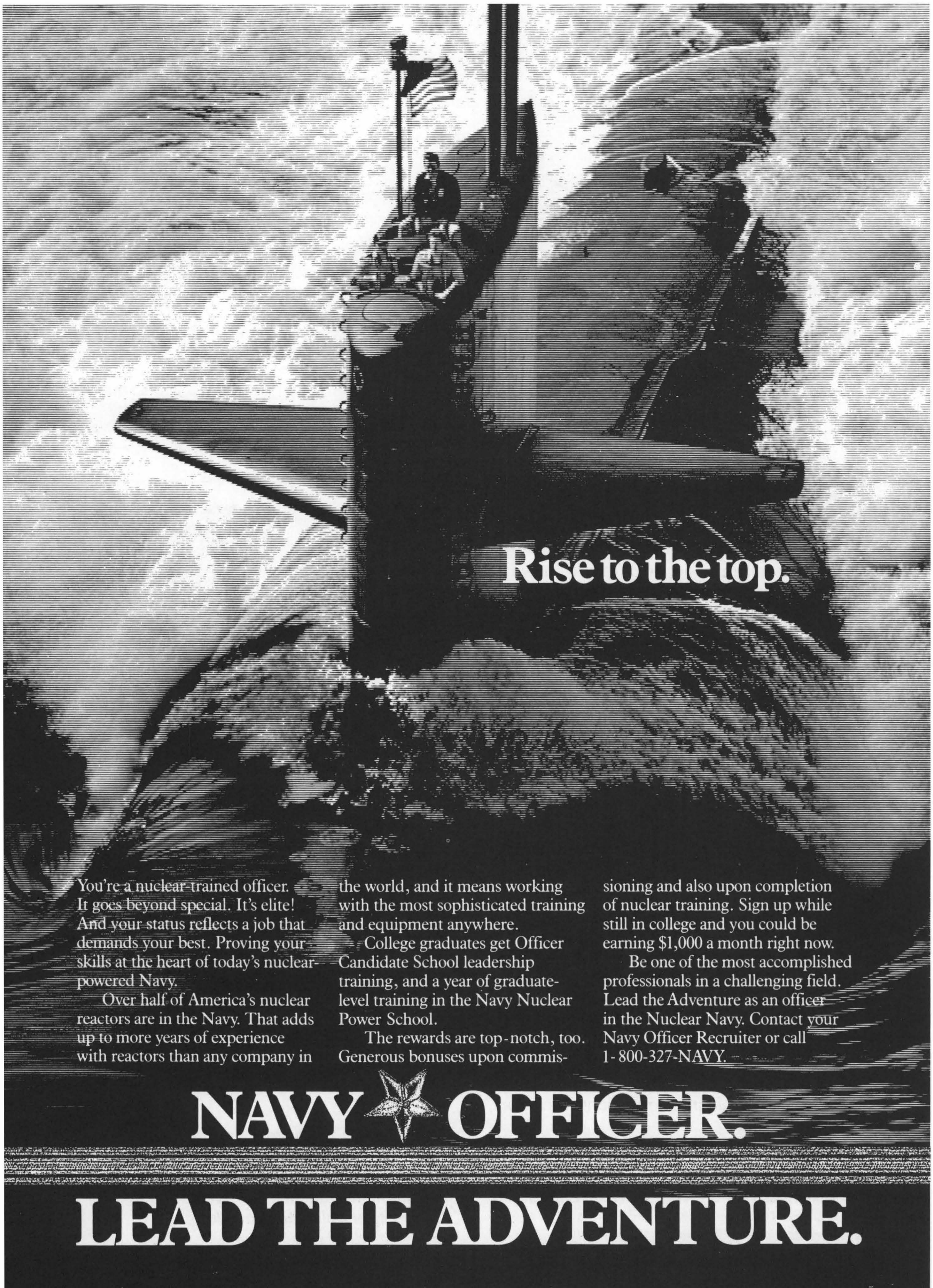
The complex geologic structures of some landslides can make a detailed interpretation of the sliding mechanism extremely difficult. Regardless of a sight's complexity, though, it is important to remember that all landslides move because the forces tending to cause motion exceed the forces resisting motion. While the sliding mechanism at a site will depend on the characteristics of the slope involved, most slides can be classified as variations of either circular slip failures or surface wedge failures.

CIRCULAR SLIP

In this mode of sliding the slip surface, or surface along which the relative motion occurs, is described by the arc of a circle whose center lies above the slope (Fig. 6a). A failure of this type involves a rotation of the entire soil mass around the hypothetical center of the circle which describes the slip surface.

The driving force behind this type of failure is the weight of the unstable soil "upslope" from the vertical projection of the circle's center. This force acts vertically downward, of course, and thereby creates a moment around the center of the circle. There are two forces resisting the rotation of the soil mass. One is the moment created by the weight of the unstable soil "downslope" of the circle's center. This moment will always oppose motion, but it is usually too small to completely offset the moment causing motion. The other force resisting rotation is caused by the shear strength of the soil itself, which develops a frictional resistance along the entire slip surface.

When the sum of these two forces is insufficient to offset the moment causing motion, a slope failure occurs along the slip surface, and the entire mass of unstable soil rotates around the center of the slip circle (Fig 6b). The net effect of this type of movement is a bulging or lifting of the soil at the toe of the slide, and a subsidence of the sliding mass at the top. It is this sinking relative to the stable portion of the slope that results in the steep scarps along the upper edges of these landslides. The total movement in this type of slope failure is usually small, since the rotation of the soil mass moves it into a more stable position: some of the soil which initially acted to cause motion has been moved downslope of the circle's center, and therefore opposes any further motion.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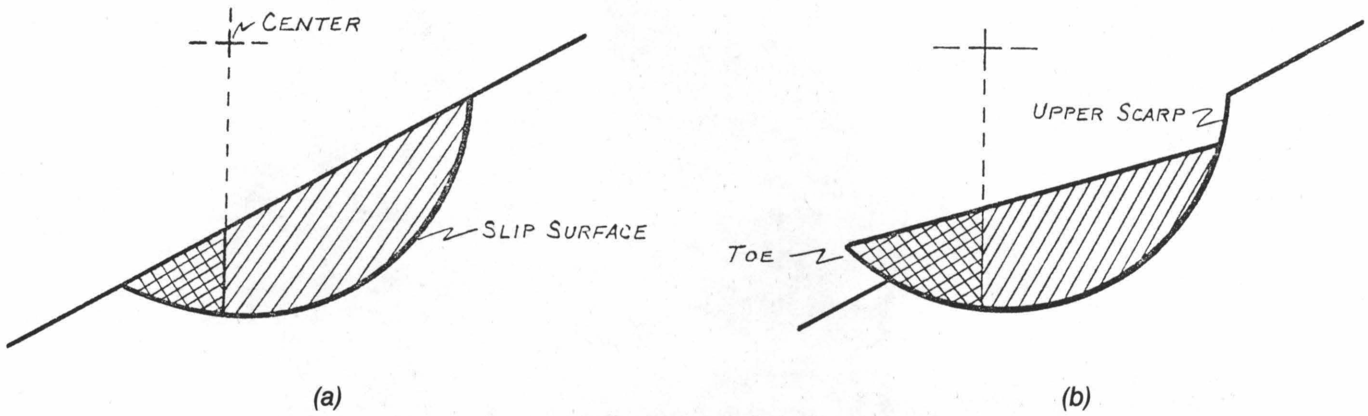


Figure 6: Dynamics of Circular Slip Failures

SURFACE WEDGE

The dynamics of this failure mode, which is also known as "slumping," are simpler than those of a circular slip. There are only two forces acting on a basic surface wedge, or mass of soil: The component of the soil's weight in the direction of motion, and the shear strength of the soil along the planar failure surface. Because of this, critical wedges are often bounded by discontinuities in the slope, such as fractures, which minimize the shear strength that can be mobilized. If the driving force exceeds the shear resistance, the entire wedge breaks free and slides down the slope. Although this failure mode is more dramatic due to the long distances the soil may move, surface wedge failures are usually limited to relatively small soil masses near the slope surface.

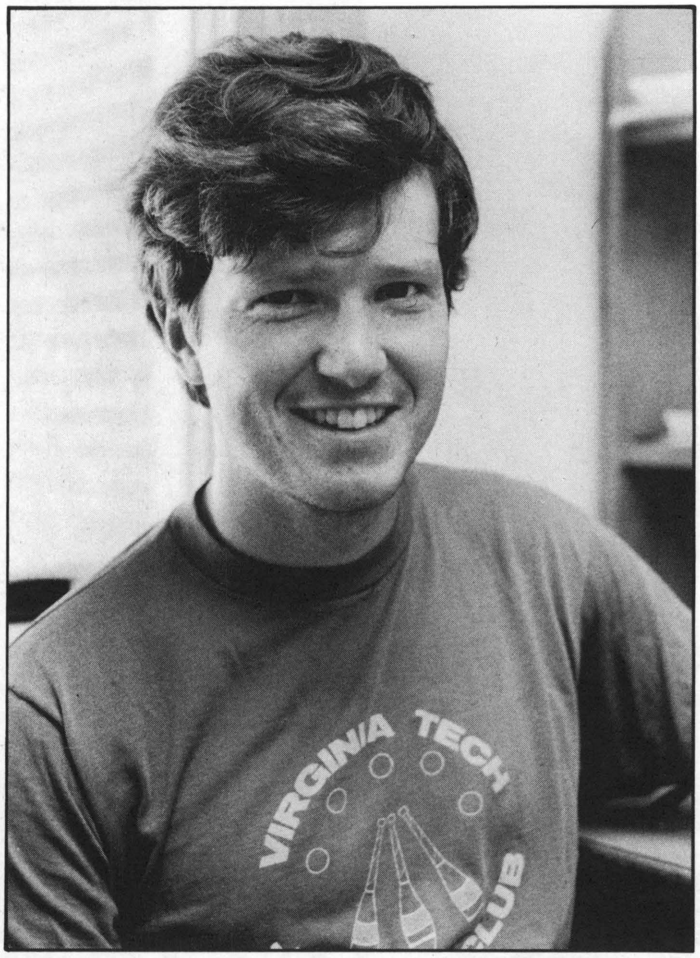
NOTES

[1] Samford, William J., *An Investigation of the Narrows Landslide, Giles County, Virginia,* Thesis for Master of Science, Geology, Virginia Polytechnic Institute and State University, Blacksburg, VA., Dec, 1981, p.94.

[2] Samford, William J., pp.4-22.

[3] Terzhagi, Karl and Ralph B. Peck, *Soil Mechanics in Engineering Practice,* 2nd ed., John Wiley & Sons, New York, 1967. pp. 426-27.

[4] Duncan, J.M., and Kai Sin Wong, *STABR: A Computer Program for Slope Stability Analysis with Circular Slip Surfaces,* Microcomputer version, Virginia Tech, Blacksburg, VA, 1984.



***Mike Riemer** graduated in Civil Engineering this past spring. While at Tech, he was a member of the Juggling Club and Chi Epsilon, the CE honor society. Presently, he is a graduate student in Geotechnical Engineering at the University of California, Berkeley.*

JONATHAN A. LEBLANG

MAGNETIC DISKS:

Advances in Materials and Storage Technology

This paper discusses some of the recent advances in magnetic storage media technology, focusing on computer disks. Computer disks are important because for the past 35 years, magnetic media have been the primary mechanism of off-line computer storage. Because of the need to keep backups of data, and because main computer memories are limited, off-line storage was needed that was inexpensive (compared to main memory) and that could provide safe long term storage.

Magnetic media can be found in two primary forms; the magnetic tape and the magnetic disk. Tapes were the first type of magnetic storage media used, but were (and still are) slow and inconvenient due to their sequential storage structure. Tapes are now used primarily for archive and transportation purposes. Disks, though more bulky and harder to care for, may be accessed randomly, thus making more efficient use of space and increasing the rate at which the data may be accessed.

Since the introduction of the personal computer in 1974, computer users have been looking for an off-line storage medium that must meet many diverse requirements. It must be relatively inexpensive, be able to store a reasonable amount of data, must have an extremely low error rate, and must be tolerant of varied operating conditions and users of different levels of proficiency. Audio cassettes were used for a short time, until the introduction of the 8 inch disk drive by Shugart in 1975 and the establishment of CP/M as a standard operating system for microcomputers. These disks held about 160K and were relatively slow. In 1978 Apple Computer introduced the Disk, a 5¼ inch format disk drive and disk, that could store 117K on one disk. Then in 1981 IBM introduced its IBM personal computer, with disk storage of 360K on a 5¼ inch diskette; soon after, Sony introduced their 3½ inch disk format, which can store from 270K to 800K on one disk. See figure 1 for a comparison of disk capacities.

Information Storage

The magnetic recording process occurs when a current is passed through an electromagnet which produces a magnetic field that orients the direction of magnetization along a track in the disk. When the pattern of magnetized particles passes under an electromagnet, it produces a voltage in the coil, which allows the recorded data to be read. The device, composed of both the electromagnet and the structure on which it is mounted, is called the head.

The whole process is based on electromagnetic magnetization and induction. In writing the data, a current flows through the windings of a coil and produces a magnetic field. The field is confined in a ringshaped core of magnetic material around which the coil is wound. The field extends itself both in front of and across a narrow slot which has been cut in the head. As the media and the magnetic oxide pass under the head gap (the space between the media and the head), the flux field penetrates the oxide on the media and orients the magnetic media in a direction dependent on the current in the head. By reversing the current, the orientation of the particles may be reversed. When the field is removed, the region of polarized media remains. This is how data is written to the disk.

In order to read the data, the same head may be used. Based on Faraday's principle of induction, the electric field intensity in a region of time-varying magnetic flux density is nonconservative. In other words, voltage is induced in an open circuit when there is a change in magnetic field. When the head passes over the region where data had been written, the magnetic flux field from the media permeates across the head gap. If the magnetic field is oriented on one specific direction, no voltage will be produced in the coil. If the head passes under a region where the oxide is oriented opposite in polarity, this represents a reversal and so the change in the field includes a voltage pulse in the coil. This analog signal is then filtered and converted from an analog to a digital signal.

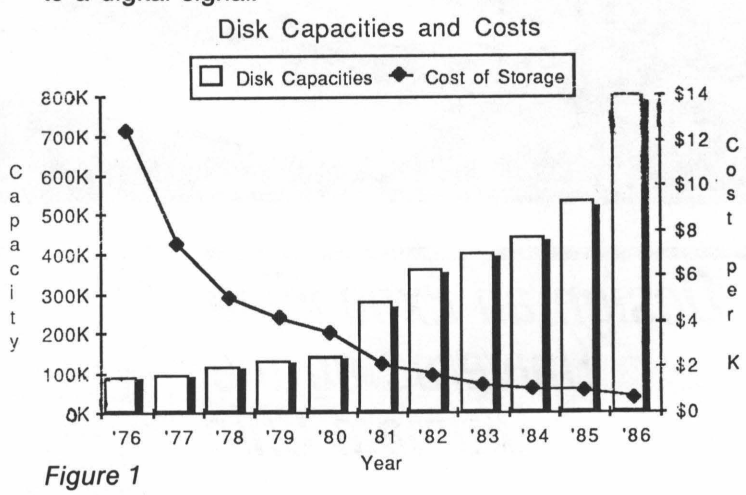


Figure 1

The actual disk is comprised of a mylar substrate, coated with a magnetic layer (to be discussed below). This disk sits inside the jacket. The jacket is the enclosure for the disk which provides protection, support and access by the read/write head to the media. The jacket is constructed from a semi-rigid Poly Vinyl Chloride (PVC). The jacket contains a specially selected soft, non-woven liner. The liner has a dual purpose of 1) Controlling the disk torque by reducing friction during disk rotation and 2) cleaning debris from the disk as it is being used.

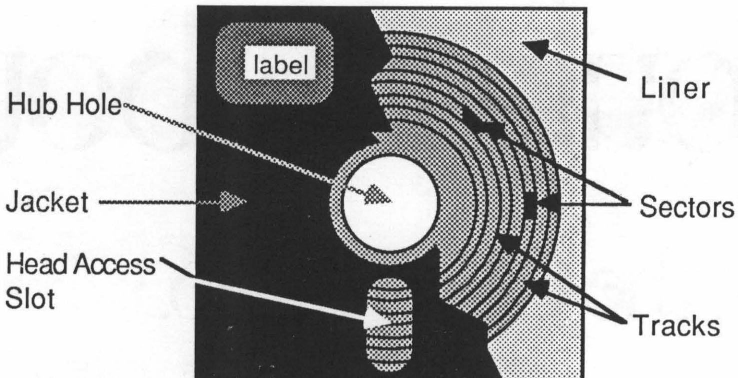


Figure 2

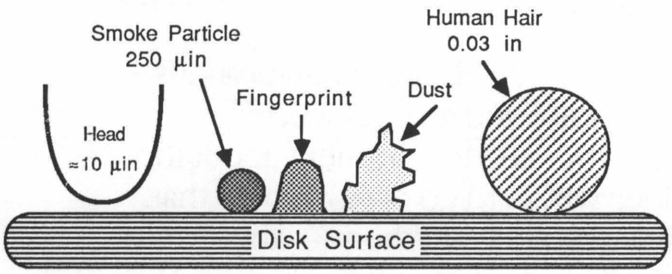


Figure 3

Storage Capacity

As the capabilities of computers increase, larger and larger external storage capacities are needed. The current limit is about 800K doubled track density, the gains in capacity tend to be accompanied by a drop in data integrity. This is due to the expansion and contraction of flexible media due to changes in temperature which make it very difficult to read to disks that were written to under significantly different conditions. However, advances in head positioning systems have greatly alleviated this problem.

Once the mechanical problems of writing data onto a high capacity disk have been solved, one must turn to the actual problem of storing more information on a disk. There are three areas that we must look into in order to see where advances may be made, 1) vertical vs. parallel recording techniques, 2) methods of depositing the magnetic material on the substrate, and 3) thin film vs. oxide media.

Vertical Recording

Although a lot of room still exists to increase track densities and thus capacity, conventional recording techniques are approaching their physical limits, and vertical (or perpendicular) recording promises to be the next step in recording techniques. In the media used now, the magnetic particles are laid end to end along the direction of the media's tracks.

This means that if one things or each computer bit (0 or 1) as a tiny permanent magnet, conventional recording put tiny permanent magnets representing digital 1s might be recorded north-pole-first along the length of the recording track, while digital 0s would be recorded south-pole-first along the same track. Because the playback heads can only detect transitions, the process of reading the recorded data actually involves detecting the change in polarity. The magnetized zones lie lengthwise, or end to end, along the recording track in conventional longitudinal recording (see figure 4a).

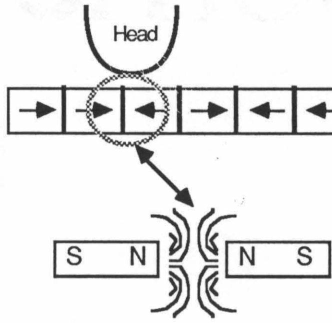


Figure 4 (a)

However, due to self-demagnetizing properties of all permanent magnets, the north and south poles tend to neutralize each other, with a net reduction in the magnet's overall effectiveness and resulting external field. So the

Some thoughts about

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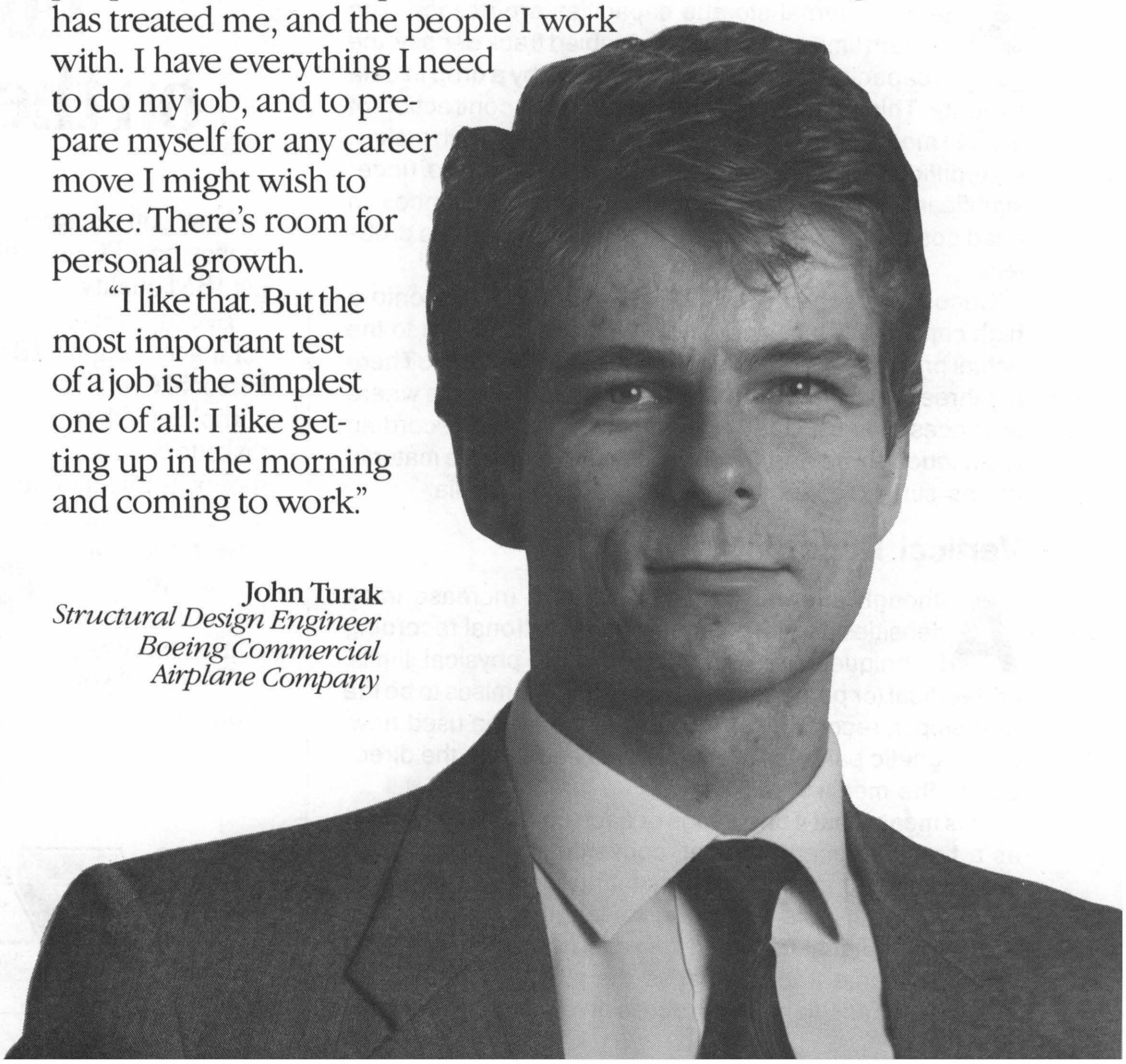

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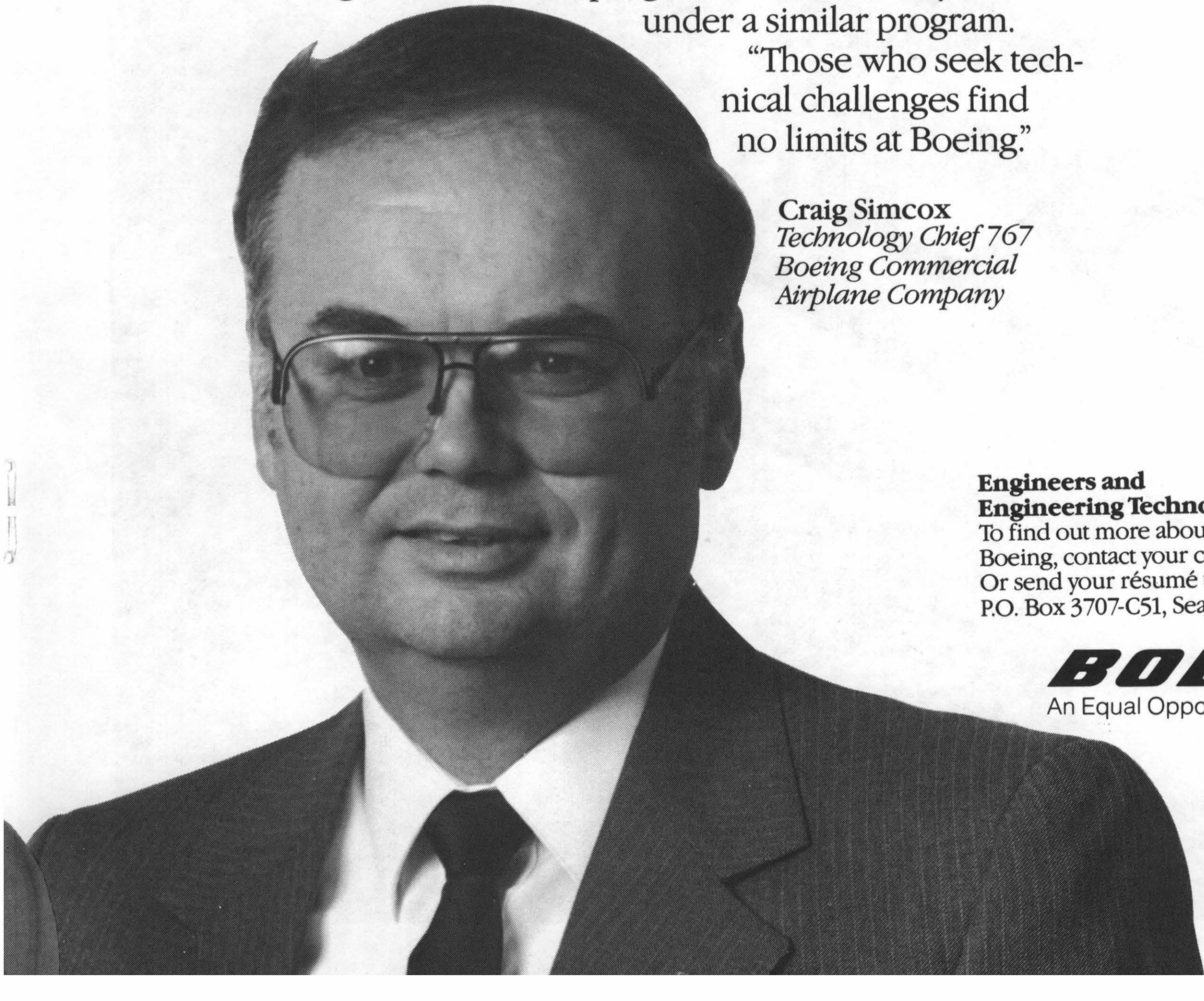

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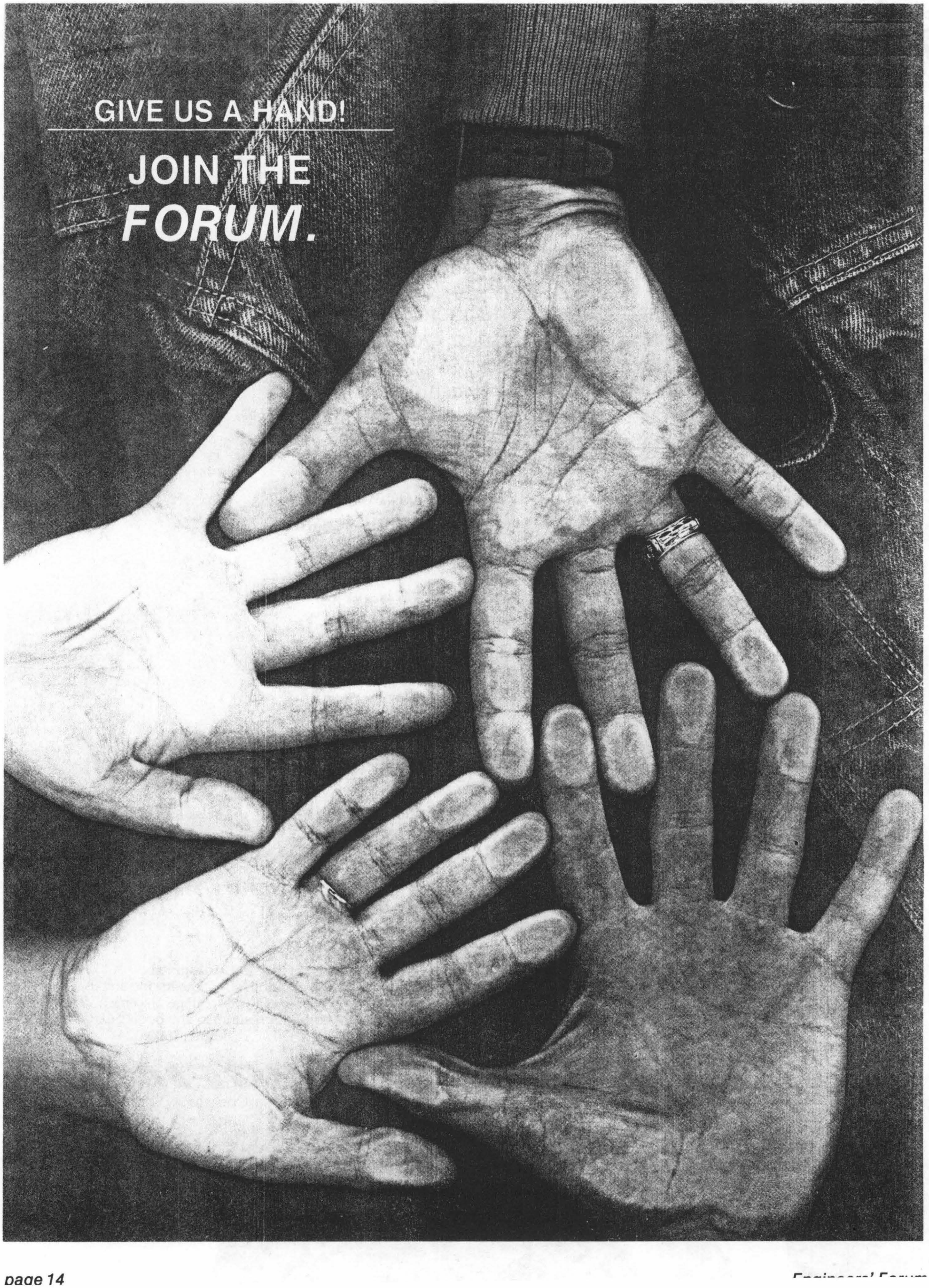
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magnet must be 'long' in order to keep the north and south poles far apart. This limits the amount of miniaturization that can be applied to the magnets. Vertical recording sidesteps this problem by turning the magnets 90 degrees, so that instead of lying along the disk's surface, the length dimension of them now stands vertically perpendicular to the surface of the disk. So now the data is recorded 'into' the magnetic material instead on 'on' the material (see figure 4b).

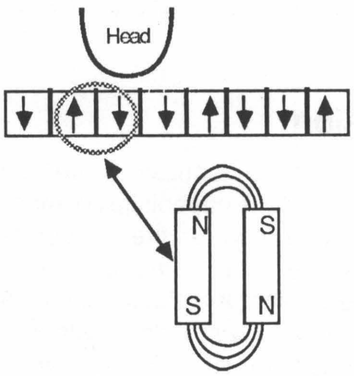


Figure 4(b)

Magnet length is now determined by the depth of the layer of magnetic material, instead of the length. As a consequence, increased recording density no longer worsens the demagnetizing effect; actually, the opposite is true. Because the densities tend to squeeze the width instead of the length, increasing the important width/length ratio. This means that by increasing the recording density, the magnetic field strength is increased.

However, there are problems with vertical recording due to the media used. Because the media are far wider than they are tall, shape anisotropy makes it much easier for the magnets to lie in the plane of the media — a lower energy situation than that of vertical orientation. The solution to this problem lies in the type of material used for the magnetic media.

One method being used is to develop isotropic media —media that have no intrinsic orientation, and thus allow themselves to be oriented vertically by an external field. In order to achieve isotropy, the iron oxide particles are doped with cobalt so that the cobalt's natural crystalline anisotropy competes with the shape anisotropy of the particles. This results in a uniform magnetization. The major drawback to this method is that media doped with cobalt have coercivites that are highly temperature dependent, up to 10 Oersteds per degree Celsius. Coercivity is a measure, in Oersteds, at which the medium reverses its magnetization.

The coercivity must be high enough so that the medium will not spontaneously demagnetize, but must not be higher than the field produced by the writing head (or data will not be able to be erased). For a normal disk, coercivities in the range of 300 to 700 Oe are typical.

As a response to the previous problem, an alloy of chromium and cobalt is now being used. It has been found that an alloy with over 13% atomic chromium have a perpendicular orientation when magnetized. The alloy is deposited on the media substrate in the form of hexagonal crystals that can be magnetized vertically.

Thin Film Techniques

A second way to increase data density and integrity is by using thin film technology for the magnetic media. The typical disk usually depended on an iron oxide particulate media. This coating usually has a thickness ranging from 25 to 35 microinches. Curing manufacturing, the Fe_2O_3 particles in the magnetic coating are oriented in one direction during the curing process to provide a uniform, basic magnetic orientation. However, this type of media has limits to the coercivity that can be obtained, due to the relative scarceness of the particles (see figure 5b).

Thin film technology solves this problem by laying down a film of pure magnetic particles about 3 microinches thick (see figure 5a), which leads to a doubling of attainable bit densities without losing signal strength. This allows for more tracks per inch, thus more storage for a given size of disk. And due to the higher coercivity of the material, the prospects for vertical recording are enhanced, because the particles have a stronger force holding them in their vertical orientation.

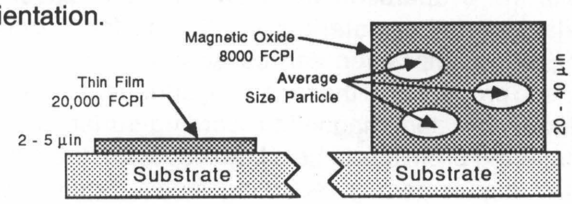


Figure 5(a) *Figure 5(b)*

Other advantages provided by thin film technology are fewer read and write errors due to the increased smoothness of the disk surface. A smoother medium will allow better contact between the disk head and the surface, which means better amplitude and resolution. This allows a lower magnetic field to flip or read a bit, reducing the fringing effect, which allows increased numbers of tracks per inch.

With oxide media, bit size is limited to the size of the ferric oxide particle. There is no such limitation with thin film media as both density is limited only by the size of the microcyrstal in the metal film. Thin film media also are not subject to problems associated with particle size variation of nonuniform particle distribution. Although more difficult to produce than oxide disks, thin film disks are the wave of the future, and advanced production capabilities are being introduced, as described in the next section. For a comparison of thin films versus oxide media, see table 1.

	Oxide Media	Thin-film	Advantages of thin film
Magnetic Properties			
Coercivity (oersteds)	350 - 400	500 - 700+	High resolution,
Remanence (gauss)	3500 - 4000	7000 - 8000	amplitude and
Squareness (M_r/M_s)	0.45 - 0.55	0.80 - 0.95	reduced bit shift
Thickness (µin.)	20 - 40	3 - 4	
Physical Properties			
Surface smoothness (µin.)	1.0 - 1.5	0.5 or less	better head contact
Overcoat	fluid	dry	less contaminants
Surface adhesion	poor to good	excellent	
Recording Properties			
Bit density (bits/in.)	≈ 8000	> 15000	increased storage
Resolution (percent)	≈ 65	> 80	capacity & lower
Amplitude	low	high	S/N ratio
Bit Shift	high	low	fewer errors

Table 1 COMPARISON OF OXIDE AND THIN FILM MEDIA

Deposition Methods

Many of the characteristics of the recording media, whether oxide or thin film, are controlled by the technique used to deposit the magnetic material on the substrate. There are four methods now in wide use, vacuum deposition, sputtering, electroless (chemical) plating, and electroplating. The advantages and disadvantages of these methods will be discussed in the following sections.

Vacuum deposition has been used to make thin film media used for both vertical and longitudinal recording. The magnetic material to be deposited is heated by means of either electrical current or radio frequency to a temperature above the melting point of the metals. The metal vapor is then deposited on the cool surface of the disk substrate. Although a high deposit rate is achieved, a serious deficiency is noted when alloys are used.

Because of the difference in vapor pressures of the metals, the evaporation rates are different, causing an imbalance of the materials on the surface. Because changes in composition can cause a large effect on the magnetic properties of the recording surface, it is difficult to produce consistent magnetic recording surfaces.

Sputtering promises to be a key process in the development of higher density recording media. Sputtering is a process in which a target, consisting of the material to be deposited, is placed opposite a substrate in a vacuum chamber. The chamber is evacuated and filled with low pressure argon gas. A potential of several kilovolts is applied between the target and an anode, the argon forms a glow discharge and argon ions are accelerated to the target, where they strike and cause an atomic cascade collision which causes some of the atoms hit to be deposited on the substrate. Sputtering has many advantages over the traditional coating method (see table 2), but as of now, sputtering is a slow process that requires rather expensive equipment. However, new technologies promise to make it a viable option for the future.

PROPERTY	COATED	SPUTTERED
Recording Density (BPI)	12,000	24,000
Film thickness (µm)	0.7	0.18
Surface roughness (µm)	0.12	0.02
Coercive force (Oe)	400	700

TABLE 2: COATING VS. SPUTTERING

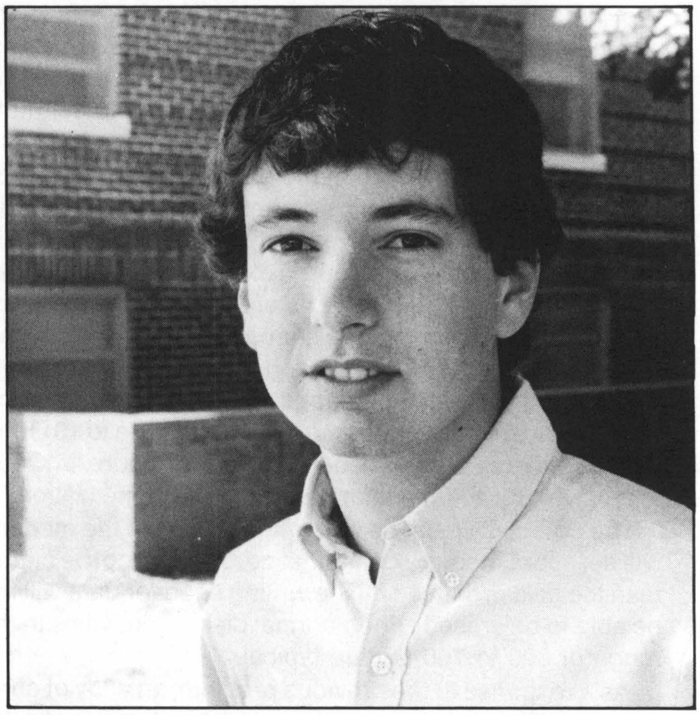
Electroless plating processes produce deposits similar to one derived from electroplating. However, it is a chemical process involving submersion in an aqueous solution of the metal to be deposited present as sulfate or chloride salt along with sodium hypophosphite as a reducing agent. Electroless plating allows several hundred disks to be plated at one time, but drawbacks to this process are a difficulty in controlling the thickness, and thus the magnetic properties, of the film. In addition, at bit densities above 8 million flux changes/second the film has low amplitude and resolution.

Electroplating deposition involves passing an electric current through a solution of dissolved metal salts, causing plating effect on the substrate. This has advantages over the electroless plating method in that the current may be varied to control the deposition process. Because of the many parameters involved, the properties of the magnetic film may be controlled with great precision. This process also requires a minimal capital investment, and can be greatly automated. However, alloy films are difficult to produce with this method, due to the varied solubilities of the metals in solution.

Conclusion

From the above discussions, we have seen that improving the storage capabilities of magnetic disk media is a task that requires the cooperation of many disciplines. The physicist, to improve processes for vertical magnetic recording; the electrical engineer, to design circuits to read and write data with more precision; the mechanical engineer, to design and build servo and stepper motors to more accurately place the drive head; and the material engineer, to actually produce the magnetic material used and the processes used for applying the material to the substrate.

It may seem that there are many directions that disk technology may take, but upon close examination, one can see that all aspects are closely related. Better processes for deposition lead to better thin film media which are better able to handle the demands of vertical recording. So as we look to the future, cooperation between the different facets of disk technology becomes increasingly important.



***Jonathan Leblang** graduated this past June in Electrical Engineering. While at Tech, he was a Resident Advisor and a member of the VTU films committee. Jonathan is presently working as a consultant with Mitre Corp. in McLean, Virginia.*

SEARCHING FOR REPLACEMENTS FOR CHROMIUM IN TYPE 304 STAINLESS STEEL

Kevin M. Loney

INTRODUCTION

Each year, the United States imports approximately 500 short tons of chromium, primarily from South Africa, Turkey, Rhodesia, and the USSR. This imported chromium accounts for 89% of the chromium used in the United States (the other 11% is recycled), and this trend is expected to continue.

As a result, the effects of a chromium embargo or the formation of a cartel which could cease all chromium exports to the United States would be extensive. The most affected industry would be the metallurgical industry, of which the stainless steel industry comprises almost 70%. Thus, a great deal of research has been done in the last ten years in an effort to discover a viable alternative to chromium in stainless steels. However, since chromium adds certain characteristics to the steels which cannot be gained by any other single alloy addition, the majority of the research has centered on the use of low-chromium steels with other alloy additions.

Therefore, it was necessary to evaluate possible alloying additions on the basis of their abilities to optimize the critical characteristics of the steel. Most of the research has centered on type 304 stainless steel, since this accounts for over 50% of the stainless steel used today. It was found that the steel should contain a minimum of 12% chromium in order help maintain the strength and oxidation resistance of the steel. On the basis of these characteristics, a recommendation was made for the use of steel that is, by weight, 12%Cr-10%Ni-1.5%Si-1%Al-2%Mo. Although there are several alloy combinations which meet the criteria, this is the one on which this paper will focus.

TECHNICAL DISCUSSION

Chromium Content

A typical stainless steel contains, by weight, 18% chromium (Cr) and 8% nickel (Ni). Since type 304 stainless steel accounts for over 50% of all stainless steel used, most of the research performed has used it as a basis for performance comparison. Since these steels contain such a large amount of chromium, one means of lowering our dependency on imported chromium would be to lower the amount used in standard stainless steels. Due to the material properties that would change as a result of this, alloying additions would be needed to compensate for the chromium loss.

The first step in the search for a replacement for the high-chromium steels was to determine how much chromium was actually needed in the steels. In the past, with no economic or strategic considerations, there was no need to limit the amount of chromium in steels. Since it was known that chromium promotes passivation, that is, the forming of a protective oxide layer on the surface of the metal, and reduces corrosion rates, it was necessary to conduct experiments in order to determine the extent to which the chromium content affected each of these factors. For both of these criteria, it was found that the critical chromium content was approximately 12% by weight. Figures 1 and 2, shown on the next page, illustrate this point.

Source: "Effects of Material Shortages on Stainless Steel Technology," *Metal Progress,* October, 1979.

Alloying Additions

As a result of the decrease in the chromium content, certain mechanical properties of stainless steels would necessarily be affected. Those given the greatest consideration in recent research have been corrosion resistance, austenitic content (the percentage of the steel which forms in the austenite range) and oxidation resistance. The effects of additions were considered for each case individually, and by varying one alloying element concentration independently of the others, the combined effects of various alloys on all of the characteristics could be determined. On the basis of these results and the given criteria, a recommendation could then be made.

One of the first alloying additions considered was aluminum, which serves primarily to increase the oxidation resistance of stainless steels. This would allow for the steel's usage in a high-temperature environment. There are currently several alloys in use for this purpose, containing 14% to 16% aluminum, but they all suffer from poor mechanical properties. In addition, aluminum lowers the tendency for passivation and decreases the pitting potential. The pitting potential is that at which pitting, or corrosion through a passive film layer, can begin. Lowering the pitting potential increases the ease of galvanic corrosion.

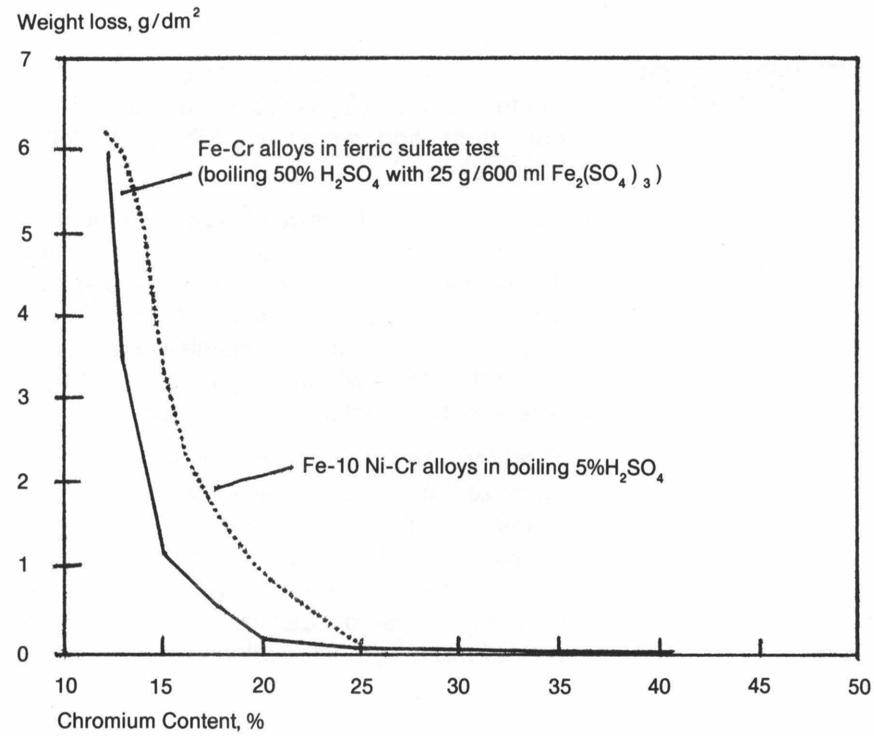


Figure 1

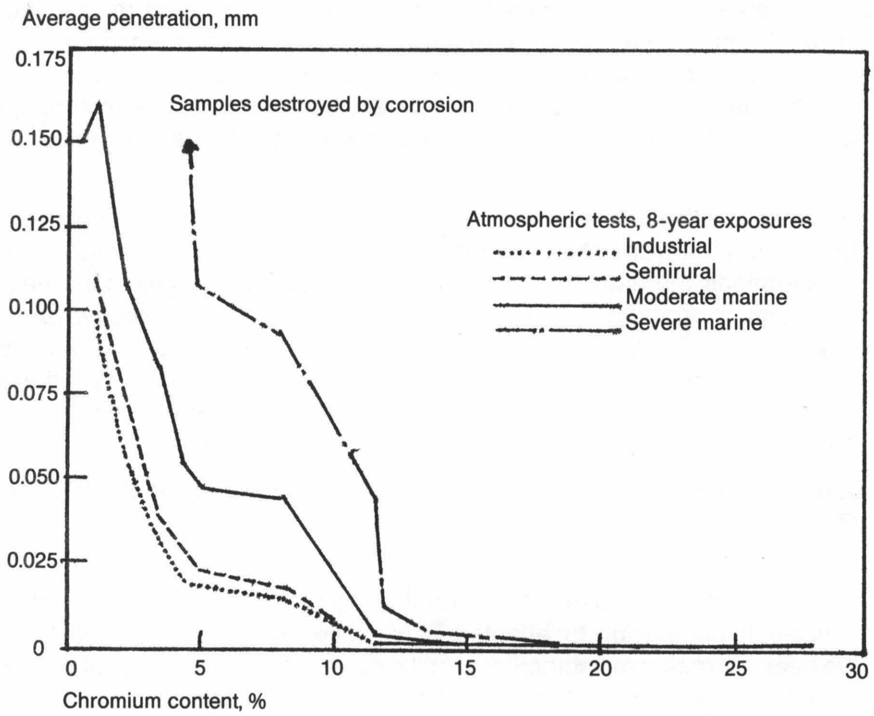


Figure 2

Source: "Effects of Material Shortages on Stainless Steel Technology," *Metal Progress,* October, 1979.

Since aluminum has these negative effects, it was necessary to use other alloying elements to improve the mechanical properties of the steel. The percentage of aluminum in the steel could then be reduced, since the oxidation resistance contributed by the other additions could compensate for the change in properties due to the loss of the aluminum. "Taking the elements that have a beneficial effect on corrosion and/or pitting resistance and eliminating cadmium, beryllium, silver, rhenium, and zinc on the basis of either toxicity, cost, or adverse effect on other properties, we are left with molybdenum (Mo), nickel (Ni), silicon (Si), copper, vanadium, and nitrogen." The impact of each of these additions on the material properties was then studied. Most of the published research has concentrated on studies of Mo, Ni, and Si, since these metals were already in use as alloy additions in steels.

Results from previous experiments had shown that Si and Mo improved the corrosion resistance, while Si and aluminum (Al) contributed to oxidation resistance. Based on the results of extensive experimentation on the interaction of these three elements, it was found that "Si, and especially Mo, are beneficial in enhancing passivation of a 12%Cr modified composition stainless steel alloy series." However, it was found that the presence of Al, while increasing the oxidation resistance, decreased the pitting potential of the metal, thereby making it more susceptible to corrosion. Molybdenum was therefore added. It was found that "the effects of combining Al and Mo ... suggest that, in general, corrosion properties are dominated by the presence of Mo." Therefore, when used in the right proportions, alloy additions of Si, Al and Mo could serve to increase both the corrosion and oxidation resistance without significantly lowering the pitting potential.

One of the reasons for the wide-spread use of type 304 stainless steel is its austenitic structure. Since a reduction in Cr content results in a reduction in the austenitic character of the steel, it is necessary to add elements which will cause the steel to become more austenitic. The two primary means of accomplishing this are the additions of either Ni or manganese (Mn).

Since both additions result in almost identical effects on the austenite content of the steel, they were evaluated in terms of their effects on the other characteristics of the steel. For the most part, these additions have little effect. However, it was found that the addition of Ni to the steel increases its pitting potential, thus increasing its corrosion resistance.

Finally, it was found that Mo is very effective in improving the tendency for passivation in the steel. Si also contributes to this effect, but to a lesser degree. The effects of the other additions on the pitting potential, and thus the passivation behavior of the metal, have been discussed above.

Optimization of the Composition

For this example, based in part on the data in Figures 1 and 2, a chromium content of 12% was chosen. Each alloy addition was then tested to see what effect it had when combined in different concentrations with chromium. It was then possible to reach an optimum case for each of the cases tested. Next, different compositions were held constant, and the combined effects of several alloy additions were considered simultaneously. Thus, by means of this univariate search, it was possible to determine the optimum composition despite the large number of variables.

Source: "Anodic Polarization Behavior of Austenitic Stainless Steel Alloys with Lower Chromium Content," *Corrosion,* October, 1979.

Other Considerations

In addition to the composition described in this report, there are several other choices for the basic composition of the alloying elements. For example, a steel with composition of 30%Mn-10%Al-Si-12%Cr was found to have a lower corrosion rate than that of type 304 stainless steel. In addition, this composition is not susceptible to stress corrosion cracking. However, it has a relatively low pitting potential due to the absence of Ni and the high concentration of Al.
An alternative means of conserving chromium is the practice of cladding materials with a high-chromium steel. This procedure, however, is restricted to a limited number of combinations of alloys and thicknesses. At present, the technology for large-scale implementation of this procedure does not exist.

CONCLUSIONS

Due to the extensive nature of American dependence on foreign chromium, it is imperative that we find replacements for the chromium products currently in use. Since no substitute has been found for chromium, most of the current research is centered on using alloy additions in low-chromium steels.

One such composition is 12Cr10Ni-1.5Si-1Al-2Mo. This composition can equal or exceed the characteristics of type 304 18Cr-8Ni stainless steel in terms of corrosion resistance, oxidation resistance, ease of passivation, and austenitic content. Whereas this composition is by no means the only material with this capability, it is a viable solution to the problem.

The effects of chromium on a steel are difficult to duplicate. However, for a given scenario and criterion, a low-chromium replacement can most likely be found which will match the characteristics of the high-chromium steel. For applications in which corrosion is a problem, the minimum amount of chromium in the sample should be 12%. Criteria such as this can be experimentally determined for each case.

As a result, the amount of chromium used in the fabrication of the steels for these cases can be decreased. Since stainless steels currently use 70% of the chromium used in the United States, even minor changes in chromium usage can have large effects. Instituting the use of 12% chromium steel in place of the 18% chromium steel currently in use, for example, could cut the chromium usage in the stainless steel industry by one-third.

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Scott M. Taylor

Electrolytic Water Disinfection:

A Preliminary Report

Summary

An electrolytic water disinfection system for the sterilization of water in a number of applications was designed and constructed for this report. The very simple system (See Figure 1) consists of the electrolytic cell (See Figure 2), a peristaltic pump to feed the water to be sterilized in the cell, and either a single reservoir, or a reservoir and a receiver. The electrical circuit consists of a DC power supply, the anode-cathode system within the electrolytic cell, a known resistance and a mulitmeter used to determine various electrical parameters in the system.

Preliminary results show that, as predicted, applying an electrical charge to a packed bed of activated carbon reduced the number of viable microorganisms present in the effluent water. At present, the mechanism of the "kill" of the organisms is unknown. However, future work, including tests run at high AC voltages (20-40 volts) in both one-pass and recirculation flow systems, is aimed at determining those mechanism(s).

Introduction

When an electrical potential is placed across a bed of activated carbon, it is believed that the individual carbon particles in the bed become polarized. The polarized particles provide sites for the "kill" of microorganisms present in the influent water. This type of electrolytic disinfection system has a number of obvious applications such as cleaning swimming pools, cooling towers, drinking water (especially in remote areas), etc.

Experimental

The apparatus used for the experimentation (See Figure 1) consisted of an electrolytic cell, a peristaltic pump to feed the water to be sterilized to the cell, and either a single reservoir, or a reservoir and a receiver. The body of the electrolytic cell (See Figure 2) was constructed from two inch Sch. 40 316 stainless steel piping. This outer shell serves as the cell cathode and has six electrical connection terminals distributed around the surface for even current distribution. Teflon end caps provide good sealing characteristics as well as insulation of the electrodes. Two Swagelock MPF fittings are located in each cap. Those on the centroid support and seal the ¼ inch anode (¼ inch 316 stainless steel tubing) which passes through the center of the cell and has electrical connections at either end. The other fittings allow entrance and exit of the influent and effluent water. The activated carbon packed bed occupies the inside of the cell except for one inch fluid distribution spaces at either end. Hard rubber bed support discs covered in 100 mesh screen, allow the passage of water but not the activated carbon particles. The bed can contain approximately 300 grams of activated carbon particles. The resulting reactor volume is 306.3 ml. The peristaltic pump which feeds the electrolytic cell can pump from 10 to 750 ml/min of influent water. The reservoir is a three liter side outlet glass jug. For recirculation tests, the effluent returns to the reservoir whereas for once-through tests, the effluent is collected in a separate receiver.

The electrical circuit (See Figure 3) consists of a DC power supply, the anode-cathode system within the electrolytic cell, a known resistance and a multimeter to determine various electrical parameters in the system. The power supply is capable of producing 1.8 to 28 volts at 0 to 5 amps. Only voltage is controllable; current is determined by the system resistivites and configuration. Two voltage measurements are routinely made: the first is across the electrode leads to determine the electrolytic cell potential, and second, a survey is conducted across the known resistance, a simple way to measure the current flowing through the cell.

Viable cell measurements are made through colony counts on agar plates. The influent water has a viable cell concentration of 10^5 to 10^6 cells/ml. This is obtained by diluting a turbid *Escherichia coli* to the point it is not turbid. Once the water is passed through the system, in addition to control sample, effluent samples are taken every 15 minutes for the recirculation tests, and only once for the single-pass trials (after the system reaches steady-state). A series of five serial dilutions are performed on the sample in order to cover the possible range of effluent viable cell concentrations. A series of culture dishes are inoculated with 0.1 ml of each of the series of dilutions. The culture dished are then incubated for eight to ten hours. The colony count for the given sample is based on the dish which contains 50 to 300 colonies. This number is then multiplied by its dilution factor to calculate the viable cell concentration as viable microorganisms per milliliter.

Results and Discussion

The preliminary testing consisted of three experiments. In the first one, a single-pass low flow rate system was used. The flow rate was set at 132 ml/min. and the voltage was set at two volts DC. The resulting current through the system was 0.73 amps. After the system was run approximately four minutes to allow the "kill" reaction to reach steady-state, the resulting cultures showed reduced microorganism growth in the system effluent.

The second test was a single-pass high flow rate system. The flow rate was set at 550 ml/min. and the voltage was set at two volts DC. The resulting current through the system was 0.32 amps. The system was run approximately two minutes in order to reach steady-state before the samples were taken. The cultures showed no significant microorganism growth reduction after treatment.

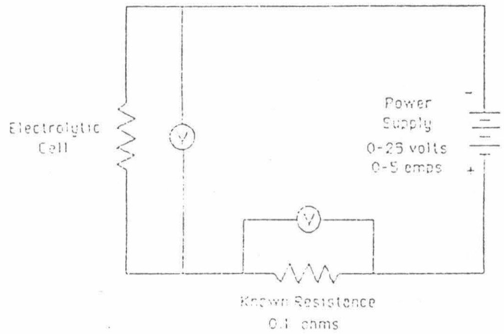


Figure 1: Experimental Apparatus

The final test was a multi-pass recirculation system. The flow rate was set at 210 ml/min. and the voltage remaining the same. The resulting current through the system was 0.5 amps. The system was allowed to pass two to three volumes, 600 to 900 ml, before the initial influent sample was taken. Then effluent samples were taken at 15 minute intervals. These cultures showed significant reduction in the number of viable cells with time of treatment in the recirculated system.

Previous work has identified the following possibilities as the mechanism by which the microorganism "kill" reaction takes place. Possibilities are: filtration by the activated carbon bed, electrolytic denaturation of the microorganisms through contact with the polarized carbon particle surfaces, and chlorination due to Cl_2 evolution. The Cl_2 evolution observed in past testing was not observed in the tests presented herein. It is possible that the voltage was not sufficient to drive the electrolysis.

Recommendations

The aim of future work will be to determine the mechanism of the microorganism "kill" reaction. The following additions to the testing scheme are recommended:

1) Tests using high DC and AC currents be performed. This may establish single-pass high flow rate operation as an alternative.
2) Tests using AC current be performed. Using AC current will eliminate the possibility of the Cl_2 denaturing as a "kill" mechanism. The cyclic nature of AC current eliminates Cl_2 evolution by electrolysis.
3) Quantitative results be obtained. This will provide a means to establish operational limits and parameters, as well as aiding in determining the "kill" mechanism.
4) Chlorine evolution be observed and measured if deemed viable.

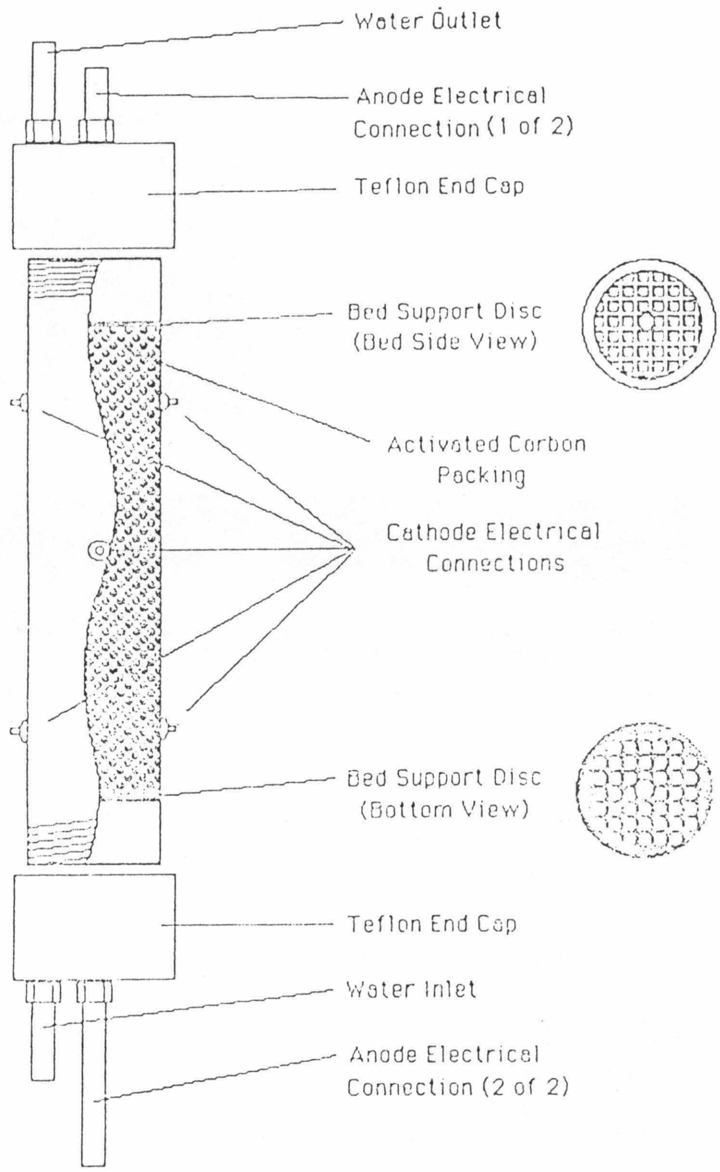
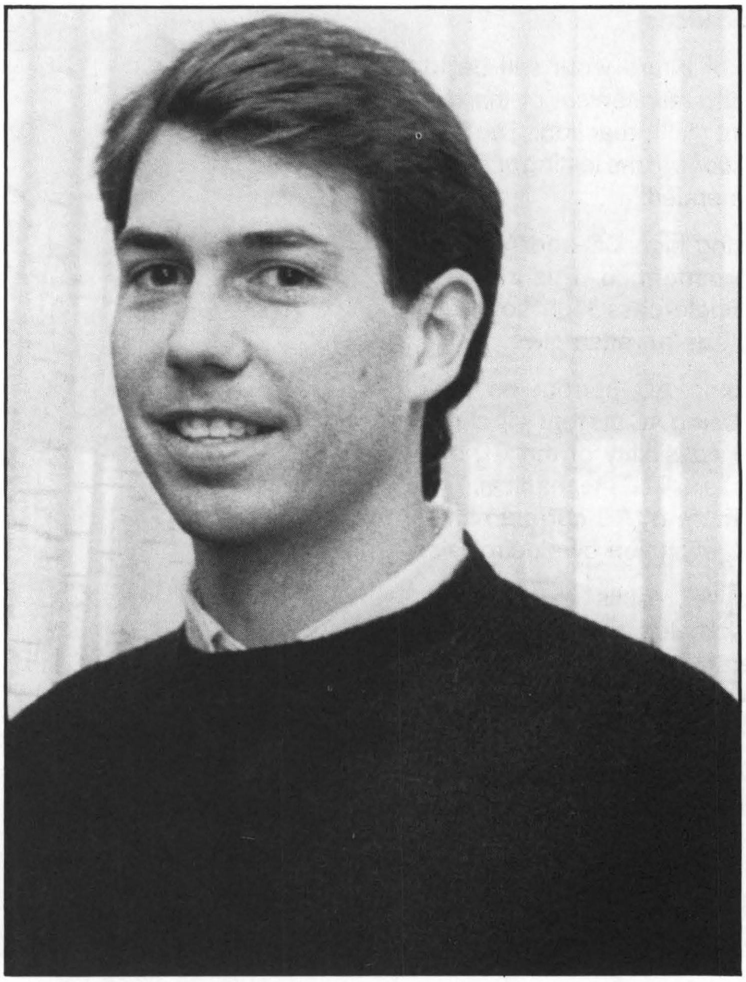


Figure 2: Electrolytic Cell



***Scott Taylor,** the illustrious ex-vice president of our Student Engineers' Council, graduated this June in Chemical Engineering. His present whereabouts are top secret.*

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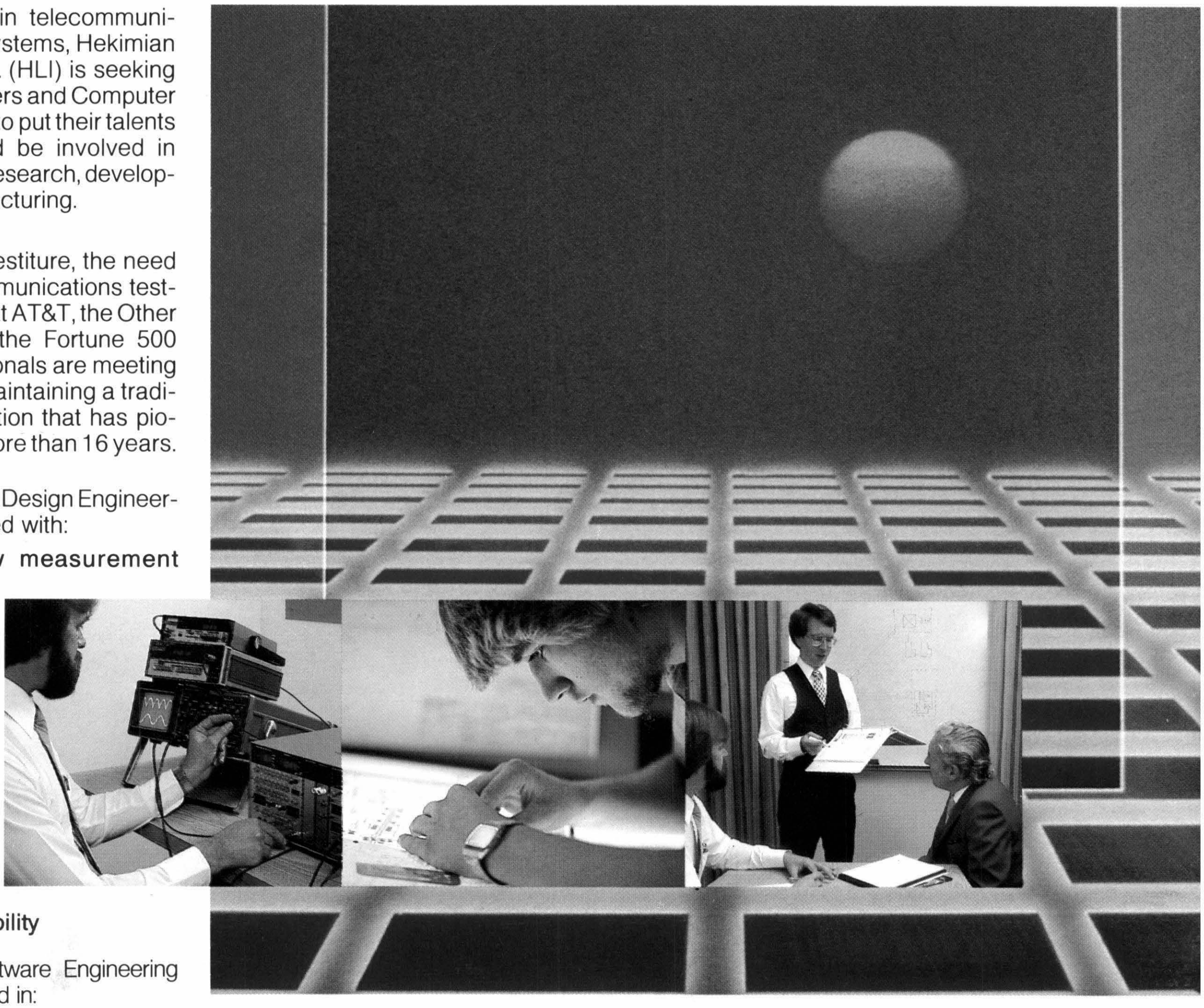

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