Screenings from the Soil Research Lab

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
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Nov. - Dec., 1957
Vol. 1, No. 6

THE STORY OF FLY ASH, OR, SMOKE GOT IN THEIR EYES

Not many years ago a melancholy shroud cloaked our cities, transforming them into stark gray pillars of brick and stone jutting upward like dirty coral into an air clouded and choked with grime.

There was too much smoke about.

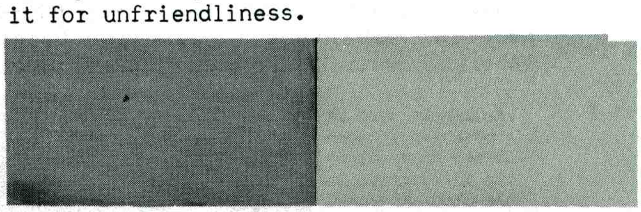
The increase in dinginess was so gradual that city dwellers did not at first give much heed. A few moved to the country; others had sick lungs. A few laid aside their cigarettes in disgust when they found they couldn't see the smoke any more.

Then the air got even grayer, and many people went back to cigarettes because they enjoyed the clear spaces the smoke made in the otherwise dark city air. Filter cigarettes became the rage; they were so much less conspicuous than wearing a gas mask.

As generations progressed and children grew up, the parents came to realize that something was amiss. A child reading his books might look up puzzled and ask, "Daddy, what's the sun?" Then Daddy had to hire an airplane and take the family up for a quick reminder.

Housewives gently (?) complained about the way their wet laundry acted as a filter, and the man in the gray flannel suit either wore a fresh, bright tie or became permanently invisible.

In fact it was during this era that city people, normally a loquacious group, learned their precious trait of never speaking to one another, simply because the neighbors had faded away into the gloom. The noble tradition has carried through to the present day, when outsiders mistake it for unfriendliness.

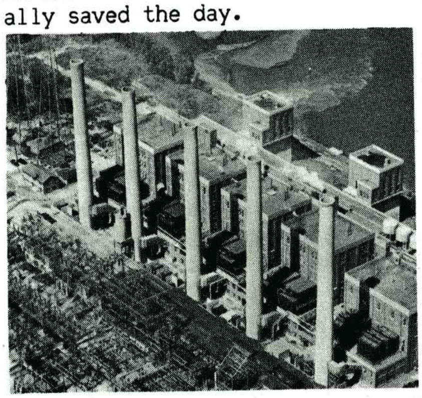


Then Now

OUR CITIES
On a gray day

Saving the Day.

In this grave oppression it was the Engineer in his track suit who boldly stepped up and literally saved the day.



Electric power station going full whirl, but no visible smoke! The fly ash is being removed by static electricity. Ash particles are first charged up and then caught on oppositely charged plates, leaving the smoke sweet as dew-kissed sunshine leaping on a sea of whispers.

Fly Ash

Smoke collectors, more properly called "precipitators," remove solids from smoke, leaving gases which ordinarily keep going up. The collected solids constitute a very fine dust called fly ash to rhyme with fly specks, which by nature it resembles.

Approximately 25,000 tons of fly ash are now collected in this country every day. Most precipitators operate either mechanically by utilizing centrifugal force, or electrically by attraction of electrically charged smoke particles.

Powdered Coal

One reason such a tremendous bulk of fly ash is being produced and collected is the changeover to use of pulverized coal. Electrical power plants operate more efficiently if coal is first powdered and then blown into the furnace. Money is saved and more power is produced. However, 90% of the ash is then fly ash instead of famous old-fashioned cinders.

A most frequent use of fly ash is to haul it out to the dump. This ash has been moistened to prevent blowing. Detroit Edison Co., Detroit, Michigan.

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DISPOSAL

Now that the fly ash is being collected there remains but one chore: What to do with it? For some reason people do not put a very high value on something which is worthless, unless of course it is pushed by clever advertising. Fly ash is a waste product which ordinarily must be hauled away, dumped, and buried. Otherwise it will blow around.

What is it?

If you visualize fly ash as soot, you're wrong. Fly ash usually contains only a minor amount of carbon. In appearance fly ash is a gray dust, somewhat like portland cement powder. Chemically it is quite a bit different.

Fly ash for the most part represents melted foreign materials from the original coal. The minerals have been melted and blown into a spray of tiny droplets, where they are cooled rapidly to form spheres of glass. Some of the spheres are hollow, like soap bubbles. Other particles are opaque and consist of magnetic iron oxides. But for the most part fly ash is a glass composed of silica (SiO_2) and alumina (Al_2O_3) with variable amounts of iron. Other elements present are carbon, calcium, magnesium, sulfur, sodium, potassium, not to mention many rare and exotic forms such as titanium, phosphorous, and germanium. The composition varies quite a bit from grain to grain, probably because the original mineral particles melted separately and never recombined.

Fly ash ×100. Diameter of the largest spheres is about 3μ, or 0.03 mm (0.001"). Very little carbon in this sample.

A Pozzolan!

Remember Pozzouli, a small town in Italy where Romans discovered the use of volcanic ash in mortars? Volcanic ash is glass, and it reacts with lime to give something hard. It is a pozzolan.*

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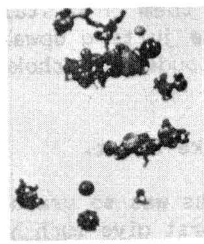
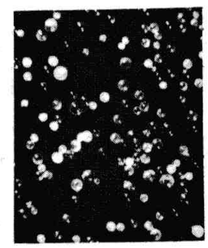
*Described in Screenings Vol. 1, No. 5

Now, with the use of modern technology and scientific knowledge plus a little fly ash, we are successfully doing what the Romans did over 2000 years ago, bless their pagan little hearts. We are using fly ash as a cheap pozzolan to increase the strength of our concrete, especially in big structures where economy is most worthwhile. The fly ash reacts with lime liberated from the hydrating portland cement. The reaction is relatively slow compared to that of hydrating cement, so there is little gain in early strength. Advantages show up later.





Oddities. Magnetic iron oxides (left) commonly compose up to 25% of fly ash. Hollow particles (right) are gas-filled bubbles. They float on water.

Whither Now the Fly Ash?

To bring our story to a happy ending we will maintain a fast report on the current uses of smoke dust.

Firstly, fly ash is used as a land fill. Ash has always been used as a land fill, and this is not a very new use. Land fill doesn't even have to be a pozzolan.

Secondly, fly ash is sometimes used as a fine filler in asphaltic concrete mixes. Because of the small amount consumed we don't wax much excitement here.

Third, and now we're getting important, fly ash is used in concrete. Since the fly ash adds a pozzolanic cementing reaction, in many cases the cement content can be safely reduced. This saves money and pleases everybody but the cement companies, who happen to be in business too. Fly ash is also used in concrete pipe and block.

Fourth, fly ash is used in grouting, especially in the placement of mortar by means of pumps. Such grouting can be used to fill cracks and voids which could not otherwise be easily filled, for example beneath foundations. Fly ash offers a peculiar advantage in grouting because the spherical particles improve flow and pumpability.

Fly ash is used as a pozzolan in concrete, often allowing a reduction in the amount of cement. Highway 31 north out of Birmingham, Ala.

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Probably the largest amount of fly ash used today is in a special kind of grouting inside of oil wells. Portland cement-fly ash mortar is pumped down wells to fill the space between the casing and the outside of the drill hole. The mortar sets up, seals the casing in the hole, and prevents unwanted water from entering and diluting the oil. Only specific layers of oil-bearing rock are allowed to produce. In oil wells because of heat involved (wells are often hot) the slowness of the pozzolanic reaction is often an advantage, as a flash set before pumping is completed can be disastrous from the viewpoint of the local stockholders. They may have to start drilling all over again.

SOIL-LIME-FLY ASH

Moistened mixtures of soil, lime, and fly ash can be compacted into a slowly hardening subbase or base course for a road, airfield, parking lot, or similar use. The lime and fly ash react pozzolanically. Immediately after compaction the road should be covered with a bituminous surface to prevent traffic abrasion and drying out.

Variables Affecting Mix Design

Research is often a study of variables, ideally to isolate each one and allow it to find its place in a formula or on a graph.

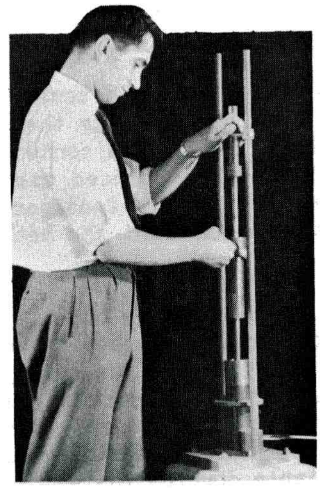
For example, a boy chasing a girl will do well to investigate such variables as climate, emotional sensibility and softness of the moon. Otherwise she may laugh at him and say, "Oh, go take a pill." He must learn to compensate for inevitable variables.

First things first: Sample size, molding procedures, etc.

Since we expect to mold about 14 billion samples (more or less), we had better keep the sample size small and convenient. A 2 inch diameter by 2 inch high size was decided on and the molding technique calibrated to give a standard compaction known as Proctor density.

Soil-lime-fly ash must cure to develop strength. The method of curing most nearly duplicating that in a road is to wrap the molded samples and put them in a moist-cure room. Wrapping is necessary to prevent a chemical change in the lime from the entry of CO_2. Temperature is commonly maintained at 70° F. Accelerated curing at higher temperatures has sometimes been found to give erroneous results.

Finally, testing. The most severe preparation for testing is to soak a soil in water. Therefore we usually soak our soil cylinders in water.



Manuel Mateos, a graduate student from Spain, bangs out a 2 by 2 inch soil-lime-fly ash sample with a special drop hammer molding device.

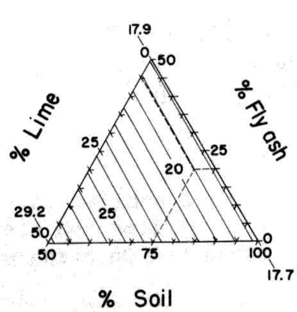
Because of the large number of variables to be studied, 7 M.S. theses relating to soil-lime-fly ash have been completed at Iowa State and 5 more plus one for a Ph.D. are in the process. Variables are kind of soil, kind and percent of lime and of fly ash, etc.

Then we know the strength, if any, is purely due to the use of admixtures. (Dry soils have some strength by themselves.) Supplementary tests are sometimes used where specimens are alternately soaked and dried or frozen and thawed to find test durability.

Optimum moisture and eureka! Now a short cut, but since nine out of ten people are confused by triangular charts we will not dwell on uncertainties. We will merely mention that the compacted (standard Proctor) density and optimum moisture content vary depending on percent lime and percent fly ash. Therefore every mix would presumably require a separate moisture-density test. This surmise ignores the fact that we are lazy.

It was found that if, for example, the addition of 20 percent fly ash increases the moisture requirement 6 percent, addition of half as much fly ash will increase it only half as much. The same is true with lime. And the same linear relations hold for the density: lime and fly ash both decrease density in an amount proportional to percent added.

Therefore three tests can be run at compositions indicated at the corners of the triangular chart. The chart is scaled off, and data for all intermediate compositions is read directly from the charts, with a fabulous saving in time, effort and exercise.



Triangular chart for the determination of optimum moisture contents of lime-fly ash mixes using an alluvial natural levee silt from Louisville, Ky. Corner points are found by test; intermediate points may be interpolated, as indicated by the dashed lines. The O.M.C. of a 75/20/5 mix is 19%.

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Lime and Other Remote Considerations

A previous issue of <u>Screenings</u> discussed soil stabilization with lime alone. Here there were three major variables: soil, lime content, and kind of lime. All three influenced strength. Added to these were other routine considerations such as density, moisture content and method of curing.

The addition of fly ash spells out even more variables, each requiring a separate investigation for each combination of the preceding ones. (Things are so variable they are getting a little confused.) A study with independent variables thus proceeds in geometric progression--that is, addition of one variable doubles the work; addition of two quadruples it.

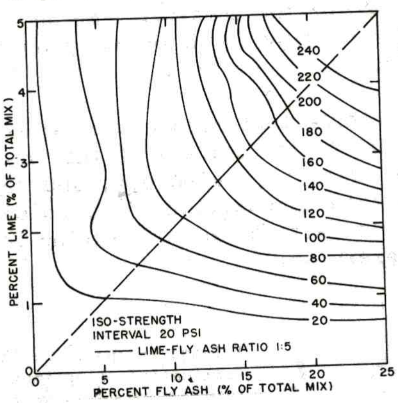
VARIABLES ONE BY ONE BY ONE

Percent Soil, Lime, and Fly ash

This may look like three variables in a lump, but it is not because all three have to add up to equal 100. That is, fix two and the other one is set automatically, like sales tax.

A study with these two variables--percent lime and percent fly ash--is shown below. Compressive strength is plotted on the z-axis. (Here's looking at you.) It is therefore shown by contours.

Construction of such a graph is not an idle hobby, for it means that soil-lime-fly ash specimens are molded at each percent lime and each percent fly ash within the area of the graph. Furthermore all tests are run in triplicate. It's enough to make one tired.



A beautifully symmetrical sand-lime fly ash graph. Contours represent 28-day strengths after soaking one day in water. Dune sand from eastern Iowa, Detroit fly ash, monohydrate dolomitic lime. The Optimum lime-fly ash ratio is about 1 to 5 except in the area at the lower left.

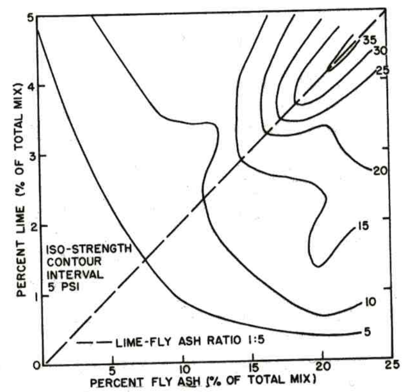
Kind of Soil

The graph presented above applies only with one kind of soil, one kind of lime and one kind of fly ash. Similar graphs can be prepared for other mixtures.

So far it has been found that lime-fly ash stabilization works best with silts, sands, and coarser soils. Clays sometimes require more lime, but not always.

Kind of Lime

The kind of lime, previously discussed for lime stabilization, also has an effect on lime-fly ash. Dolomitic monohydrate lime was usually found to be the most satisfactory. Calcitic lime is almost as good in certain mix combinations, not so good in others. The graph below is for sand-lime-fly ash as above, but with calcitic lime. Note the very much lower strengths.



Kind of Fly Ash

Fly ashes differ depending mainly on method of collection and efficiency of combustion. The poorer the efficiency the more unburned carbon remains in the fly ash. And, as it turns out, the poorer the fly ash for use as a pozzolan. Several tests have been found to give a fairly reliable indication of the quality of fly ash. Two are the percent loss on ignition, and the percent retained on the No. 325 sieve. Both tests actually take a sidelong look at the carbon. The carbon in fly ash occurs as large, porous chunks of coke; they absorb water and do little good.

Fly ash	Loss on ignition	Compacted density	45-day compressive strength
Mix: 8% calcitic lime, 92% fly ash, 0% soil. Moisture added for optimum compaction.			
Louisville, Kentucky	3.2%	83.2 pcf	2220 psi
Minneapolis, Minnesota	10.2	69.4	969
Venice, Illinois	15.6	62.2	905
Kansas City, Missouri	27.7	52.8	178

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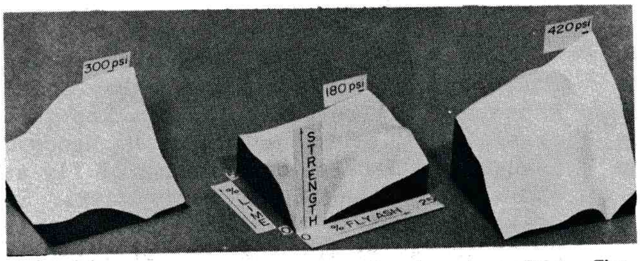


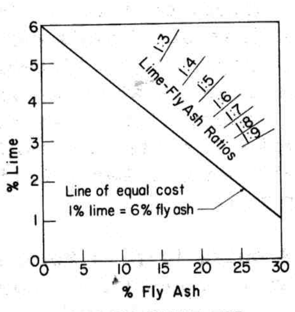
Three-dimensional diagrams may be shown by models. The model at the left indicates strengths of an Iowa gumbotil containing much montmorillonitic clay. At the center is a Detroit lake clay with calcitic lime, at the right is the same clay with monohydrate dolomitic lime. Models were prepared by Lt. Robert Crosby, U. S. Corps of Engineers.

Short-cut for Design Purposes

While studies of different variables and plotting on three-dimensional graphs is thoroughly delightful, short-cuts are even more so. Actually the detailed studies belong to research, to find universal rules that could be applied in design.

One universal rule already discovered is that the best ratio of lime to fly ash is not very critical and varies somewhat from soil to soil. Best strengths are developed when the fly ash far outweighs the lime. This happens to give the best economy too. Since design is already partly a matter of economy, one approach to design is to test different mixes proportioned on an economically equivalent basis.

That is, if lime were to cost six times as much per ton used on the job as fly ash, stabilization with 8 percent lime would cost the same as stabilization with 7 percent lime and 6 percent fly ash, the reduction in the cost of lime being offset by the increased cost of fly ash. Another mix would be 4 percent lime and 24 percent fly ash. (8-4 = 4; 4×6 = 24). These mixes can be tested as representing a reasonable degree of economic equivalence. Such a cost ratio would have to be figured for each job.



Points along the line represent economically equivalent mixes, provided that lime costs 6 times as much as fly ash. With zero fly ash the graph indicates 6 percent lime. Richer or leaner mixes would have parallel cost lines.

DESIGN CHART FOR
LIME-FLY ASH TRIAL MIXES

Durability and Effect of Density

Durability is like woman's love--turbulent and mysterious, but sometimes answering to pampering. And testing inevitably contributes towards destruction. Durability of soil-lime-fly ash is tested by wetting and drying or freezing and thawing. Specimens usually gain strength through wetting and drying, so this is nothing to worry about.

Freezing and thawing offers more problems. The molded soil specimens are allowed to absorb water, after which they are frozen. The water expands, tending to push things apart. The resistance depends to a large degree on the kind of soil, which influences cementation and permeability.

In an effort to increase strength and durability, soils may be compacted utilizing heavier rollers giving a greater compactive effort. Tests of strength showed that on the average,

$$S = So + 43.5\ P,$$

where S is the strength after 28 days, So is the strength when compacted to standard Proctor density, and P is the percent increase in density over standard Proctor. Compaction was most beneficial to clay, least beneficial to sand.

Increased density also increases the resistance to freeze-thaw, partly because of increased strength from better cementation, but also because tighter voids reduce the take-up of water.

Density	Immersed strength after 14 days moist curing	Strength after 12 cycles freeze-thaw
Material:	Friable loess. Std. Proctor density = 98 pcf	
103.0 pcf	528 psi	754 psi
106.4 pcf (Mod. Proctor)	503 psi	774 psi
108.0 pcf	506 psi	785 psi

Test Roads

Extensive test work has been conducted by the Detroit Edison Company, Detroit Michigan. Construction includes primary and secondary roads as well as parking lots. Soil types include fine sand, lake clay, material in an old gravel road, and various mixtures of these materials. Variables tested in the field include: kind of soil, kind of lime, percents lime and fly ash, kind of mixer, thickness of base, and kind of surfacing. Truly a noteworthy test! (P.S. We did the design.) Results are not yet completed.

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The Iowa Highway Commission test sections in Highway 117 north out of Colfax contain 4000 feet of soil-lime-fly ash, much of it containing a secret accelerator believed useful because of the late-season construction. The soil is 75 percent fine sand 25 percent loess. The mix is 27 percent fly ash from Cedar Rapids and from Chicago, and 3 percent monohydrate dolomitic lime.

Commercial Prospects

Some of the work on lime-fly ash is motivated by profit, as contrasted with our own which is of a more heroic nature. Commercial use of lime-fly ash has begun in areas close to sources of fly ash, mainly Philadelphia, St. Louis and Chicago. Utilization is still mainly in the driveway-parking lot stage, although with future improvements through research the use will surely extend more to airports and highways. It has been found that soil-lime-fly ash offers a peculiar resistance to heat, making it suitable for use as jet aircraft landing aprons, where other materials quickly go to pieces. We are obliged not to comment on patents existing on soil-lime-fly ash; we still live in awe of the early Romans.

References Sighted

We know that reading of scientific papers is an unnatural task, just as writing them is, but here are a few jokeless wonders anyway. Best to classify them according to subject:

Methods of test: Chu, Davidson, Goecker, Moh. Hwy. Res. Bd. Bul. 108. 1955.

Optimum moisture from triangular chart: Goecker Moh, Davidson, Chu. Appendix. Hwy. Res. Bd. Bul. 129. 1956.

Short-cut design: Not in print. Mimeo on request.

Kind of soil; kind of lime: Hwy. Res. Bd. Bul. 129. 1956.

Kind of fly ash: Hwy. Res. Bd. Bul. 129. Also Davidson, Sheeler, Delbridge, Reactivity of four types of fly ash with lime. Presented to Hwy. Res. Bd. 1958.

Durability and density: Viskochil, Handy, Davidson. Hwy. Res. Bd. Proc. 1957. Also Hoover, Davidson, Handy. Durability of lime-fly ash-soil mixes compacted above standard Proctor density. Presented to Hwy. Res. Bd. 1958.

Commercial uses: See Minnick, L. J., and Meyers, W. F. Properties of lime-fly ash-soil compositions employed in road construction. Hwy. Res. Bd. Bul. 69. 1953.

Acknowledgements

Many thanks to the Iowa Highway Research Board and the Iowa State Highway Commission whose controlled benevolence makes this work possible. Also to the Walter N. Handy Co. of Evanston, Illinois, distributor of fly ash and sponsor of some of our early work. Special gratitude goes to the many lime companies and power companies for the tons of free lime and fly ash consumed in the lab.

And we thank the U.S. Army Corps of Engineers for wanting their top young officers to have M.S. degrees; we think it's a good idea too. Officers who have completed portions of the lime-fly ash research are Lts. R. L. Crosby, N. G. Delbridge Jr., C. E Sell Jr., R. Segal, and Capt. R. H. Viskochil. Other work has been done by Za Chieh Moh formerly of Formosa now of M.I.T., and Wes Goecker, now with the U.S.C.E. in Sacramento.

EDITORIAL PAGE:

Christmas Giving

In answer to the inquiries concerning subscription rates and the offers to pay (!), please accept Screenings as a wee little Christmas gift from us to you with no strings attached, other than that you must want it. If gratitude causes your heart to wax irrevocably mellow, just send your Christmas donations and old clothes along to Ye Olde Editor and he will see they are proportioned amongst the professors and other needy persons on the staff.

Meantime if your name is new on our gift list and you want back issues we'll send what we have, but mostly we're out. If requests keep coming we may test their sincerity by printing up a few more copies and charging to defray the cost.

Requests for several copies of a specific issue will also be gladly honored, provided you're willing to come through with about 10 cents per copy. We hate to be so mercenary, but our kind-hearted secretary sometimes objects when we pay all the costs out of her salary. (She has not yet learned to starve like the rest of us.) And if it hasn't been said before, Merry Christmas and a Happy New Year too.

IN THE NEXT ISSUE: A quick trip to Mexico City to see some world-famous foundation problems.

RLH

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