University of Alberta

Cemented Rockfill Optimization in Vertical Block Mining

by

Stephen Mark Peterson ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science (MSc)

in

Mining Engineering

Department of Mining, Metallurgical and Petroleum Engineering

Edmonton, Alberta

Fall 1996

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Name of Author: Stephen Mark Peterson

Title of Thesis: Cemented Rockfill Optimization in Vertical Block Mining

Degree: Master of Science

Year this Degree Granted: 1996

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ABSTRACT

Optimization of INCO Limited's cemented rockfill system is discussed in great detail. The three main aspects investigated are:

- Factorial design work (slurry design),
- Fragmentation analyses,
- Fill raise orientation.

Extensive rockfill cylinder testing was performed to determine the effect that aggregate size, aggregate moisture, portland cement, flyash and cement dispersant addition has on compressive strength. "Two-level factorial" and "central composite" designs were used to determine the single and interaction effects that each factor have on the overall strength. The results from the design-work indicated that the <u>percent of aggregate fines</u> had the greatest influence on the compressive strength of the rockfill cylinders. From the factorial design results, a compressive strength estimation equation was derived, which enables the strength to be estimated, given varying input values.

Fragmentation of the aggregate, while travelling through the surface-to-underground aggregate transport raise, was investigated and a "fines estimation" equation was determined. When used with the strength estimation equation, the fines estimation equation enables an accurate estimation of the compressive strength to be derived theoretically.

Optimum fill raise orientation was examined and

recommendations are given depending on the varying stope dimensions. If the maximum dimension of the stope is less than 100 feet, a single, centrally located fill raise will suffice. However, as the stope dimensions increase, the number and orientation of the fill raises becomes more complicated and each stope must be examined on an individual basis.

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1. BACKFILL - GENERAL

1.1 OBJECTIVES:

The aim of this thesis is to examine the areas where cemented rockfill costs are high and attempt to find cheaper alternatives to these current standards.

Below are the main reasons for backfilling:

1) Ground Control - **"STRENGTH"**. Backfill must provide strength for a safe working environment and limited dilution.

2) Pillar Recovery - **"ECONOMICS"**. The recovery of the ore pillars adjacent to backfilled blocks must prove economical with respect to the cost of the backfill.

3) Waste Disposal - **"ECONOMICS"**. The costs associated with disposing of waste piles and tailings dams must be factored into the economic equation. The backfill of waste must be cheaper (in the long run) than other available environmentally acceptable methods.

High compressive strength, high placement tonnages, cleanliness and simplicity, make cemented rockfill one of the most effective methods of backfilling in underground mining. Although cemented rockfill is a high compressive strength backfill and therefore reduces ore/backfill dilution, cemented rockfill can be a high cost method. Currently, the average cemented rockfill costs are approximately $12/ton rockfill placed. Over fifty percent of these costs are associated with binder costs (purchasing cement and flyash). Therefore, efforts to reduce the total percentage of binder are greatly encouraged. The remaining fifty percent of the costs are associated with crushing, screening and hauling the aggregate and also the underground materials handling of the rockfill material. On average, INCO Limited Manitoba Division, produces approximately 250,000 tons of rockfill annually ($3 million dollars Canadian per year is spent on rockfill). Obviously INCO Limited wants to optimize their rockfill systems and reduce these substantial operating costs.

This thesis will target areas where current rockfill practice can be improved upon. Aggregate attrition, rockfill placement methods and slurry design will be discussed thoroughly, and recommendations for improving current practices will be given.

1.2 LITERATURE REVIEW PERTINENT TO THE THESIS:

Literature reviews were performed to determine what information was available from previous test-work performed in mining and other industries. Three literature reviews were performed:

1) Several papers were collected during the first literature review, "Mines utilizing cemented rockfill". Many of the papers collected were written by Thiann Yu from Falconbridge's Kidd Creek Mine. INCO Limited relied on previous test-work performed by the engineers at Kidd Creek when determining the initial set-up of their cemented rockfill system. For example, Yu had declared that the slurry recipe should contain 5 percent total binder containing 30 percent flyash and 70 percent portland cement (through additional test-work, INCO has improved upon these original settings). Yu also declared that 25 percent aggregate fines creates optimum rockfill (Yu, Counter, 1983). INCO engineers still try to achieve this target percentage, but if proper mixing is achieved, percentages ranging from 20 - 40 percent have proven to deliver the necessary strengths. Valuable information associated with rockfill fill-raises was obtained from a paper written by Farsangi and Hara (Farsangi, Hara, 1992), also from Kidd Creek. The ideas that Farsangi and Hara suggested, were analyzed thoroughly by INCO engineers with the aid of a plexiglass model (explained in detail during this thesis). The

results from the model testing have since been verified in actual production blocks.

2) The second search was associated with "portland cement substitutes". The review revealed that flyash was the most frequently used cement substitute. Two other portland cement substitutes discovered through the search were "anhydrite" and "pozzolanic slag". However, due to availability, economics, and proven industry performance, INCO Limited decided to use flyash as their cement substitute (hence, the thesis test work is concerned with flyash as the cement substitute). The Bureau of Mines performed a study on "Laboratory Analysis of Pozzolanic (Flyash) Concrete (Phillips, 1981)". Phillip's test-work indicated that the addition of flyash would result in higher final compressive strengths (the strength would increase due to the slower hydration reaction). Engineers at Kidd Creek state that mining can be performed beside a block containing 33 percent flyash after a curing period of 28 days (Yu, Counter, 1985).

3) The third literature review, "statistical designs", revealed that **two-level factorial designs** (explained in detail later in this thesis) could be used accurately and easily used when analysing processes with several variables influencing the response of interest (Mular, 1990). Variables associated with the cemented rockfill slurry recipe were analyzed using these designs. The two-level factorial designs yielded equations which can be used to estimate the compressive

strength of the cemented rockfill. Other statistical methods discovered by the search included:

- **central composite designs** - modified two level factorial designs, also used during this thesis work.

- **fractional factorial designs** - although quicker to perform than the full two-level factorial designs, the fractional designs are less accurate (Mular, 1990) and were not used in our test-work.

- **grid searches** - a slow method involving two factors at a time and therefore were not used in our test-work.

- **steepest ascent method** - a useful method which utilizes two-level factorial designs, but is too time consuming for our purpose. Several factorial designs are required and would result in too many cylinders having to be prepared. A factorial design is performed to determine an optimum value (i.e. highest compressive strength) for the test range. Then a second factorial design is performed at this new highest compressive strength value. The process is repeated until an overall optimum value is obtained (Bacon, 1967).

- **the EVOP method, and the SSDEVOP method** - empirical optimization techniques that have been applied successfully in other industries (Carpenter, 1965), but were not chosen for our test-work.

1.3 COMPARISON OF INCO'S BACK-FILLING METHODS:

There are several geological, environmental and operational factors which determine the most appropriate backfilling technique. The geology of the deposit, including the physical and mechanical properties of the ore and surrounding country rock mass will effect the final decision. Factors such as ore body "dip", "thickness", "grade" and "depth of orebody" will effect the mining method and therefore effect the backfilling technique. Also, environmental aspects such as the elimination of tailings ponds and surface waste-rock piles must be considered in the final scheme. Operational concerns such as: mining method, production rates and filling cycles are significant aspects determining the backfilling method. Also, the availability of backfilling material will greatly influence the backfilling method. For example, if there is access to nearby quarries or alluvial aggregate deposits, then rockfill may be the obvious method. However, if large quantities of surface aggregate are not readily available, methods utilizing mill tailings will probably be more economical.

1.3.1 HYDRAULIC BACKFILL:

INCO Limited's T-1 Mine currently utilizes cemented hydraulic backfill. Recently, the hydraulic backfilling method has been replaced by cemented rockfilling at INCO's T-3 and

Birchtree mines. High dilution associated with the low compressive strength of hydraulic fill influenced INCO to switch to cemented rockfill at their "newer" mines.

INCO Limited employs bulk mining methods, opening large voids underground, requiring substantial amounts of backfill. At the T-1 Mine, the backfilling aggregate is from the mill tailings. The sand is classified mill tailings, with sizes ranging between 85 percent 48 mesh and 200 mesh, and 15 percent below 200 mesh. A fully automated sandplant is located in the mill building and is described as follows:

Two outlets equipped with knife-gates allow the sand to be extracted from the 2300 ton storage tank and directed into two mix tanks. Dilution water is added to the mix tanks, where large impellers keep the mix agitated. Cement, contained in a 150 ton cement silo, is added to the mix tank via airslides. The mixed product is sent underground through a series of six inch vertical boreholes. Distribution on the horizontal levels is through six inch, heavy walled sandfill pipe. The gravity head is adequate for placing hydraulic fill in all areas of the south end of the T-1 Mine. However, due to headloss while travelling long distances (13,500 feet) to the north end of the mine, sandfill pumps are required. Centrifugal pumps with variable speed motors are used to deliver the additional head required to move the hydraulic fill to the north end.

Hydraulic Backfill Advantages:

- relatively simple to install and operate and requires minimum supervision.

- tailing, as mill waste, is readily available and its utilization can reduce surface waste disposal.
- use of hydraulic fill is well documented and understood in Canadian mining history.
- in deep mines, pumping can normally be avoided, unless very long horizontal distances are required.
- additional aggregate is not required and is therefore a fairly inexpensive method.

Hydraulic Backfill Dis-Advantages:

- excessive water needs to be dewatered from the stope and pumped to surface.
- low compressive strength method cause high dilution.
- cement slimes experienced underground require time and money to remove.
- costly bulkhead construction is required.
- curing time between hydraulic pours can interrupt the filling and mining cycles.
- high water content, causes high cement consumption.

1.3.2 CEMENTED ROCKFILL:

Backfill materials generally consist of a graded aggregate combined with a blended binder of Portland cement and flyash. INCO Limited utilizes their open pit waste aggregate, which must be screened to plus 3/8 inch prior to being sent underground through a ten foot diameter vertical raise. Slurry is mixed at the surface plant and sent underground via six inch vertical boreholes. The aggregate and slurry are mixed at the underground rockfill stations. The slurry and aggregate are dumped into underground haulage trucks, which deliver the rockfill to the open stopes.

The overall effectiveness of the backfill is affected by a number of parameters which are usually addressed and incorporated into the fill specifications. These include aggregate sizing, amounts of cement and flyash, and percentage of mixing water. Factors extraneous to initial design also contribute to the overall quality of the fill. These include aggregate attrition and segregation during filling, improper mixing during placement, impact damage caused by falling aggregates and quality of the mix water.

Cemented Rockfill Advantages:

- waste rock from the open pit and underground is used as backfill, reducing waste disposal on surface.
- simple preparation system.
- high compressive strengths.
- low dilution when mining adjacent ore blocks.
- stope dewatering is avoided.
- no "down-time" between pours for dewatering is needed.
- clean method, limited underground slimes.
- high placement tonnages.

Cemented Rockfill Dis-Advantages:

- high aggregate crushing, screening and delivery costs.

coning of placed material can cause segregation layering.

- mill tailings are not utilized and surface disposal must be considered.

- underground station and/or equipment is required (eg. trucks or conveyors).

2. INTRODUCTION - INCO

2.1 INTRODUCTION:

A large portion of future ore production at Inco Limited's Manitoba Division will come from the 1-C orebody of the Thompson Mine. Backfilling played an integral part of the initial planning and development of this unique orebody. At the T-3 Mine, the design and construction of Inco's first cemented rockfill system commenced in 1990 and was commissioned by August 1991. Currently, there are 5 cemented rockfill stations in the Thompson Division.

This paper will focus on the design and layouts of the T-3 and Birchtree cemented rockfill systems as well as placement methods and rockfill quality control.

2.2 BACKGROUND:

Thompson is located approximately 750 kilometres north of Winnipeg in North Central Manitoba. The Manitoba Division of Inco Limited has produced approximately 50 million tons of nickel bearing ore since mining was introduced to the region in 1958. Operating facilities include the Thompson Open Pit and two underground mines - the Thompson Mine and Birchtree Mine.

The Birchtree Mine was shutdown in 1978, but resumed production in 1989 with plans for expansion. It is located ten kilometres southwest of the city of Thompson and currently produces 1700 tons of ore per day, with a planned production rate of 3000 tons per day.

Located five kilometres south of the city, Thompson Mine currently produces about 6000 tons per day. An extension to the north of the Thompson Mine is currently being developed, employing ramp and level accesses from existing workings and the sinking of a new ventilation and service shaft.

The Thompson Open Pit, situated between the T-1 and T-3 headframes, mines the surface crown pillar above the Thompson Mine. The Thompson Open Pit is presently winding down production and will be completed by the end of the first quarter of 1995.

Adjacent to the T-1 headframe, the division operates a fully integrated processing complex which handles all mine production. Production from the Birchtree Mine is transported to the complex using surface haul trucks. All production from the Thompson Mine is hoisted at the T-1 shaft, directly into the mill. The ore is concentrated, smelted and refined to 99.9 percent pure electrolytic nickel at the complex, which has a production capacity of 140 million pounds of finished nickel annually. Finished product is in the form of either 140 pound cathodes or small button-shaped nickel ROUNDS.

2.3 THE 1-C OREBODY:

The 1-C orebody is located below the 2400 haulage level in the T-3 area of the Thompson Mine. The orebody contains mineralized schist and pegmatite as well as massive sulphides. The 1-C is an isolated high grade zone with a strike length extending over 1000 feet between 2400 and 3200 levels. The orebody dips at approximately 45 degrees, with varying widths depending on depth. The average width of the orebody is 150 feet, reaching a maximum of 350 feet on 2850 level. Although originally intersected in 1966, development of the 1-C did not start until the fall of 1986, with proven and probable reserves of over six million tons grading 3.4 percent nickel.

2.4 MINING METHOD:

Early production from the 1-C started in 1990, while the ramp access to the orebody was still being developed. The 1-C zone currently operates at 1600 tons per day, reaching its full production rate of 2100 tons per day in 1996.

There are two mining methods presently employed in the 1-C orebody: Vertical Block Mining (VBM), a modified form of crater retreat, and sublevel open stope mining, using a slot and slash technique. Mining blocks are taken transversely in 100 foot lifts using primary and secondary sequencing (see **FIGURE #1**).

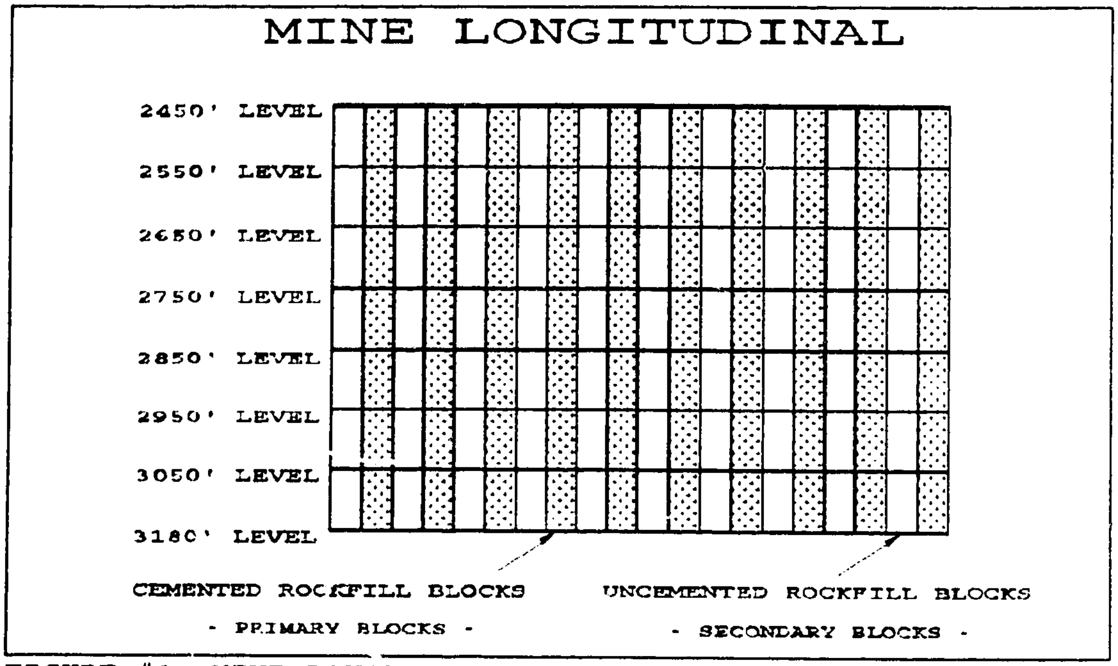

FIGURE #1: MINE LONGITUDINAL

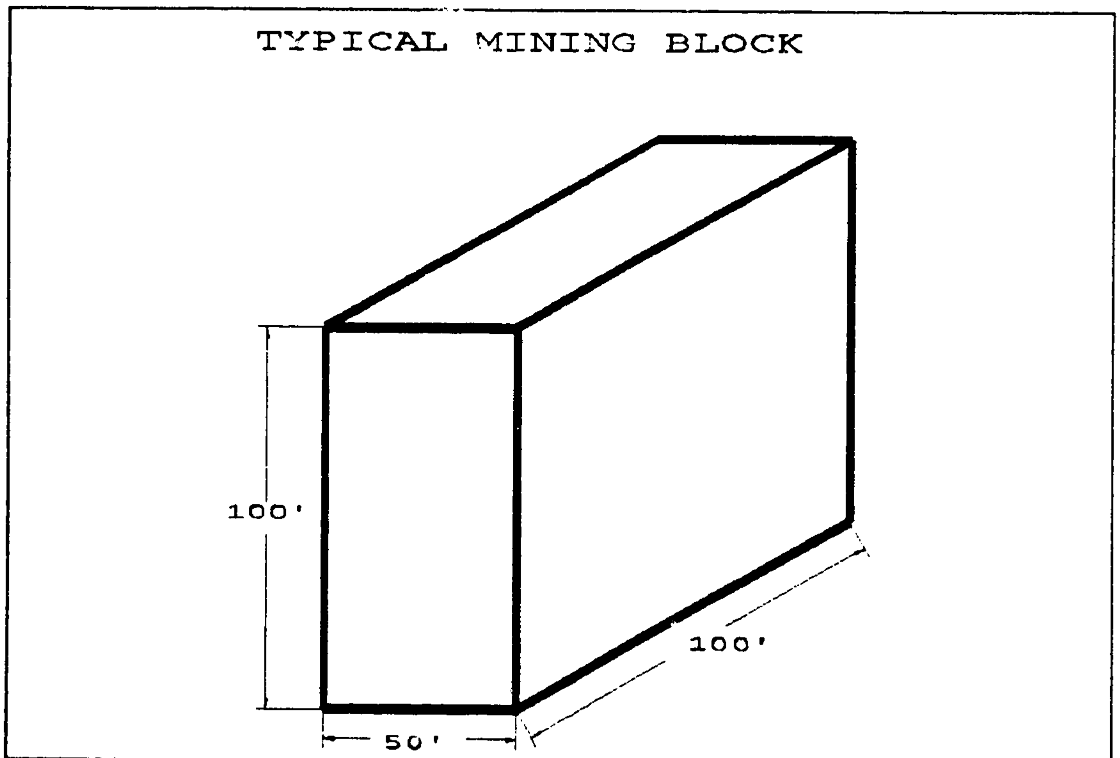

FIGURE #2: TYPICAL MINING BLOCK

The average stope size at the Inco Thompson T-3 Mine is 100 feet in height, 100 feet in length and 50 feet wide (see **FIGURE #2**).

3. ROCKFILL SYSTEMS

3.1 THE T-3 SLURRY BATCH PLANT:

Cemented rockfill was chosen as the filling method for the 1-C orebody. The system consists of a fully automated batching plant located on surface, and an underground rockfill station located on the 2450 and 2650 foot levels. Cement and flyash are transported from the two silos to the surface weigh hopper by air-slides. Once the proper amounts of binder (Portland cement and binder) and mix water are weighed, both are sent to the surface mix tank where they are agitated (see **FIGURE #3**). After mixing to a pulp density of 55 percent solids by weight, the slurry is sent underground via a six inch borehole. The surface slurry plant can be controlled from the underground truck loadout stations (a P.L.C. unit allows the underground operator to mix a surface batch of slurry from the underground

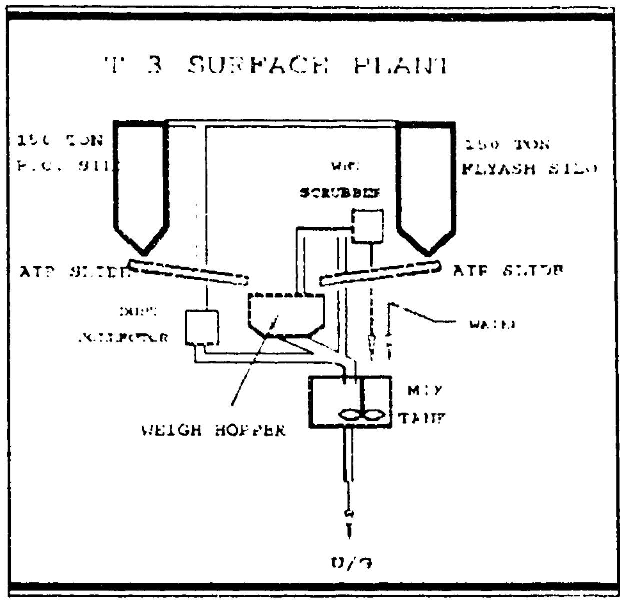

FIGURE 3: T-3 SURFACE PLANT

station). Waste rock from the open pit is crushed, screened and stockpiled before it is sent underground through a 10 foot square raise.

3.2 UNDERGROUND ROCKFILL STATION:

The slurry empties into the underground surge tank, which is designed to hold two surface batches. The slurry is applied to the rock while the trucks are being loaded, using a simple spray bar arrangement (see **FIGURE #4**). A predetermined amount of slurry (enough for one truck load of backfill) is pumped into the batch hopper located directly above the truck loading pad. Initially, the rockfill chute and slurry spraybar are activated simultaneously allowing both ingredients to mix while entering the truck box. Once the haulage truck is half filled with rock, the rockfill chute is closed and the operator manoeuvres the truck back and forth underneath the batch hopper while the slurry continues to drain. After half of the slurry has drained from the batch

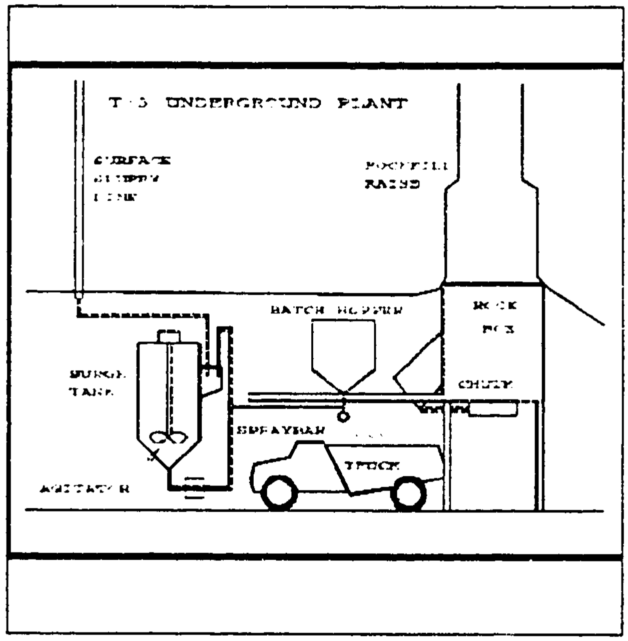

FIGURE 4: T-3 UNDERGROUND PLANT

hopper, the chute is reopened and the remaining rock and slurry is dumped into the truck. The rockfill is dumped into the open stopes via 42 inch raisebore holes. Note that the slurry and aggregate become mixed when the rockfill tumbles through the raisebore holes into the block (very little mixing actually occurs in the truck box at the underground rockfill station).

Note, the Birchtree system is similar to the 1-C system, except that the surface plant cannot be activated from underground. Telephone communication between the underground operator and surface operator must be made.

3.3 TESTING FACILITIES:

The rockfill testing laboratory is located at the underground station, and includes a sample drying oven, an electric sieving screen, a compressive strength press, and a digital weigh scale. Six inch diameter cylinders are manufactured at the lab to estimate the compressive strengths occurring within the block. Rock and binder samples are periodically sent to an outside company where 18 inch diameter cylinders are produced and tested. The 18 inch diameter cylinders allow the "entire aggregate size range" to be included in the cylinder testing. When the smaller, six inch cylinders are prepared, the coarser material (+2 inch material) must be removed from the recipe. Although the six inch cylinders don't include the entire aggregate size range, the cylinder results provide an estimate of how the insitu material will respond.

Currently, the following factors are being investigated through compressive cylinder testing:

- flyash sources,
- flyash percentages,
- total binder percentages (cement plus flyash)
- chemical additives,
- fines percentages (where "fines" are minus 3/8 inch material),
- moisture percentages.

The cemented rockfill is designed to withstand gravity loading as well as dynamic effects produced by blast vibration. Minimum compressive strengths of 0.70 MPa are required to support the gravity loading produced by the overlying rockfill (note that higher compressive strengths are needed in the lower portions of the filled stope and at the walls of the stopes). The 0.70 MPa required strength is equivalent to 1.0 p.s.i. per foot of stope elevation (eg. a 100 foot high stope requires 100 p.s.i. rockfill or 0.70 MPa). While at Falconbridge's Kidd Creek Mine, Thiann Yu (Yu and Counter, 1983), determined that a safety factor of 2 is sufficient to allow for blast vibration, segregation of aggregates and poor binder mixing within the blocks.

Therefore, 1.4 MPa (200 p.s.i) is the actual uniaxial compressive strength required within the filled blocks. Due to size limitations between lab cylinders and the actual insitu product, the strengths occurring within the actual filled blocks are 1.5 to 2 times lower than those of the rockfill cylinders produced in the laboratory (Mark Scripnick, 1991), resulting in desired lab results of 2.1 to 2.8 MPa (300-400 p.s.i.) compressive strength. Weak segregation layers and/or impact damage from subsequent filling cycles cause the insitu rockfill product to fail sooner than a pampered lab cylinder. Although this additional laboratory safety factor is considered in the design, insitu samples taken from the T-3 and Birchtree Mines have been similar and have even exceeded laboratory results (depending on sample location within the block). The most relevant method of comparing rockfill cylinders is to compare their compressive strengths against a "control mix", for example, a cylinder prepared with 5 percent binder consisting of 100 percent portland cement.

4. SLURRY DESIGN:

The amount of total binder, the type of binder and the amount of mix water must be carefully considered when producing the cement slurries. Various slurry recipes are designed to compensate for the varying mining conditions experienced underground. Portland cement and type C flyash are the primary constituents making up the binder slurry used to coat the rockfill material. Normal type 10 portland cement is a hydraulic cement comprised mainly of calcium silicates. When hydraulic cements are combined with water a chemical reaction (hydration) occurs and the resulting paste forms a stonelike mass. The rate at which the "stiffening" occurs is influenced by many factors including the mix proportions, the fineness of the cement, the temperature during the reaction and by the addition of portland cement substitutes. Type C flyash is used as a portland cement substitute at the Inco Thompson T-3 and Birchtree mines. Flyash is a by-product produced from the combustion of coal in electric power generating plants. The flyash is a high calcium, pozzolanic material used due to its low cost when compared to portland cement. Flyash retards the setting time, which can increase the final strength of the rockfill. However, the flyash is not as cementitious as portland cement and cannot be used as the sole ingredient in the binder slurry (flyash percentages ranging as high as 60-70 percent flyash have proven to deliver sufficient strength). Compressive strength requirements and the mining cycle dictate the amount of flyash that can be added to the slurry recipes. Due to the retarding tendency of the flyash, a longer curing period is needed before mining adjacent ore blocks, resulting in possible disruptions to the logical mining sequence.

Empirical results (literature review), compounded with extensive cylinder testing resulted in the initial decision to use 5 percent total binder (by weight of the aggregate) at the T-3 Mine. Initially, 70 percent portland cement (P.C.) and 30 percent flyash was used in the slurry recipe. However, additional cylinder testing has shown that a blend of 50 percent P.C./50 percent flyash will deliver the required compressive strength. Because higher compressive strengths are required in the lower portions of the filled stopes, the percentage of binder added is decreased during the later stages of the filling cycle, granted there is sufficient binder to coat the aggregate (the Birchtree Mine has recently successfully switched to 4 percent binder in more recent blocks). Binder costs represent 50 percent of the total rockfill cost (approximately $3.00/ton ore removed), and therefore attempts to reduce the binder percentage are encouraged. Note that cemented rockfill will only be used to fill the blocks that are adjacent to unmined ore (primaries), while uncemented rockfill and/or development rock will be used to fill the secondary blocks ("secondary" blocks are situated between the cemented "primary" blocks and therefore do need to be cemented themselves).

5. ROCKFILL WATER:

Controlling the amount of water within the system is vital in order to produce strong, effective rockfill.

Increasing the compressive strength by adding fines induces no additional costs to the operation, but reducing the moisture content within the system can be a costly and taxing exercise.

A slurry containing 55 percent solids by weight is currently being used at the T-3 Mine (water to cement ratio of 0.82). At this density, slurry travels easily through the system without plugging the borehole or piping, yet still effectively coats the aggregate material.

Monitoring includes taking slurry density readings at the surface plant and at the underground rockfill station. Aggregate moisture tests are also performed at the laboratory located underground. Because the desired amount of mix water in the slurry is only 4 percent by weight of aggregate, even a small amount of moisture within the aggregate will significantly increase the total water in the system, causing a considerable reduction in compressive strength. Approximately one third of the added mix water is needed to complete the hydration reaction, the remaining mix water is used to coat the surface of the aggregate material. The minimum water to cement ratio (by weight) for complete hydration is approximately 0.22 to 0.25 (C.P.C.A.,1984).

If the T-3 and/or Birchtree rockfill operations are shut-down for an extended period of time, the material within the raise becomes saturated by water. Excess water not only reduces the strength of cemented fill, but could also cause safety problems when pulling the chute.

An accurate measurement of the size distribution is difficult to obtain when the rock becomes saturated, due to the fines content being washed through the material by the ground water. If there is a lull in production (shut-down), the system must be operated for a sufficient period of time after the lull before the moisture content reaches an equilibrium. Prior to future shut-downs, the rockfill raise should be pulled until it is almost empty to reduce these ground water induced problems.

Although curtain grouting around the rockfill raise helped reduce the percentage of rock moisture to almost one percent at the T-3 Mine, the Birchtree Mine has experienced continuing ground water problems even after grouting around the rockfill raise (up to 4 percent moisture by weight of aggregate). Because there is too much water contained within the Birchtree aggregate, the percent solids in the slurry was increased from 55 to 65 percent. Initially the engineers were unsure whether the pipes would remain clear at this higher solids percentage, but no problems have occurred in three years of operation. More slurry must be added if the fines content is high (ie. over 30 percent fines), otherwise the rockfill product is too dry and brittle.

6. FRAGMENTATION ANALYSIS:

Waste rock from the Thompson open pit is crushed and then screened to minus 8 inches plus 3/8 inches. The screened aggregate is then delivered to the T-3 Mine crushed rock stockpile or dumped directly into the 10 foot diameter rockfill raise. The waste rock is composed mainly of metasediments (quartzite, skarn, schist). The initial size of the aggregate was predetermined to produce the proper size distribution once the aggregate reached the underground rockfill station. Degradation occurs while the rock travels through the raises, eventually arriving at the rockfill stations located as deep as the 2650' level. **Figure #5** shows typical size

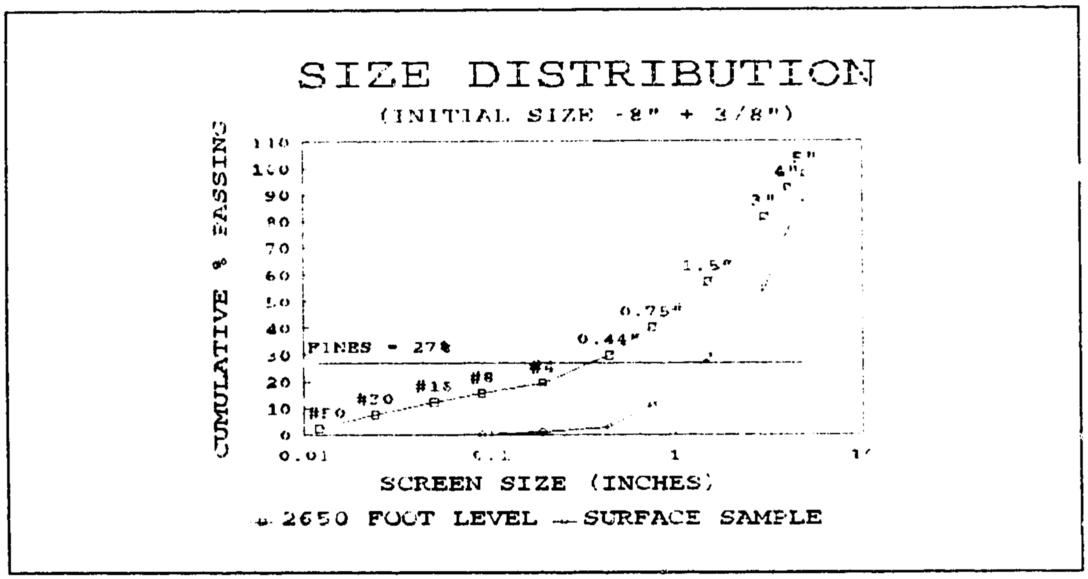

FIGURE #5: SIZE DISTRIBUTION

distributions for the rockfill material:

a) prior to being dumped into the raise,

b) taken from the chute on 2650' level.

Fragmentation analyses are performed to determine whether the size distribution of the raise material is within an acceptable range of 20-30 percent fines (Yu and Counter, 1983). During the commissioning of the rockfill system, daily size analyses were performed on the raise material. However, now that the T-3 and Birchtree rockfill systems are performing effectively, a monthly analysis is sufficient for maintaining the proper size distribution.

The raise rock samples are collected directly from the rockfill chute by scooptram bucket or from the box of the haulage truck prior to the addition of slurry (a 400 kg sample is considered to be representative). The sample is then passed through an electrical vibrating screen equipped with wire mesh sieves ranging from 5 inches through 100 mesh. Although the percentage of fine aggregate (minus 3/8 inch) used in concrete is usually 35 to 45 percent of the total aggregate, empirical results associated with rockfill indicate that 25 percent fines is desirable (Yu and Counter, 1983). Although the strength of our rockfill cylinders continued to increase as the fines were increased (strength increased within our range of 15 to 40 percent fines), the cement consumption can increase dramatically unless ideal mixing is obtained (ideal mixing is obtained in a laboratory cement mixer, but may not be achieved in a production situation). If the percentage of fines is less than 25 percent there will be insufficient matrix material to bind the coarse particles together, weakening the overall product.

The aggregate fragmentation varied as the free-fall distance from surface was altered. **Table #1** shows that when the raise rock experienced a long free-fall more fines were produced than with a shorter initial free-fall distance. Prior to testing, a long grinding (full-raise) period was thought to produce more fines than a lengthy free-fall period. However,

TABLE #1

FREE-FALL DISTANCE (FEET)	FULL-RAISE DISTANCE (FEET)	ACTUAL FINES PERCENTAGE	FINES EQUATION ESTIMATION	PERCENT ERROR
200	2450	24	25	4.3
365	2285	26	26	0.4
650	2000	28	28	-0.4
1100	1550	31	31	-0.9
1320	1330	31	32	3.4
1345	1305	34	32	-5.4
1500	1150	36	33	-8.3
1575	1075	33	34	2.1
2000	650	34	36	6.5

during the free-fall, the tremendous energy that is produced by the violent collisions between the rock itself and the raise walls creates more fines than the slow surface to surface grinding occurring during full-raise flow.

These aggregate samples were collected from the 2650 foot level (note, that corresponding free-fall plus full-raise values add to 2650 feet of vertical distance).

The "level-from-surface" or "free-fall distance" of the fill raise aggregate was recorded during the sampling periods. A measuring line was lowered from surface into the fill raise prior to every "day-shift", so the raise level could be determined.

Initially, the T-3 Mine requested that an equation be derived that could estimate the percentage of fines arriving at the 2650 level rockfill station (this was the only operating rockfill station at the time), so the following analysis was performed:

EQUATION #1 = INFO CURVE FOR "2650 LEVEL ROCKFILL STATION"

Y = mX + b

Y = (constant)*(free-fall distance in feet) + (constant#2)

The "actual fines percentages" and the "free-fall distances" taken from **Table #1** were entered into Lotus 123 Data Regression and the following statistics are shown in **Table #2**.

Table #2

CONSTANT (Y-INTERCEPT)	23.83
STANDARD ERR OF Y-INT	1.66
"R-SQUARED"	0.85
X-COEFFICIENT (SLOPE)	0.0062
STANDARD ERROR OF X-COEFF	0.0010

When the constants from the data regression are entered to **Equation #1**, we receive the following:

Equation #1:

FINES AT 2650' STATION = (0.0062)*(**FREE-FALL DISTANCE**)+(23.83)
Where distance is in feet.

The estimations derived from **Equation #1** are shown in **Table #1** (note, they are very close to the actual percentages). The "R-Squared" value from the Data Regression (see **Table #2**) is 0.85 (note, that a value of 1.0 would be a perfect correlation). Therefore, there is an 85 percent confidence that this equation will deliver an accurate estimate of the fines percentage.

The equation allowed the engineers to predict the percentage of fines arriving underground without actually

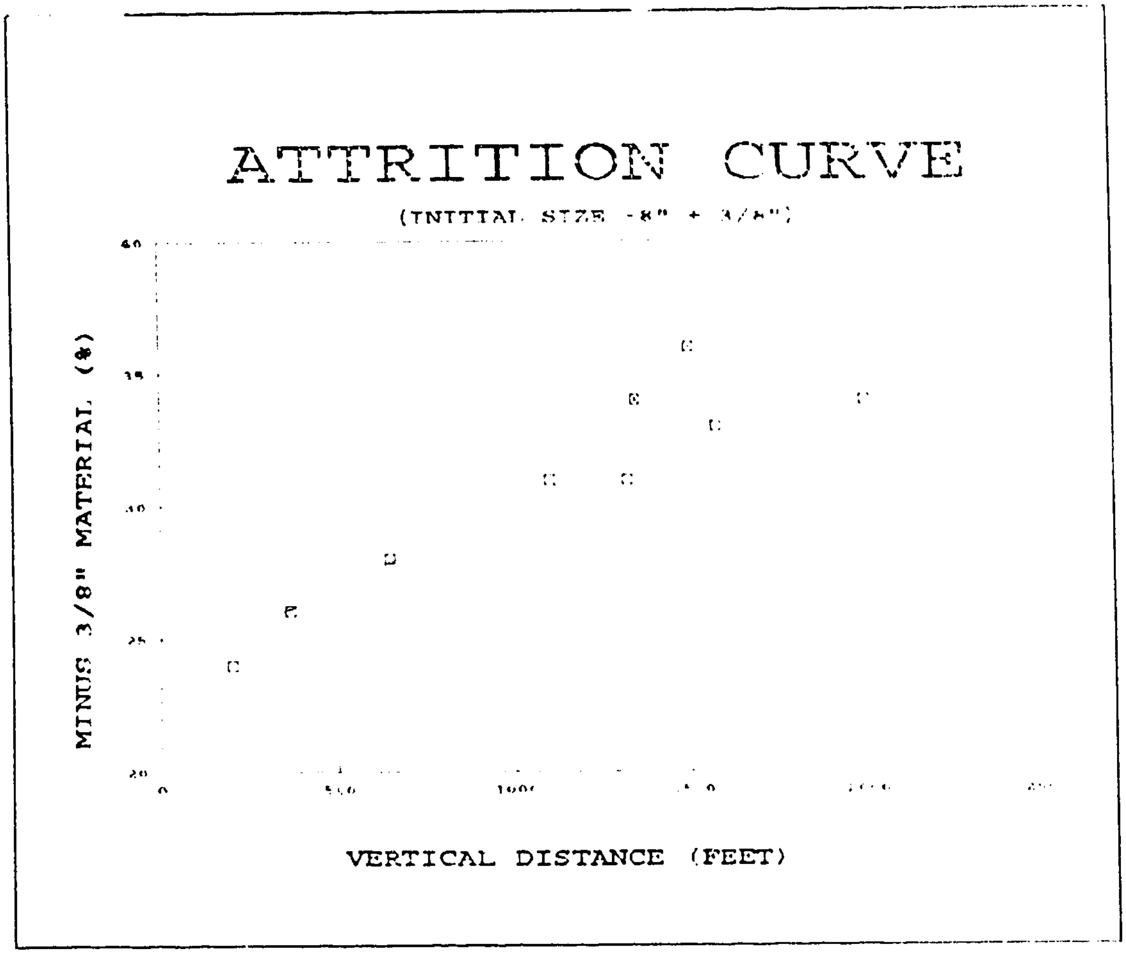

FIGURE #6: ATTRITION CURVE

performing the laborious task of sampling and screening the aggregate material. **Figure #6** shows the 2650 level attrition curve.

Although **Equation #1** proved to be very accurate for predicting the percentage of fines at the 2650 level rockfill station, the equation could not effectively predict fines percentages for vertical distances greater or smaller than 2650 feet. Therefore, a general equation had to be derived. The values from **Table #1** were used to derive the general equation.

EQUATION #2 = GENERAL CASE - GOOD FOR ANY MINESITE

Y = (m1)*(X1) + (m2)*(X2) + b

Y = (const1)*(free-fall) + (const2)*(full-raise) + b

where b = fines prior to being dumped into raise

or b = surface fines

The "actual fines percentages", the "free-fall distances" and the "full-raise distances" taken from **Table #1** and a data regression was performed and the corresponding statistics are shown in **Table #3.**

When the constants from the data regression are entered into **Equation #2,** we receive the following:

Table #3

CONSTANT (Y-INTERCEPT)	0.00
STANDARD ERR OF Y-INT	1.66
"R-SQUARED"	0.98
X1-COEFFICIENT (SLOPE)	0.01520
X2-COEFFICIENT (SLOPE)	0.00899
STANDARD ERROR OF X1-COEFF	0.00087
STANDARD ERROR OF X2-COEFF	0.00078

EQUATION #2: FINES PERCENTAGE FOR GENERAL CASE =

= (0.01520)*(FREE-FALL) + (0.00899)*(FULL-RAISE) + (0)

where free-fall and full-raise distances are measured in feet.

Equation #2 allows the engineers to estimate the percentage of fines for rockfill stations on <u>any</u> level. The equation enables the engineer to:

a) estimate the initial size distribution of the surface rock needed in order to produce the proper amount of fines arriving underground.

b) adjust the raise level to generate more or less fines depending on the situation.

Note: Access to the 1-C rockfill raise is possible on the 1200, 2200 ad 2650 foot levels. A sample taken from the 1200 level (free-fall distance approximately 1000 feet followed by a 200 foot full-raise portion) contained approximately 19 percent fines (Equation #2 estimates 17 percent fines should have been in the sample). A sample taken from the 2200 foot level (free-fall distance approximately 1000 feet followed by a 1200 foot full-raise portion) contained approximately 29 percent fines (Equation #2 estimates 26 percent fines should have been in this sample).

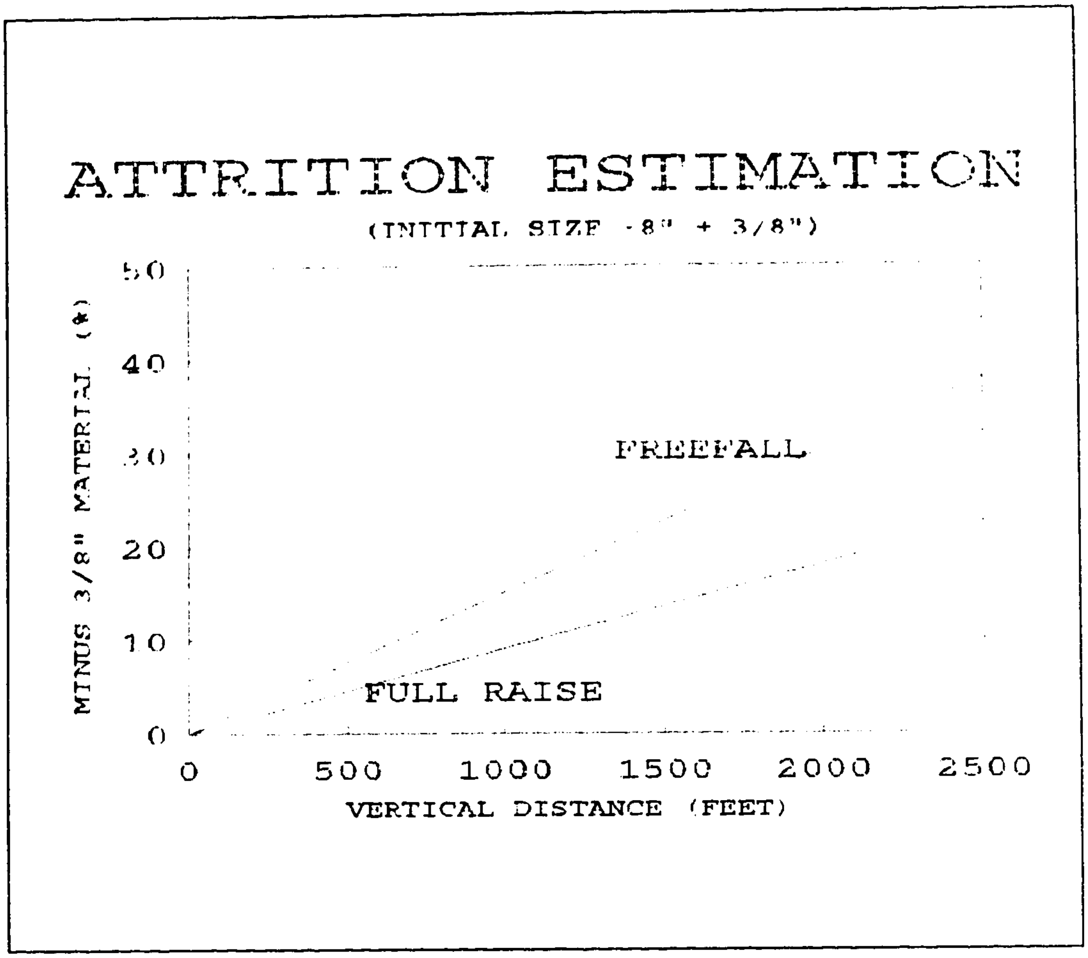

FIGURE 7: ATTRITION ESTIMATION

Figure #7 shows the general case curves for free-fall and full-raise flow.

Equation #2 can be broken-down into two halves:

Equation #2A

Free-fall fines percentage = (0.01520)*(**free-fall distance**)

From this equation, 1.0 percent fines is generated every 66 feet of free-fall.

Equation #2B

Full-raise fines percentage = (0.00899)*(full-raise distance)

From this equation, 1.0 percent fines is generated every 111 feet of free-fall.

The level of the aggregate raise is calculated daily, allowing the fines content to be estimated without obtaining and screening samples. By convening the binder, flyash and fines percentages from the rockfill production reports, and using the average aggregate moisture percentage (moisture percentage remains fairly constant), the insitu compressive strength can be predicted with the strength estimation equation (derived later in the thesis). The fines estimation equation combined with the strength estimation equation allow the insitu compressive strength to be predicted from the daily rockfill production reports (intermittent cylinders should be prepared to verify the accuracy of the equations). The fines equations were accurate for free-fall distances ranging from 0 to 2650 feet. The equations suggest that for every 66 feet of free-fall experienced by the rock, one percent fines will be generated and for every 111 feet of full-raise flow an additional one percent fines will be generated. Note that these equations may differ depending on the geological composition of the aggregate. However, this equation can deliver an estimate that other mines can build upon. The "trend" of how the free-fall portion and full-raise portion effect the aggregate should be similar for other mines.

Example Calculation:

If the -8" + 3/8" rock free-falls 1000 feet and then travels an additional 1650 feet in full-raise flow, there will be approximately 30 percent fines produced:

FREE-FALL FINES = 0.01520(1000 FEET) = 15.20 PERCENT

FULL-RAISE FINES= 0.00899(1650 FEET) = 14.83 PERCENT

TOTAL FINES = 30.03 PERCENT

NOTE: The fines content within the surface material must be added to this total value (this is "b" from Equation #2).

The use of underground development rock is being investigated as a substitute for the costly crushed raise rock. Although early tests showed that the fines content was within an acceptable range, the inconsistency of the development rock could cause serious problems. The large particles associated with the development rock may create voids within the rockfill that the limited amount of matrix material cannot fill, causing point contact to occur between the rockfill particles rather than one solid mass. Excessive fines were found in several of the development rock samples, which could also decrease the overall strength of the backfill. Testing will be done to see if the size distribution within the development rock can be altered to produce an effective fill (eg. grizzly-off the larger material). Both mines are currently experimenting with unscreened development rock. By using the unscreened development rock, huge savings will be realized by eliminating the costs associated with crushing and screening the open pit rock (also, the waste piles will diminish and costly reclamation costs will be avoided). However, caution must be used to avoid excessive fines. The Birchtree Mine is currently experimenting with a mix of screened and unscreened aggregate.

7. FILL RAISE ORIENTATION:

Proper orientation of the fill raise(s) is vital for producing effective rockfill. Segregation problems can be reduced if the proper number of fill raises and their orientation is established. The number and orientation of the fill raises entering each stope varies depending on the size and geometry of the stope and the number of adjacent unmined blocks. Coarse particles within the rockfill tend to migrate away from the impact area(s) and form weak layers, which may cause stability problems once the adjacent blocks are mined.

A physical model was used to aid the Mines Research Department in determining the number of necessary fill raises and their orientations. A "one to forty scale" plexiglass

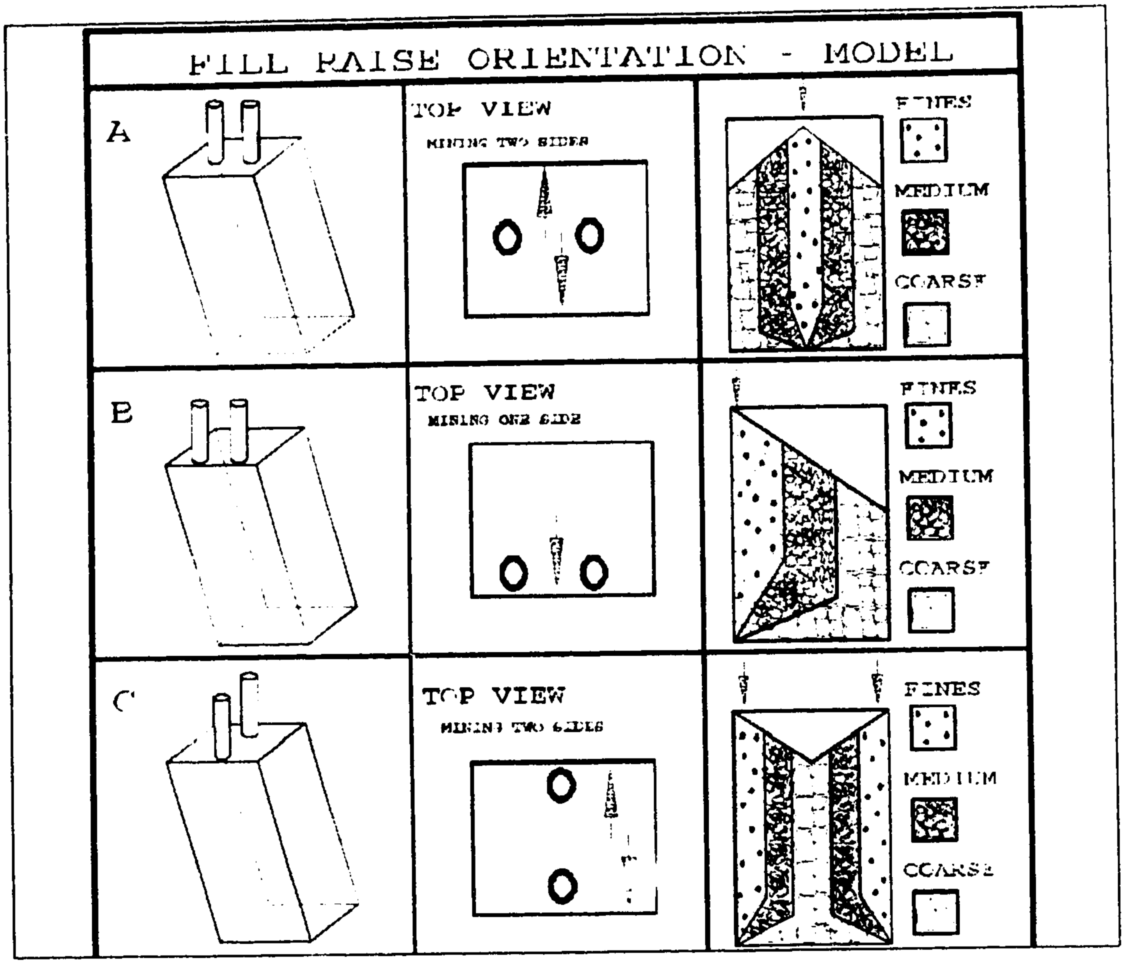

FIGURE 8: FILL RAISE ORIENTATION

model was constructed to simulate the filling cycle and determine effective raise orientations. Although the scaling down factor associated with the model may have produced some variation from the actual insitu situation, the physical model proved to be an inexpensive means of estimating where the coarse/fine layers would occur when different raise orientations were tested. **Figure #8** shows typical raise layouts of:

a)centrally located fill raises with mining on more than one side of the block,

b) fill raises located at one wall with mining on one side of the block,

c) fill raises oriented so that the impact cones are close to the stope walls.

When the ore pillars are mined and the rockfilled blocks are exposed, segregation layering is present. The layers vary in aggregate size and moisture content. The layers containing a higher percentage of fines possessed greater compressive strengths than the layers containing much coarser material. These segregation layers are formed when the coarser aggregate rolls down the fill cone and/or if poor mixing occurs between the aggregate and binder slurry. Proper fill raise orientation could help to reduce these low strength areas.

The model testing proved that the chance of segregation is much greater if the rockfill hits the footwall prior to hitting the impact cone. When the slurry-covered aggregate hits the footwall, the cement slurry coating is removed from the aggregate. Therefore, the coarser aggregate rebounds off the footwall and rolls to the far end of the stope, producing a weak, coarse pile of uncemented rock. Meanwhile, the slurry and fine aggregate that was removed from the coarse material, slumps down the footwall, producing a strong highly cemented area. If the fill raises are properly designed, this technique of hitting the footwall and/or hitting any wall can be used to the engineers advantage. For example, if there is only to be mining on one side of the rockfilled block, the engineer will position the fill raise so that the weaker, coarser aggregate will bounce towards the unimportant side of the block where it will be used merely as "filler". This will produce a high cement content at the important wall, adjacent to the unmined ore (see **Photo #1 and #2**).

Photo #1 shows a stope that was filled by a centrally located fill raise. Note the coarse aggregate (painted orange) close to the walls. Whereas, **Photo #2** shows almost no coarse aggregate near the walls. The fill raises in **Photo #2** are located close to the walls, so all of the coarse material rolled towards the center of the model.

PHOTO #1: CENTRALLY LOCATED FILL RAISES

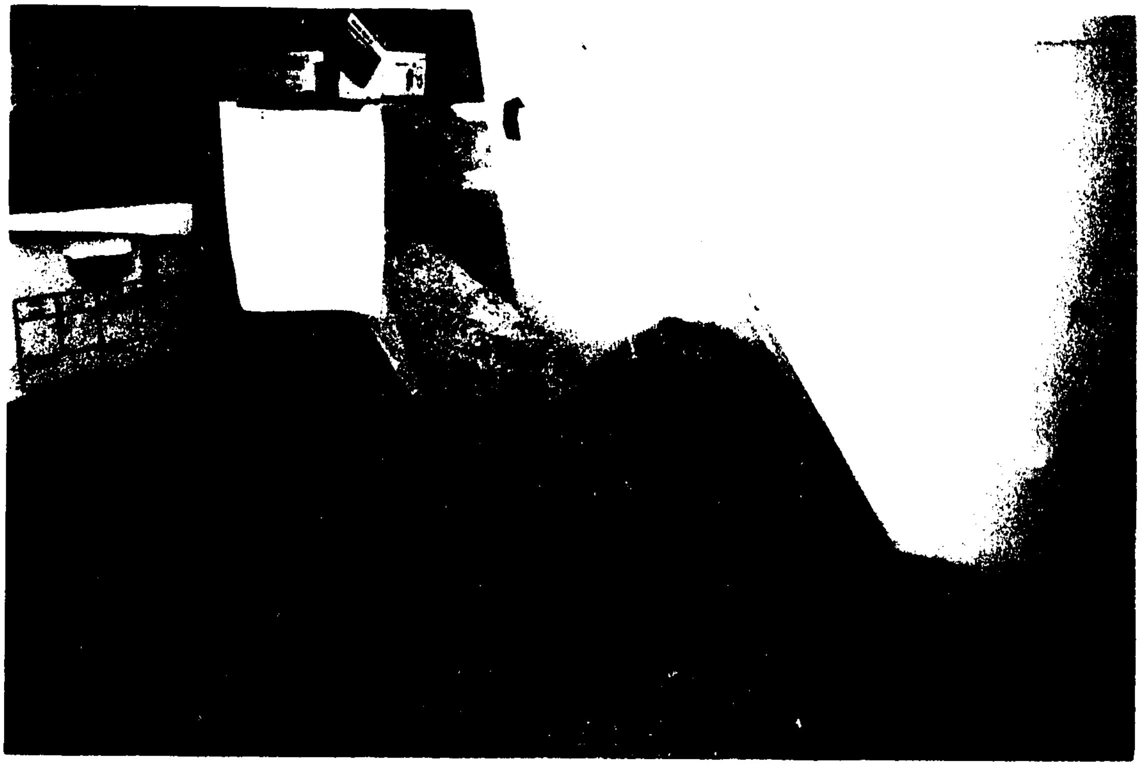

PHOTO #2: FILL RAISES NEAR STOPE WALLS

If possible, uncemented rockfill (eg. development rock) should be used to fill portions of the empty blocks. For example, if the fill raise is located near the [illegible] of the block or angled towards the stope wall, the impact cone will be leaning against this side of the empty block (see "B" in **Figure #8**). Because the finer, high-cement-content material remains in the fill cone, the high-strength material will be leaning against this stope wall. If mining is adjacent to this high strength stope wall only and not adjacent to the opposite side of the block, uncemented material can be placed into the unimportant side of the empty block (a huge savings).

Possible fill failure can occur if the length and/or width of the stope to be filled is greater than 100 feet per fill raise (Farsangi and Hara, 1992). For example, if the dimensions of the stope are 100 feet in height, 100 feet wide and 150 feet in length, two fill raises should be utilized due to the length of the block being greater than 100 feet. If only one fill raise is utilized, extreme segregation can occur. The long dimensions (plus 100 foot spans) will enable greater segregation than in smaller blocks. Therefore, the coarser aggregate will separate-out from the fine aggregate and produce low strength areas within the larger blocks. When blocks with dimensions of greater than 100 feet are designed, multiple fill raises should be incorporated into the design.

The average stope dimensions at the INCO Thompson mines are 100 feet in height, 100 feet in length and 30-50 feet in width. Therefore, single, centrally located fill raises are standard (the small block sizes limit the amount of segregation). Occasionally the 1-C orebody at the T-3 Mine experiences blocks with lengths greater than 100 feet and therefore use multiple fill raises. However, because of poor hanging wall rock conditions (peridotites), the Birchtree Mine's blocks are kept small (less than 30,000 tons) and do not require multiple fill raises.

Due to development problems in some of the secondary drawpoints (pillar-spalling due to high ground stresses and/or

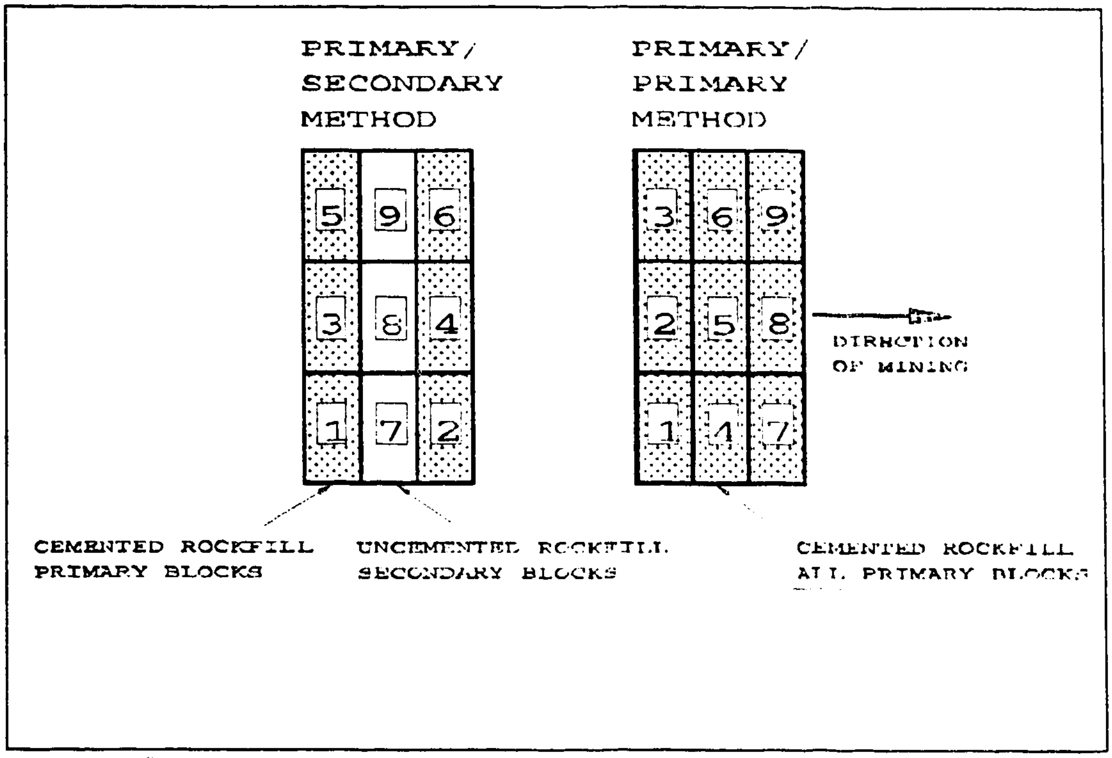

FIGURE #9: PRIMARY/PRIMARY MINING METHOD

nearby blasting), the Birchtree Mine is considering changing from their standard primary/secondary mining method to a primary/primary method (see **Figure #9**). This change in mining technique would mean that there would only be mining on one side of the rockfilled blocks. This would place great importance on fill raise location and orientation.

8. INSITU TESTING:

Compressive strength cylinders can be collected at the drawpoints located at the bottom of the block, or at the top of the block once it has been completely filled. Six inch diameter cylinders are collected from the drawpoints. The samples are collected via a scooptram, which collects a bucket of fresh, uncured rockfill from the drawpoint. The larger aggregate (+2 inch material) must be screened-out prior to cylinder preparation. Although the insitu cylinders have varied depending on the effectiveness of the mixing between the slurry and rock, the cylinder strengths have been as high as 6 MPa (ample strength for the block heights). Self-supporting walls and even over-hangs can be seen in several drawpoints throughout the mines. Rockfill samples were collected and sectioned with a rock-saw for compressive strength testing and to determine if voids and segregation were present within the samples. Voids and segregation depend greatly upon the sample location within the block (Farsangi and Hara, 1992). Samples recovered close to the impact cone (taken from the Birchtree footwall drawpoints) contained few voids and mostly fine material yielding high compressive strengths, while the rockfill located further away from the impact cone contained more voids due to larger material sizes and therefore reduced compressive strengths.

Better mixing occurs when the rockfill is dumped from the haulage trucks into the blocks through "fill raises" (100 foot long boreholes with 42 inch diameters) as compared to being dumped directly into the blocks via the haulage truck (very little mixing occurs once the block is close to being filled with the second method).

Representative insitu samples are difficult to obtain, therefore the Mines Research Department will use their borehole camera to determine the competency of the insitu cemented rockfill. The borehole camera will enable cracks, segregation and voids within the fill to be detected. By monitoring the fill prior to and after the adjacent ore blocks are mined, an estimate of the amount of rockfill slough can be determined. Because the rockfill factors vary considerably from block to block, considerable knowledge associated with the performance of the different slurry recipes within the blocks can be obtained. Detailed data associated with the rockfill factors within the cemented blocks has been recorded. The cemented blocks within the orebody simulate a large scale cylinder test. By monitoring the slough from each block, a relationship between dilution (slough) and slurry design could be established. Extensometers may be installed to complement the results obtained from the borehole camera. The extensometers would aid the engineers in determining whether the movement within the fill was occurring "plastically" (moving like a stiff liquid) or if the fill was failing in a "brittle" fashion.

Because representative insitu samples are difficult to obtain, future testing may include seismic borehole tomography, ground penetrating radar techniques or an alternate geophysical method to determine the quality of the insitu rockfill. These non-destructive insitu testing methods may allow rockfill strengths to be estimated without costly, difficult and site specific cylinder or core sample extraction. Geophysical testing could allow entire rockfill stopes to be tested as opposed to the current method of obtaining small site-specific random sampling.

9. STATISTICAL DESIGNS

An extensive testing strategy (**"two-level factorial"** and **"central composite"** designs) examining the effects of varying five rockfill factors was performed. The goal of a factorial design is to relate a response, such as strength, to selected controllable system variables or factors that influence the response. An engineer could predict the response (strength) if a reliable equation or model which expressed the response as a function of the operating variables was provided.

Before examining the methodology of the two-level factorial designs, some definitions associated with statistical design terminology should first be given. A <u>factor</u> will refer to a controllable process variable which is set at a prescribed value for each test. A quantitative factor is one such as pH or percent solids, i.e., one whose values can be arranged in order of magnitude. The value at which a factor is set for a particular test as called the <u>level</u> of that factor. When several factors are to be involved, the levels of all factors must be specified for each test or <u>experimental run</u>. The group of experimental runs for one phase of an investigation is called an <u>experimental design</u>. The level of each factor must be held constant during an experimental run but may well change for the next run. At each run the measured <u>response</u>, a numerical result such as a grade, a recovery, a compressive strength or any quantitative measure of interest is recorded. Notice that a response is not a factor since it is not under the direct control of the experimenter. Rather, it is the result of particular settings of certain process variables. A two-level factorial design is one in which only two levels are used for each factor. These levels are referred to as the "low" and "high" level. All possible combinations of levels are run. Thus for a two-level factorial design with five factors, there are 2*2*2*2*2 = 32 experimental runs.

Linear regression analysis (least squares regression) is used to derive a linear relationship (an equation) between the factors and the response being measured. Multiple regression analysis is a method for measuring the effects of several factors concurrently. The coefficient of determination ("r squared" value) is used to determine how well the equation "fits" when used to estimate the response (compressive strength in our case). The "r squared" statistic measures closeness as the percentage of total variation in the dependent variable explained by the regression line (Schroeder, Sjoquist, Stephan, 1986). If the data points were all to lie directly on the regression line, the observed values of the dependent variable would be equal to the predicted values, and the r-squared would be equal to 1. Therefore, if the r-squared value is 0.85, there is an 85 percent chance that the equation will accurately estimate the response.

A factorial design uses statistical methods to determine a model which will enable the user to estimate the outcome (response) given a set of input parameters (factor levels). In our experimental design, we use statistical methods to determine the effects produced when varying the rockfill factors. The designs are superior to the "one-at-a-time" approach and are of significant value in exploratory work when:

1) the individual and joint influence of several variables must be determined quickly,

2) obtaining empirical models over a range of operating conditions (i.e. a compressive strength estimation equation).

3) statistical analysis is desired to determine the competency of the results (i.e. "R-Squared" values are desired).

In order to optimize the rockfill product, the effects of varying the factors within the system singularly or as a group had to be determined and quantified. The "**effect**" of any factor is defined as "the overall change in compressive strength produced by an increase in the level of that factor".

A properly designed experiment allows the engineer to estimate the individual influence of each factor on the compressive strength and to estimate the extent to which each depends (interacts) upon values of the other factors (eg. the effect on the total binder as the percent flyash within the binder is varied). By taking the interaction effects into consideration, the statistical designs allow the total number of test runs to be reduced significantly.

Steps involved when performing two-level factorial designs:

1) Define the problem or goal to be reached:

Producing cemented rockfill with higher strengths and/or lower costs are the goals to be reached by our experiments. INCO Thompson currently spends approximately "$6.00/ton of ore mined" on cemented rockfill. Fifty percent of these rockfill costs are related to cement binder (portland cement and flyash). Therefore, efforts to reduce binder costs are of high importance to the company. The statistical designs will allow the optimum recipes to be determined.

2) Select the responses to be measured:

The responses to be measured are compressive strength and binder costs. The compressive strengths will be determined through crushing rockfill cylinders in a hydraulic compressive strength press. The costs of the individual binder constituents are known.

3) **List the factors to be varied:**

The five factors to be varied are:

i) the total binder,

ii) percent flyash within the binder,

iii) cement dispersant addition,

iv) aggregate fines percentage (the amount of minus 3/8 inch material in the aggregate rock),

v) aggregate moisture content.

NOTE: A duplicate experiment was performed so that cylinder strengths could be analyzed at 28 days curing and also at 100 days curing (the 100 day curing was thought to be a typical mining cycle before mining the adjacent pillar). An average increase in compressive strength of 30 percent was discovered for the cylinders that were allowed to cure for the extra 72 days. Therefore, after 28 days curing, the rockfill has acquired approximately 70 percent of its final compressive strength.

The five factors can be accurately controlled in the underground laboratory. The first three factors: total binder, percent flyash and cement dispersant addition can also be easily controlled in a production situation. The other two factors: percent fines and percent aggregate moisture are somewhat harder to control in the underground environment. The percentage of fines can be predicted using the fines estimation equation, but controlling the ground water is a difficult task. However, knowledge concerning how they affect the other factors is vital for producing a strong final rockfill product.

4) Choose the factor ranges:

The next step was to choose two suitable levels for each factor. This required extensive knowledge of the process, based on previous cylinder testing (two years of previous rockfill cylinder test work). The factorial and central composite designs examined the effects of five factors, each tested at two levels, a high level and a low level. There are 32 possible combinations (2 to the fifth) of the high and low levels of these five factors and therefore 32 rockfill recipes were tested. Additional testing at the "midpoints" of each of the five factor ranges was performed, to determine the strength at the center of the design and the error estimate associated with the test. Additional "extreme" or "outlier" cylinders associated with the central composite design were also tested (a central composite design is merely a two level factorial design with these additional outlier tests).

The five factor's low and high settings are:

i) total binder (4.0 and 5.0 percent),

ii) percent flyash within the binder
(0 and 50 percent) for Coal Creek Flyash,
(0 and 60 percent) for Shand Flyash,

iii) cement dispersant addition (0 and 5mL/ton binder),

iv) aggregate fines percentage
(15 and 35 percent) for Coal Creek tests,
(20 and 40 percent) for Shand tests,

v) aggregate moisture content (1.0 and 4.0 percent).

Note, the settings for percent flyash and percent fines were changed for the Shand tests. The Shand tests were performed after the Coal Creek tests ... the Shand settings were altered so that a wider range of flyash and fines percentages could be accurately included in the tests. INCO was considering using 60 percent flyash in their operations, so the test ranges had to include these new values. Also, the percent fines range was altered so that predictions relating to the addition of unscreened development rock would be included in the testing range.

Previous cylinder testing (empirical results from INCO and other mines) indicated that the acceptable total binder range was between 4 and 5 percent. Higher binder percentages results in high slurry costs, while percentages below 4 percent are considered too weak (however, percentages below 4 percent have produced adequate strengths, but require ideal mixing).

The acceptable flyash percentage range was also obtained through previous cylinder testing (INCO and elsewhere).

W.R.Grace recommends 2 ml/kg binder. However, the range of 0 through 5 ml/kg was used to examine the effects above and below the recommended amount.

The acceptable fines percentage range is between 20 to 30 percent fines (note, that cylinder strengths increased for percentages above 30 percent during testing, but ideal mixing was experienced by the laboratory cylinders). The fines percentage was increased to 40 percent fines to include possible development rock addition.

The aggregate moisture range (1 through 4 percent) is due to the ground-water conditions experienced at the INCO mines. The T-3 Mine contains favourable conditions resulting in approximately 1 percent aggregate moisture. However, when the Birchtree Mine was sampled, results as high as 4 percent aggregate moisture were recorded.

5) **Perform tests at the specified conditions and record all data:**

A total of 118, "6 inch diameter by 12 inch high" rockfill cylinders were prepared and tested during the testing period. All data was recorded and is tabulated in **Tables #4, #5 and #6**. The experiments were performed using rockfill

TABLE #4 - SHAND FLYASH DESIGN - 100 DAYS CURING

ROCKFILL CYLINDER TESTING
COMPLETE CENTRAL COMPOSITE DESIGN

FACTORE BEING INVESTIGATED AND THEIR SETTINGS:

X1 = BINDER PERCENTAGE (4.0, 4.5, 5.0)
X2 = SHAND FLYASH PERCENTAGE (0, 30, 60)
X3 = DISPERSANT ml/Kg (0, 2.5, 5.0)
X4 = FINES PERCENTAGE (20, 30, 40)
X5 = AGGREGATE MOISTURE PERCENTAGE (1.0, 2.5, 4.0)

2 LEVEL FACTORIAL CYLINDERS

CYLINDER NUMBER	X1 BINDER %	X2 CC FLYASH %	X3 HYDRAFIL (ml/Kg)	X4 FINES %	X5 MOISTURE %	COMP STRENGTH (MPa)	SLURRY COSTS ($ CAN)
1	4	0	0	20	1	1.29	$5.43
2	5	0	0	20	1	2.22	$6.79
3	4	60	0	20	1	1.32	$3.90
4	5	60	0	20	1	1.61	$4.87
5	4	0	5	20	1	1.39	$5.83
6	5	0	5	20	1	2.19	$7.29
7	4	60	5	20	1	2.03	$4.30
8	5	60	5	20	1	1.22	$5.37
9	4	0	0	40	1	2.34	$5.43
10	5	0	0	40	1	3.00	$6.79
11	4	60	0	40	1	1.88	$3.90
12	5	60	0	40	1	3.05	$4.87
13	4	0	5	40	1	2.50	$5.83
14	5	0	5	40	1	4.88	$7.29
15	4	60	5	40	1	4.00	$4.30
16	5	60	5	40	1	4.88	$5.37
17	4	0	0	20	4	0.63	$5.43
18	5	0	0	20	4	0.50	$6.79
19	4	60	0	20	4	0.46	$3.90
20	5	60	0	20	4	0.27	$4.87
21	4	0	5	20	4	0.61	$5.83
22	5	0	5	20	4	0.59	$7.29
23	4	60	5	20	4	0.54	$4.30
24	5	60	5	20	4	0.63	$5.37
25	4	0	0	40	4	1.76	$5.43
26	5	0	0	40	4	3.08	$6.79
27	4	60	0	40	4	3.32	$3.90
28	5	60	0	40	4	3.86	$4.87
29	4	0	5	40	4	3.17	$5.83
30	5	0	5	40	4	4.51	$7.29
31	4	60	5	40	4	2.88	$4.30
32	5	60	5	40	4	4.05	$5.37

CENTER-POINT CYLINDERS

33	4.5	30	2.5	30	2.5	2.93	$5.47
34	4.5	30	2.5	30	2.5	4.17	$5.47
35	4.5	30	2.5	30	2.5	2.49	$5.47
36	4.5	30	2.5	30	2.5	2.92	$5.47

CENTRAL COMPOSITE CYLINDERS (OUTLIERS)

37	3.3	30	2.5	30	2.5	1.68	$4.01
38	5.7	30	2.5	30	2.5	2.49	$6.93
39	4.5	0	2.5	30	2.5	2.46	$6.33
40	4.5	100	2.5	30	2.5	0.41	$3.46
41	4.5	30	0.0	30	2.5	1.56	$5.25
42	4.5	30	8.5	30	2.5	3.30	$6.01
43	4.5	30	2.5	6	2.5	0.12	$5.47
44	4.5	30	2.5	54	2.5	4.88	$5.47
45	4.5	30	2.5	30	0.0	4.14	$5.47
46	4.5	30	2.5	30	6.1	1.05	$5.47

TABLE #5 - COAL CREEK FLYASH DESIGN - 28 DAYS CURING

ROCKFILL CYLINDER TESTING
COMPLETE FACTORIAL DESIGN

FACTORE BEING INVESTIGATED AND THEIR SETTINGS

X1 = BINDER PERCENTAGE (4.0, 4.5, 5.0)
X2 = COAL CREEK FLYASH PERCENTAGE (0, 25, 50)
X3 = DISPERSANT ml/Kg (0, 2.5, 5.0)
X4 = FINES PERCENTAGE (15, 25, 35)
X5 = AGGREGATE MOISTURE PERCENTAGE (1.0, 2.5, 4.0)

2 LEVEL FACTORIAL CYLINDERS

CYLINDER NUMBER	X1 BINDER %	X2 CC FLYASH %	X3 HYDRAFIL (ml/Kg)	X4 FINES %	X5 MOISTURE %	COMP. STRENGTH (MPa)	SLURRY COSTS ($ CAN)
47	4	0	0	15	1	1.12	$5.43
48	5	0	0	15	1	1.95	$6.79
49	4	50	0	15	1	0.93	$4.15
50	5	50	0	15	1	1.07	$5.19
51	4	0	5	15	1	1.95	$5.83
52	5	0	5	15	1	2.93	$7.29
53	4	50	5	15	1	0.98	$4.55
54	5	50	5	15	1	1.51	$5.69
55	4	0	0	35	1	1.24	$5.43
56	5	0	0	35	1	2.34	$6.79
57	4	50	0	35	1	1.07	$4.15
58	5	50	0	35	1	2.24	$5.19
59	4	0	5	35	1	2.44	$5.83
60	5	0	5	35	1	5.27	$7.29
61	4	50	5	35	1	1.90	$4.55
62	5	50	5	35	1	3.56	$5.69
63	4	0	0	15	4	0.44	$5.43
64	5	0	0	15	4	1.02	$6.79
65	4	50	0	15	4	0.63	$4.15
66	5	50	0	15	4	0.49	$5.19
67	4	0	5	15	4	0.49	$5.83
68	5	0	5	15	4	0.46	$7.29
69	4	50	5	15	4	0.49	$4.55
70	5	50	5	15	4	0.32	$5.69
71	4	0	0	35	4	1.56	$5.43
72	5	0	0	35	4	2.34	$6.79
73	4	50	0	35	4	1.17	$4.15
74	5	50	0	35	4	2.29	$5.19
75	4	0	5	35	4	1.71	$5.83
76	5	0	5	35	4	2.68	$7.29
77	4	50	5	35	4	1.71	$4.55
78	5	50	5	35	4	1.81	$5.69

CENTER-POINT CYLINDERS

79	4.5	25	2.5	25	2.5	1.90	$5.61
80	4.5	25	2.5	25	2.5	1.93	$5.61
81	4.5	25	2.5	25	2.5	2.05	$5.61
82	4.5	25	2.5	25	2.5	1.56	$5.61

TABLE #6 – COAL CREEK FLYASH DESIGN – 100 DAYS CURING

ROCKFILL CYLINDER TESTING
COMPLETE FACTORIAL DESIGN

FACTORE BEING INVESTIGATED AND THEIR SETTINGS:

X1 = BINDER PERCENTAGE (4.0, 4.5, 5.0)
X2 = COAL CREEK FLYASH PERCENTAGE (0, 25, 50)
X3 = DISPERSANT ml/Kg (0, 2.5, 5.0)
X4 = FINES PERCENTAGE (15, 25, 35)
X5 = AGGREGATE MOISTURE PERCENTAGE (1.0, 2.5, 4.0)

2 LEVEL FACTORIAL CYLINDERS

CYLINDER NUMBER	X1 BINDER %	X2 CC FLYASH %	X3 HYDRAFIL (ml/Kg)	X4 FINES %	X5 MOISTURE %	COMP STRENGTH (MPa)	SLURRY COSTS ($ CAN)
83	4	0	0	15	1	1.29	$5.43
84	5	0	0	15	1	2.52	$6.79
85	4	50	0	15	1	1.11	$4.15
86	5	50	0	15	1	1.40	$5.19
87	4	0	5	15	1	2.93	$5.83
88	5	0	5	15	1	3.45	$7.29
89	4	50	5	15	1	1.08	$4.55
90	5	50	5	15	1	2.28	$5.69
91	4	0	0	35	1	1.76	$5.43
92	5	0	0	35	1	4.27	$6.79
93	4	50	0	35	1	1.35	$4.15
94	5	50	0	35	1	2.61	$5.19
95	4	0	5	35	1	3.10	$5.83
96	5	0	5	35	1	5.50	$7.29
97	4	50	5	35	1	2.52	$4.55
98	5	50	5	35	1	5.68	$5.69
99	4	0	0	15	4	0.59	$5.43
100	5	0	0	15	4	1.00	$6.79
101	4	50	0	15	4	0.53	$4.15
102	5	50	0	15	4	0.76	$5.19
103	4	0	5	15	4	0.59	$5.83
104	5	0	5	15	4	0.59	$7.29
105	4	50	5	15	4	0.59	$4.55
106	5	50	5	15	4	0.41	$5.69
107	4	0	0	35	4	2.37	$5.43
108	5	0	0	35	4	2.87	$6.79
109	4	50	0	35	4	2.11	$4.15
110	5	50	0	35	4	3.86	$5.19
111	4	0	5	35	4	2.09	$5.83
112	5	0	5	35	4	2.99	$7.29
113	4	50	5	35	4	1.84	$4.55
114	5	50	5	35	4	2.34	$5.69

CENTER-POINT CYLINDERS

115	4.5	25	2.5	25	2.5	1.52	$5.61
116	4.5	25	2.5	25	2.5	2.40	$5.61
117	4.5	25	2.5	25	2.5	1.76	$5.61
118	4.5	25	2.5	25	2.5	3.22	$5.61

aggregate and process water collected at the underground rockfill station located at the 2650 foot level. Two sources of flyash were tested (flyash from the "Coal Creek" and "Shand" power plants). Separate designs were performed for each of the two flyash sources.

The experimental results proved to be slightly lower than those collected from experiments using concrete aggregates. However, by using the actual rockfill materials and allowing the cylinders to cure underground, the results collected during the experiment represented more accurate insitu strength estimates than results collected from experiments using graded, washed concrete aggregates. The cylinder results proved to be accurate and the strengths were reproducible (similar results were produced for duplicated cylinders).

6) **Select an appropriate model and fit it to the measured data:**

"Two-level factorial" and "central composite" designs were used to derive the strength estimation equations. "Linear" and "Reduced-Quadratic" models were derived and proved to be acceptable, producing R-Squared values ranging between 0.81 and as high as 0.99 (note, 1.00 is a perfect fitting model).

7) **Test the adequacy of the fitted model:**

The models estimated the actual results from the test cylinders accurately. All three of the strength estimation equations (described in following section) predicted similar results when the factors were varied (note, that the two flyash sources varied in competency). The equation was also used to predict strengths of cylinders from previous testing periods (again, the results were very accurate). An adequate fit was obtained and the resulting models have been used for prediction purposes at the INCO Thompson mines. Statistical analyses were performed to ensure the results were statistically significant (explained later in thesis).

The statistical designs proved to be an efficient method of determining the degree of influence that each rockfill variable had on the compressive strength. The designs allowed "strength estimation equations" to be established, which allow insitu strengths to be predicted. Although the reliability of the equations may decrease outside of the ranges tested (factor ranges), the equations were very accurate for predicting the strengths of the cylinders within the test. The strength estimation equations allow the engineers to consider the rockfill system in a more controlled, scientific manner.

The accuracy of the estimation equations can be improved by performing additional testing outside of the previous test ranges. The estimated strengths may change depending on the sources of the rockfill products (binder, flyash, dispersant, rock, water). However, the equation fits very well for the

INCO Thompson mines, and could perhaps be used as a rough estimate for strengths received at other rockfill mines.

The equations allow the engineer to vary the factors within the rockfill in order to discover the most cost effective rockfill product that will deliver high compressive strengths for the least amount of money. Note, the strength estimating equation is only used as a guide in determining potential recipes. Periodic compressive cylinders are still produced and tested to verify the accuracy of the equation and/or the quality of the binder products.

10. THE SHAND DESIGN

10.1 THE SHAND FLYASH CENTRAL COMPOSITE DESIGN

NOTE: This section of the paper will be directed mainly towards "The **Shand Flyash** Central Composite Design". INCO is currently using this flyash source and is therefore more interested in these results than the Coal Creek flyash results (Coal Creek results can be found in **Appendix #1 and #2**). NOTE, a complete analysis has been performed on the Coal Creek results). Due to superior strength of the Shand power-plant flyash (determined through prior cylinder testing), it has replaced Coal Creek flyash as INCO's flyash supplier.

10.2 STATISTICAL SOFTWARE

Two statistical software packages were used to assist in deriving accurate strength estimation equations ("Design Ease" and "Design Expert"). Both programs produced strength estimation equations with high "R-Squared" values. The "Design Ease" equation had an R-Squared value of 0.891, while the "Design Expert" produced a value of 0.853 (note, a perfect model would have an R-Squared value of 1.000). Both equations had "PROB > F" values of 0.0001 (see **Appendix #3** for statistical results).

A linear model was used to fit the data with the "Design Ease" software, while a reduced-quadratic model was used in "Design Expert" (again, both derived equations that predicted similar strengths and predicted similar trends).

10.3 METHODOLOGY OF DESIGNS

The "single effects" and "interaction effects" associated with the five rockfill factors were calculated. Multiple regression techniques were used to derive possible equations. Probabilities were given to each of the single and interaction coefficients. Only coefficients with 95 percent (or greater) confidence values were kept in the strength equation (95 percent confidence was suggested by A.Mular, 1990). The factors associated with these significant coefficients were:

A = BINDER EFFECT

(the effect on compressive strength when altering the <u>binder</u> from its high level to its low level)

B = SHAND FLYASH EFFECT

(the effect on compressive strength when altering the flyash from its high level to its low level)

C = HYDRAFIL EFFECT

(the effect on compressive strength when altering the Hydrafil from its high level to its low level)

D = FINES EFFECT

(the effect on compressive strength when altering the fines from its high level to its low level)

E = MOISTURE EFFECT

(the effect on compressive strength when altering the moisture from its high level to its low level)

A/D = BINDER/FINES INTERACTION EFFECT

C/D = HYDRAFIL/FINES INTERACTION EFFECT

D/E = FINES/MOISTURE INTERACTION EFFECT

NOTE: The other interaction effects had confidence values less than 95 percent and were discarded from the final equation (equations containing "all" interaction effects can be found in **Appendix #3**). Insignificant effects (less than 95 percent confidence) should be dropped from the equation (Mular, 1990).

Once the significant effects were determined, the final strength estimation equations were produced:

The "Linear" strength estimation equation (MPa) =

= 5.349167

- 0.935000 * (percent binder)

+ 0.001375 * (percent Shand flyash)

- 0.170000 * (ml/kg Hydrafil)

- 0.198125 * (percent fines)

- 0.756667 * (percent moisture)

+ 0.052875 * (percent binder) * (percent fines)

+ 0.009625 * (ml/kg Hydrafil) * (percent fines)

+ 0.019000 * (percent fines) * (percent moisture)

The "Reduced Quadratic" strength estimation equation (MPa) =

= 5.649000

- 1.016100 * (percent binder)

+ 0.014060 * (percent Shand flyash)

- 0.162790 * (ml/kg Hydrafil)

- 0.162910 * (percent fines)

- 0.821400 * (percent moisture)

- 0.000280 * (percent Shand flyash)^2 ... squared

- 0.000636 * (percent fines)^2 ... squared

+ 0.052870 * (percent binder) * (percent fines)

+ 0.009625 * (ml/kg Hydrafil) * (percent fines)

+ 0.019000 * (percent fines) * (percent moist)

10.4 SINGLE FACTOR EFFECTS

The <u>single factor effect</u>, or "main effect" of any factor is defined as the overall average change in compressive strength produced by an increase in the level of that factor (i.e. the change in the compressive strength going from 4 to 5 percent binder).

There are 5 single factor effects:

1 - total binder effect,

2 - Shand flyash effect,

3 - Hydrafil effect (cement dispersant),

4 - Aggregate fines effect,

5 - Aggregate moisture effect.

1) The total binder single effect:

Figure #10 shows the single factor effect that varying the total binder percentage has on the compressive strength. Note, the average values associated with the other four factors are used while the total binder percentage is varied.

ID STRENGTH A- corresponds to the average compressive strength of the rockfill at the low level (4 percent) of the total binder = 1.882 MPa.

ID STRENGTH A+ corresponds to the average compressive strength of the rockfill at the high level (5 percent) of the total binder = 2.533 MPa.

Obviously, as the total percent binder is increased, the compressive strength is increased. However, total binder (portland cement plus Shand flyash) is a very expensive item ($3.00/ton ore mined). Therefore, increasing the total percent binder is an expensive method of increasing the compressive strength.

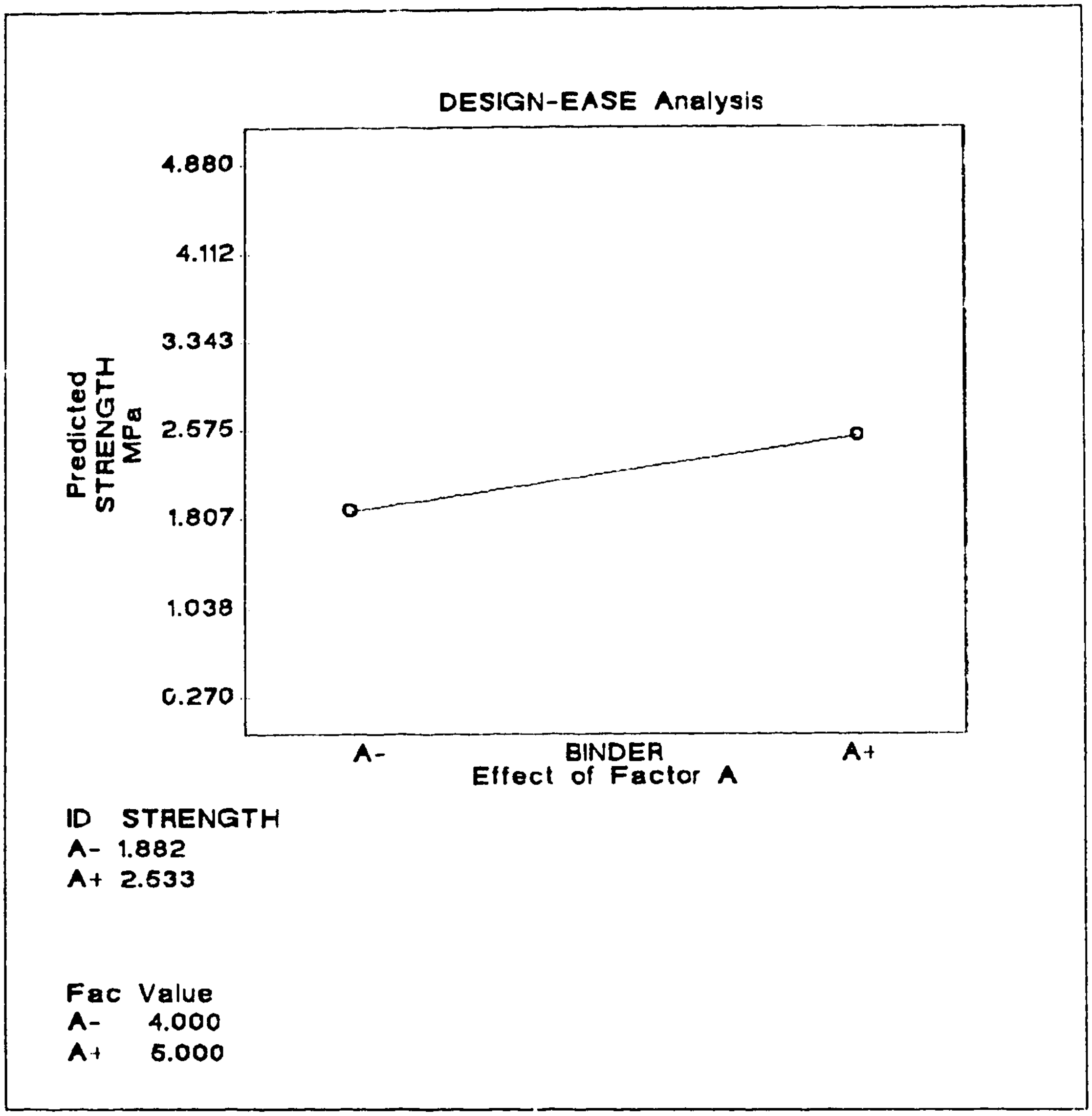

FIGURE #10: BINDER SINGLE EFFECT

Note, the sum of A- and A+ = 4.415 MPa. When the average of these two values is calculated (4.415/2 = 2.208 MPa), the average value of the statistical design is produced. This value can be verified by calculating the sum of all the two-level factorial cylinder results and dividing by the total number of two-level factorial cylinders tested (the average compressive strength value).

A- = 1.882 MPA

A+ = 2.533 MPa

By subtracting A- from A+, we can find the difference (single factor effect).

"A" effect = (2.533 MPa - 1.882 MPa) = 0.651 MPa

= total binder single factor effect.

This single factor effect is the amount that the average compressive strength is altered as the total binder percentage is varied from 4 to 5 percent total binder.

2) Shand flyash single effect:

Figure #11 shows the single factor effect that varying the Shand flyash percentage has on the compressive strength. Note, the average values associated with the other four factors are used while the Shand flyash percentage is varied.

ID STRENGTH B- corresponds to the average compressive strength of the rockfill at the low level (0 percent) of the Shand flyash = 2.166 MPa.

ID STRENGTH B+ corresponds to the average compressive strength of the rockfill at the high level (60 percent) of the Shand flyash = 2.249 MPa.

Surprisingly, as the percentage of Shand flyash is increased, the compressive strength also increased slightly (up until maximum percentage of 60 percent flyash was determined). By using up to 60 percent Shand flyash we were

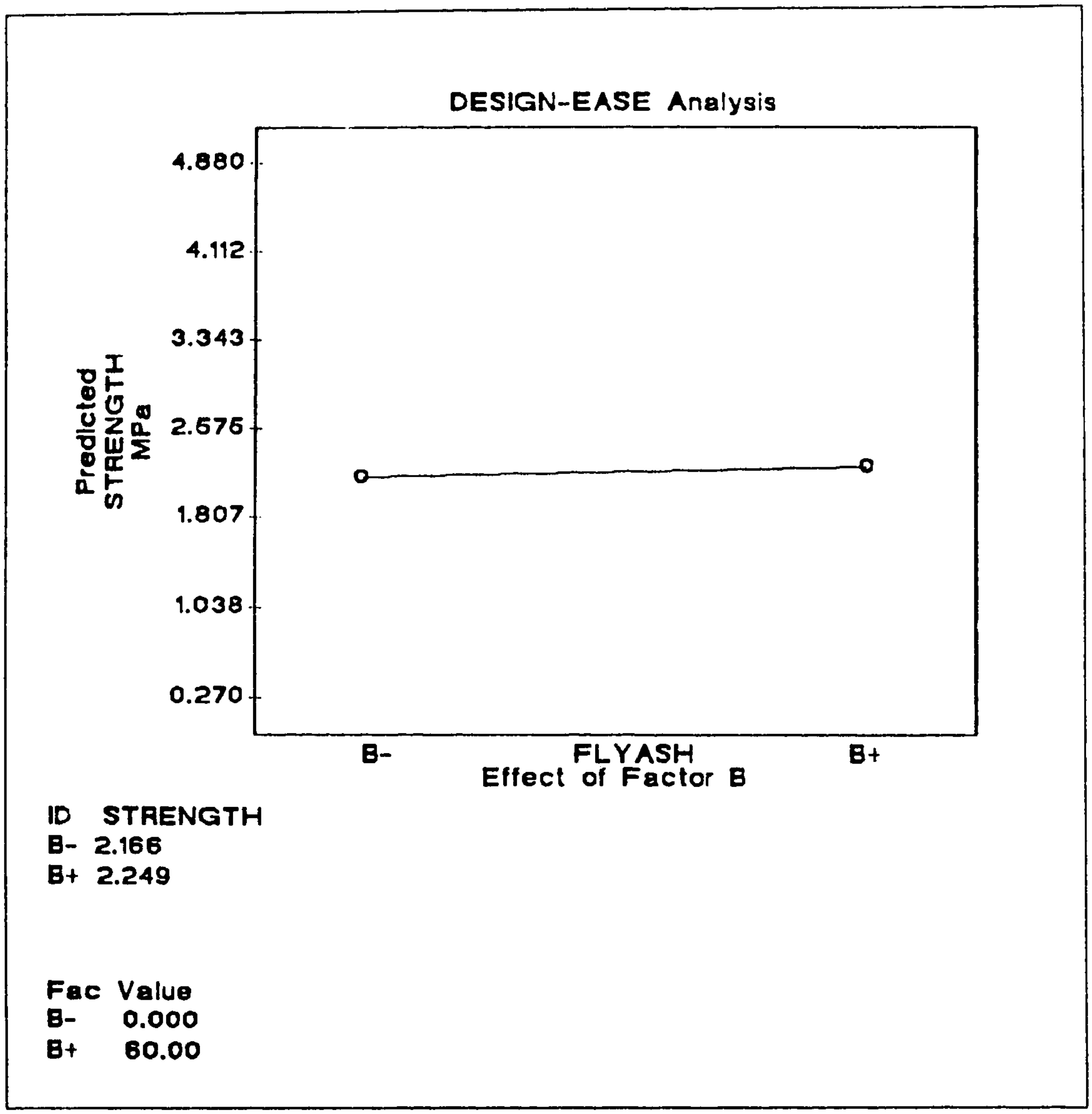

FIGURE #11: FLYASH SINGLE EFFECT

receiving higher final strengths than with 100 portland cement (at cheaper cost). The curing period of this central composite design was 100 days. Because the flyash delays the hydration process, the cylinders with a high percentage of flyash hydrated more slowly and therefore acquired slightly higher final strengths than those cylinders with lower flyash percentages (Note, the Coal Creek cylinders were tested at 28 and 100 days curing. The 100 day compressive strengths increased by approximately 30 percent over the 28 day strengths). The Coal Creek flyash cylinders never reached the compressive strength of the 100 percent portland cement cylinders (the Coal Creek flyash did not strengthen the cylinders, ever after a long curing period). The Coal Creek flyash was not as pozzolanic as the Shand flyash.

Shand flyash proves to be an effective means of increasing the compressive strength (if given long curing periods). However, earlier cylinder testing showed that lower 28 day strengths were evident with the cylinders containing higher flyash percentages. Therefore, because Shand flyash is an inexpensive substitute for portland cement ($40/ton less than portland cement), increasing the flyash content is an effective means of producing strong rockfill at low cost, provided quick mining cycles are not required (i.e. sufficient curing periods are given prior to mining the adjacent pillars). If quick mining cycles are required (i.e. when using the primary/primary mining method), increasing the flyash content may not be the ideal solution. Also, additional cylinder testing proved that the final strengths of the cylinders began to decrease as the percent flyash exceeded 60 percent.

B- = 2.166 MPA

B+ = 2.249 MPa

By subtracting B- from B+ we can find the difference (single factor effect).

(2.249 MPa - 2.166 MPa) = <u>0.083 MPa</u>

= Shand flyash single factor effect.

This single factor effect is the amount that the average compressive strength is altered as the percentage of Shand flyash is varied from 0 to 60 percent.

3) **The Hydrafil single effect (cement dispersant):**

Figure #12 shows the single factor effect that varying the amount of Hydrafil has on the compressive strength. Note, the average values associated with the other four factors are used while the amount of Hydrafil is varied.

ID STRENGTH C- corresponds to the average compressive strength of the rockfill at the low level (0 ml/kg) of the Hydrafil = 1.911 MPa.

ID STRENGTH C+ corresponds to the average compressive strength of the rockfill at the high level (5 ml/kg) of the Hydrafil = 2.504 MPa.

As the amount of Hydrafil is increased, the compressive strength also increased. The Hydrafil dispersing agents impart negative electrical charges to the water suspended cement particles. These negatively charged binder particles repel each other. The result is uniform dispersion (Grace, 1989). Hydrafil, using this principle, allows more cement to be involved in binding the backfill together. This delivers

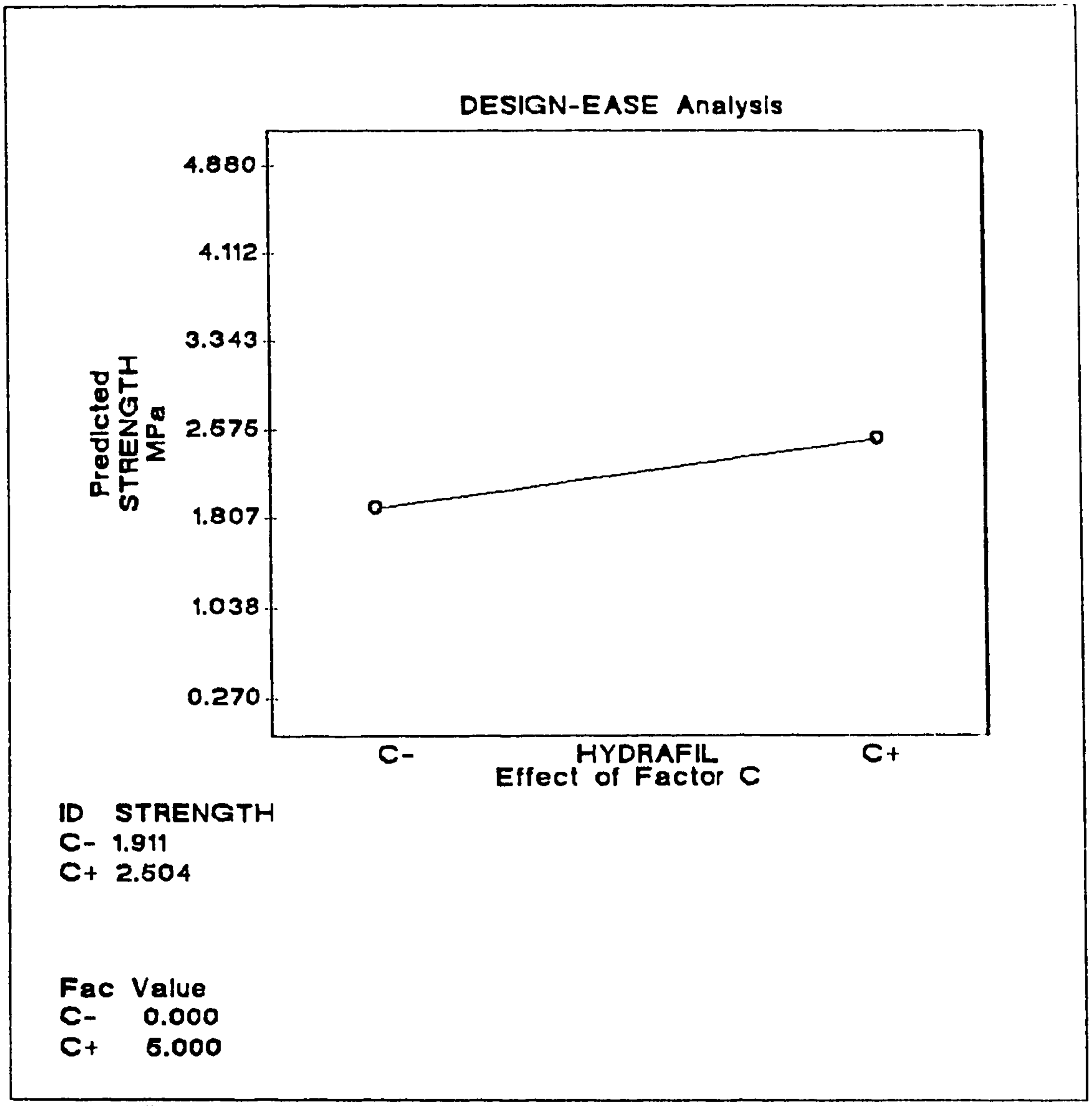

FIGURE #12: HYDRAFIL SINGLE EFFECT

increased compressive strength to the backfill, without the addition of more cement (Grace, 1989). Excess water can severely reduce compressive strength and can contribute to segregation. By reducing the water content of the backfill, both increased strength and less segregation can be achieved (Grace, 1989).

Hydrafil proves to be an effective means of increasing the compressive strength and at $4.00/ton binder (relatively inexpensive), the extra strength gained is well worth the extra cost.

C- = 1.911 MPA

C+ 2.504 MPa

By subtracting C- from C+ we can find the difference (single factor effect).

(2.504 MPa - 1.911 MPa = 0.593 MPa

= Hydrafil single factor effect.

This single factor effect is the amount that the average compressive strength is altered as the amount of Hydrafil is varied from 0 to 5 ml/kg.

4) The aggregate fines single effect:

Figure #13 shows the single factor effect that varying the percentage of fines has on the compressive strength. Note, the average values associated with the other four factors are used while the fines percentage is varied.

ID STRENGTH D- corresponds to the average compressive strength of the rockfill at the low level (20 percent) of the aggregate fines = 1.094 MPa.

ID STRENGTH D+ corresponds to the average compressive strength of the rockfill at the high level (40 percent) of the aggregate fines = 3.321 MPa.

As the percentage of fines is increased, the compressive

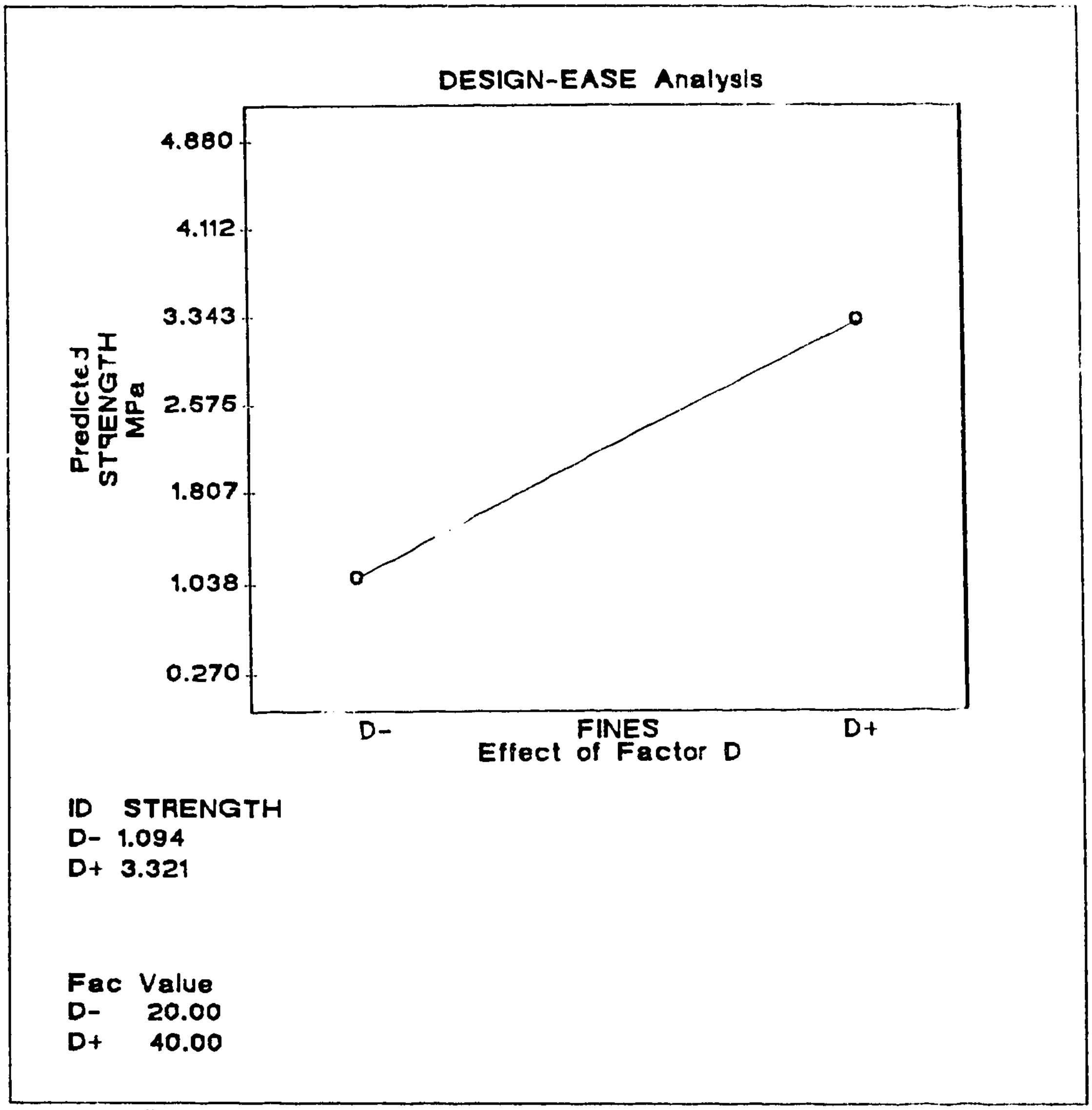

FIGURE #13: FINES SINGLE EFFECT

strength is also drastically increased.

Increasing the fines percentage is an inexpensive (free) means of increasing the compressive strength. However, caution must be used that too many fines (above 30 percent) are not used in a production situation. The increased surface area associated with the increase in percent fines requires more binder to effectively "cement-cover" the aggregate. Therefore, unless perfect mixing (i.e. laboratory environment) is produced, an ineffective product will be produced.

The worst case scenario is having too few fines. When the percent fines was at the low level (20 percent), the strengths were much lower than those at the high level (40 percent). Above 40 percent fines the laboratory results began to drop. If the fines content is too low, there is not enough "matrix fines" to properly fill the voids created by the larger aggregate material. Therefore, point-contact between the aggregate material is produced (a very weak situation).

The fines content should be monitored regularly to ensure that the fines percent remains within acceptable limits (25 percent is recommended (Yu and Counter, 1983)). Testing has shown that if reasonable mixing is produced, too many fines is more desirable than too few (25-40 percent if good mixing is produced).

D- = 1.094 MPA

D+ = 3.321 MPa

By subtracting D- from D+ we can find the difference (single factor effect).

(3.321 MPa - 1.094 MPa) = <u>2.227 MPa</u>

= aggregate fines percent single factor effect.

This single factor effect is the amount that the average compressive strength is altered as the fines percentage is varied from 20 to 40 percent.

5) The aggregate moisture single effect:

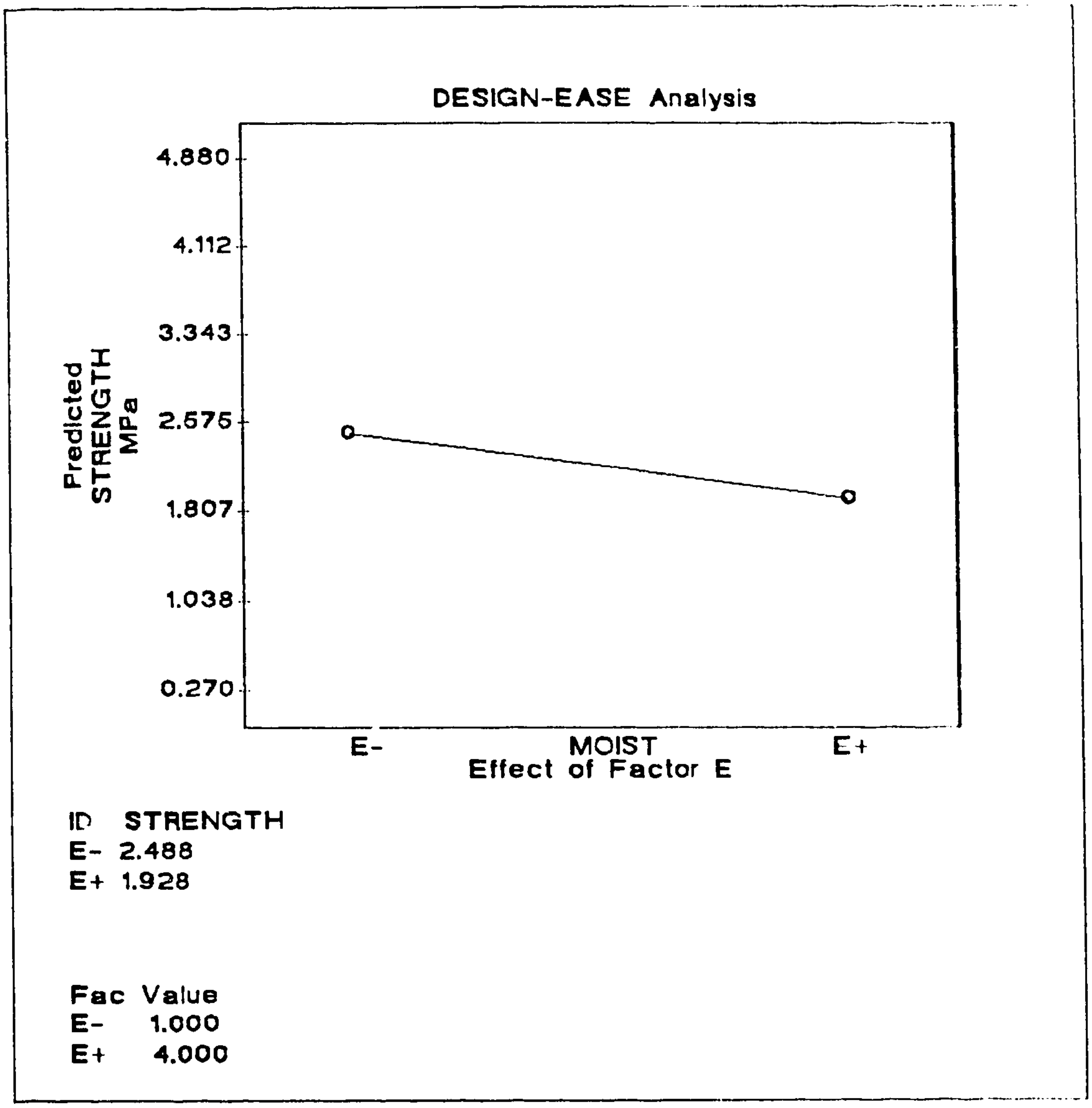

FIGURE #14: MOISTURE SINGLE EFFECT

Figure #14 shows the single factor effect that varying the aggregate moisture percentage has on the compressive strength. Note, the average values associated with the other four factors are used while the moisture percentage is varied.

ID STRENGTH E- corresponds to the average compressive strength of the rockfill at the low level (1.0 percent) of the aggregate moisture = 2.488 MPa.

ID STRENGTH E+ corresponds to the average compressive strength of the rockfill at the high level (4.0 percent) of the aggregate moisture = 1.928 MPa.

As the percentage of moisture is increased, the compressive strength is decreased.

Decreasing the moisture percentage is a difficult exercise. Groundwater and excess slurry water can radically decrease the strength of the rockfill product. Curtain grouting was successfully performed at INCO's T-3 Mine. The percentage of groundwater was reduced to approximately 1.0 percent. The Birchtree Mine has been less successful in preventing groundwater from mixing with the raise aggregates (water contents ranging from 2-4 percent water). However, additional grouting will be performed to try and reduce this persistent problem. To combat this predicament, the Birchtree Mine has increased the percent solids in the binder slurry from 55 to 65 percent.

The moisture content should be monitored regularly to ensure that the aggregate moisture remains within acceptable limits. If the moisture is too high (i.e. + 4 percent), addition binder and/or fines may be added to compensate for the weak situation (low fines and high water are an awful combination. The fines that are present, will be washed through the porous raise material, making the situation even worse).

E- = 2.488 MPA

E+ = 1.928 MPa

By subtracting E- from E+ we can find the difference (single factor effect).

(1.928 MPa - 2.488 MPa) = -0.560 MPa

= aggregate moisture single factor effect.

This single factor effect is the amount that the average compressive strength is altered as the moisture percentage is varied from 1 to 4 percent.

SUMMARY OF SINGLE FACTOR EFFECTS:

TABLE #7: SUMMARY OF SINGLE FACTOR EFFECTS

ROCKFILL FACTOR	SINGLE FACTOR EFFECT (MPa)	SINGLE FACTOR EFFECT (% CHANGE)
PERCENT BINDER	0.651	+/- 14.8
PERCENT FLYASH	0.083	+/- 1.9
HYDRAFIL	0.593	+/- 13.5
PERCENT FINES	2.227	+/- 50.5
PERCENT MOISTURE	-0.560	+/- 12.7

Table #7 shows a summary of the single factor effects (main effects). The fines percentage is the most outstanding result. The strength was dramatically increased when the high setting (40 percent) was used. The percent change column represents the percentage of change from the average (2.208 MPa) that each factor produced varying from their low to high setting. For example, by varying the fines from 20 to 40 percent, the corresponding strength values were 50.5 percent above and below the average. The total binder, Hydrafil and aggregate moisture percentage had similar influences on the compressive strength. The percentage of Shand flyash had a minimal effect on the compressive strength of the cylinders (valuable results considering that flyash is cheaper than portland cement).

10.5 TWO-WAY INTERACTION EFFECTS:

A two-way interaction effect between two factors is "the average difference between the effect of an increase in the level of the first factor at the higher level of the second factor and the effect of an increase in the level of the first factor at the lower level of the second factor" (Mular,1990).

TOTAL BINDER versus SHAND FLYASH

Figure #15 shows a square plot of the predicted values for the two-way interaction between **total binder and Shand**

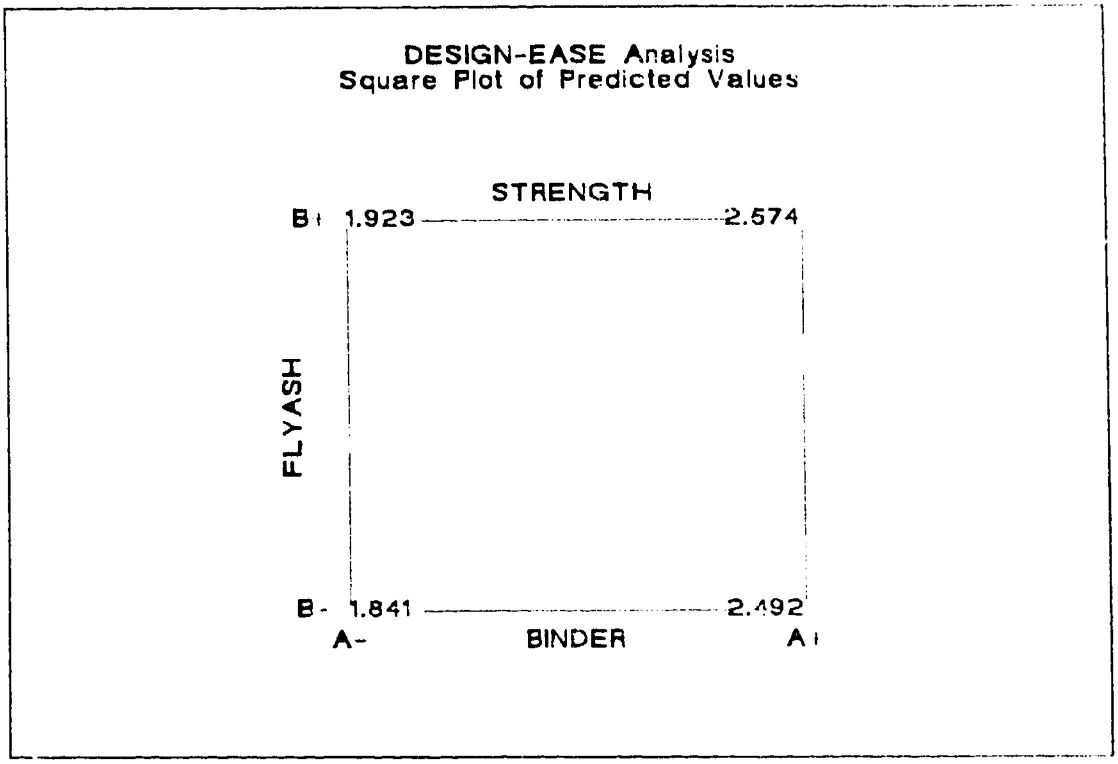

FIGURE #15: BINDER/FLYASH INTERACTION

flyash.

The maximum difference occurring between A-,B- and A+,B+ = 2.574 MPa - 1.841 MPa = 0.733 MPa

The compressive strength is at the lowest when the total binder and Shand flyash are both at their low settings and at the highest when total binder and Shand flyash are at their high settings.

Figures #16 and #17 show the two way plots (2 D and 3 D plots). The contours in **Figure #16** show lines of equal strength (reduced quadratic model). The figure shows that at high percentages of flyash (greater than 33 percent), the percentage of total binder must increase as the flyash

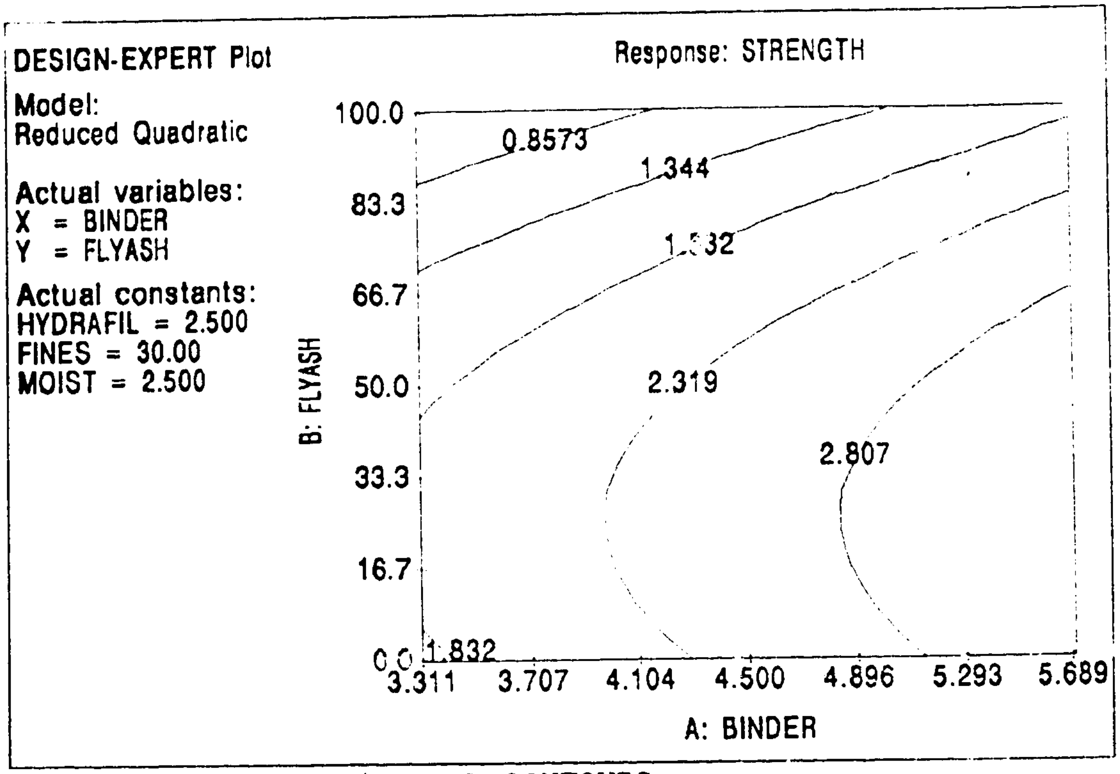

FIGURE #16: BINDER/FLYASH CONTOURS

percentage is increasing in order to obtain the same strength. At approximately 33 percent flyash, the contour lines change from being positively sloped to negatively sloped (a change in trend).

Although the strength of the cylinders decreases as the percentage of flyash is increased past 33 percent (change in trend line), due to the reduced cost of flyash when compared to portland cement, increasing the percentage of flyash may still prove to be economic. Because flyash is cheaper than portland cement, a higher percentage of total binder containing a higher percentage of flyash may be cost effective (i.e. more "total binder" at a higher flyash percentage may prove to be more economical than lower "total binder" at a

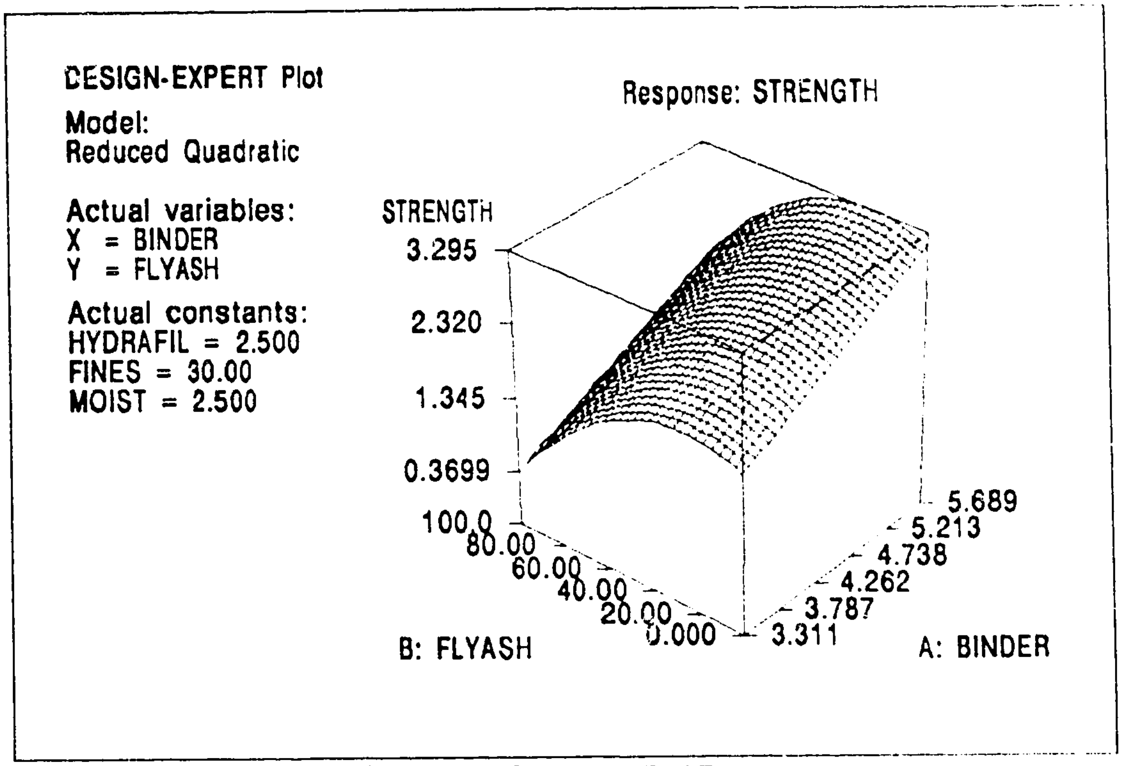

FIGURE #17: BINDER/FLYASH 3-D SURFACE

lower flyash percentage).

Figure #16 also shows that, at flyash percentages below 33 percent, less total binder is required as the flyash percentage is increased in order to produce equal compressive strengths.

Figure #17 shows the 3-D response surface. An accurate numerical value is difficult to obtain from these 3-D plots. However, the plots are useful as visual aids (describing the trend nicely).

TOTAL BINDER versus HYDRAFIL

Figure #18 shows a square plot of the predicted values

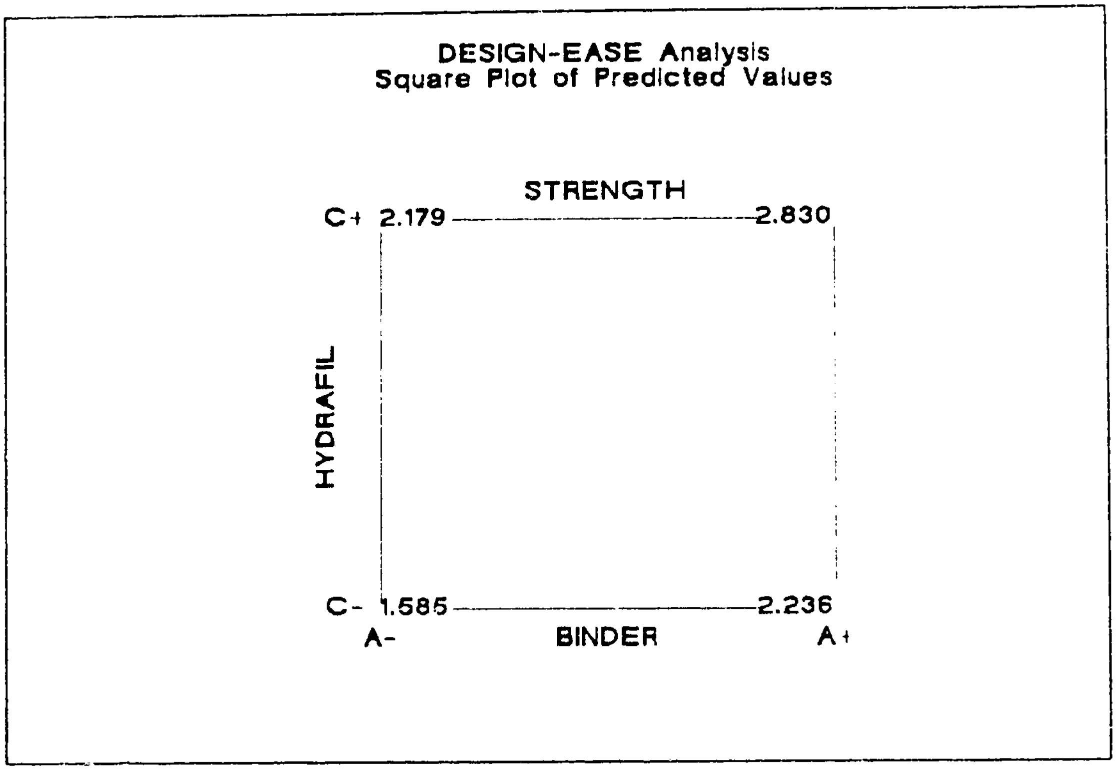

FIGURE #18: BINDER/HYDRAFIL INTERACTION

for the two-way interaction between **total binder and Hydrafil.**

The maximum difference occurring between A-,C- and A+,C+ = 2.830 MPa - 1.585 MPa = 1.245 MPa

The compressive strength is at the lowest when the total binder and Hydrafil are both at their low settings and at the highest when total binder and Hydrafil are at their high settings.

Figures #19 and #20 show the two-way linear plots (2-D and 3-D plots). The contours in **Figure #19** show lines of equal strength. The figure shows that as the amount of Hydrafil is decreased, the percentage of total binder must be increased in order to obtain the same strength. Because Hydrafil is cheaper

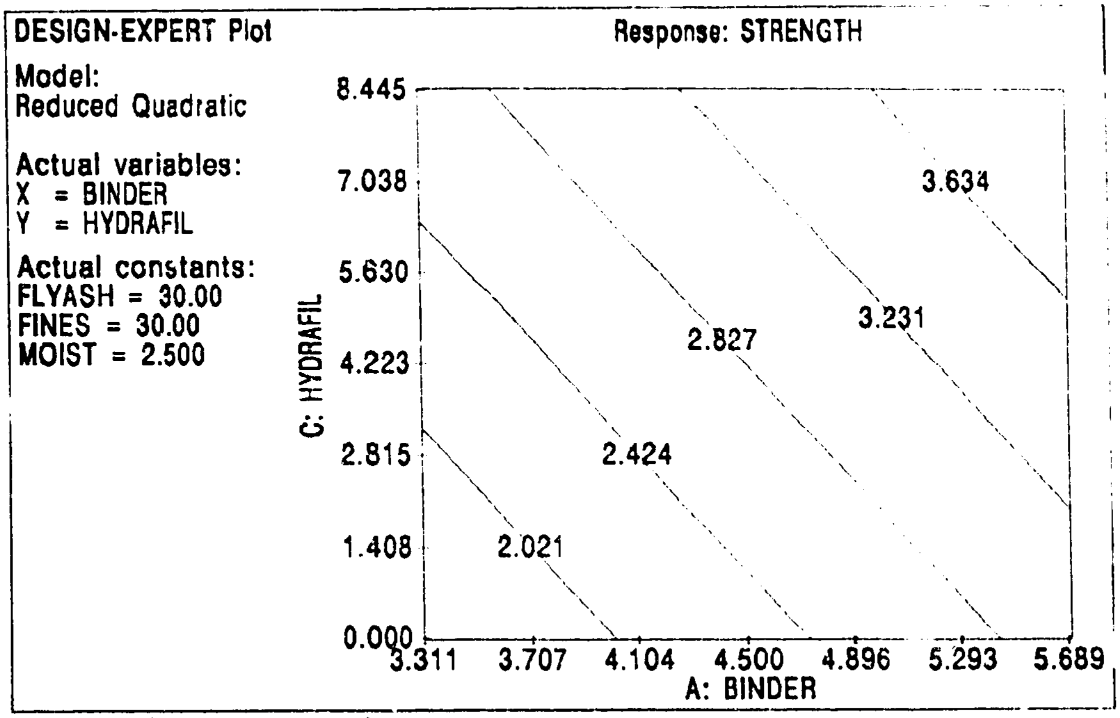

FIGURE #19: BINDER/HYDRAFIL CONTOURS

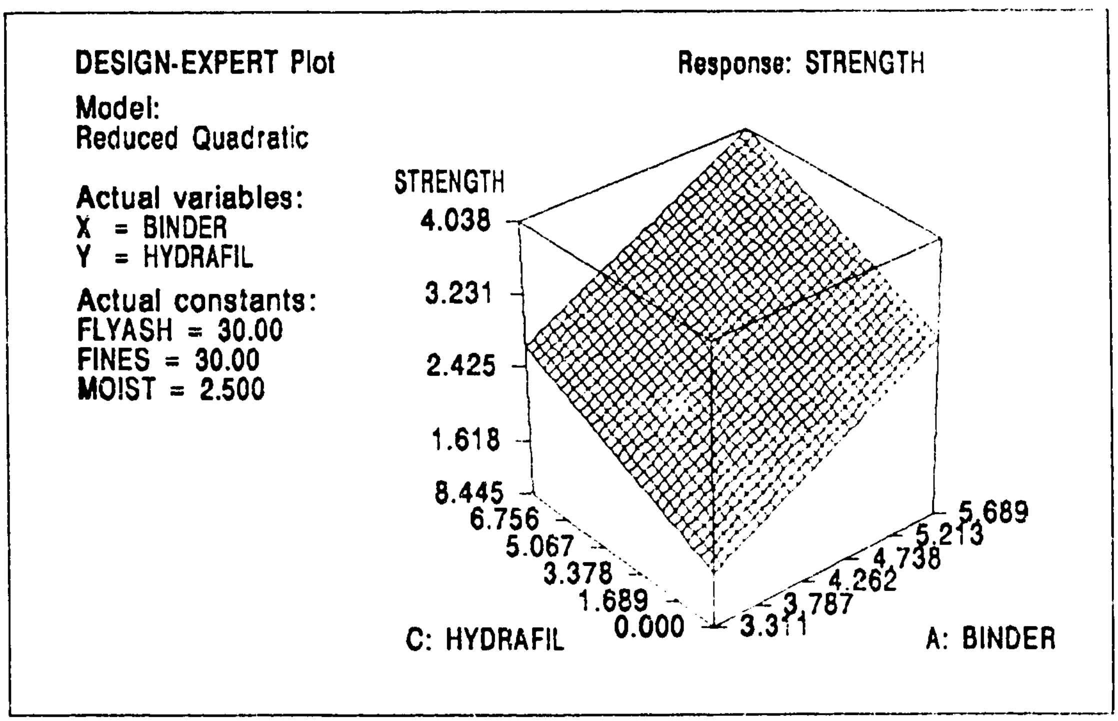

FIGURE #20: BINDER/HYDRAFIL 3-D SURFACE

than portland cement, the maximum amount of Hydrafil should be used to reduce the total binder percentage (try to find optimum amount of Hydrafil to add, yet still produce cost effective rockfill). Unlike the quadratic (curved) relationship between total binder and Shand flyash, the relationship between total binder and Hydrafil is very linear (parallel straight-line trend).

TOTAL BINDER versus AGGREGATE FINES

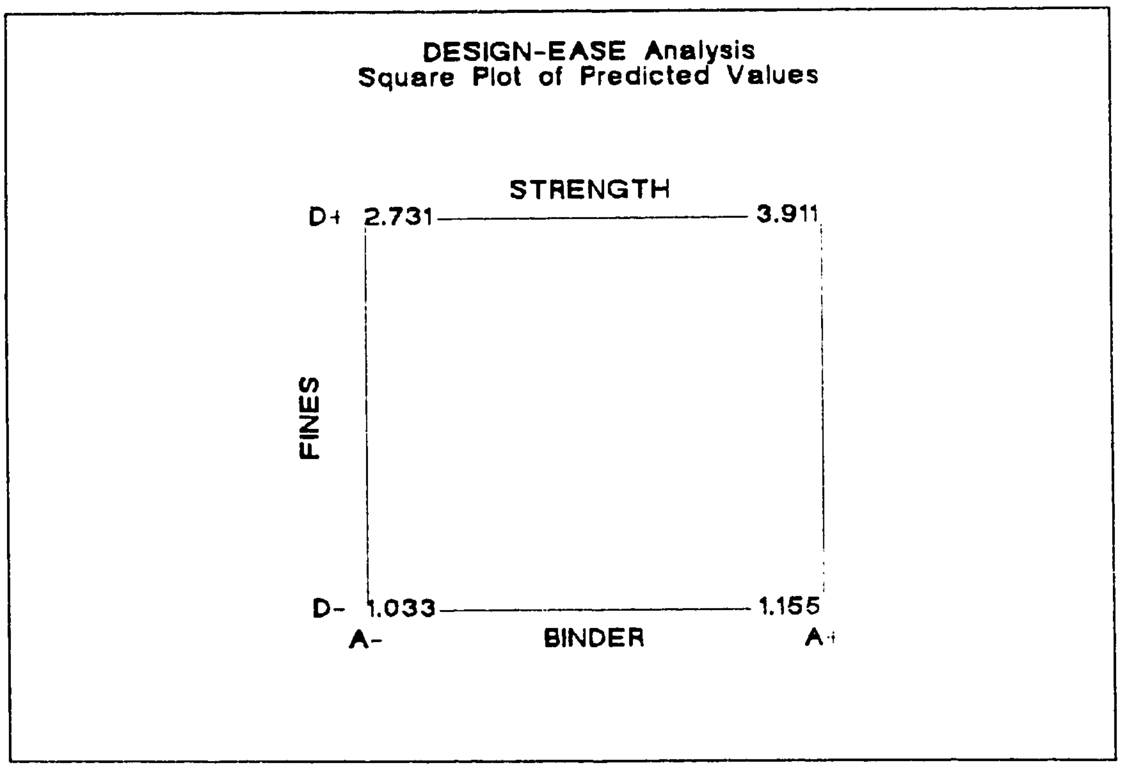

FIGURE #21: BINDER/FINES INTERACTION

Figure #21 shows a square plot of the predicted values for the two-way interaction between **total binder and aggregate fines**.

The maximum difference occurring between A−,D− and A+,D+ = 3.911 MPa - 1.033 MPa = 2.878 MPa

The compressive strength is at the lowest when the total binder and aggregate fines are both at their low settings and at the highest when total binder and aggregate fines are at their high settings.

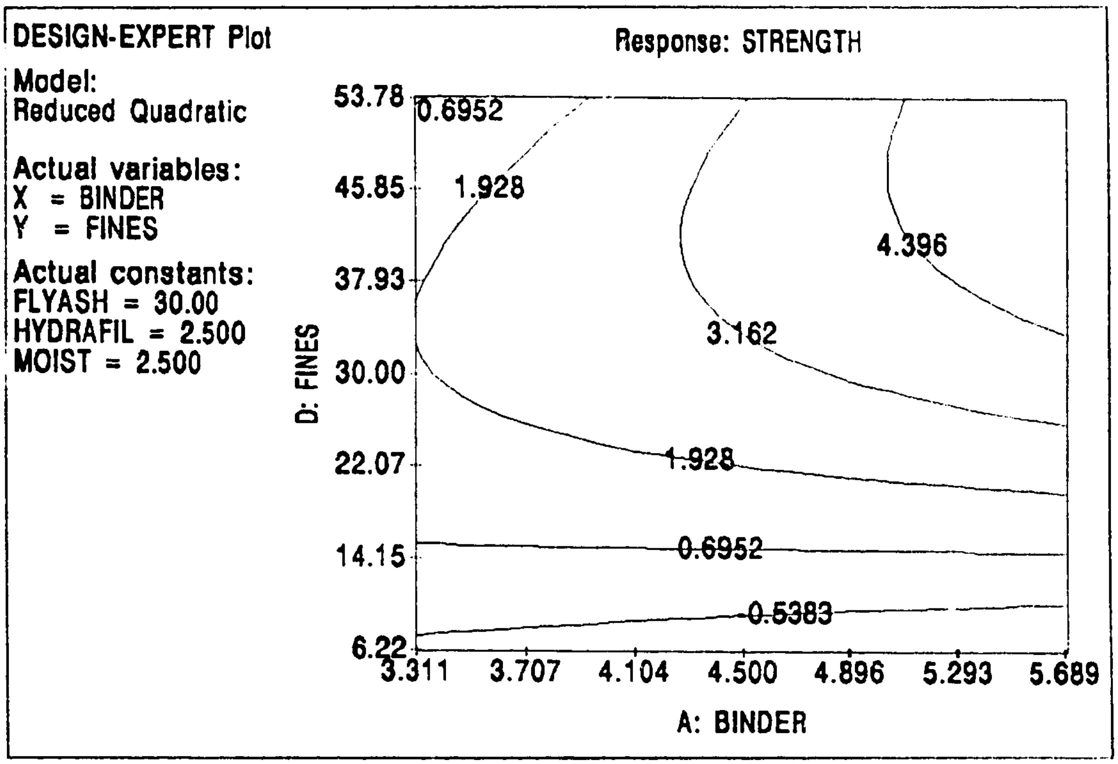

FIGURE #22: BINDER/FINES CONTOURS

Figures #22 and #23 show the two-way quadratic plots (2-D and 3-D plots). The contours in **Figure #22** show lines of equal strength. Note, that at low aggregate fines percentages, no amount of total binder addition will increase the strength (very weak situation). As the percentage of fines increases,

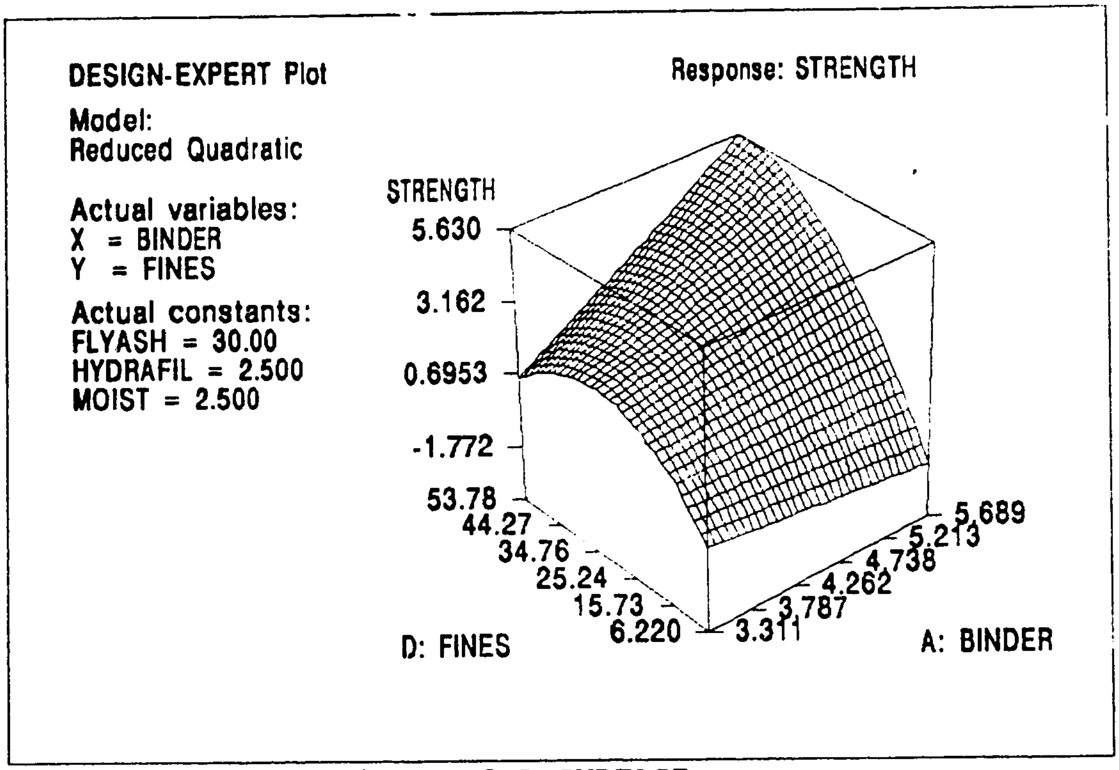

FIGURE #23: BINDER/FINES 3-D SURFACE

the compressive strength increases (increase in fines percentage is directly proportional to increase in strength). However, once the fines percentage exceeds 35-45 percent (a change in trend is evident), an additional increase in fines will decrease the compressive strength (this is due to the increase in surface area of the aggregate, resulting in the need for additional total binder to maintain adequate coverage).

Because increasing the percentage of aggregate fines is simple and cost effective (eliminates screening costs), the optimum percentage of fines should be discovered. The trend between total binder and aggregate fines changes dramatically depending on response surface location (not a linear relationship, but a quadratic relationship).

TOTAL BINDER versus AGGREGATE MOISTURE

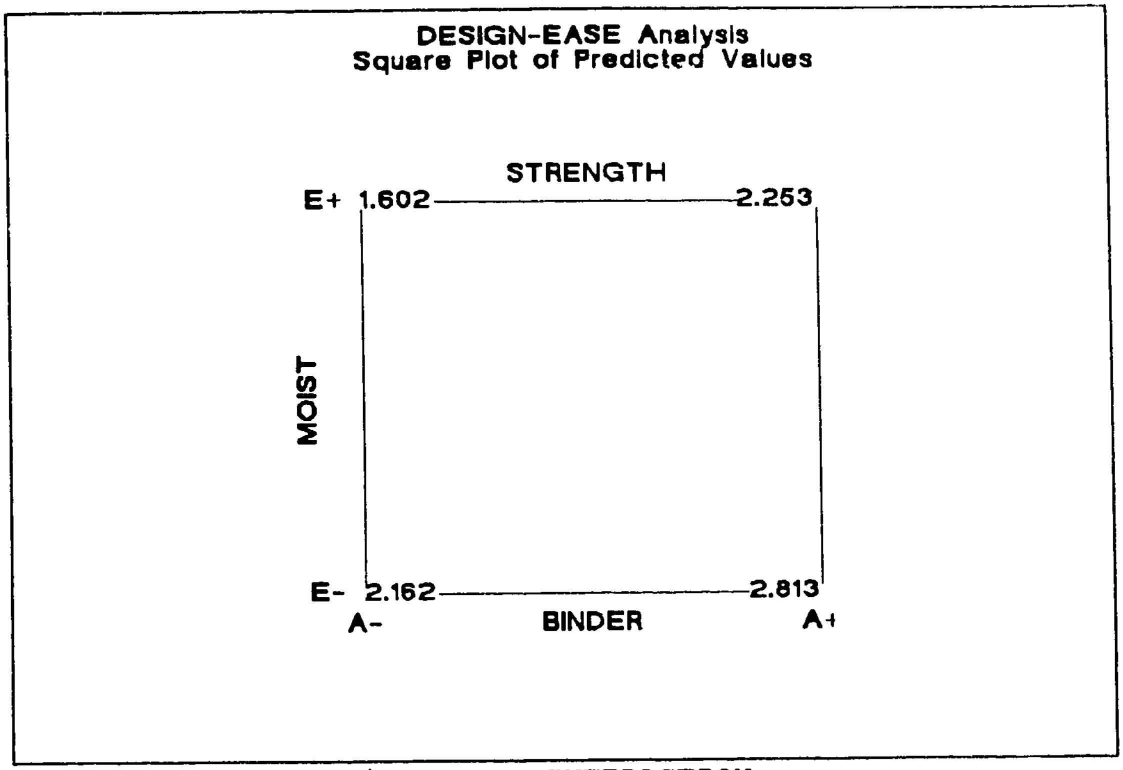

FIGURE #24: BINDER/MOISTURE INTERACTION

Figure #24 shows a square plot of the predicted values for the two-way interaction between **total binder and aggregate moisture.**

The maximum difference occurring between A-,E+ and A+,E-

= 2.813 MPa - 1.602 MPa = 1.211 MPa

The compressive strength is at the lowest when the total binder is at its low setting and aggregate moisture is at its high setting and vice versa.

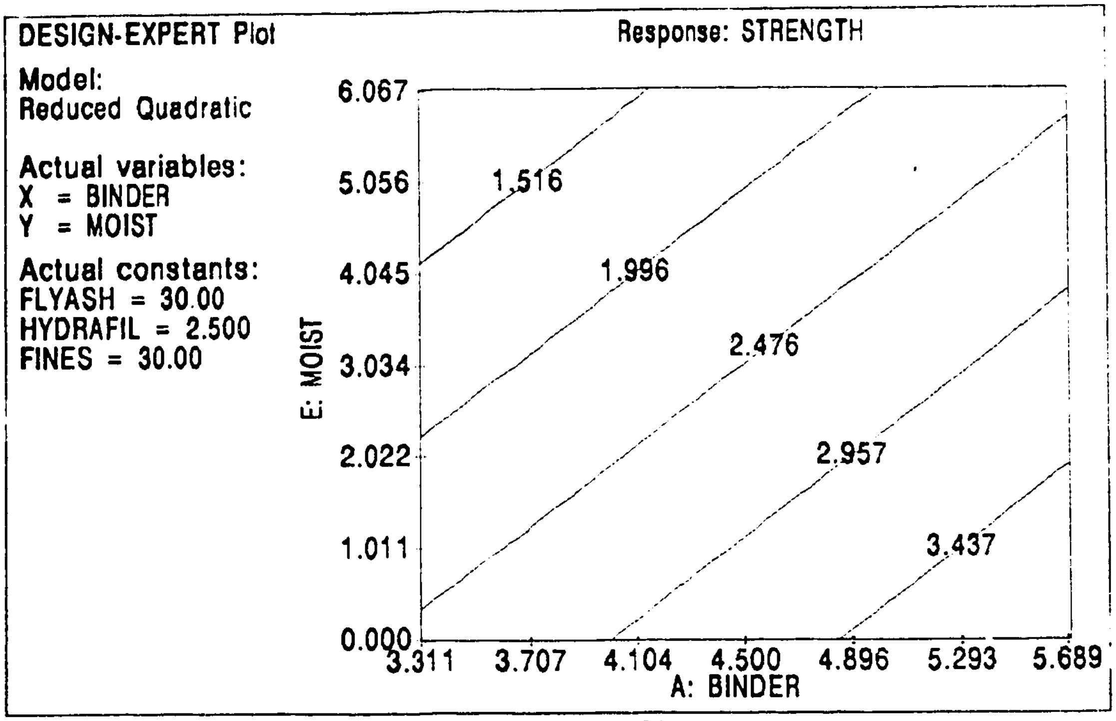

FIGURE #25: BINDER/MOISTURE CONTOURS

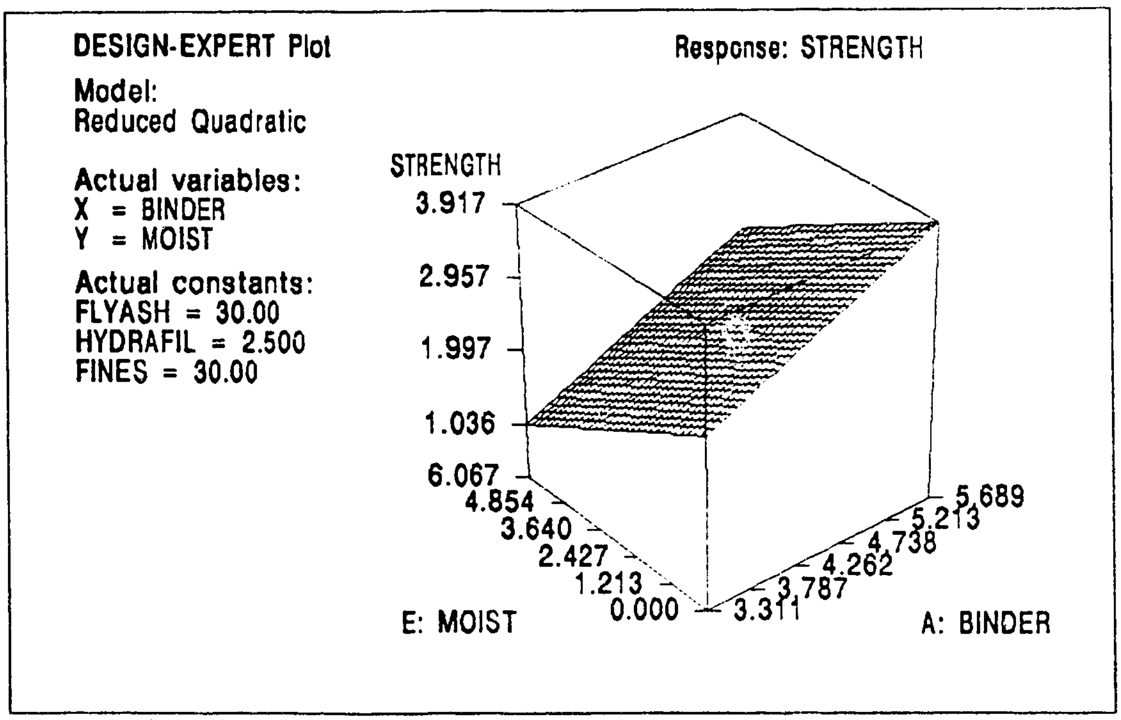

FIGURE #26: BINDER/MOISTURE 3-D SURFACE

Figures #25 and #26 show the two-way linear plots (2-D and 3-D plots). The contours in Figure 25 show lines of equal strength. As the percentage of moisture increases, the compressive strength decreases. Additional total binder is required to maintain the same compressive strength.

Excess water is a problem for several reasons in an underground environment (rust, tire-wear, roadbed degradation and cemented rockfill weakening). However, excess water is very difficult to eliminate.

SHAND FLYASH versus HYDRAFIL

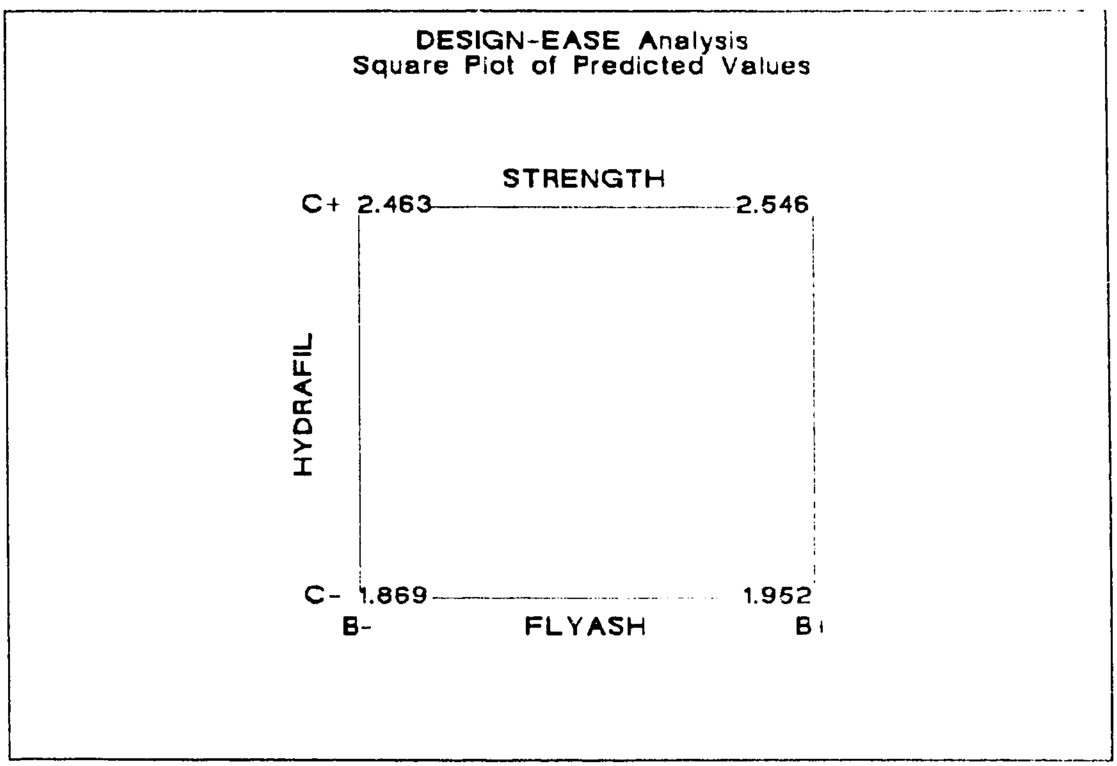

FIGURE #27: FLYASH/HYDRAFIL INTERACTION

Figure #27 shows a square plot of the predicted values for the two-way interaction between **Shand flyash** and **Hydrafil**.

The maximum difference occurring between B ,C and B',C'

= 2.546 MPa - 1.869 MPa = 0.677 MPa

The compressive strength is at the lowest when the Shand flyash percentage and amount of Hydrafil are both at their low settings and at the highest when the Shand flyash percentage and amount of Hydrafil are at their high settings. **Figures #28 and #29** show the two-way quadratic plots (2-D and 3-D plots). The contours **gure #28** show lines of equal strength.

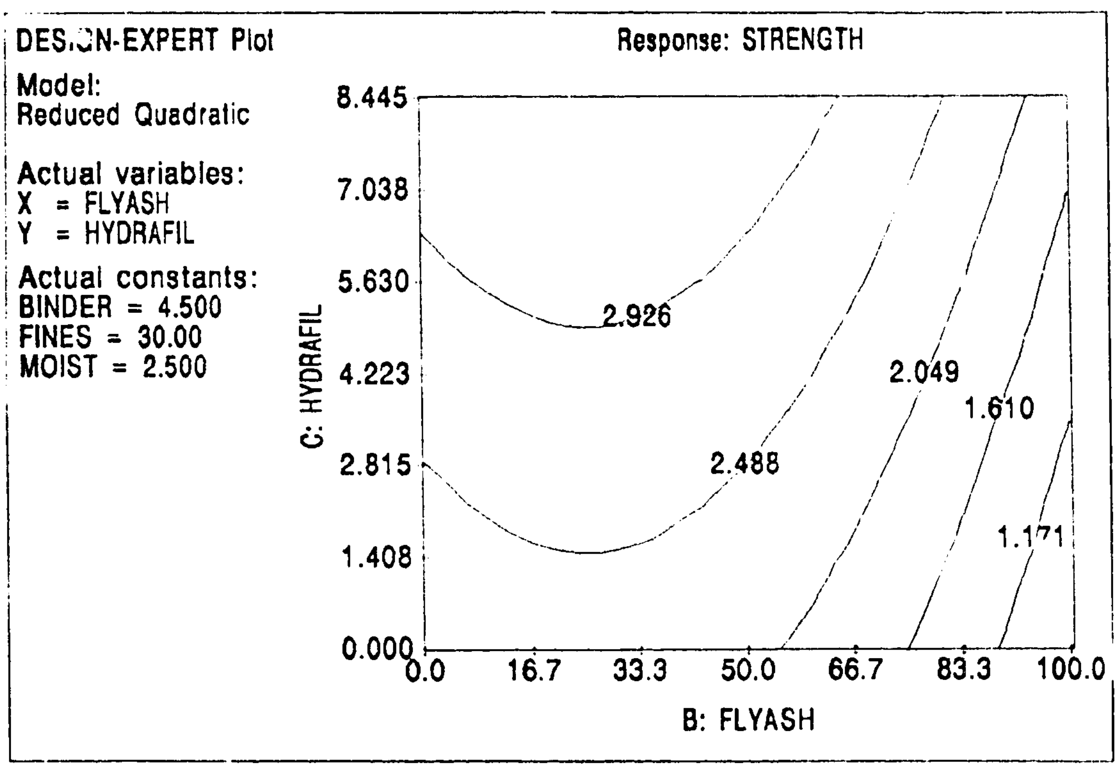

FIGURE #28: FLYASH/HYDRAFIL CONTOURS

The change in the trend-line occurs at approximately 25 percent flyash. At low percentages of Shand flyash (between 0-25 percent), as the flyash percentage is increased,

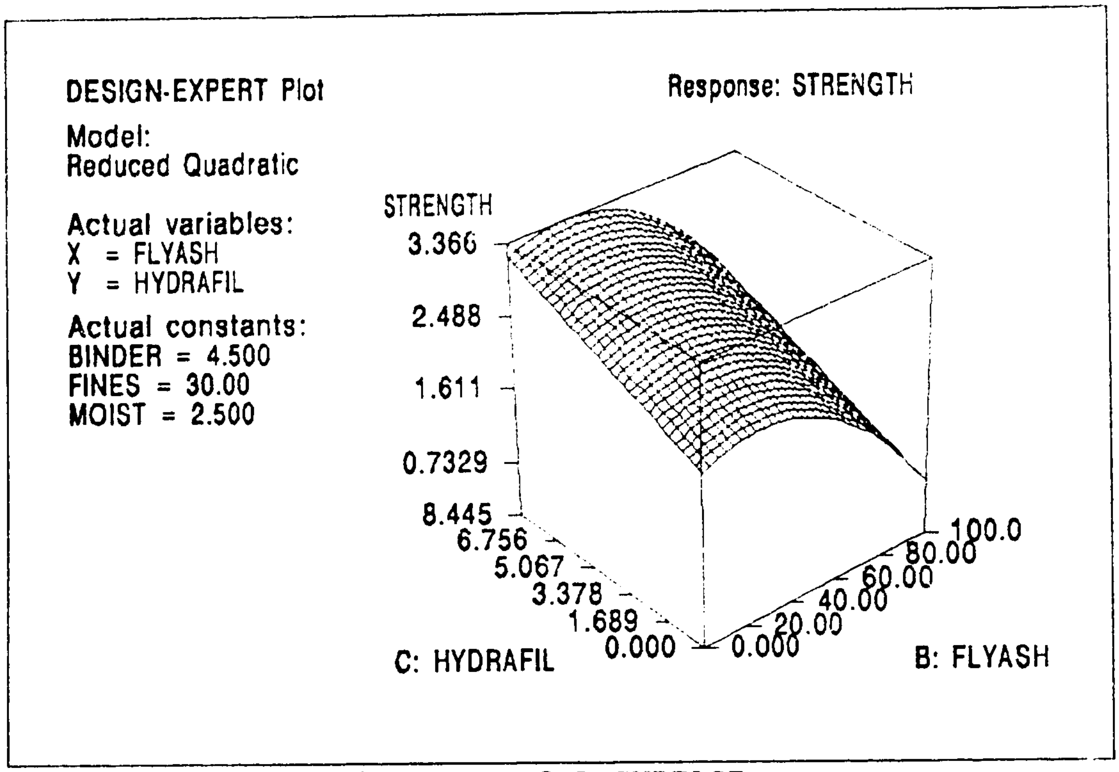

FIGURE #29: FLYASH/HYDRAFIL 3-D SURFACE

less Hydrafil is required to maintain the same strength. However, at higher percentages of Shand flyash (greater than 25 percent), an increase in flyash will require additional Hydrafil if the same strength is to be maintained. At high flyash percentages (greater than 60 percent), the contour lines become steeper, indicating less of an effect as the Hydrafil is increased (note: if the contour lines were vertical, there would be no change in strength as the Hydrafil was increased).

SHAND FLYASH versus AGGREGATE FINES

Figure #30 shows a square plot of the predicted values

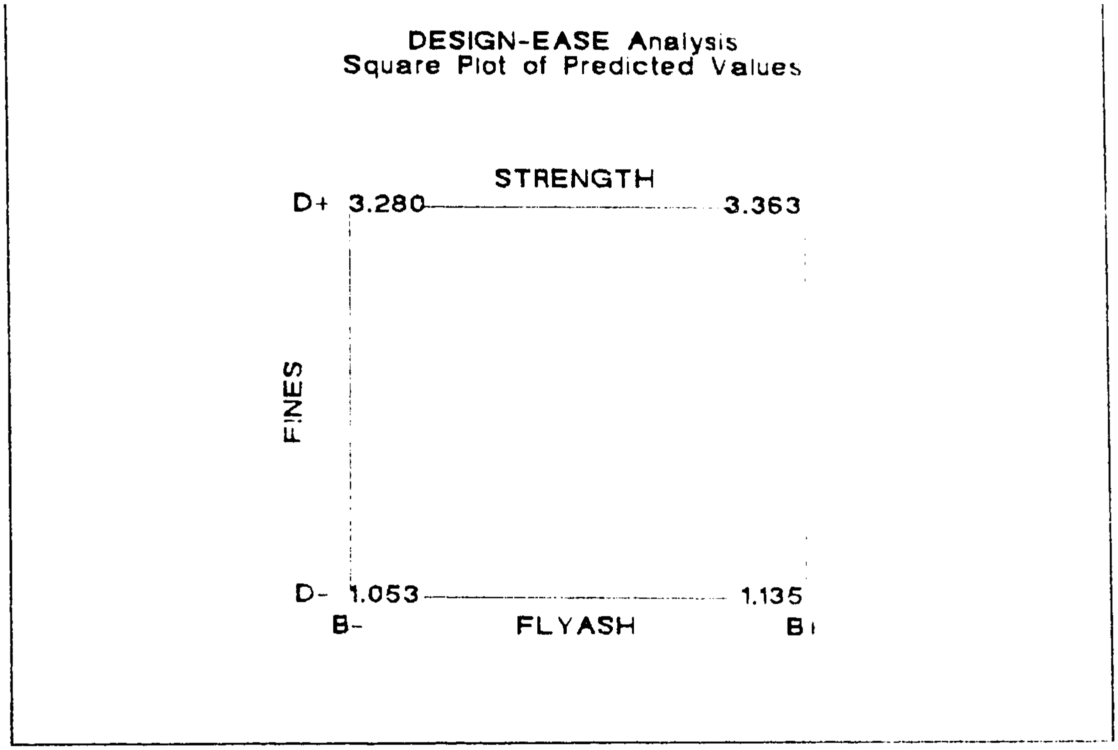

FIGURE #30: FLYASH/FINES INTERACTION

for the two way interaction between Shand flyash and aggregate fines.

The maximum difference occurring between B ,D and B+,D+

3.363 MPa - 1.053 MPa = 2.310 MPa

The compressive strength is at the lowest when the Shand flyash percentage and percentage of aggregate fines are both at their low settings and at the highest when the Shand flyash and aggregate fines percentages are at their high settings.

Figures #31 and #32 show the two-way quadratic plots (2 D and 3-D plots). The contours in **Figure #31** show lines of equal strength. The change in trend-line occurs between approximately 30-40 percent fines. For aggregate fines

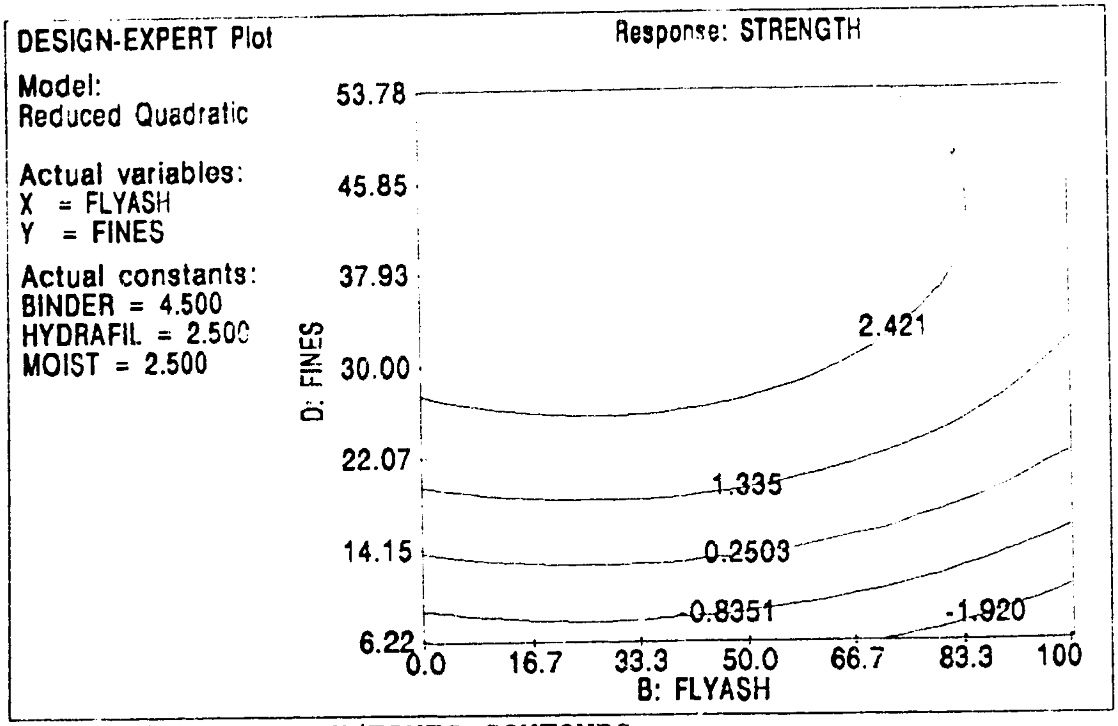

FIGURE #31: FLYASH/FINES CONTOURS

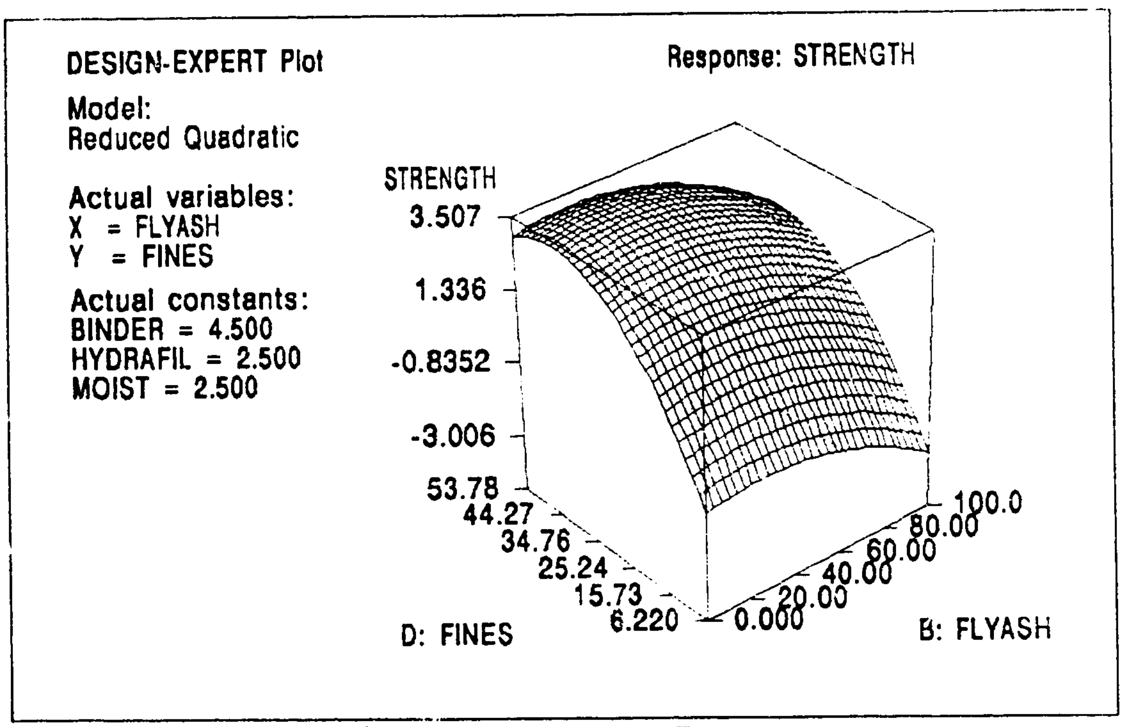

FIGURE #32: FLYASH/FINES 3-D SURFACE

percentages between 0 and 30 percent, altering the percentage of Shand flyash from 0 to 50 percent, has a minimal affect on the compressive strength. For flyash percentages above 50 percent, the fines percentage must be increased to maintain the same compressive strength.

SHAND FLYASH versus AGGREGATE MOISTURE

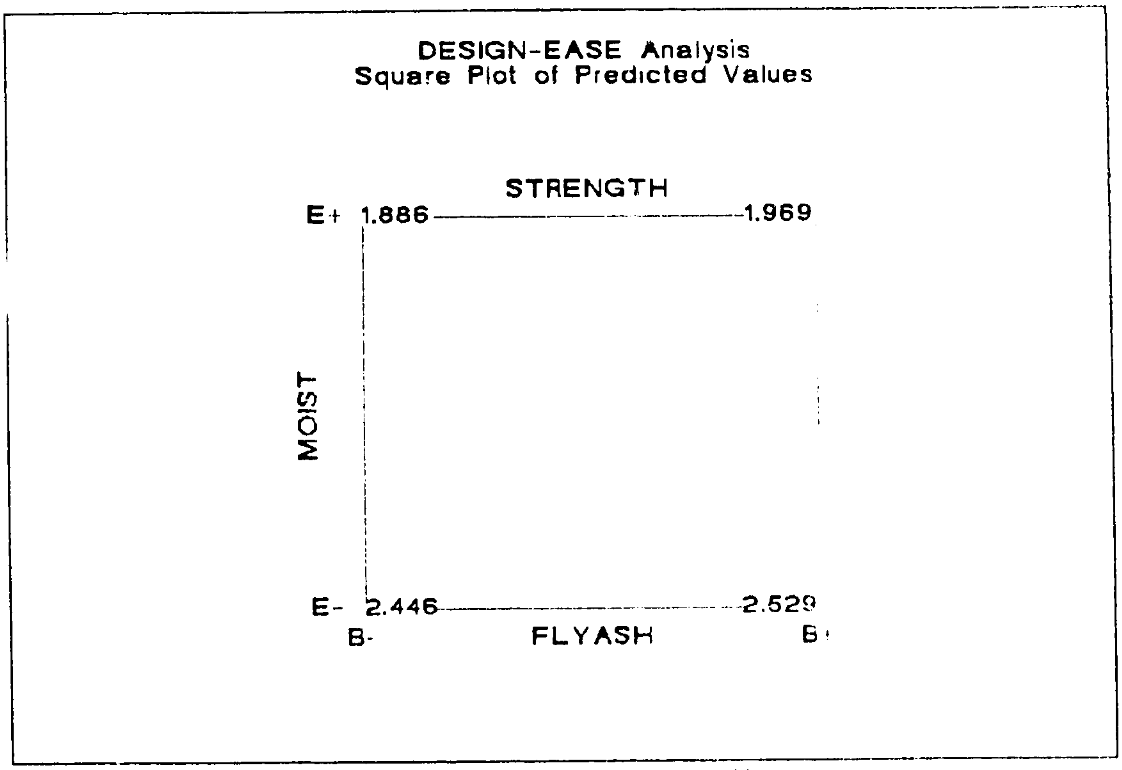

FIGURE #33: FLYASH/MOISTURE INTERACTION

Figure #33 shows a square plot of the predicted values for the two-way interaction between **Shand flyash and aggregate moisture.**

The maximum difference occurring between B-,E+ and B+,E-

= 2.529 MPa - 1.886 MPa = <u>0.643 MPa</u>

The compressive strength is at the lowest when the Shand flyash percentage is at its low setting and the percentage of

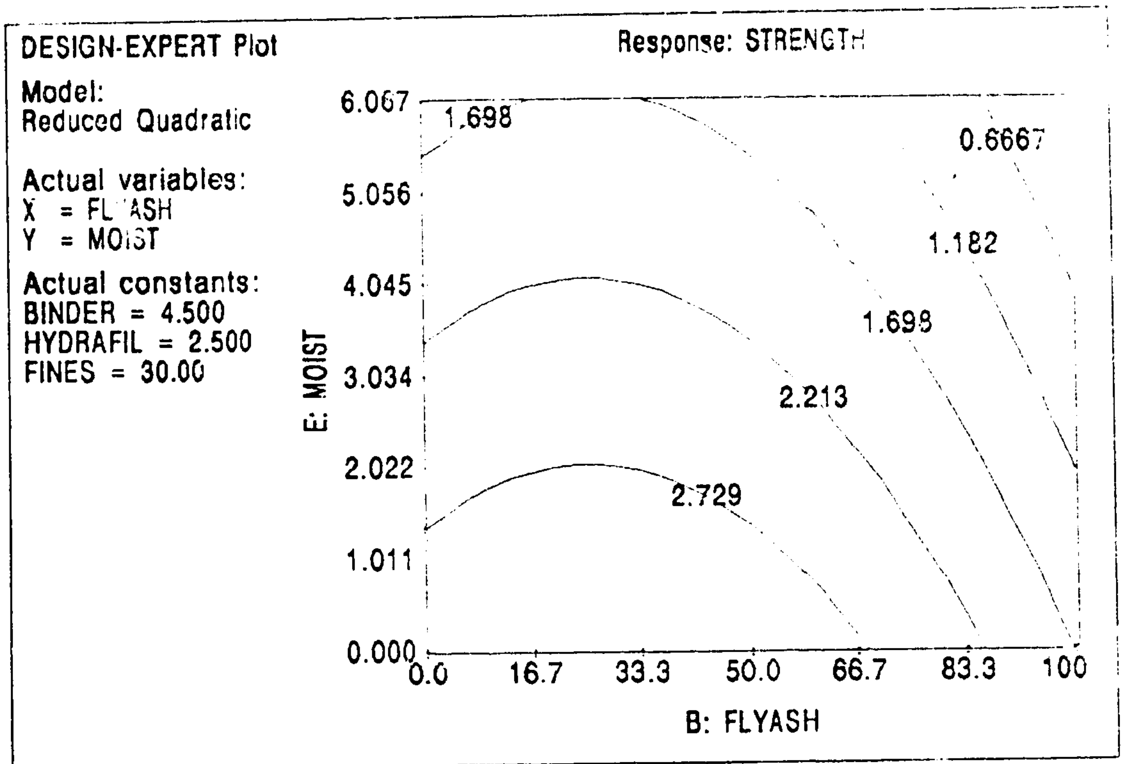

FIGURE #34: FLYASH/MOISTURE CONTOURS

aggregate moisture is at its high settings and vice versa.

Figures #34 and #35 show the quadratic two-way plots (2-D and 3-D plots). The contours in **Figure #34** show lines of equal strength. The change in trend-line occurs at approximately 30 percent flyash. For flyash percentages between 0 and 30 percent, the contour lines slope positively (uphill). As the moisture is increased, additional flyash is required to remain on the same strength contour. However, for flyash percentages above 30 percent, there is a negative slope (downhill). An increase in flyash will require a reduction in aggregate

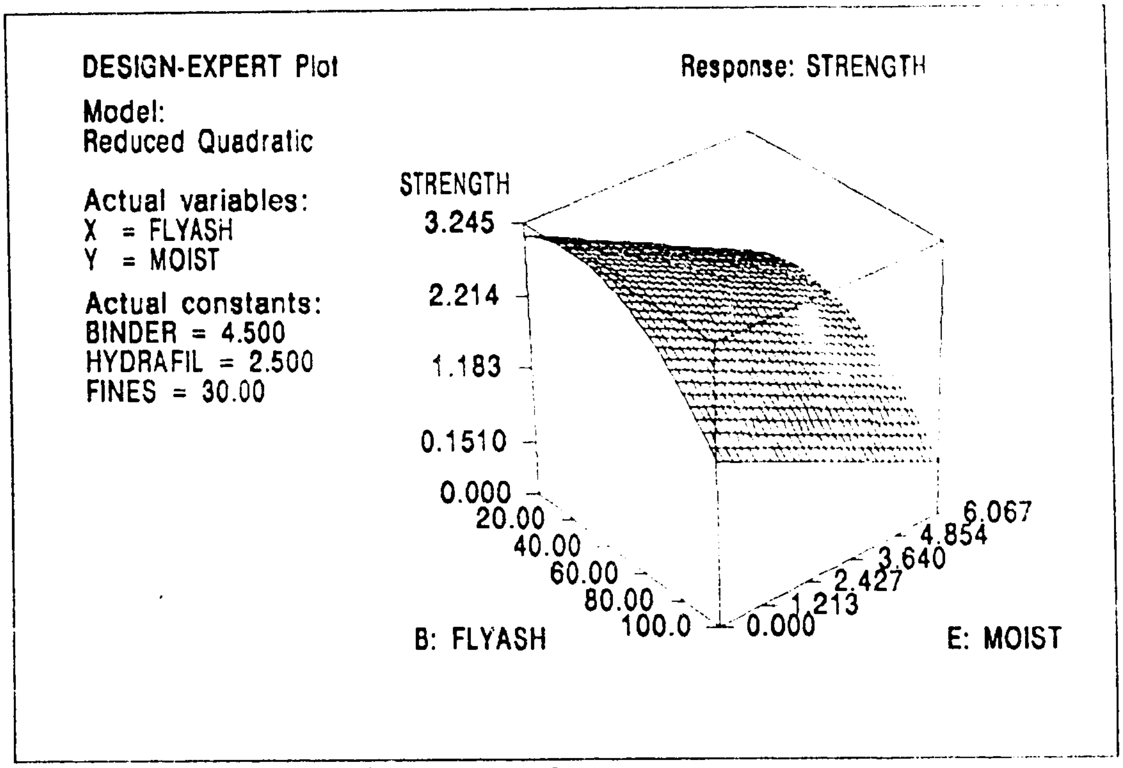

FIGURE #35: FLYASH/MOISTURE 3-D SURFACE

moisture to maintain the same strength.

As the percentage of flyash is increased above 30 percent, while the moisture percentage is held constant, the compressive strength is decreased (the strength drops dramatically at high percentages of flyash).

HYDRAFIL versus AGGREGATE FINES

Figure #36 shows a square plot of the predicted values for the two-way interaction between Hydrafil and aggregate fines.

The maximum difference occurring between C-,D- and C+,D+

= 3.859 MPa - 1.038 MPa = 2.821 MPa

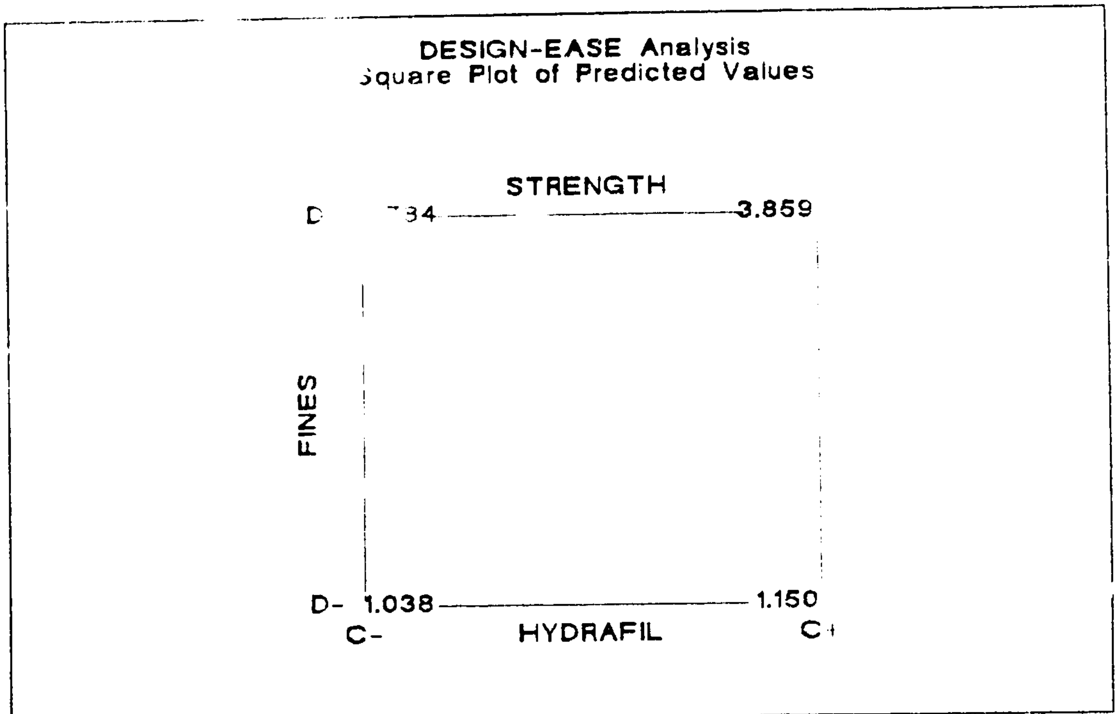

FIGURE #36: HYDRAFIL/FINES INTERACTION

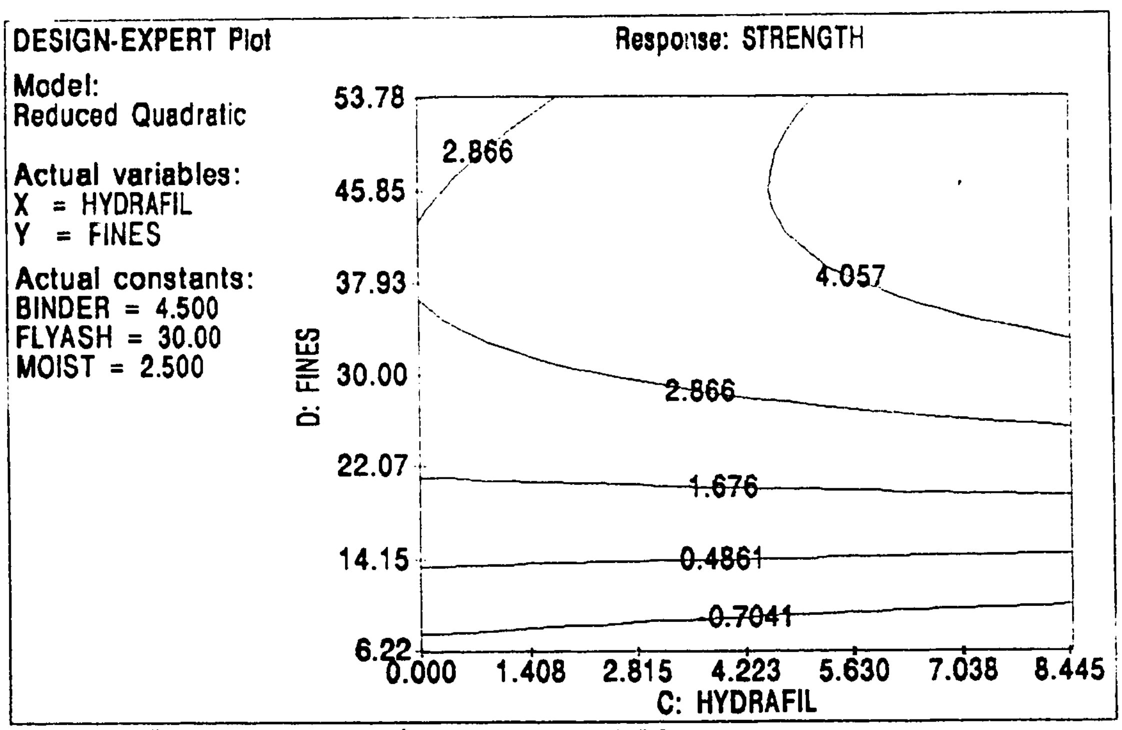

FIGURE #37: HYDRAFIL/FINES CONTOURS

The compressive strength is at the lowest when the amount of Hydrafil and percentage of aggregate fines are both at their low settings and vice versa.

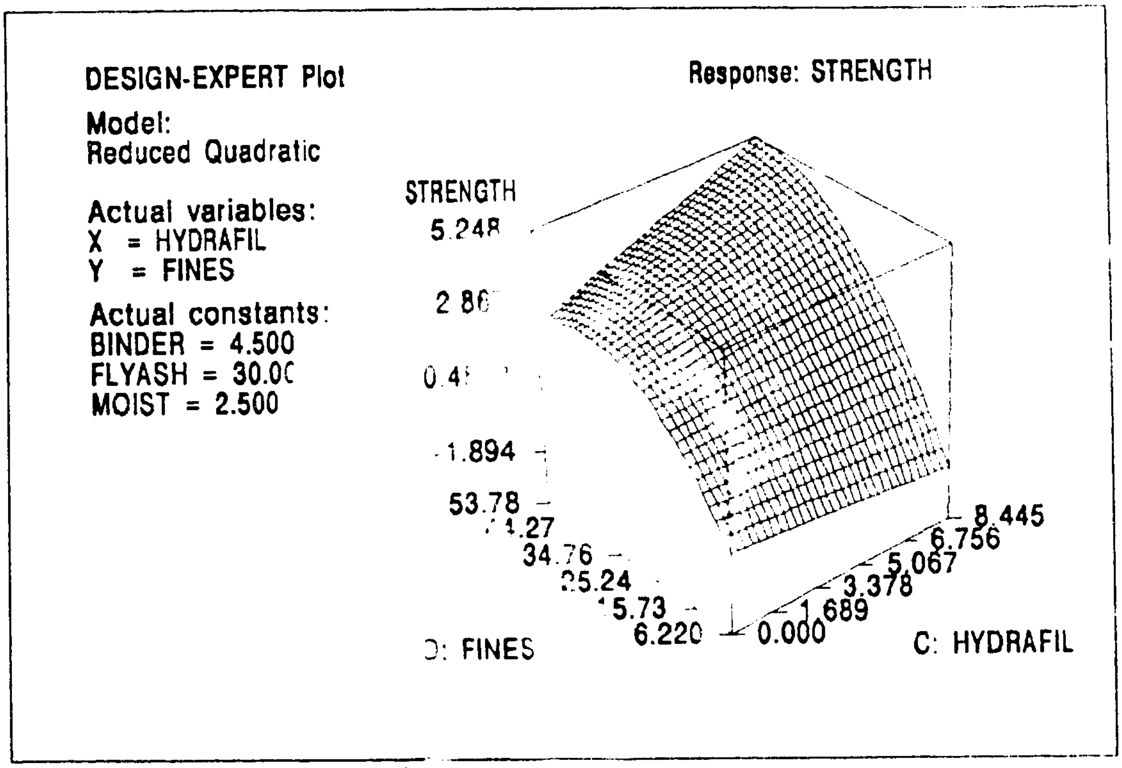

FIGURE #38: HYDRAFIL/FINES 3 D SURFACE

Figures #37 and #38 show the quadratic two-way plots (2-D and 3-D plots). The contours in **Figure #37** show lines of equal strength. At low fines percentages, increasing the Hydrafil has an insignificant affect on the compressive strength. The effect of adding Hydrafil becomes slightly more effective at higher fines percentages (above 30 percent fines). The change in trend-line occurs at approximately 40 percent fines. Hydrafil is a cement dispersant and therefore disperses the cement particles within the slurry. When the cement particles are evenly dispersed within the slurry, less slurry is required to effectively coat the aggregate material. Therefore, at high fines percentages, Hydrafil is an excellent strengthener. Note, this is an inexpensive means of increasing the compressive strength.

HYDRAFIL versus AGGREGATE MOISTURE

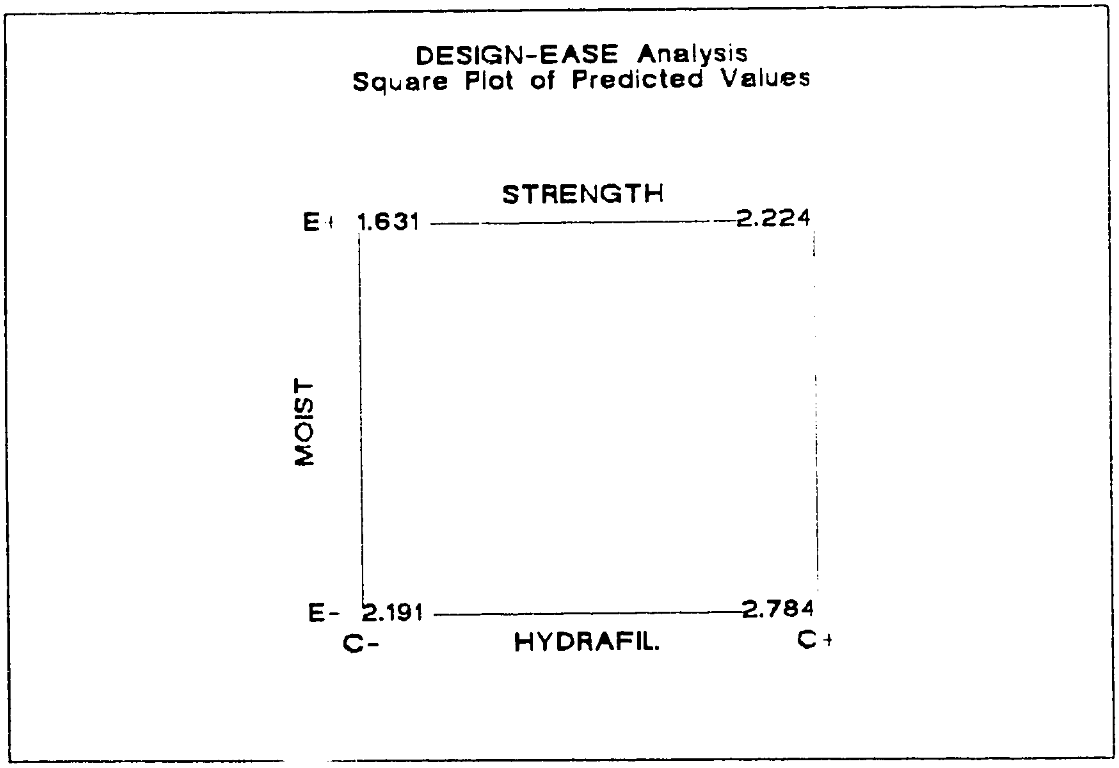

FIGURE #39: HYDRAFIL/MOISTURE INTERACTION

Figure #39 shows a square plot of the predicted values for the two-way interaction between **Hydrafil and aggregate moisture.**

The maximum difference occurring between C-,E+ and C+,E- = 2.784 MPa - 1.631 MPa = 1.153 MPa

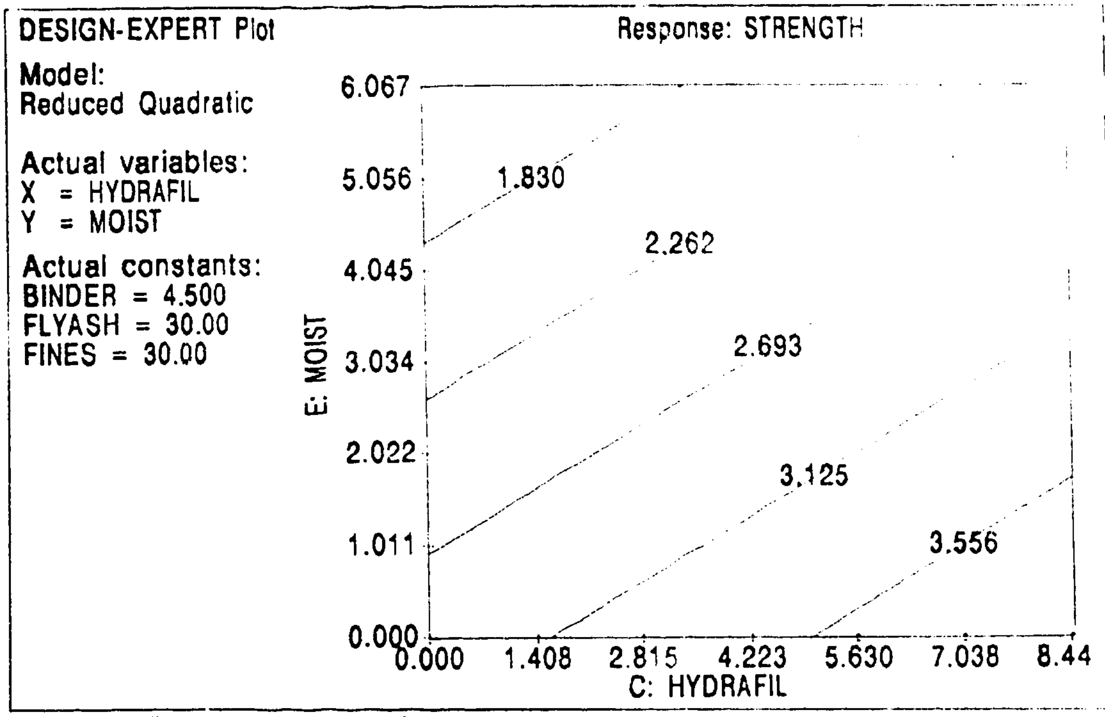

FIGURE #40: HYDRAFIL/MOISTURE CONTOURS

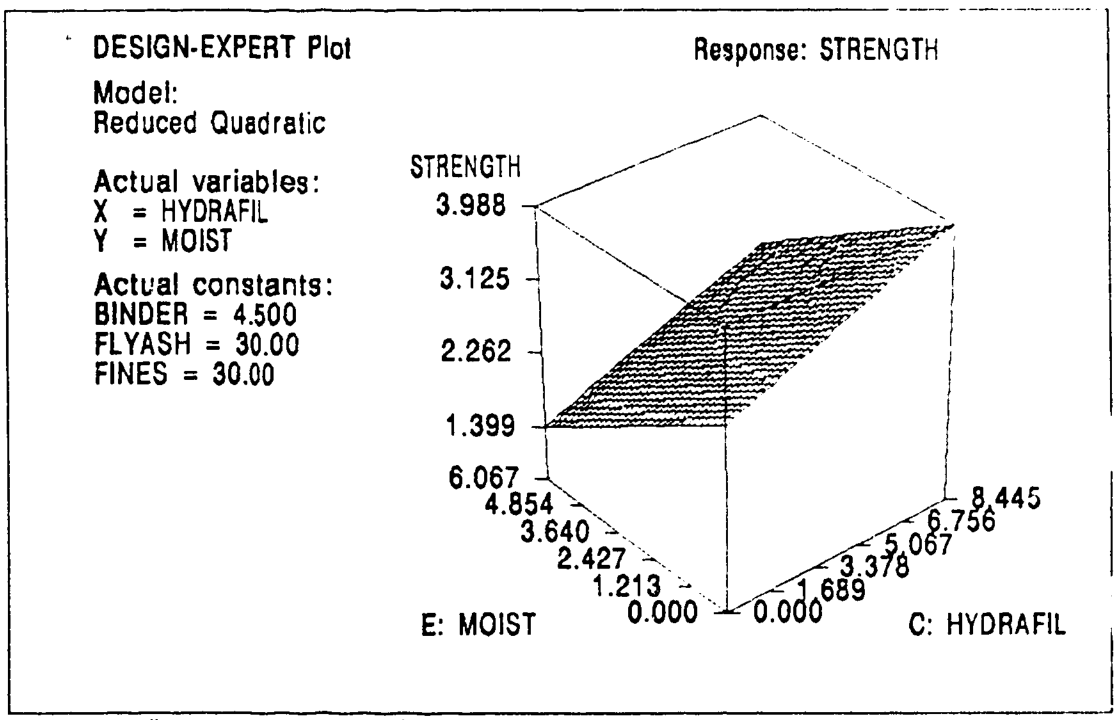

FIGURE #41: HYDRAFIL/MOISTURE 3-D SURFACE

The compressive strength is at the lowest when the amount of Hydrafil is at its low setting and the percentage of aggregate moisture is at its high setting and vice versa.

Figures #40 and #41 show the two-way linear plots (2-D and 3-D plots). The contours in **Figure #40** show lines of equal strength. The plots show a very linear relationship (the contour lines are parallel and evenly spaced, showing no dramatic trend changes). As the moisture content is increased, the amount of Hydrafil must also be increased if the same strength is desired.

AGGREGATE FINES versus AGGREGATE MOISTURE

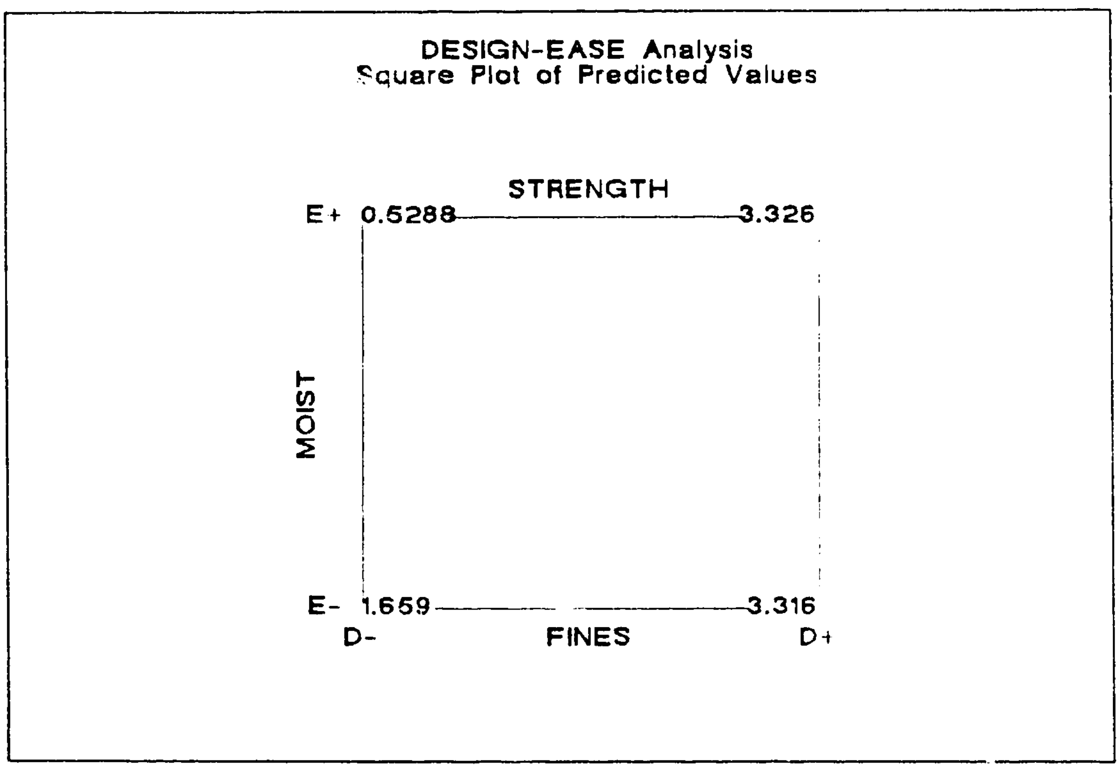

FIGURE #42: FINES/MOISTURE INTERACTION

Figure #42 shows a square plot of the predicted values for the two-way interaction between **aggregate fines** and **aggregate moisture.**

The maximum difference occurring between D-,E+ and D+,E-

= 3.316 MPa - 0.5288 MPa = <u>2.787 MPa</u>

The compressive strength is at the lowest when the percentage of aggregate fines is at its low setting and the percentage of aggregate moisture is at its high setting and vice versa.

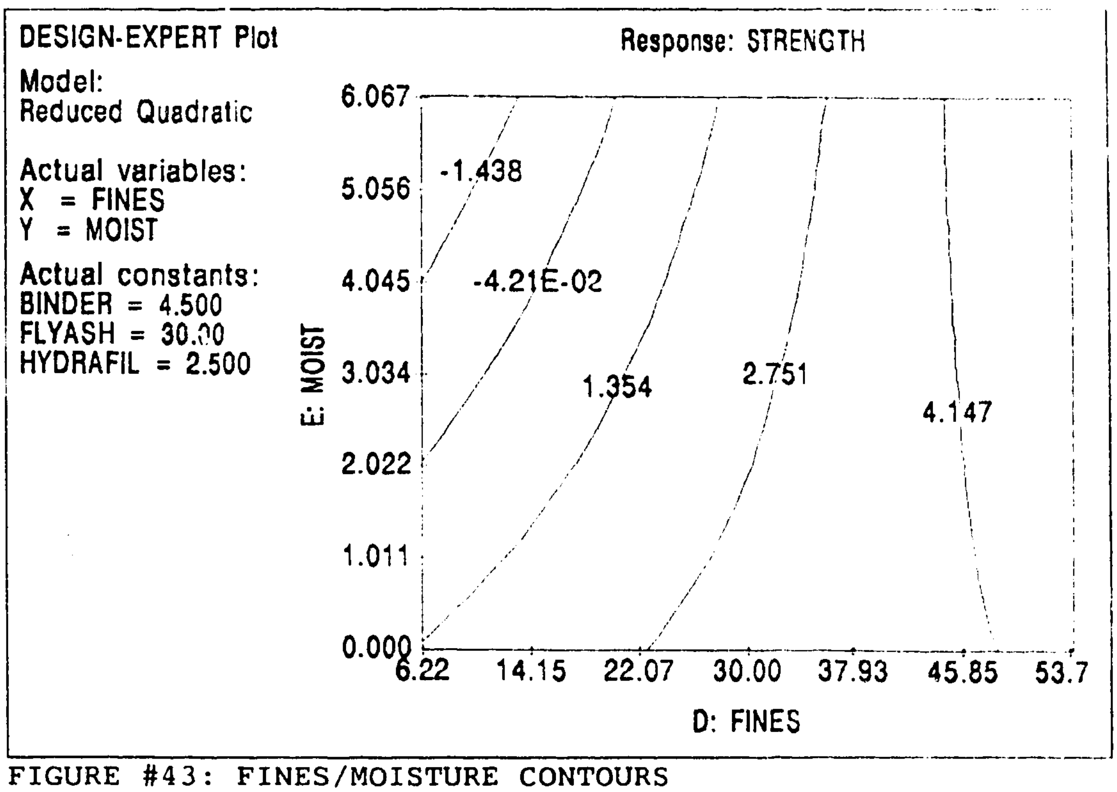

FIGURE #43: FINES/MOISTURE CONTOURS

Figures #43 and #44 show the quadratic two-way plots (2-D and 3-D plots). The contours in **Figure #43** show lines of equal strength. NOTE: The plots show a negative compressive strength

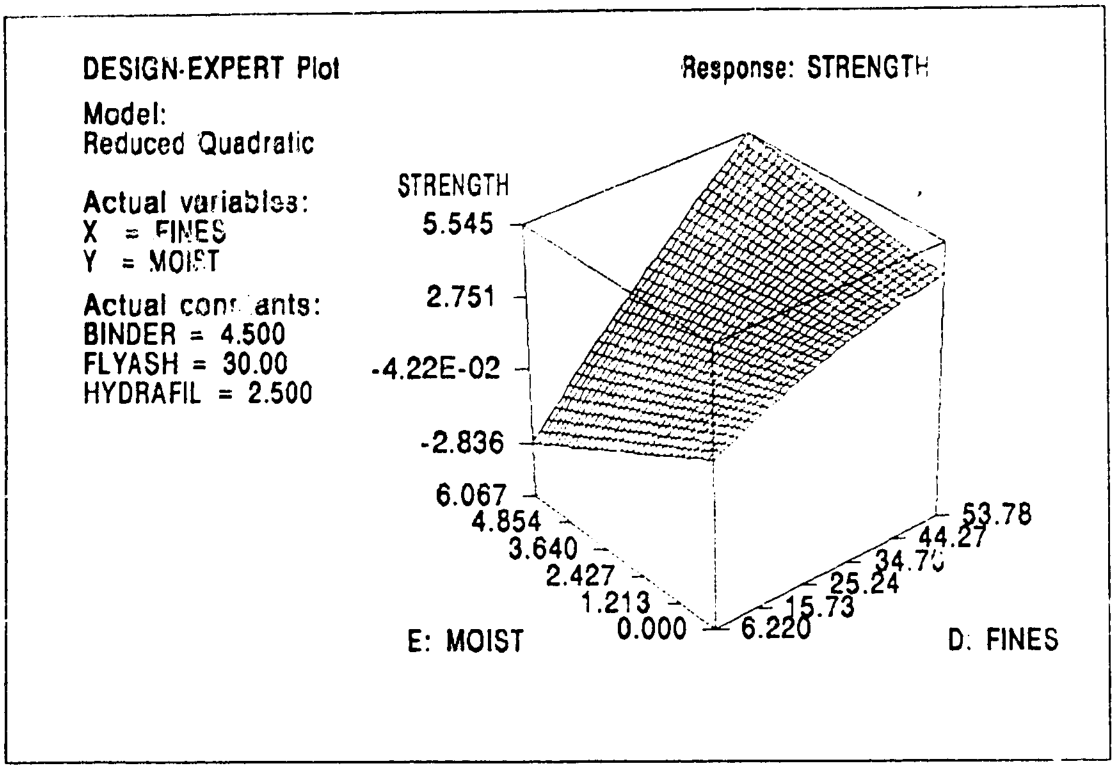

FIGURE #44: FINES/MOISTURE 3-D SURFACE

at low fines/high moisture percentages ... this is obviously not possible (strengths of zero MPa are the lowest strengths possible).

The change in trend-line occurs at approximately 30-40 percent fines. At low fines percentages, an increase in moisture results in a loss of compressive strength, but at high fines percentages (above 30 percent fines), an increase in moisture will not decrease the compressive strength. In fact, at very high fines percentages (above 45 percent), an increase in moisture will actually "**increase**" the compressive strength (this is probably due to the fact that more water is needed to properly coat the increased aggregate surface area).

SUMMARY OF TWO-WAY INTERACTION EFFECTS

Table #8 summarizes the "maximum differences" calculated in this section. The table is sorted from highest to lowest "maximum difference".

TABLE #8: SUMMARY OF TWO-WAY INTERACTION EFFECTS

TWO-WAY INTERACTIONS	"MAX DIFFERENCE" (MPa)
AD	2.878
CD	2.821
DE	2.787
BD	2.310
AC	1.245
AE	1.211
CE	1.153
AB	0.733
BC	0.677
BE	0.643

The largest differences contained "D" (the aggregate fines percentage). The aggregate fines single factor effect was very large and therefore greatly influenced the two way interaction effects. Similarly, two-way interaction effects containing "B" (Shand flyash percentage) had the smallest differences (the Shand flyash single factor effect was very small).

10.6 THREE-WAY INTERACTION EFFECTS:

A <u>three-way interaction effect</u> is "the average difference in the interaction effect between the first and second factor when the third factor is at its high level and the interaction effect between the first and second factor when the third factor is at its low level.

Describing the foll ing "cube plots" is very difficult (they are easier to under tand by visual inspection). Therefore, the plots will be displayed, but few comments will be added.

NOTE: Three-way interactions are usually quite insignificant (Mular, 1990), and are therefore seldom used in estimation equations (unless proven to be significant). NOTE: The three-way interaction effects from our tests were proven to be insignificant (less than a 95 percent confidence value and were not used in the strength estimation equations). The three-way interaction between Shand flyash/Hydrafil/Moisture had a 68 percent confidence value (the highest of all the three-way interactions, but not significant for our estimation equation). **Appendix #3** shows a list of all of the effects generated during the tests.

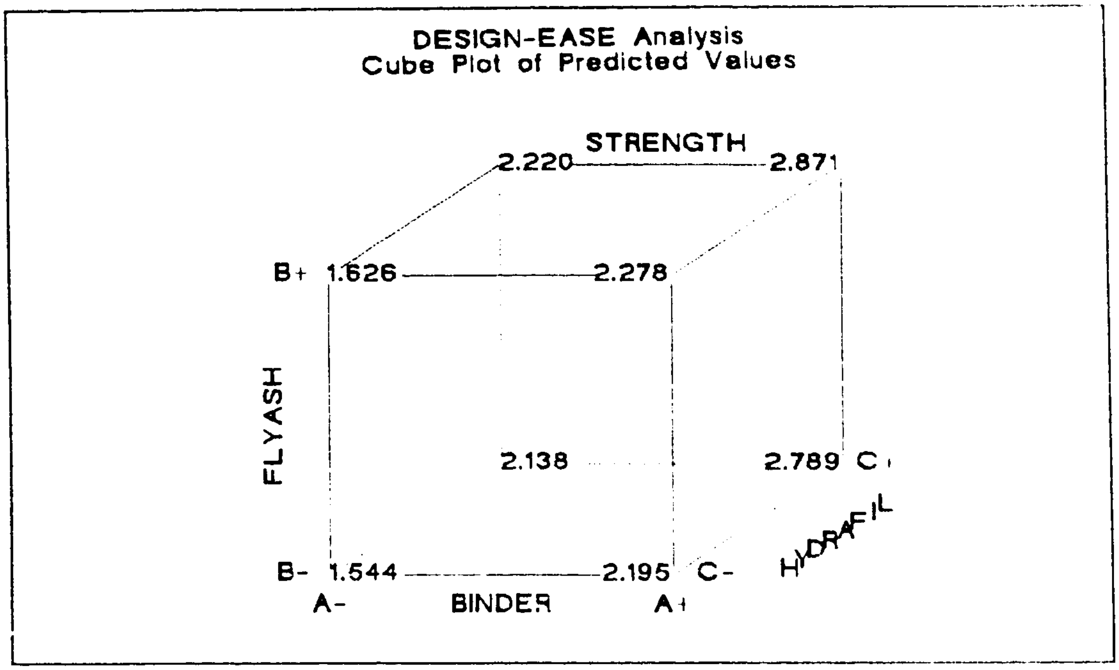

FIGURE #45: BINDER/FLYASH/HYDRAFIL

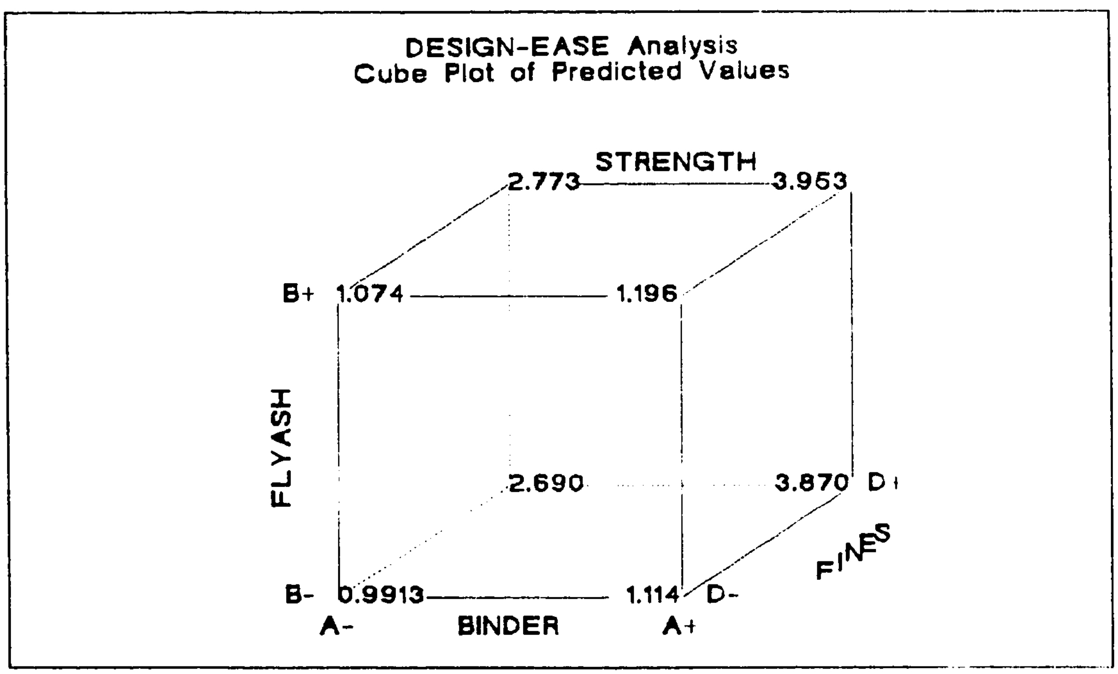

FIGURE #46: BINDER/FLYASH/FINES

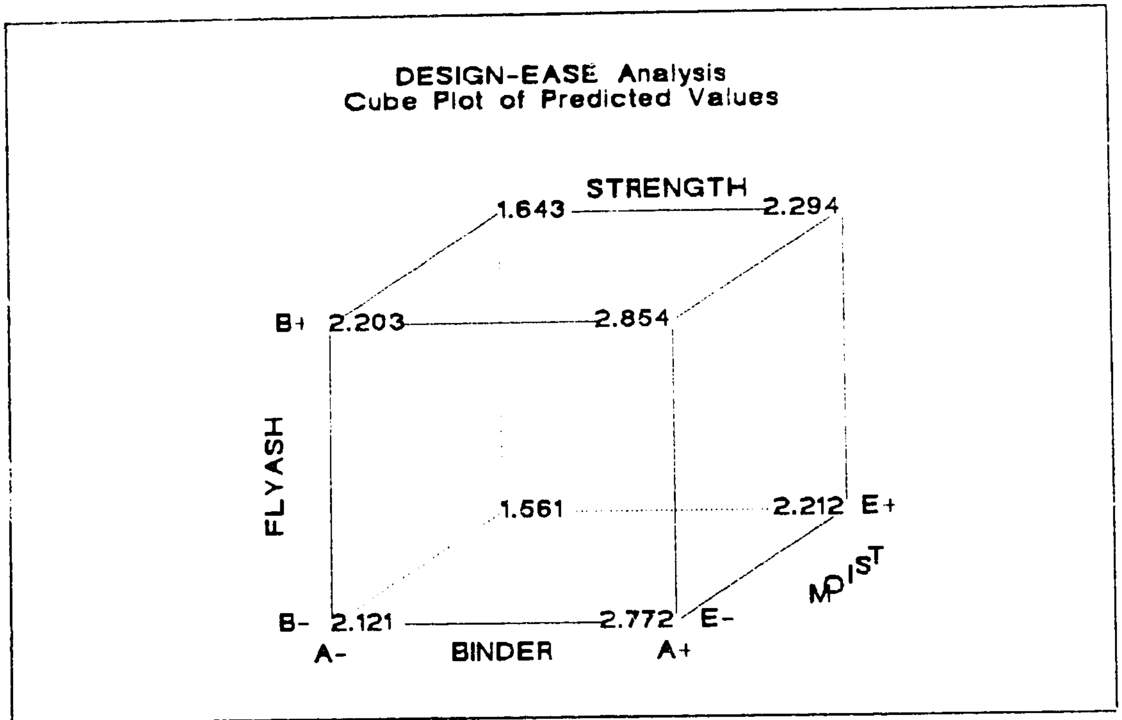

FIGURE #47: BINDER/FLYASH/MOISTURE

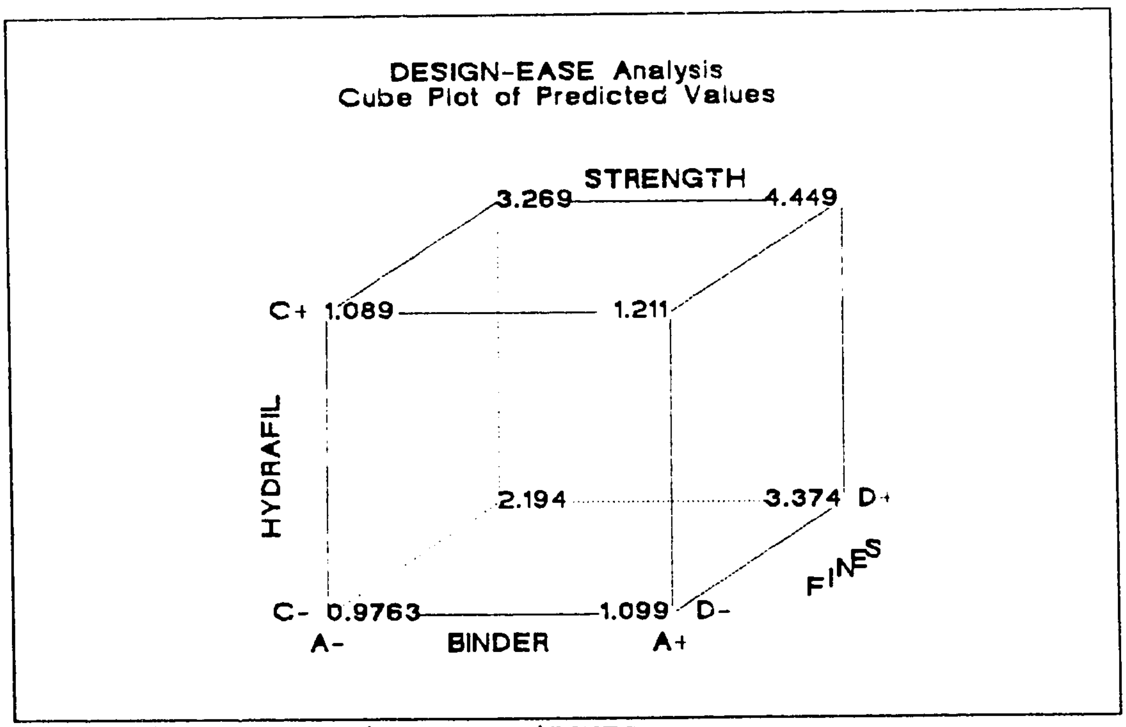

FIGURE #48: BINDER/HYDRAFIL/FINES

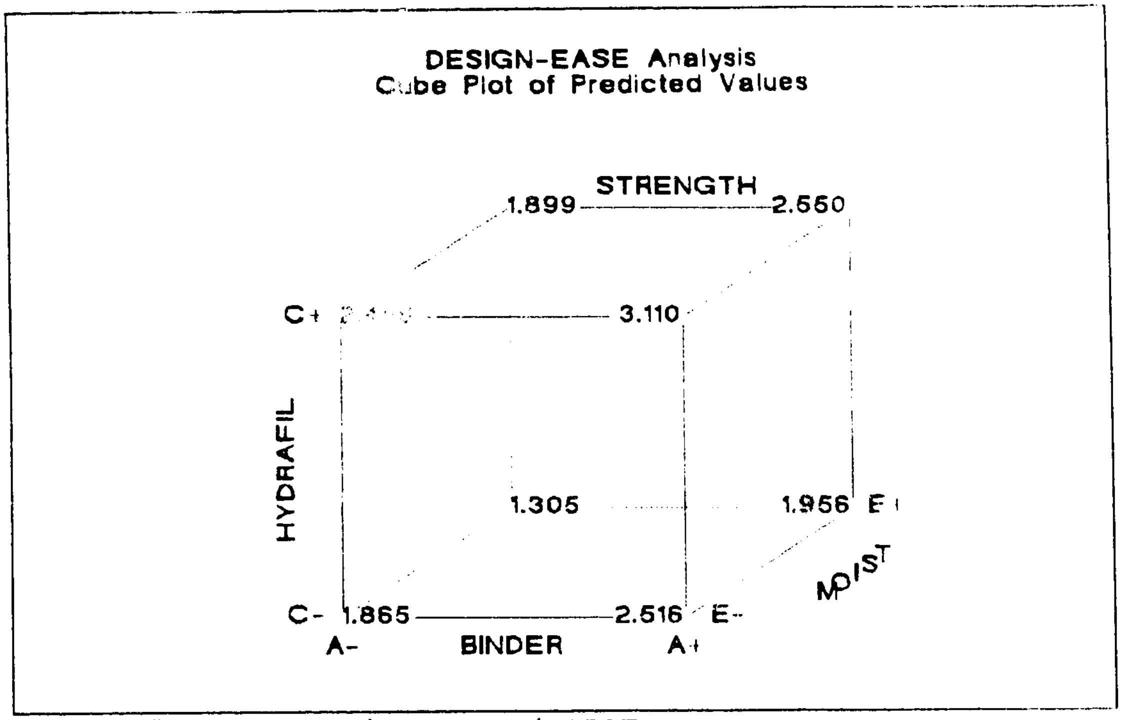

FIGURE #49: BINDER/HYDRAFIL/MOIST

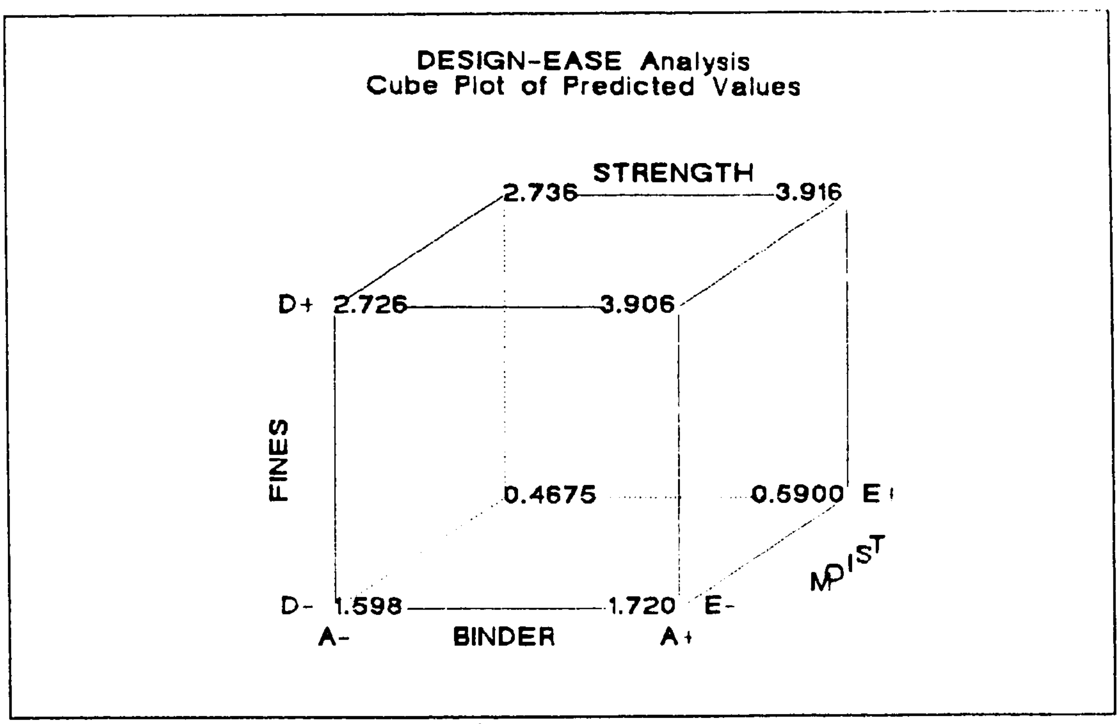

FIGURE #50: BINDER/FINES/MOIST

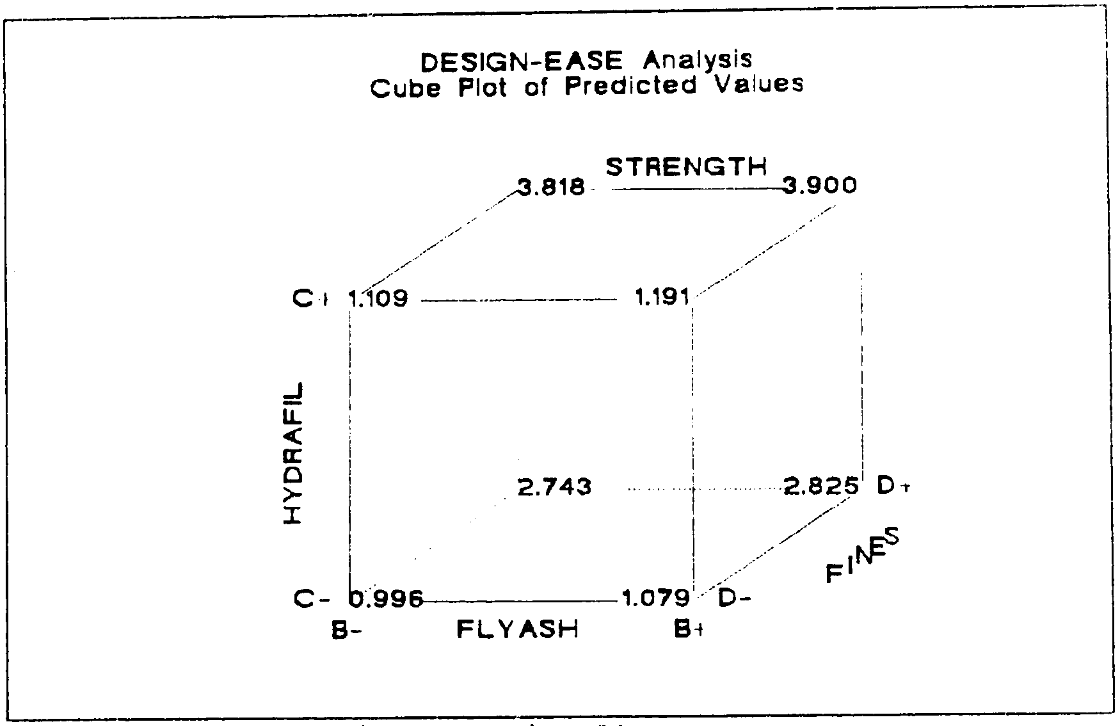

FIGURE #51: FLYASH/HYDRAFIL/FINES

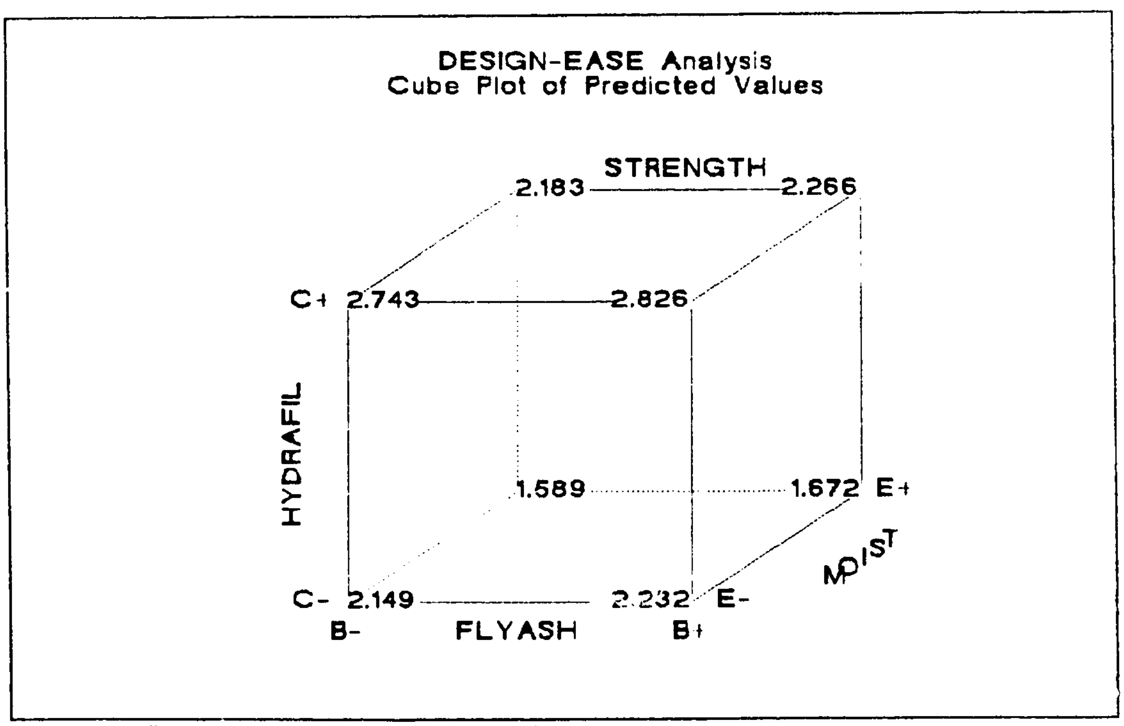

FIGURE #52: FLYASH/HYDRAFIL/MOIST

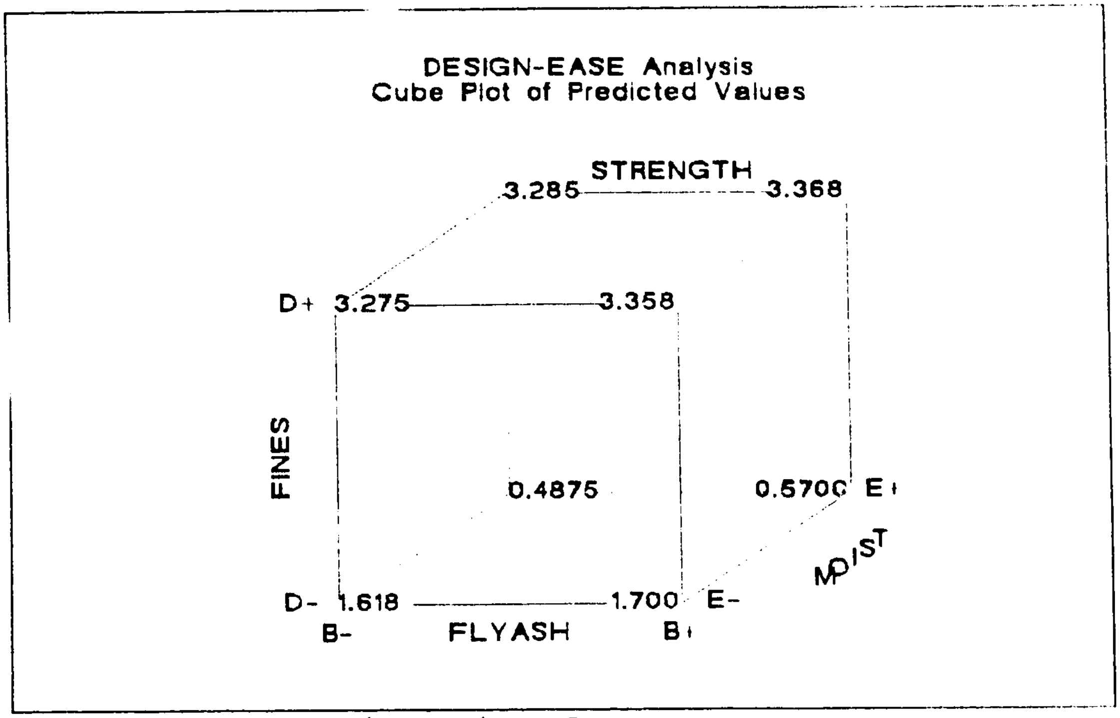

FIGURE #53: FLYASH/FINES/MOIST

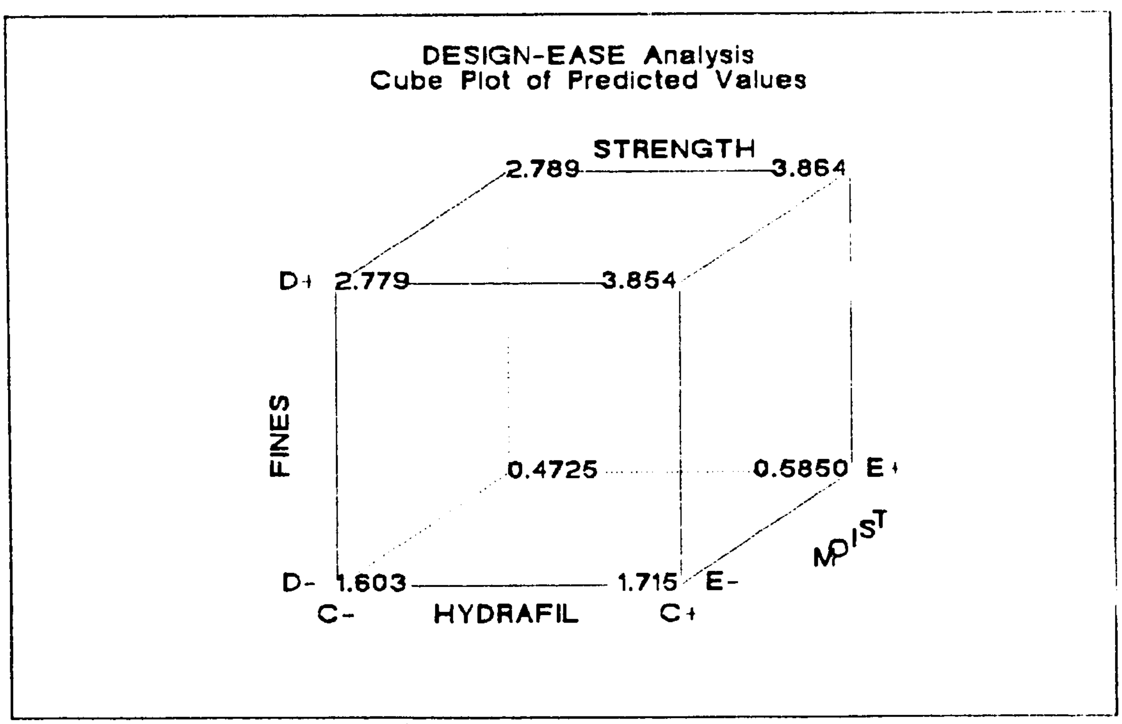

FIGURE #54: HYDRAFIL/FINES/MOIST

TABLE #9: "ORDERED" SUMMARY OF "ALL" ANALYZED EFFECTS

EFFECT NAME	EFFECT VALUE	ORDER NUMBER
D	2.22	1
A	0.65	2
C	0.59	3
DE	0.57	4
E	-0.56	5
AD	0.52	6
CD	0.48	7
BCE	-0.30	8
AB	-0.26	9
BD	0.25	10
CDE	-0.22	11
CE	-0.20	12
ACD	0.18	13
ABE	0.15	14
AE	-0.14	15
ABC	-0.14	16
BCD	-0.11	17
B	0.08	18
AC	0.08	19
BE	0.06	20
ACE	0.05	21
ADE	0.05	22
BC	-0.04	23
ABD	0.02	24
BDE	0.00	25

Table #9 shows the single, two-way and three-way effects. The values have been ordered from highest to lowest effect. The percentage fines single effect is by far the most significant. The single effects "total binder", "Hydrafil" and "moisture" are also very significant (#2, #3 and #5). The "Shand flyash" single effect was surprisingly low on the overall list (#18). Several of the two-way and three-way interaction effects containing "D" (fines) were near the top of the list (highly significant effects). The three-way effects tend to be less significant than the single and two-way effects (the four-way and five-way effects are the least significant and are seldom included in the final model).

11. TEST ADEQUACY

11.1 TEST THE ADEQUACY OF THE FITTED MODEL:

The equations that were derived are in the form:

$$y = a0 + a1x1 + a2x2 + \ldots + a12x1x2 + \ldots + a123x1x2x3 + \ldots + e$$

The "e" term must be carefully examined. It arises because of a) departure of the fitted equation from the actual equation (called lack of fit) and b) "pure error" associated with inherent process fluctuations, disturbances and measuring techniques (Mular, 1990). The term "e" is called the residual, and is assumed to be normally distributed (see **Figure #55** showing Normal % probability versus Residual). The mean of the residuals should be close to zero.

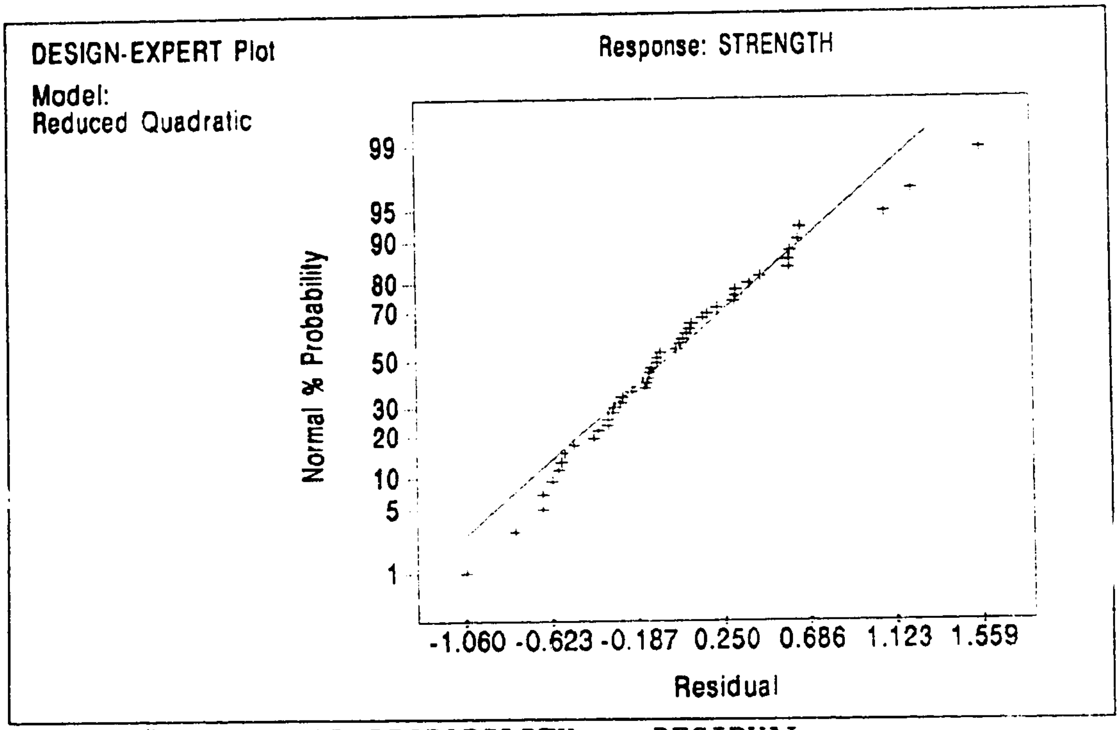

FIGURE #55: NORMAL PROBABILITY vs RESIDUAL

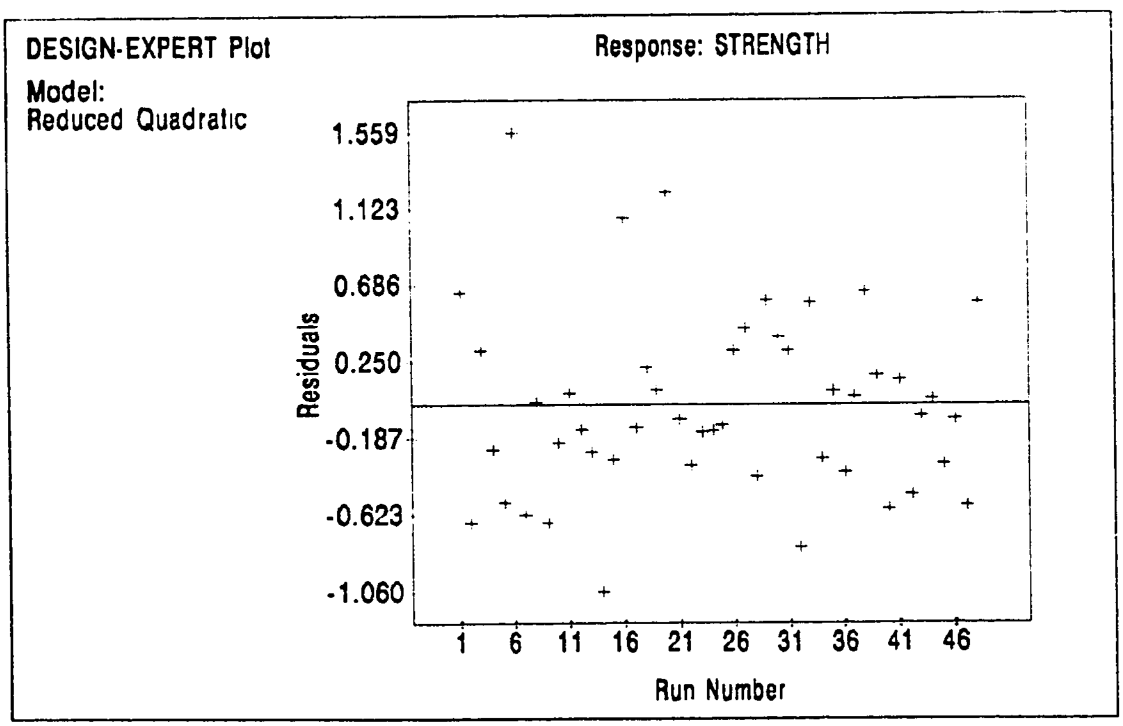

FIGURE #56: TIME SEQUENCE PLOT

The "Time Sequence Plot" shown in Figure #56 illustrates how the residuals fluctuate during the experiment. If the time order of residuals is known (eg. which order the tests were performed), the plot can be constructed. If the plot appears to be a random horizontal band of residuals, the time effect is not affecting the data (Mular, 1990). The horizontal scatter of residuals in **Figure #56** is a classic example of a non-time affected experiment (run number did not affect the results). NOTE: A proper factorial design is set-up so that the run order is totally random. The order in which the rockfill cylinders were prepared was generated by a random number generator.

A plot of the **"Residuals versus Predicted Responses"** is

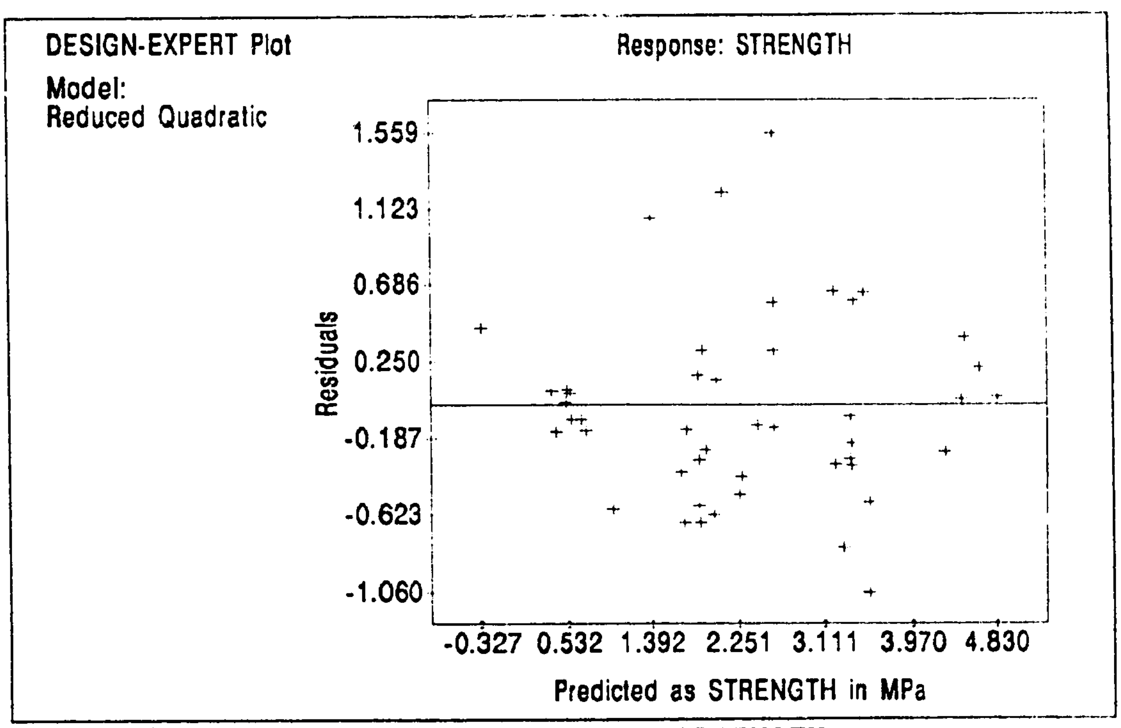

FIGURE #57: RESIDUALS vs PREDICTED STRENGTH

shown in **Figure #57**. If there are no abnormalities, this plot should also show a horizontal "band" of residuals (the majority of our results lie within a horizontal grouping, with some occasional outliers). The sum of the values should equal zero. Plots of the **"Residuals versus Each Factor"** should also show random horizontal grouping. **Figures #58 through Figure #62** illustrate residuals versus the five rockfill factors. Note that each of the five figures show horizontal grouping (with a few possible outliers from the central composite outlier cylinders). Note also that our cylinders were made at three settings: a low setting, a high setting and a mid-point setting (hence the three vertical bands). Two extreme outlier cylinders were purposely made to examine the effects "outside" the experiment. The sum of the values should equal zero.

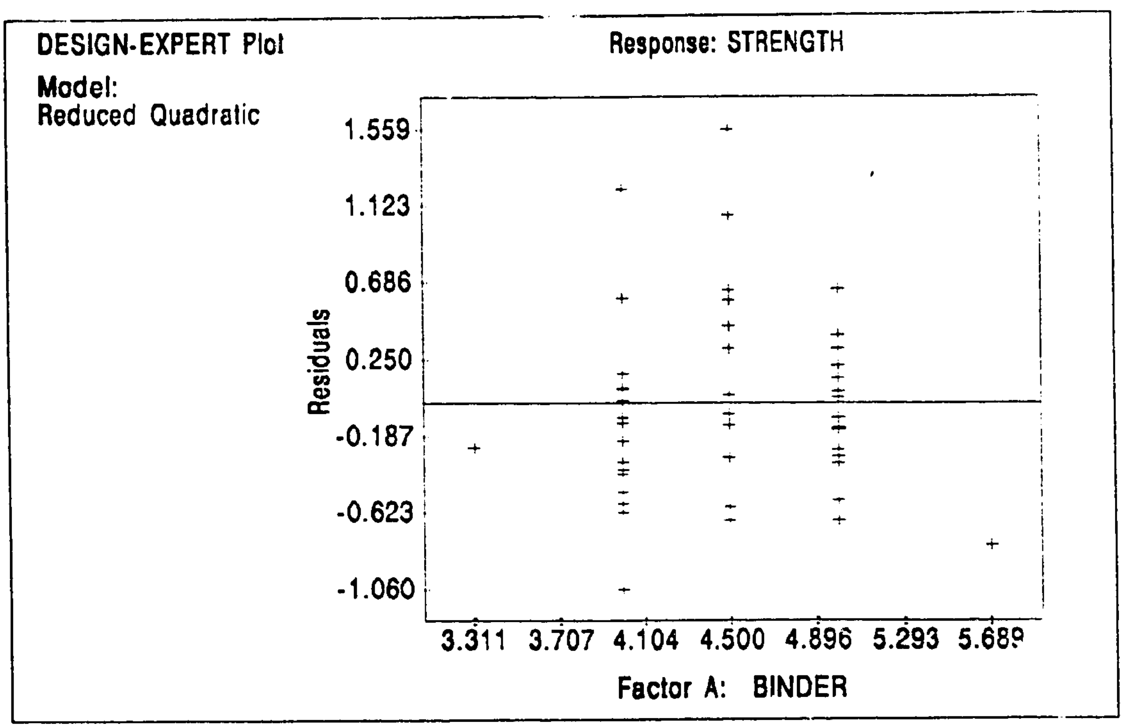

FIGURE #58: RESIDUALS vs BINDER

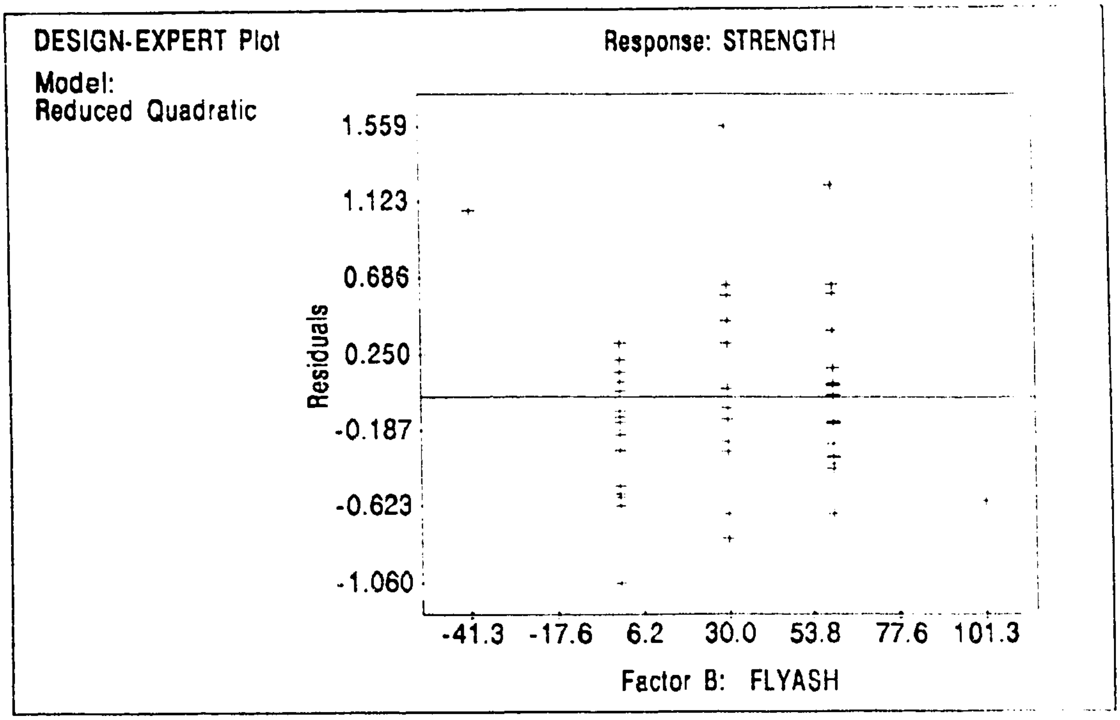

FIGURE #59: RESIDUALS vs FLYASH

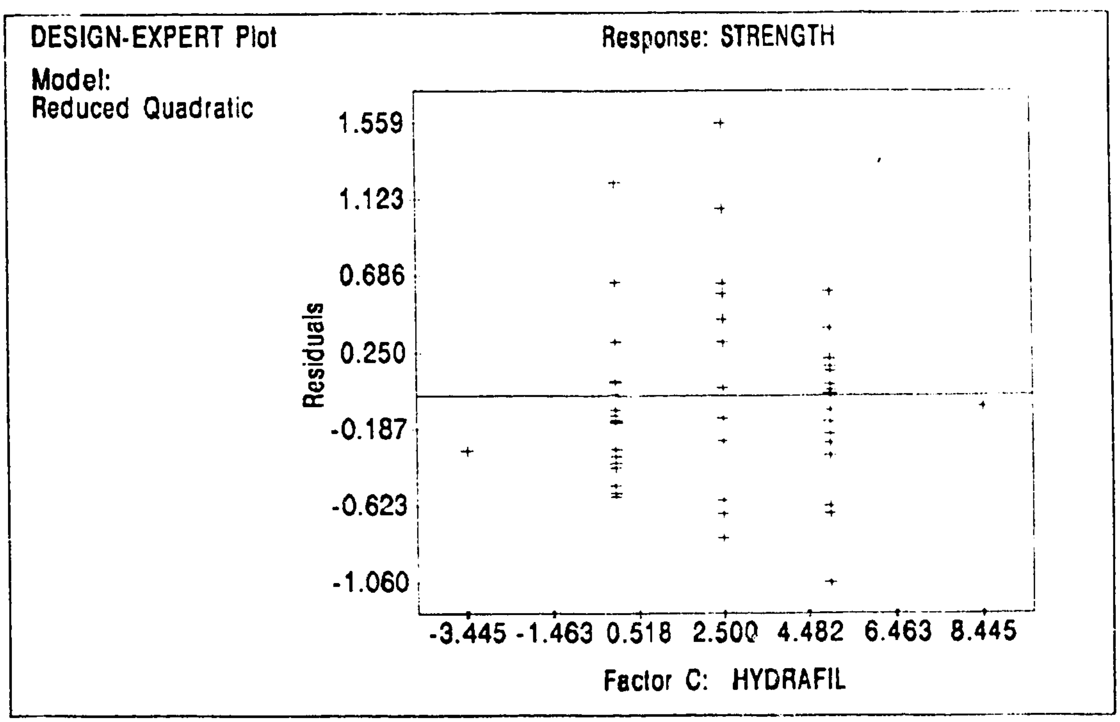

FIGURE #60: RESIDUALS vs HYDRAFIL

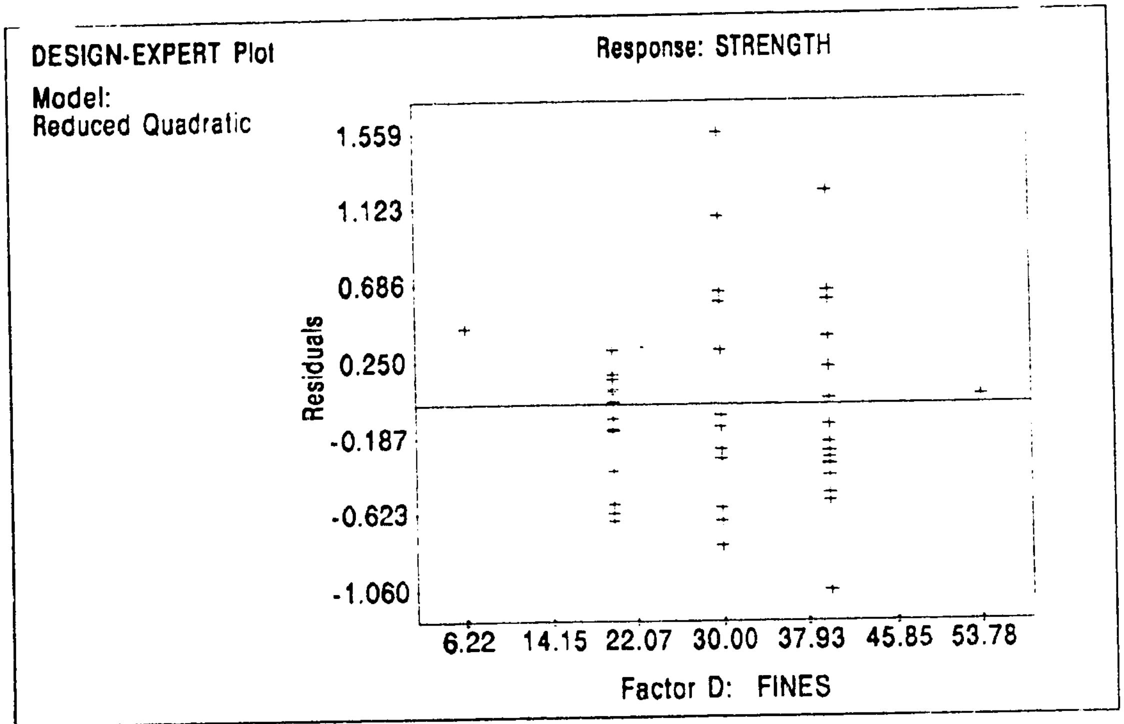

FIGURE #61: RESIDUALS vs FINES

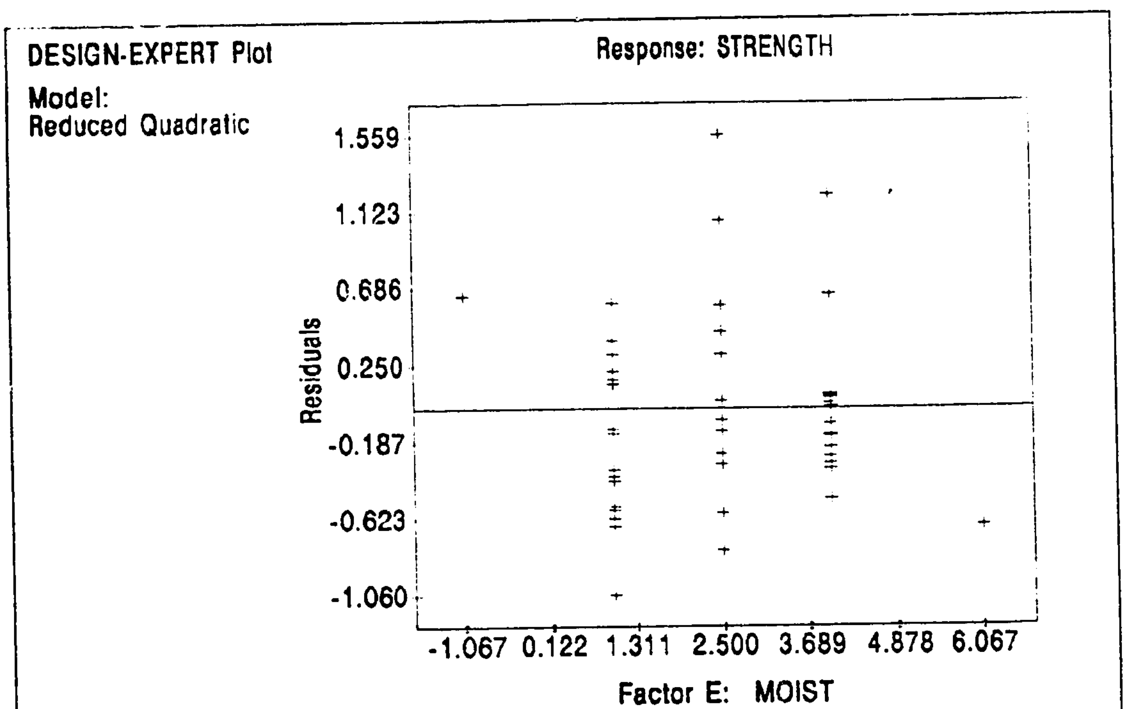

FIGURE #62: RESIDUALS vs MOIST

An "Outliers plot" is shown in **Figure #63**. An outlier among residuals is one that is far greater than the rest in absolute value, perhaps three to four standard deviations or more from the mean of residuals (Mular, 1990). These values should be carefully examined before they are rejected. The history of these outliers could result in valuable information about the process (Mular, 1990). **Figure #63** shows three or four points that may be outliers (However, the questionable points are not far enough outside the average to remove from the experiment).

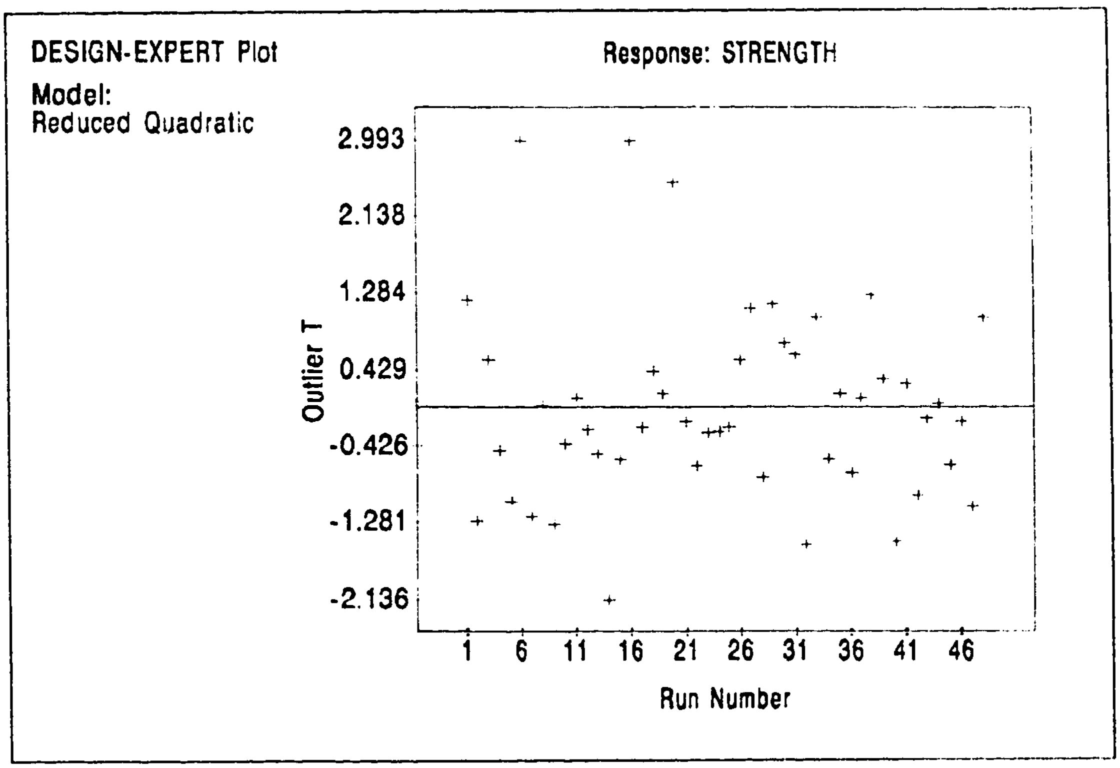

FIGURE #63: OUTLIER vs RUN NUMBER

The adequacy analyses indicate the results are very reliable. The two-level factorial design (central composite design) proved to be an ideal method of producing accurate models (strength equations) for analysing the affects that the rockfill factors had on the compressive strength.

11.2 ESTIMATION EQUATIONS versus ACTUALS

The linear strength estimation equation =

= 5.349167

- 0.935000 * (percent binder)

+ 0.001375 * (percent Shand flyash)

- 0.170000 * (ml/kg Hydrafil)

- 0.198125 * (percent fines)

- 0.756667 * (percent moisture)

+ 0.052875 * (percent binder) * (percent fines)

+ 0.009625 * (ml/kg Hydrafil) * (percent fines)

+ 0.019000 * (percent fines) * (percent moisture)

The quadratic strength estimation equation =

= 5.649000

- 1.016100 * (percent binder)

+ 0.014060 * (percent Shand flyash)

- 0.162790 * (ml/kg Hydrafil)

- 0.162910 * (percent fines)

- 0.821400 * (percent moisture)

- 0.000280 * (percent Shand flyash)^2 ... squared

- 0.000636 * (percent fines)^2 ... squared

+ 0.052870 * (percent binder) * (percent fines)

+ 0.009625 * (ml/kg Hydrafil) * (percent fines)

+ 0.019000 * (percent fines) * (percent moist)

Figure #64 shows the "average equation predictions" versus the "actual values" (the values from the linear and quadratic estimation equations were calculated and then averaged).

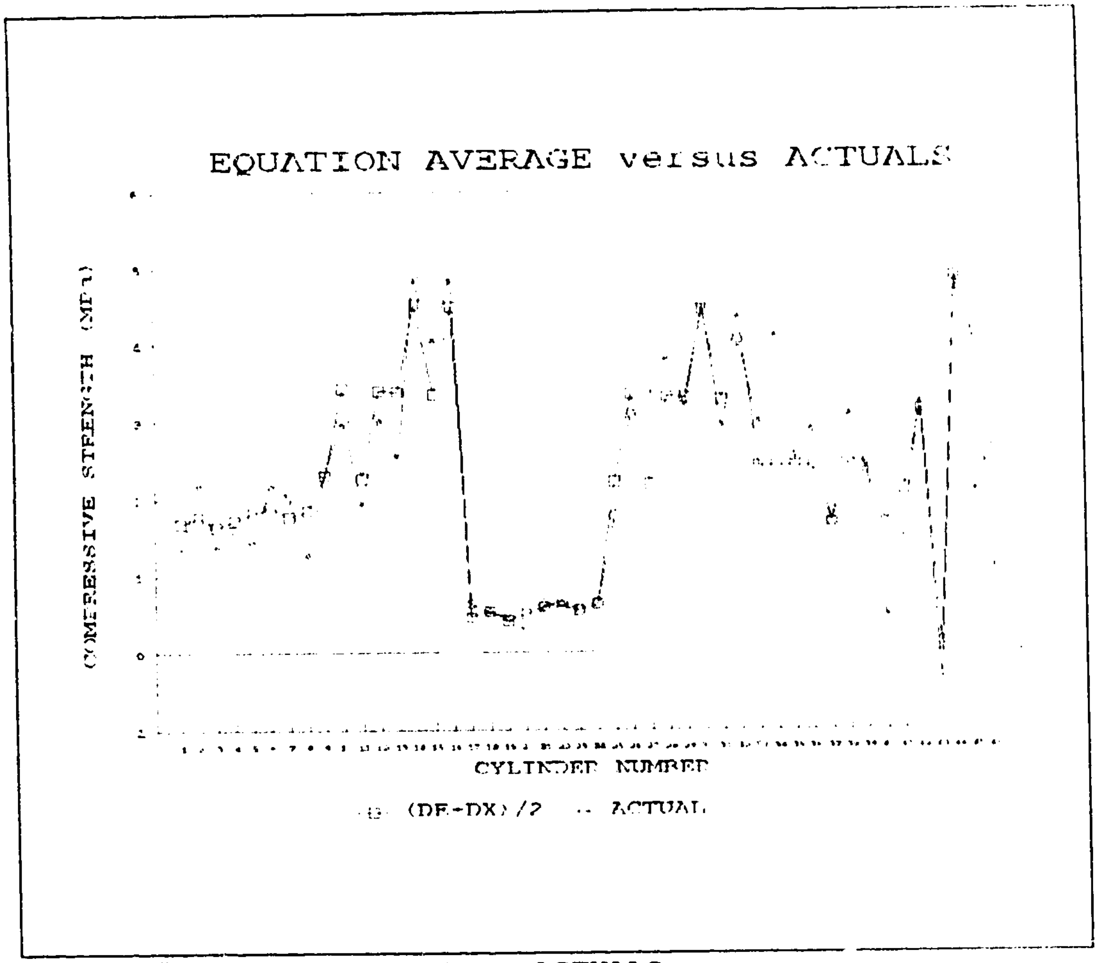

FIGURE #64: ESTIMATIONS vs ACTUALS

An obvious correlation is evident ... the fit is almost perfect. Because the equations were derived from the cylinder results of the experiment, the fit is very accurate for "these" rockfill cylinders. When the equation was used to predict the strength of cylinders from other tests, the fit was still remarkably accurate. The results of these "laboratory" cylinders seem to be reproducible. The results from both, the Shand experiments and the Coal Creek experiments show similar trends for the rockfill factors (excluding the flyash trend, which differed for Shand and Coal Creek).

Now that the statistical designs have been performed, repetitive, costly cylinder testing can be reduced dramatically. Cylinders should still be prepared occasionally to verify that the binder material is performing adequately (quality check). However, until a different flyash source or aggregate source is used, the cylinder testing program is finished (the equations are reliable enough to estimate the strengths of possible recipes).

12. COST OPTIMIZATION

Optimizing the costs associated with cemented rockfill is of major importance to INCO Thompson. Because the cemented rockfill costs are approximately $10 to $14 per ton of rockfill ($5 to $7 per ton of ore), finding less expensive slurry recipes is encouraged. Approximately 50 percent of this cost is related to binder (portland cement plus flyash).

Appendix #4 contains a complete cost optimization analysis. Several settings of the five rockfill factors were chosen for this analysis (NOTE, any number of settings could be chosen and tested, but for our example the following settings were chosen):

- Total binder values were varied by 0.2 percent binder 3.2/3.4/3.6/3.8/4.0/4.2/4.4/4.6/4.8/5.0/5.2/5.4

- Shand flyash values chosen were 30/40/50/60 percent

- The only value for Hydrafil was the manufacturers (W.R.Grace) recommended amount of 2.0 L/ton (however, now that strength estimation equations are available, <u>any</u> values can easily be "plugged in" to the spreadsheet and be analyzed quickly and at no significant extra cost ... no more costly cylinders are required).

- The fines percentages analyzed were 25 and 30 percent
- The moisture percentages analyzed were 1.0 and 2.0 percent

Table #10 shows some of the information that was gained during the analysis (see **Appendix #4** for all data). The strength and cost of the current recipe being used at T-3 Mine was determined and also possible less expensive recipes have been recommended.

Table #10: The T-3 Mine - Slurry Optimization

	A	B	C	D	E	MPa	COST
CURRENT RECIPE	4.0	50	2	30	1	2.30	$4.22
POSSIBLE RECIPE	3.8	50	2	30	1	2.18	$4.01
POSSIBLE RECIPE	4.0	60	2	30	1	2.22	$4.05

Where: A = TOTAL BINDER PERCENT

B = SHAND FLYASH PERCENT

C = HYDRAFIL (CEMENT DISPERSANT)

D = AGGREGATE FINES PERCENT

E = AGGREGATE MOISTURE PERCENT

The current T-3 recipe can be improved upon by increasing the Shand flyash percentage or decreasing the total binder percent and remaining at the same slurry recipe. The optimum recipe contains 4.0 percent total binder, 60 percent of which is Shand flyash. A savings of $0.17 per ton of cemented rockfill can be realized. Note, that approximately 125,000 tons of cemented rockfill are also placed at T-3 Mine each year ... resulting in a annual savings of $21,250. Therefore, over the remaining 20 years mining life (including the 1-D orebody), the T-3 Mine can save $425,000 on their backfill costs.

Table #11 shows some of the information that was gained during the analysis. The strength and cost of the current recipe being used at Birchtree Mine was determined and also possible less expensive recipes have been recommended.

Table #11: The Birchtree Mine - Slurry Optimization

	A	B	C	D	E	MPa	COST
CURRENT RECIPE	4.0	30	2	30	2	2.15	$4.56
POSSIBLE RECIPE	4.2	60	2	30	2	2.13	$4.25
POSSIBLE RECIPE	4.0	40	2	30	2	2.13	$4.39

Where: A = TOTAL BINDER PERCENT
B = SHAND FLYASH PERCENT
C = HYDRAFIL (CEMENT DISPERSANT)
D = AGGREGATE FINES PERCENT
E = AGGREGATE MOISTURE PERCENT

The current Birchtree recipe can be improved upon by increasing the Shand flyash percentage. The optimum recipe contains 4.2 percent total binder, 60 percent of which is Shand flyash. A savings of $0.31 per ton of cemented rockfill can be realized. Note, that approximately 125,000 tons of cemented rockfill are placed at Birchtree Mine each year ... resulting in a annual savings of $38,750. Therefore, over the remaining five years mining life, the Birchtree Mine can reduce the backfill costs by $200,000.

Because the Birchtree Mine has inherent ground water problems (approximately 2.0 percent aggregate moisture), the reduction of binder cannot be as great as that of the T-3 Mine.

Between the Birchtree and T-3 mines, a total savings of $625,000 can be saved on slurry costs alone. If development rock is used as a replacement aggregate, additional savings associated with the reduction in crushing and screening costs can also be realized (approximately $2.41 per ton of rockfill associated with crushing and screening ... see **Appendix #5** for cost details). If tests prove that development rock can be used as a substitute for the consult screened material, rockfill costs will be reduced significantly.

i.e. If 25 percent development rock could be used then:

0.25*(125,000 tons)*($2.41/ton) = $75,313

Therefore $75,313 could be saved annually at each of the two mines utilizing cemented rockfill. Over a five year period, $753,130 savings could be generated.

13. SUMMARY OF TESTING

The fragmentation analysis enabled an attrition equation to be established. This fines estimation equation was the first step in optimizing the rockfill systems. By knowing the relationship between free-fall distance and fines generation, the laborious chore of daily size analyses was eliminated (the fines percentage could be accurately estimated by the equation). Rather than taking a large random sample at the underground rockfill station and then screening the material to find the fines percentage, all that is needed now is a daily aggregate raise level reading. The equation proved to be accurate over the test range of 0 to 2650 feet. Although the equation is derived from INCO waste rock (skarns, metasediments, etc.), it may be used as a rough estimate for minesites using other types of aggregates. Future testing should be performed to link the current strength estimation equation with varying rock types, so that it could be accurately used at all minesites utilizing cemented rockfill.

Fill-raise orientation is another area where considerable savings can be generated. If mining is only on one side of the rockfilled block, the fill raise should be located close to the wall adjacent to the unmined ore. By locating the raise close to the stope walls, the more competent, finer aggregate and slurry material will remain at the wall, while the coarser, weaker aggregate will roll to the unimportant side of the block (the coarse aggregate will act as void filler ... no compressive strength required of it). However, if the blocks dimensions are less than 100 per fill raise, centrally located fill raise should suffice. The INCO blocks average 100 feet in width and 40 feet in length and therefore, centrally located fill raises are acceptable, yet locating the fill raises close to the walls is still recommended.

Extensive testing was performed encompassing all of the relevant factors within the rockfill system to try and determine the most cost effective cement slurries for the T-3 and Birchtree Mines. To assist in optimizing the current rockfill systems, three factorial designs (Shand Flyash at 100 days curing, Coal Creek at 100 days curing, Coal Creek at 28 days curing), consisting of 118 cemented rockfill cylinders were performed. The "2 to the fifth power" factorial designs enabled strength equations to be developed, which proved to be very accurate when predicting laboratory results. The equations allow engineers to examine the slurry options in a more scientific manner. The adequacy tests and statistical analysis (**Appendix #3**) indicated that the strength equations were significant.

When the fines estimation equation is used in conjunction with the strength estimation equation, a daily strength value can be estimated without even sampling the system. By obtaining the binder, flyash and Hydrafil percentages from the daily production sheets and by checking the daily aggregate raise level (therefore knowing the fines percentage), a rockfill strength value can be calculated from the strength estimation equation (note, the average moisture content must be assumed and/or sampled occasionally). If the daily strengths are known, then the overall strength of each rockfilled mining block can be estimated. Note, periodic testing should still be performed to verify results.

The statistical design results indicated that there is great potential for savings at the INCO mines. When all aspects of the rockfill system are considered, the possible savings opportunities are staggering (slurry optimization, development rock addition, proper fill raise placement, etc). During the last few years INCO's rockfill costs have been reduced dramatically. INCO's initial slurry recipe in 1992 was 5 percent binder, 0 percent flyash, 0 ml/kg Hydrafil. This initial recipe was very costly and very ineffective. The possible slurry recipes that were generated by the strength estimation equations are far less expensive, yet will still produce strong, safe cemented rockfill.

The initial recipe cost = $6.15

The most cost effective recipe suggested by the strength estimation equation = $4.01 ... approximately 2/3 the cost of the initial recipe.

However, unless new chemical additives are invented, or the safety factor associated with the effect of blasting is reduced, the evolution of the slurry recipe has come to an end. A "leaner" recipe than the ones suggested by the equation, may result in unsafe conditions underground. Caution must be used when reducing the existing recipes. To date, INCO's cemented rockfill has performed marvellously. Hopefully this analysis will aid in reducing INCO's cemented rockfill costs even further.

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Appendix #1

Coal Creek

Factorial Design

28 Days Curing Period

ROCKFILL CYLINDER TESTING
COMPLETE FACTORIAL DESIGN

FACTORS BEING INVESTIGATED

X1 = BINDER PERCENTAGE (4.0, 4.5, 5.0)
X2 = C.C. FLYASH PERCENTAGE (0, 25, 50)
X3 = HYDRAFIL ml/KG (0.0, 2.5, 5.0)
X4 = FINES PERCENTAGE (15, 25, 35)
X5 = ROCK MOISTURE PERCENTAGE (1.0, 2.5, 4.0)

CYLINDERS WERE CUT OPEN AFTER 14 DAYS

CURING TIME (DAYS)	ACTUAL STRENGTH (POUNDS)	ACTUAL STRENGTH (P.S.I.)	ACTUAL STRENGTH (MPa)	PERCENT BINDER (%)	PERCENT FLYASH (%)	HYDRAFIL ADDITION (L/TONNE)	PERCENT FINES (%)	PERCENT MOISTURE (%)
28	4600	162.7	1.122	4	0	0	15	1
84	5280	186.8	1.288	4	0	0	15	1
28	8000	283.0	1.952	5	0	0	15	1
84	10320	365.1	2.518	5	0	0	15	1
28	3800	134.4	0.927	4	50	0	15	1
84	4560	161.3	1.112	4	50	0	15	1
28	4400	155.6	1.073	5	50	0	15	1
84	5760	203.7	1.405	5	50	0	15	1
28	8000	283.0	1.952	4	0	5	15	1
84	12000	424.5	2.927	4	0	5	15	1
28	12000	424.5	2.927	5	0	5	15	1
84	14160	500.9	3.454	5	0	5	15	1
28	4000	141.5	0.976	4	50	5	15	1
84	4440	157.1	1.083	4	50	5	15	1
28	6200	219.3	1.513	5	50	5	15	1
84	9360	331.1	2.283	5	50	5	15	1
28	5100	180.4	1.244	4	0	0	35	1
84	7200	254.7	1.756	4	0	0	35	1
28	9600	339.6	2.342	5	0	0	35	1
84	17520	619.7	4.274	5	0	0	35	1
28	4400	155.6	1.073	4	50	0	35	1
84	5520	195.3	1.347	4	50	0	35	1
28	9200	325.4	2.244	5	50	0	35	1
84	10680	377.8	2.605	5	50	0	35	1
28	10000	353.7	2.440	4	0	5	35	1
84	12720	449.9	3.103	4	0	5	35	1
28	21600	764.1	5.269	5	0	5	35	1
84	22560	798.0	5.504	5	0	5	35	1
28	7800	275.9	1.903	4	50	5	35	1
84	10320	365.1	2.518	4	50	5	35	1
28	14600	516.4	3.562	5	50	5	35	1
84	23280	823.5	5.679	5	50	5	35	1
28	1800	63.7	0.439	4	0	0	15	4
84	2400	84.9	0.585	4	0	0	15	4
28	4200	148.6	1.025	5	0	0	15	4
84	4080	144.3	0.995	5	0	0	15	4
28	2600	92.0	0.634	4	50	0	15	4
84	2160	76.4	0.527	4	50	0	15	4
28	2000	70.7	0.488	5	50	0	15	4
84	3120	110.4	0.761	5	50	0	15	4
28	2000	70.7	0.488	4	0	5	15	4
84	2400	84.9	0.585	4	0	5	15	4
28	1900	67.2	0.464	5	0	5	15	4
84	2400	84.9	0.585	5	0	5	15	4
28	2000	70.7	0.488	4	50	5	15	4
84	2400	84.9	0.585	4	50	5	15	4
28	1300	46.0	0.317	5	50	5	15	4
84	1680	59.4	0.410	5	50	5	15	4
28	6400	226.4	1.561	4	0	0	35	4
84	9720	343.8	2.371	4	0	0	35	4
28	9600	339.6	2.342	5	0	0	35	4
84	11760	416.0	2.869	5	0	0	35	4
28	4800	169.8	1.171	4	50	0	35	4
84	8640	305.6	2.108	4	50	0	35	4
28	9400	332.5	2.293	5	50	0	35	4
84	15840	560.3	3.864	5	50	0	35	4
28	7000	247.6	1.708	4	0	5	35	4
84	8556	302.7	2.087	4	0	5	35	4
28	11000	389.1	2.683	5	0	5	35	4
84	12240	433.0	2.986	5	0	5	35	4
28	7000	247.6	1.708	4	50	5	35	4
84	7560	267.4	1.844	4	50	5	35	4
28	7400	261.8	1.805	5	50	5	35	4
84	9600	339.6	2.342	5	50	5	35	4

28	7800	275.9	1.903	4.5	25	2.5	25	2.5
84	6240	220.7	1.522	4.5	25	2.5	25	2.5
28	7900	279.4	1.927	4.5	25	2.5	25	2.5
84	9840	348.1	2.400	4.5	25	2.5	25	2.5
28	8400	297.1	2.049	4.5	25	2.5	25	2.5
84	7200	254.7	1.756	4.5	25	2.5	25	2.5
28	6400	226.4	1.561	4.5	25	2.5	25	2.5
84	13200	466.9	3.220	4.5	25	2.5	25	2.5

SINGLE FACTOR EFFECTS
28 DAY CURING

The single factor effect of any factor is defined as the overall average change in compressive strength produced by an increase in the level of that factor (eg. the change in compressive strength going from 4 to 5% binder).

There are 5 single factor effects:

- binder effect,
- flyash effect,
- hydrafil effect,
- fines effect,
- moisture effect.

The following page shows all 5 of the single factor effects and a chart comparing their influence on the compressive strength (MPa and %).

The order of influence on the compressive strength was as follows:

1) **fines percentage** influenced the compressive strength by 53 percent.

2) **aggregate moisture** influenced the compressive strength by 40 percent.

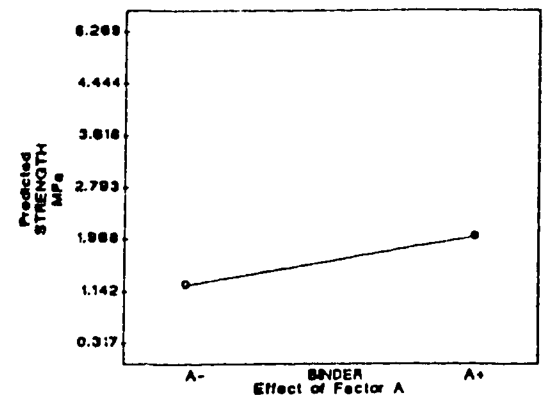
3) **binder percentage** influenced the compressive strength by 39 percent.

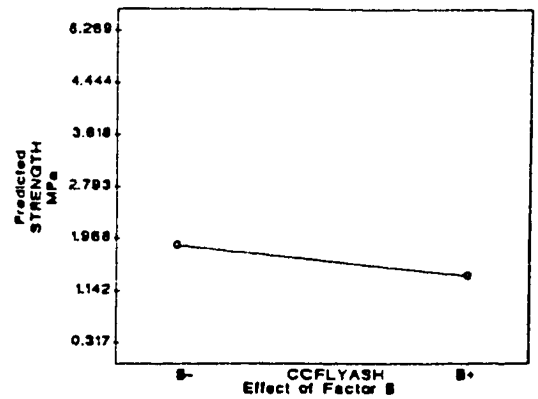
4) **hydrafil addition** influenced the compressive strength by 27 percent.

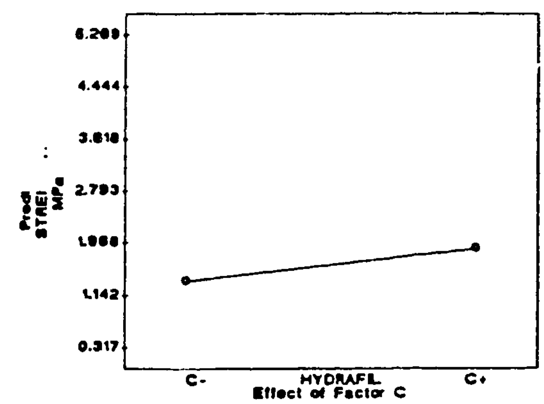
5) **ccflyash percentage** influenced the compressive strength by 26 percent.

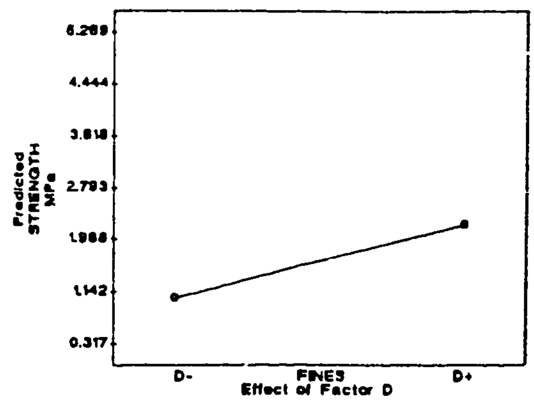
Surprisingly, the percentage of fines and aggregate moisture had a greater affect on the compressive strength than did the binder percentage and/or the percentage of flyash addition.

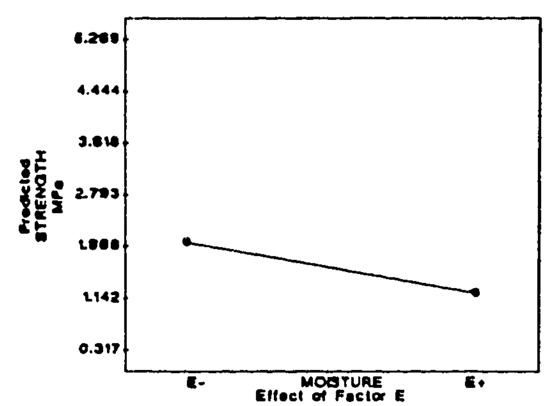
SINGLE FACTOR EFFECTS
28 DAY STRENGTH











ROCKFILL FACTOR	STRENGTH INFLUENCE (MPa)	STRENGTH INFLUENCE (%)
FINES	+ 1.16 MPa	+ 53 %
MOISTURE	− 0.81 MPa	− 40 %
BINDER	+ 0.78 MPa	+ 39 %
HYDRAFIL	+ 0.52 MPa	+ 27%
CCFLYASH	− 0.49 MPa	− 26 %

TWO-WAY INTERACTION EFFECTS
28 DAY CURING

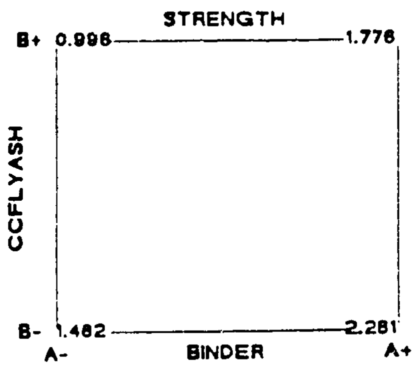
A 2-way interaction effect between two factors is the average difference between the effect of an increase in the level of the first factor at the higher level of the second factor and the effect of an increase in the level of the first factor at the lower level of the second factor.

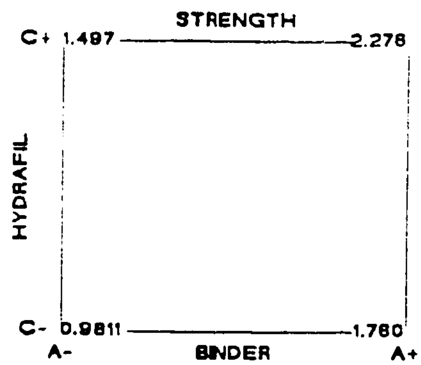
There are 10 two-way interaction effects:

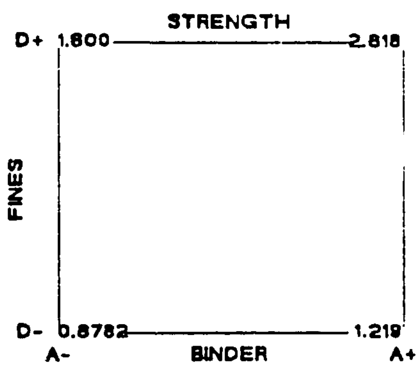
- binder/flyash,
- binder/hydrafil,
- binder/fines,
- binder/moisture,
- flyash/hydrafil,
- flyash/fines,
- flyash/moisture,
- hydrafil/fines,
- hydrafil/moisture,
- fines/moisture.

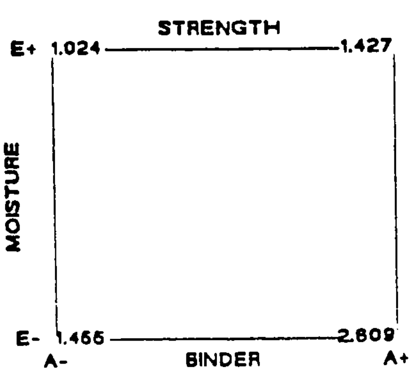
Pages 8 and 9 show all 10 two-way interaction effects.

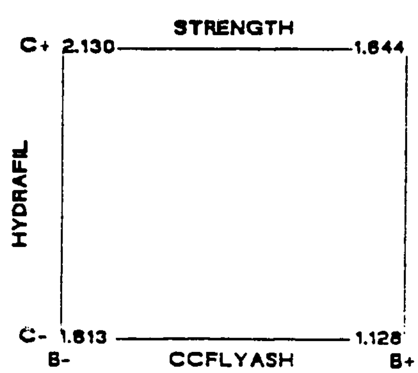
TWO FACTOR EFFECTS
28 DAY STRENGTH



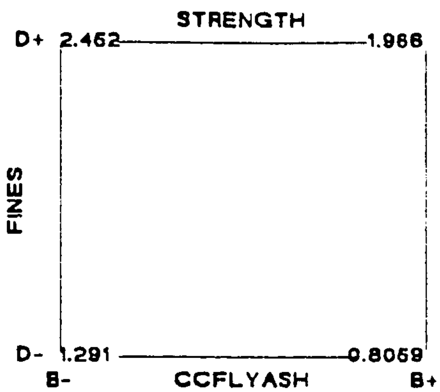


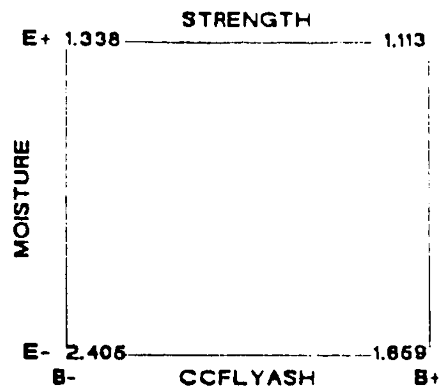


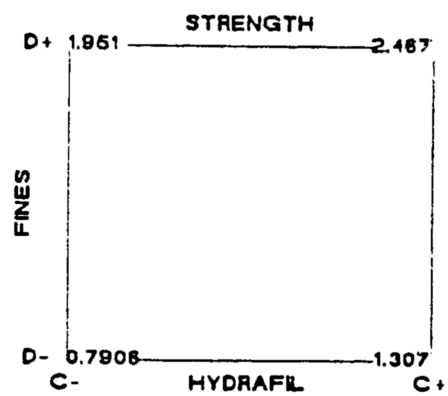


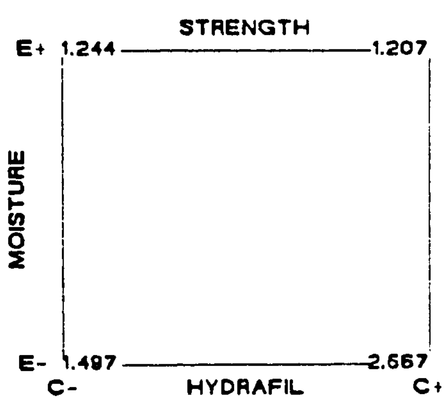


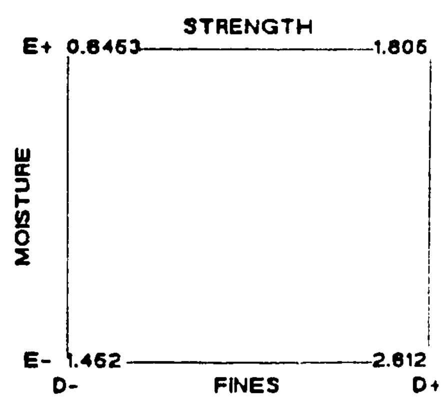
TWO FACTOR EFFECTS
28 DAY STRENGTH











THREE-WAY INTERACTION EFFECTS

28 DAY CURING

In general, an interaction which is statistically significant implies that the effect of one factor has different values at different levels of another factor

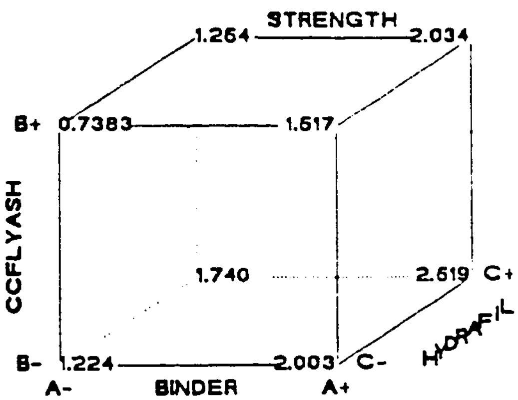
There are 10 three-way interaction effects:

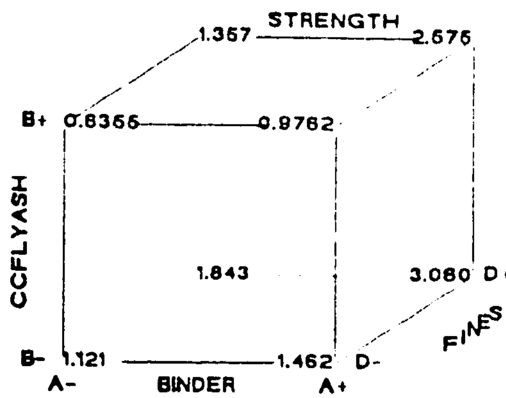
- binder/flyash/hydrafil,
- binder/flyash/fines,
- binder/flyash/moisture,
- binder/hydrafil/fines,
- binder/hydrafil/moisture,
- binder/fines/moisture,
- flyash/hydrafil/fines,
- flyash/hydrafil/moisture,
- flyash/fines/moisture,
- hydrafil/fines/moisture.

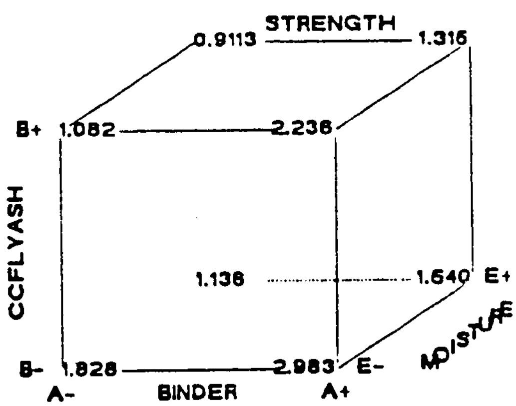
NOTE: Any interactions effects beyond three-way interaction effects (eg. four-way) are considered too insignificant to be considered in an equation.

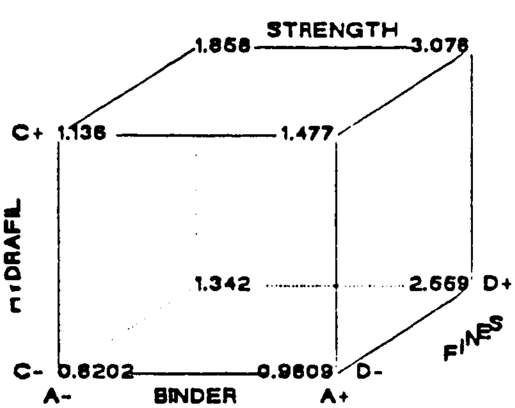
Pages 11 and 12 show all 10 three-way interaction effects.

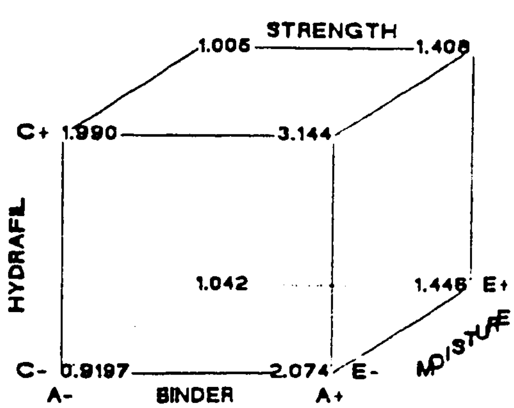
THREE FACTOR EFFECTS
28 DAY STRENGTH



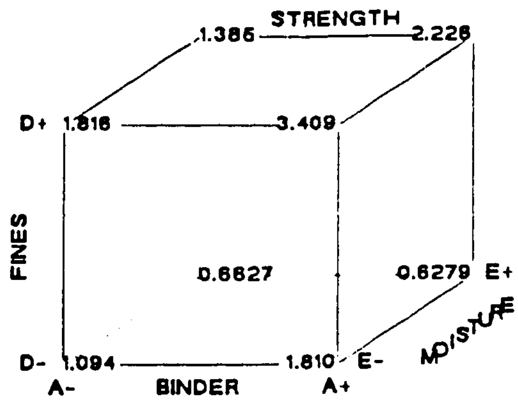


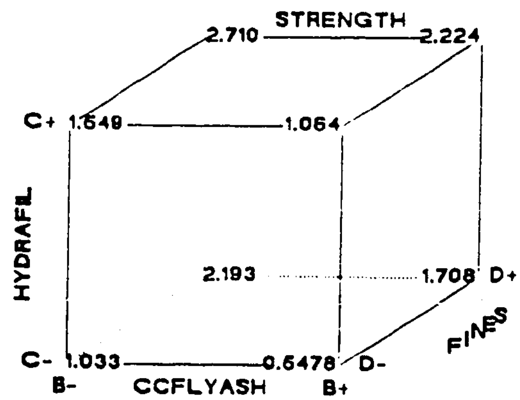


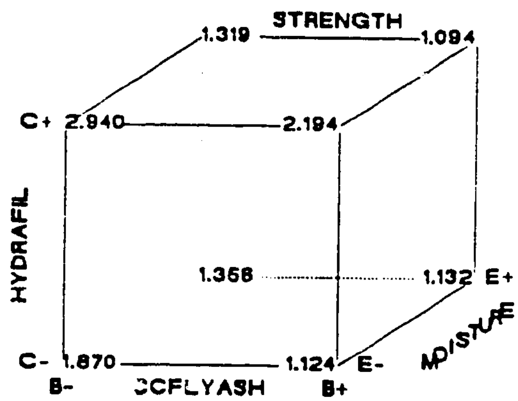


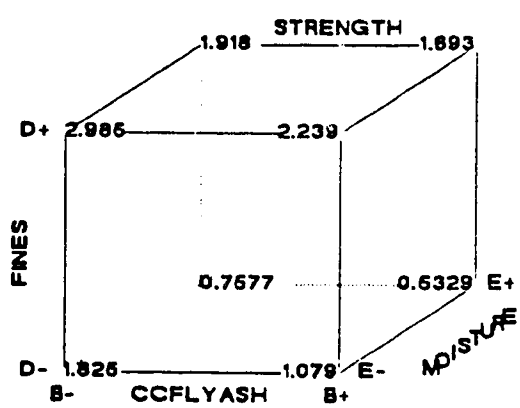


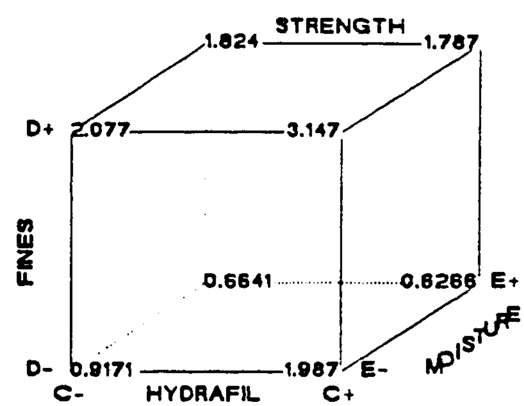
THREE FACTOR EFFECTS
28 DAY STRENGTH











D E S I G N - E A S E   A N A L Y S I S

Response: STRENGTH; File = CC28DAY   Run on 04/02/95 at 16:45:07

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	CC FLYASH	PERCENT	0.000	50.000
C	HYDRAFIL	ml/Kg	0.000	5.000
D	FINES	PERCENT	15.000	35.000
E	MOISTURE	PERCENT	1.000	4.000

VARIABLE	COEFFICIENT	STANDARDIZED EFFECT	SUM OF SQUARES
OVERALL AVERAGE	1.65417		
A	0.38906	0.77813	4.84383
B	-0.24281	-0.48563	1.88665
C	0.25969	0.51938	2.15800
D	0.57969	1.15938	10.75320
E	-0.40281	-0.80562	5.19225
AB	-0.11344	-0.22688	0.41178
AC	0.04031	0.08063	0.05200
AD	0.21906	0.43813	1.53563
AE	-0.18844	-0.37688	1.13628
BC	-0.11031	-0.22063	0.38940
BD	0.00344	0.00688	3.781E-04
BE	0.13094	0.26188	0.54863
CD	0.16719	0.33438	0.89445
CE	-0.27656	-0.55313	2.44758
DE	0.10344	0.20687	0.34238
ABC	-0.05094	-0.10187	0.08303
ABD	0.01156	0.02313	0.00428
ABE	0.02656	0.05312	0.02258
ACD	0.04656	0.09313	0.06938
ACE	-0.13219	-0.26438	0.55915
ADE	-0.04844	-0.09688	0.07508
BCD	-0.04031	-0.08063	0.05200
BCE	0.09594	0.19188	0.29453
BDE	-0.05531	-0.11063	0.09790
CDE	-0.08156	-0.16312	0.21288
ABCD	-0.10219	-0.20438	0.33415
ABCE	0.01156	0.02313	0.00428
ABDE	0.00906	0.01812	0.00263
ACDE	-0.05844	-0.11687	0.10928
BCDE	9.375E-04	0.00187	2.812E-05
ABCDE	-0.00969	-0.01938	0.00300
CENTER POINT	0.23156		0.19065

Computations done for Factorial

Model selected for Factorial:

Results of Factorial Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	34.51662	31	1.11344	25.19	0.0108
CURVATURE	0.19065	1	0.19065	4.313	0.1294
RESIDUAL	0.13260	3	0.04420		
PURE ERROR	0.13260	3	0.04420		
COR TOTAL	34.83987	35			

ROOT MSE	0.210238	R-SQUARED	0.996
DEP MEAN	1.654167	ADJ R-SQUARED	0.9566
C.V.	12.71%		

Case(s) with leverage of 1.0000: PRESS statistic not defined.

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > oto
INTERCEPT	1.628437	1	0.037165		
A	0.389063	1	0.037165	10.47	0.0019
B	-0.242813	1	0.037165	-6.533	0.0073
C	0.259688	1	0.037165	6.987	0.0060
D	0.579688	1	0.037165	15.60	0.0006
E	-0.402812	1	0.037165	-10.84	0.0017
AB	-0.113438	1	0.037165	-3.052	0.0553
AC	0.040313	1	0.037165	1.085	0.3574
AD	0.219063	1	0.037165	5.894	0.0097
AE	-0.188438	1	0.037165	-5.070	0.0148
BC	-0.110313	1	0.037165	-2.968	0.0592
BD	0.003438	1	0.037165	9.25E-02	0.9321
BE	0.130938	1	0.037165	3.523	0.0388
CD	0.167188	1	0.037165	4.498	0.0205
CE	-0.276563	1	0.037165	-7.441	0.0050
DE	0.103437	1	0.037165	2.783	0.0688
ABC	-0.050937	1	0.037165	-1.371	0.2641
ABD	0.011563	1	0.037165	0.3111	0.7761
ABE	0.026562	1	0.037165	0.7147	0.5264
ACD	0.046563	1	0.037165	1.253	0.2990
ACE	-0.132188	1	0.037165	-3.557	0.0379
ADE	-0.048438	1	0.037165	-1.303	0.2835
BCD	-0.040313	1	0.037165	-1.085	0.3574
BCE	0.095938	1	0.037165	2.581	0.0817
BDE	-0.055313	1	0.037165	-1.488	0.2334
CDE	-0.081563	1	0.037165	-2.195	0.1158
ABCD	-0.102188	1	0.037165	-2.750	0.0708
ABCE	0.011563	1	0.037165	0.3111	0.7761
ABDE	0.009062	1	0.037165	0.2438	0.8231
ACDE	-0.058437	1	0.037165	-1.572	0.2139
BCDE	9.375E-04	1	0.037165	2.52E-02	0.9815
ABCDE	-0.009688	1	0.037165	-0.2607	0.8112
CENTER POINT	0.231563	1	0.111496	2.077	0.1294

Final Equation in Terms of Coded Variables:

STRENGTH =

1.628437

```
+         0.389063 * A
-         0.242813 * B
+         0.259688 * C
+         0.579688 * D
-         0.402812 * E
-         0.113438 * A * B
+         0.040313 * A * C
+         0.219063 * A * D
-         0.188438 * A * E
-         0.110313 * B * C
+         0.003438 * B * D
+         0.130938 * B * E
+         0.167188 * C * D
-         0.276563 * C * E
+         0.103437 * D * E
-         0.050937 * A * B * C
+         0.011563 * A * B * D
+         0.026562 * A * B * E
+         0.046563 * A * C * D
-         0.132188 * A * C * E
-         0.048438 * A * D * E
-         0.040313 * B * C * D
+         0.095938 * B * C * E
-         0.055313 * B * D * E
-         0.081563 * C * D * E
-         0.102188 * A * B * C * D
+         0.011563 * A * B * C * E
+         0.009062 * A * B * D * E
-         0.058437 * A * C * D * E
+        9.375E-04 * B * C * D * E
-         0.009688 * A * B * C * D * E
```

Final Equation in Terms of Uncoded Variables:

```
STRENGTH =
                -1.266667
+         0.693333 * BINDER
+         0.084367 * CC FLYASH
+         0.930333 * HYDRAFIL
-         0.069333 * FINES
-         0.213333 * MOISTURE
-         0.023500 * BINDER * CC FLYASH
-         0.195333 * BINDER * HYDRAFIL
+         0.014667 * BINDER * FINES
-         0.065833 * BINDER * MOISTURE
-         0.023513 * CC FLYASH * HYDRAFIL
-         0.002420 * CC FLYASH * FINES
+         0.012333 * CC FLYASH * MOISTURE
-         0.069000 * HYDRAFIL * FINES
+         0.008167 * HYDRAFIL * MOISTURE
+         0.021333 * FINES * MOISTURE
+         0.004637 * BINDER * CC FLYASH * HYDRAFIL
+        6.600E-04 * BINDER * CC FLYASH * FINES
-         0.001700 * BINDER * CC FLYASH * MOISTURE
+         0.018400 * BINDER * HYDRAFIL * FINES
-         0.011667 * BINDER * HYDRAFIL * MOISTURE
-         0.001167 * BINDER * FINES * MOISTURE
+         0.001172 * CC FLYASH * HYDRAFIL * FINES
```

-	0.002437	* CC FLYASH * HYDRAFIL * MOISTURE
-	6.000E-04	* CC FLYASH * FINES * MOISTURE
+	0.009500	* HYDRAFIL * FINES * MOISTURE
-	2.753E-04	* BINDER * CC FLYASH * HYDRAFIL * FINES
+	7.633E-04	* BINDER * CC FLYASH * HYDRAFIL * MOISTURE
+	1.000E-04	* BINDER * CC FLYASH * FINES * MOISTURE
-	0.002600	* BINDER * HYDRAFIL * FINES * MOISTURE
+	9.400E-05	* CC FLYASH * HYDRAFIL * FINES * MOISTURE
-	2.067E-05	* BINDER * CC FLYASH * HYDRAFIL * FINES * MOIST

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.12000	1.12000	2.814E-12	1.000	0.000	0.000	0.000	32
2	1.95000	1.95000	1.506E-12	1.000	0.000	0.000	0.000	27
3	0.93000	0.93000	4.007E-12	1.000	0.000	0.000	0.000	30
4	1.07000	1.07000	4.178E-12	1.000	0.000	0.000	0.000	9
5	1.95000	1.95000	1.279E-12	1.000	0.000	0.000	0.000	34
6	2.93000	2.93000	-1.393E-12	1.000	0.000	0.000	0.000	35
7	0.98000	0.98000	3.268E-12	1.000	0.000	0.000	0.000	28
8	1.51000	1.51000	3.098E-12	1.000	0.000	0.000	0.000	18
9	1.24000	1.24000	-2.643E-12	1.000	0.000	0.000	0.000	20
10	2.34000	2.34000	-1.421E-13	1.000	0.000	0.000	0.000	31
11	1.07000	1.07000	-2.132E-12	1.000	0.000	0.000	0.000	16
12	2.24000	2.24000	-3.496E-12	1.000	0.000	0.000	0.000	23
13	2.44000	2.44000	-4.121E-12	1.000	0.000	0.000	0.000	7
14	5.27000	5.27000	-7.475E-12	1.000	0.000	0.000	0.000	17
15	1.90000	1.90000	-9.948E-13	1.000	0.000	0.000	0.000	6
16	3.56000	3.56000	-2.473E-12	1.000	0.000	0.000	0.000	36
17	0.44000	0.44000	1.506E-12	1.000	0.000	0.000	0.000	12
18	1.02000	1.02000	8.527E-14	1.000	0.000	0.000	0.000	26
19	0.63000	0.63000	9.948E-13	1.000	0.000	0.000	0.000	1
20	0.49000	0.49000	3.325E-12	1.000	0.000	0.000	0.000	3
21	0.49000	0.49000	1.108E-12	1.000	0.000	0.000	0.000	2
22	0.46000	0.46000	3.610E-12	1.000	0.000	0.000	0.000	5
23	0.49000	0.49000	-6.537E-13	1.000	0.000	0.000	0.000	19
24	0.32000	0.32000	-2.842E-14	1.000	0.000	0.000	0.000	11
25	1.56000	1.56000	-1.620E-12	1.000	0.000	0.000	0.000	21
26	2.34000	2.34000	-1.052E-12	1.000	0.000	0.000	0.000	22
27	1.17000	1.17000	-2.814E-12	1.000	0.000	0.000	0.000	24
28	2.29000	2.29000	1.165E-12	1.000	0.000	0.000	0.000	10
29	1.71000	1.71000	-3.098E-12	1.000	0.000	0.000	0.000	25
30	2.68000	2.68000	-3.894E-12	1.000	0.000	0.000	0.000	8
31	1.71000	1.71000	-3.723E-12	1.000	0.000	0.000	0.000	15
32	1.81000	1.81000	-5.429E-12	1.000	0.000	0.000	0.000	4
33	1.90000	1.86000	0.04000	0.250	0.220	0.000	0.181	14
34	1.93000	1.86000	0.07000	0.250	0.384	0.001	0.322	29
35	2.05000	1.86000	0.19000	0.250	1.044	0.011	1.068	13
36	1.56000	1.86000	-0.30000	0.250	-1.648	0.027	-4.364	33

Case(s) with leverage of 1.0000: SRSD, DIST, T set to 0.000.

D E S I G N - E A S E   A N A L Y S I S

Response: STRENGTH: File = CC28[illegible]   Run on 04/02/95 at 16:50:08

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	CC FLYASH	PERCENT	0.000	50.000
C	HYDRAFIL	ml/Kg	0.000	5.000
D	FINES	PERCENT	15.000	35.000
E	MOISTURE	PERCENT	1.000	4.000

VARIABLE	COEFFICIENT	STANDARDIZED EFFECT	SUM OF SQUARES
OVERALL AVERAGE	1.65417		
A	0.38906	0.77813	4.84383
B	-0.24281	-0.48563	1.88665
C	0.25969	0.51938	2.15800
D	0.57969	1.15938	10.75320
E	-0.40281	-0.80562	5.19225
AB	-0.11344	-0.22688	0.41178
AC	0.04031	0.08063	0.05200
AD	0.21906	0.43813	1.53563
AE	-0.18844	-0.37688	1.13628
BC	-0.11031	-0.22063	0.38940
BD	0.00344	0.00688	3.781E-04
BE	0.13094	0.26188	0.54863
CD	0.16719	0.33438	0.89445
CE	-0.27656	-0.55313	2.44758
DE	0.10344	0.20687	0.34238
ABC	-0.05094	-0.10187	0.08303
ABD	0.01156	0.02313	0.00428
ABE	0.02656	0.05312	0.02258
ACD	0.04656	0.09313	0.06938
ACE	-0.13219	-0.26438	0.55915
ADE	-0.04844	-0.09688	0.07508
BCD	-0.04031	-0.08063	0.05200
BCE	0.09594	0.19188	0.29453
BDE	-0.05531	-0.11063	0.09790
CDE	-0.08156	-0.16312	0.21288
ABCD	-0.10219	-0.20438	0.33415
ABCE	0.01156	0.02313	0.00428
ABDE	0.00906	0.01812	0.00263
ACDE	-0.05844	-0.11687	0.10928
BCDE	9.375E-04	0.00187	2.812E-05
ABCDE	-0.00969	-0.01938	0.00300
CENTER POINT	0.23156		0.19065

Computations done for Factorial

Model selected for Factorial:

Results of Factorial Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	31.39651	10	3.13965	23.17	0.0001
CURVATURE	0.19065	1	0.19065	1.407	0.2472
RESIDUAL	3.25272	24	0.13553		
LACK OF FIT	3.12012	21	0.14858	3.361	0.1732
PURE ERROR	0.13260	3	0.04420		
COR TOTAL	34.83987	35			

ROOT MSE	0.368144	R-SQUARED	0.9061
DEP MEAN	1.654167	ADJ R-SQUARED	0.8670
C.V.	22.26%		

Predicted Residual Sum of Squares (PRESS) = 7.48063

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR HO COEFFICIENT=0	PROB > öto
INTERCEPT	1.628437	1	0.065079		
A	0.389063	1	0.065079	5.978	0.0001
B	-0.242813	1	0.065079	-3.731	0.0010
C	0.259688	1	0.065079	3.990	0.0005
D	0.579688	1	0.065079	8.907	0.0001
E	-0.402812	1	0.065079	-6.190	0.0001
AD	0.219063	1	0.065079	3.366	0.0026
AE	-0.188438	1	0.065079	-2.896	0.0079
BE	0.130938	1	0.065079	2.012	0.0556
CD	0.167188	1	0.065079	2.569	0.0168
CE	-0.276563	1	0.065079	-4.250	0.0003
CENT' POINT	0.231563	1	0.195238	1.186	0.2472

Fir quation in Terms of Coded Variables:

```
STRENGTH =
              1.628437
     +        0.389063 * A
     -        0.242813 * B
     +        0.259688 * C
     +        0.579688 * D
     -        0.402812 * E
     +        0.219063 * A * D
     -        0.188438 * A * E
     +        0.130938 * B * E
     +        0.167188 * C * D
     -        0.276563 * C * E
```

Final Equation in Terms of Uncoded Variables:

```
STRENGTH =
             -0.390260
     +        0.310938 * BINDER
     -        0.018442 * CC FLYASH
     +        0.121063 * HYDRAFIL
     -        0.155906 * FINES
     +        0.959167 * MOISTURE
```

+	0.043813	* BINDER * FINES
-	0.251250	* BINDER * MOISTURE
+	0.003492	* CC FLYASH * MOISTURE
+	0.006688	* HYDRAFIL * FINES
-	0.073750	* HYDRAFIL * MOISTURE

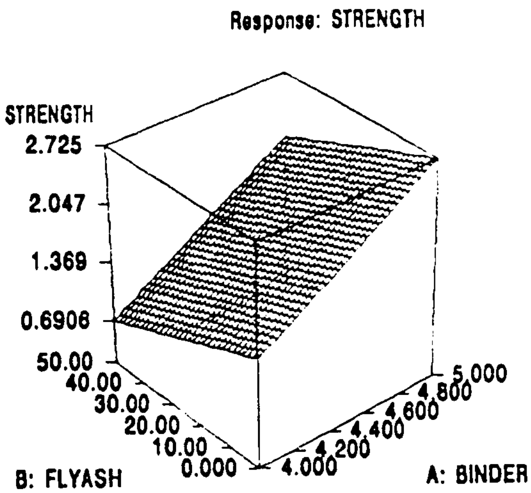
Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.12000	1.09781	0.02219	0.344	0.074	0.000	0.073	32
2	1.95000	1.81469	0.13531	0.344	0.454	0.009	0.446	27
3	0.93000	0.35031	0.57969	0.344	1.944	0.165	2.073	30
4	1.07000	1.06719	0.00281	0.344	0.009	0.000	0.009	9
5	1.95000	1.83594	0.11406	0.344	0.382	0.006	0.376	34
6	2.93000	2.55281	0.37719	0.344	1.265	0.070	1.282	35
7	0.98000	1.08844	-0.10844	0.344	-0.364	0.006	-0.357	28
8	1.51000	1.80531	-0.29531	0.344	-0.990	0.043	-0.990	18
9	1.24000	1.48469	-0.24469	0.344	-0.820	0.029	-0.815	20
10	2.34000	3.07781	-0.73781	0.344	-2.474	0.267	-2.806	31
11	1.07000	0.73719	0.33281	0.344	1.116	0.054	1.122	16
12	2.24000	2.33031	-0.09031	0.344	-0.303	0.004	-0.297	23
13	2.44000	2.89156	-0.45156	0.344	-1.514	0.100	-1.559	7
14	5.27000	4.48469	0.78531	0.344	2.633	0.303	3.057	17
15	1.90000	2.14406	-0.24406	0.344	-0.818	0.029	-0.813	6
16	3.56000	3.73719	-0.17719	0.344	-0.594	0.015	-0.586	36
17	0.44000	0.96031	-0.52031	0.344	-1.745	0.133	-1.828	12
18	1.02000	0.92344	0.09656	0.344	0.324	0.005	0.318	26
19	0.63000	0.73656	-0.10656	0.344	-0.357	0.006	-0.351	1
20	0.49000	0.69969	-0.20969	0.344	-0.703	0.022	-0.696	3
21	0.49000	0.59219	-0.10219	0.344	-0.343	0.005	-0.336	2
22	0.46000	0.55531	-0.09531	0.344	-0.320	0.004	-0.314	5
23	0.49000	0.36844	0.12156	0.344	0.408	0.007	0.400	19
24	0.32000	0.33156	-0.01156	0.344	-0.039	0.000	-0.038	11
25	1.56000	1.34719	0.21281	0.344	0.714	0.022	0.706	21
26	2.34000	2.18656	0.15344	0.344	0.514	0.012	0.506	22
27	1.17000	1.12344	0.04656	0.344	0.156	0.001	0.153	24
28	2.29000	1.96281	0.32719	0.344	1.097	0.053	1.102	10
29	1.71000	1.64781	0.06219	0.344	0.209	0.002	0.204	25
30	2.68000	2.48719	0.19281	0.344	0.647	0.018	0.638	8
31	1.71000	1.42406	0.28594	0.344	0.959	0.040	0.957	15
32	1.81000	2.26344	-0.45344	0.344	-1.520	0.101	-1.566	4
33	1.90000	1.86000	0.04000	0.250	0.125	0.000	0.123	14
34	1.93000	1.86000	0.07000	0.250	0.220	0.001	0.215	29
35	2.05000	1.86000	0.19000	0.250	0.596	0.010	0.588	13
36	1.56000	1.86000	-0.30000	0.250	-0.941	0.025	-0.939	33

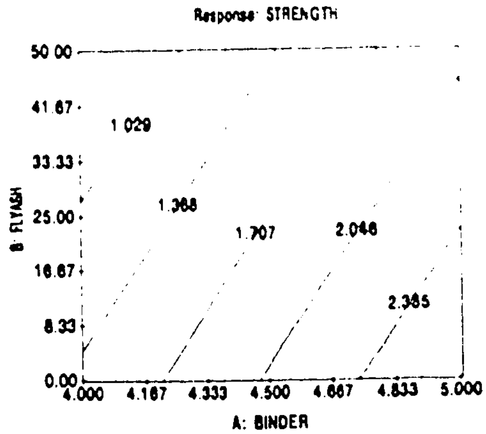
T-3 MINE versus BIRCHTREE MINE ANALYSIS
28 DAY CURING

The following 10 pages contain an analysis comparing the T-3 Mine against the Birchtree Mine. Two-way interaction effects are used to compare the two rockfill systems.

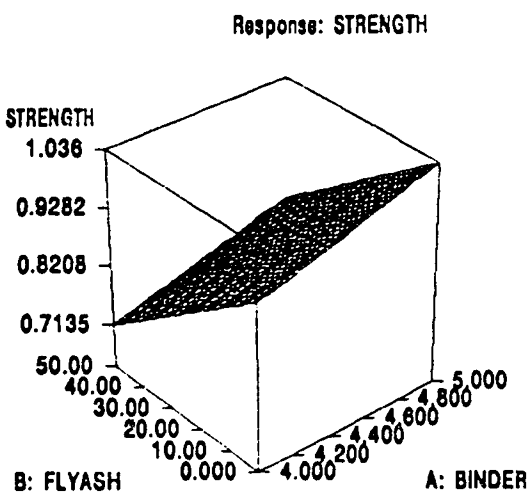
The first two-way interaction plots (page 19) compare **binder versus flyash** at each of the two mines. Note that the rockfill strength at the T-3 Mine is greatly affected by a change in binder and flyash (close to 45 degree slopes in T-3 plot). The Birchtree plot is slightly shallower, indicating a smaller interaction effect but still an effect nonetheless. Because the T-3 Mine has higher fines percentages and lower aggregate moisture percentages, the compressive strengths at the T-3 Mine are higher.

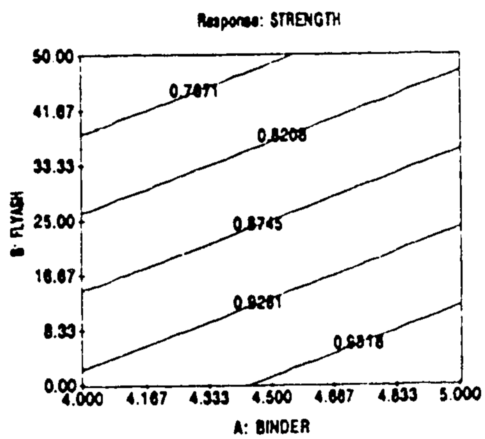
T−3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS



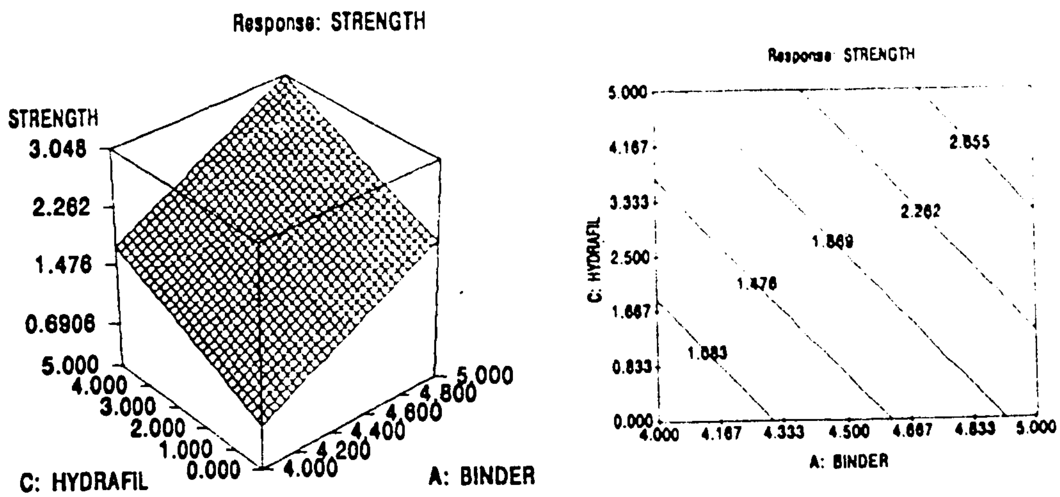


T-3 MINE versus BIRCHTREE MINE ANALYSIS

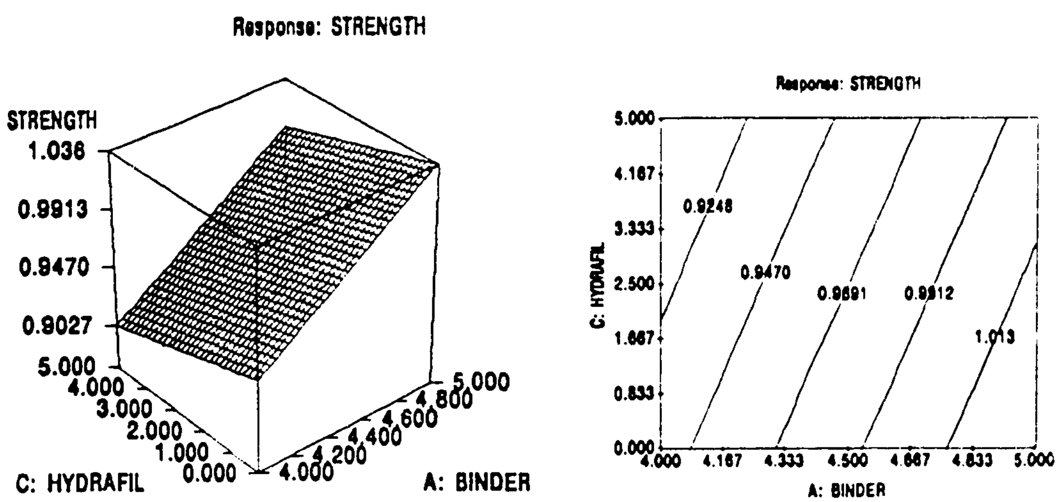
28 DAY CURING

The following two-way interaction plots (page 21) compare the **binder versus hydrafil** at each of the two mines. Both plots show that there is a definite two-way interaction effect occurring. Note that the slopes of the plots are opposite at each mine. The T-3 plot shows that the strength will increase as hydrafil (a cement dispersant) is added, while the Birchtree plot shows the opposite, a reduction in compressive strength. The factorial design has assisted in determining which, if any, of the Inco Mines should be using the cement dispersant (cost analysis performed later in the report).

T–3 ROCKFILL @ 28 DAYS



BIRCHTREE ROCKFILL @ 28 DAYS



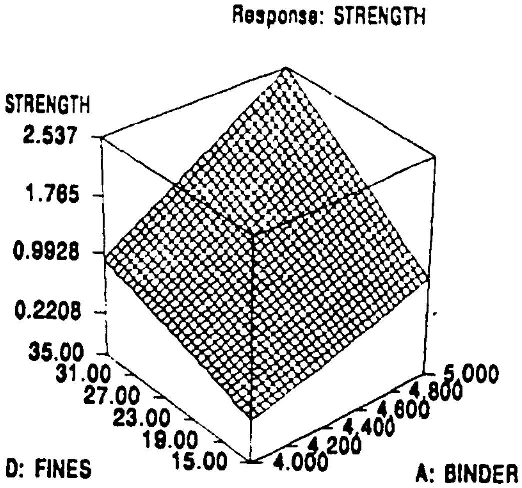
T-3 MINE versus BIRCHTREE MINE ANALYSIS
28 DAY CURING

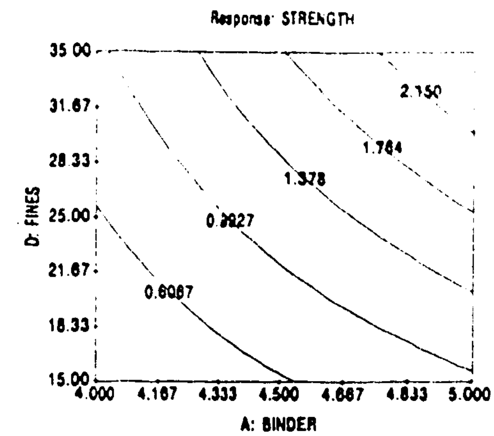
The following two-way interaction plots (page 23) compare the **binder versus fines** at each of t [illegible] two mines. Both plots show a definite two-way interaction effect occurring. As the fines and binder percentages are increased, the compressive strengths are also increasing. However, note that at lower fines percentages, the binder content at the Birchtree Mine has little affect on the compressive strength (almost horizontally sloped lines).

The factorial design has allowed us to determine how the strength varies as the fines percentage is adjusted.

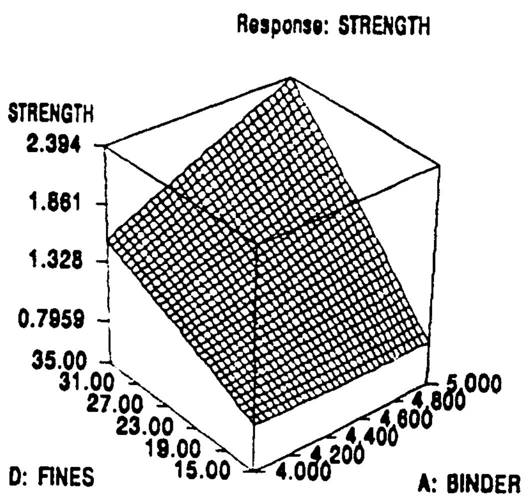
The Birchtree Mine should increase their fines percentage from 18% to 25-30% in order to increase their compressive strengths.

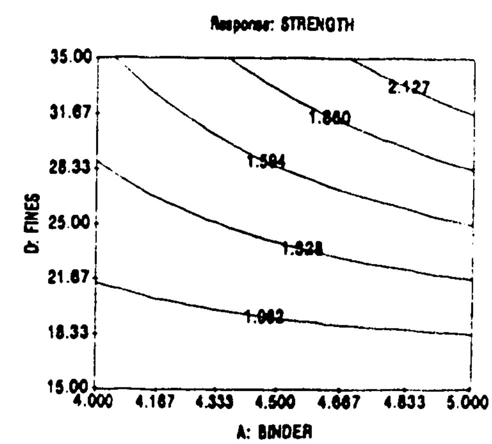
T−3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS



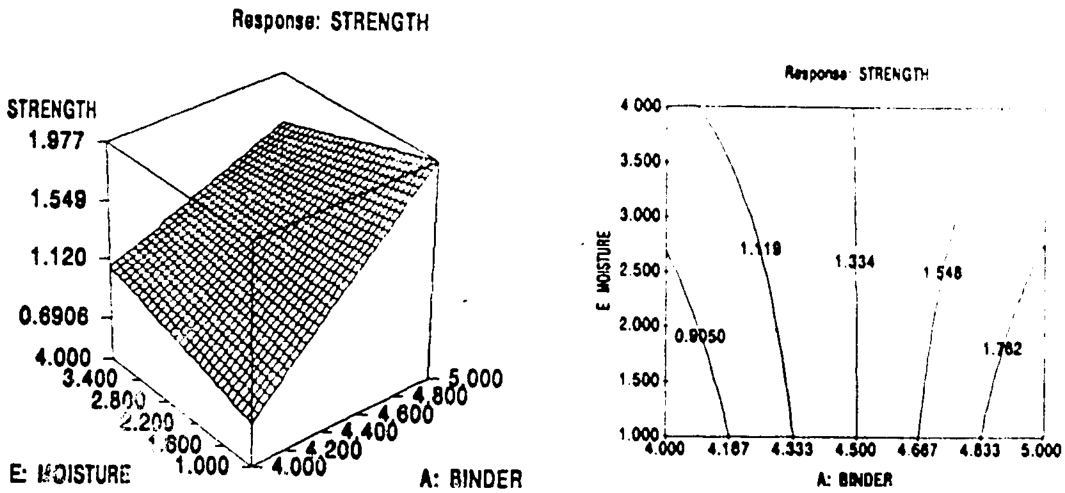


T-3 MINE versus BIRCHTREE MINE ANALYSIS

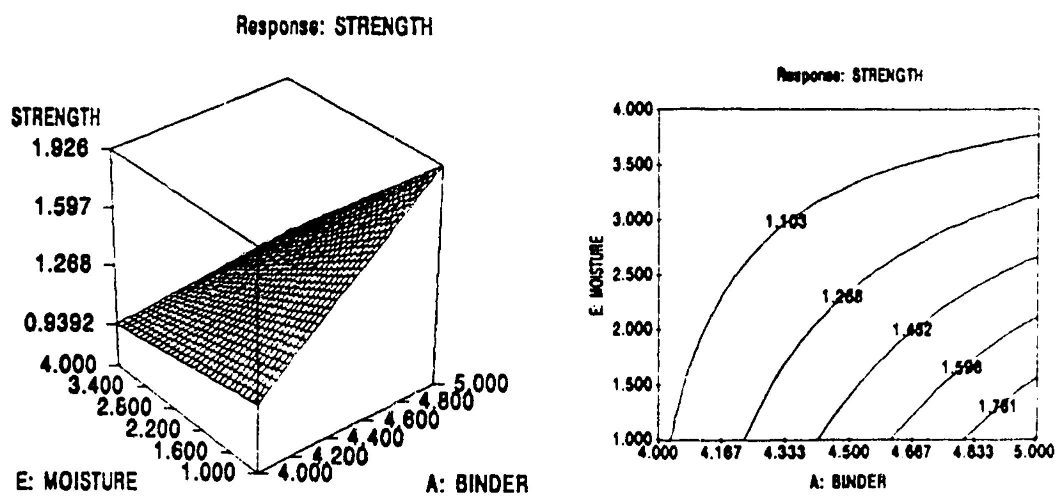
28 DAY CURING

The following two-way interaction plots (page 25) compare the **binder versus aggregate moisture** at each of the two mines. The two plots are very different, indicating once again that the slurry designs at each of the two rockfill mines must be considered seperately. The T-3 plot shows that at low binder percentages, the strength will actually increase when the aggregate moisture is increased, while at higher binder percentages the strength will decrease when the moisture is increased. At the Birchtree Mine, the addition of moisture causes a decrease in the strength at all binder percentages (due to the low fines content in the aggregate...the added moisture washes the fines through the aggregate voids and leaves layers of weakly bonded coarse particles).

T−3 ROCKFILL @ 28 DAYS



BIRCHTREE ROCKFILL @ 28 DAYS

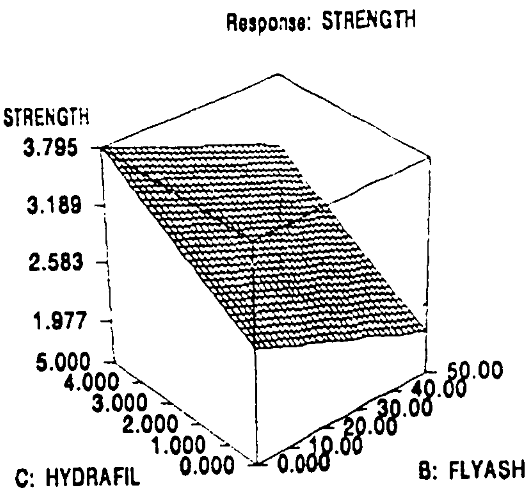


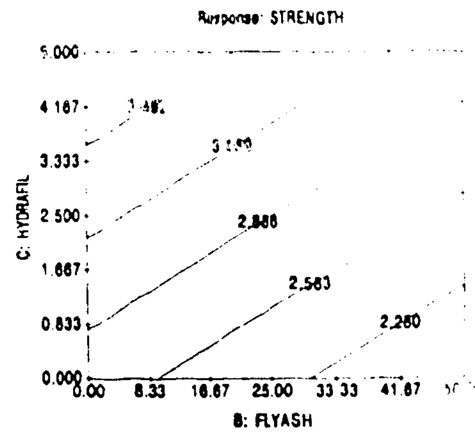
T-3 MINE versus BIRCHTREE MINE ANALYSIS
28 DAY CURING

The following two-way interaction plots (page 27) compare the **flyash versus hydrafil** at each of the two mines. The two plots are very different from one another. Once again the addition of hydrafil to the T-3 system has a positive, strengthening influence, while the cement dispersant decreases the compressive strength at the Birchtree Mine.

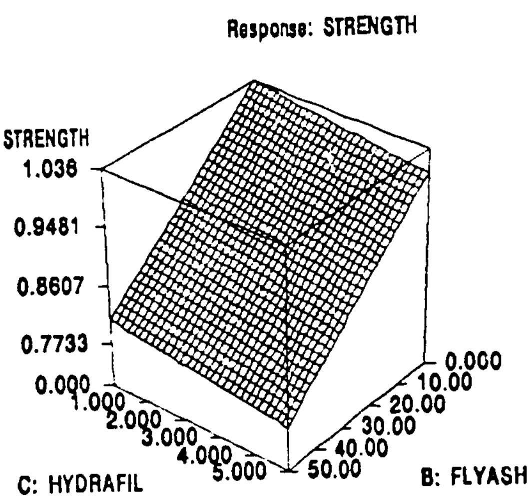
The shallower, closer to 45 degree lines in the T-3 plot indicate a stronger two-way interaction effect than the steeper, more vertical lines of the Birchtree plot.

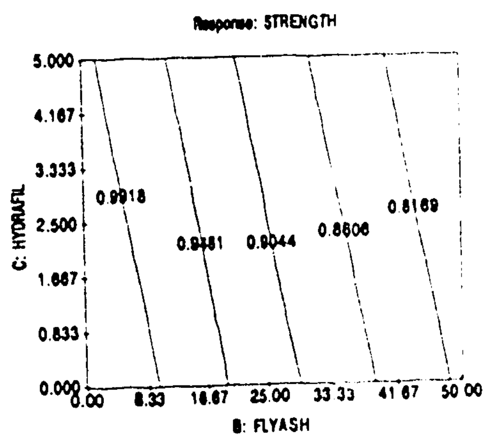
T-3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS





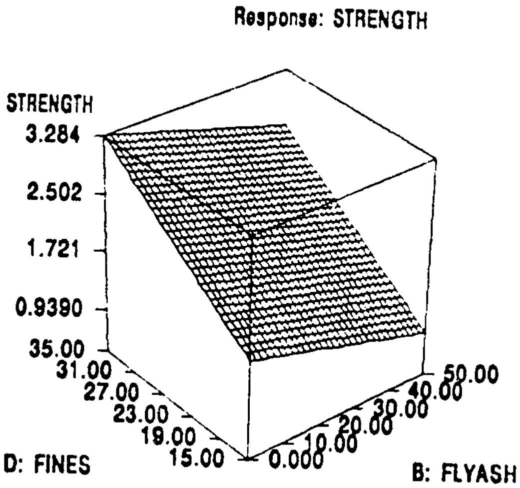
T-3 MINE versus BIRCHTREE MINE ANALYSIS

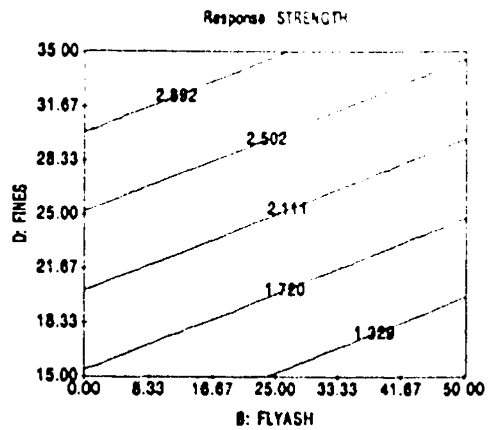
28 DAY CURING

The following two-way interaction plots (page 29) compare the **flyash versus fines** at eah of the two mines. Both plots show two-way interactions occurring, but the steeper, closer to 45 degree lines in the T-3 plot indicate a stronger interaction effect than the shallower, more horizontal lines of the Birchtree plot.

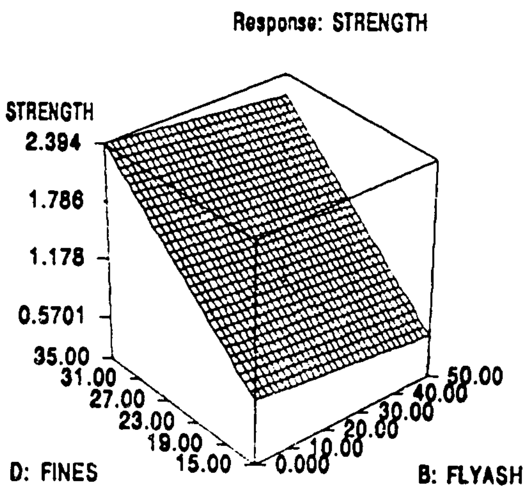
The shallower lines of the Birchtree plot indicate that the compressive strength decreases only slightly as the percent flyash is varied from 0 to 50 percent. This information generated by the factorial design is vital for optimizing the Birchtree slurry design...if the compressive strength is only slightly reduced by the addition of flyash, then due to the lower cost per tonne of flyash, the maximum amount of flyash should be used at the Birchtree Mine (50 percent flyash is currently the maximum). The Birchtree plot shows that there is only a small decrease in the compressive strength when changing from 0 to 50 percent compared to the considerable change in strength at the T-3 Mine.

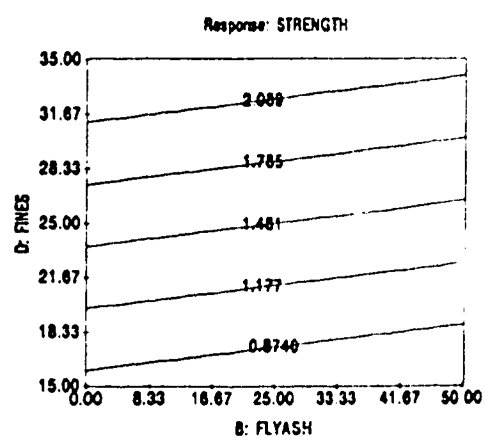
T-3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS

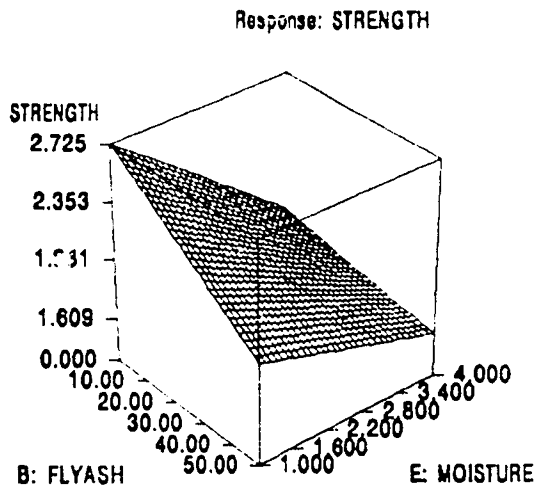


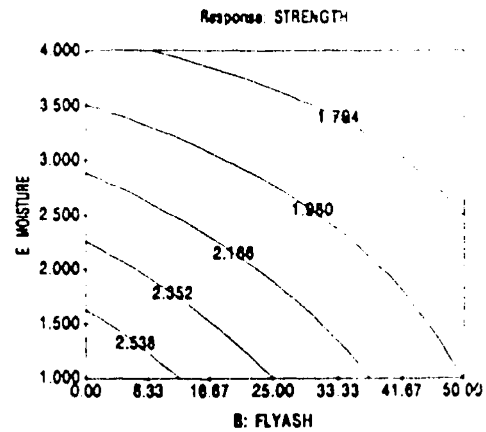


T-3 MINE versus BIRCHTREE MINE ANALYSIS
28 DAY CURING

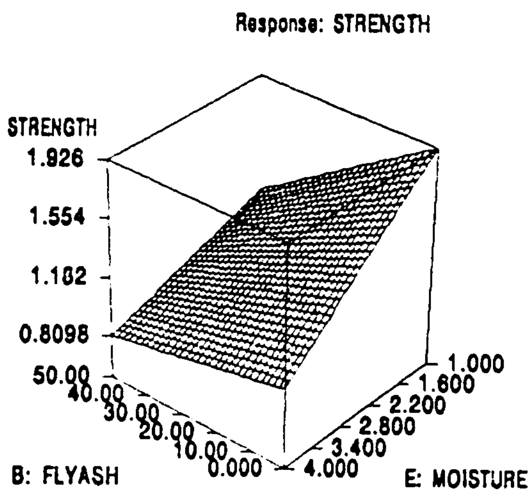
The following two-way interaction plots (page 31) compare the **flyash versus aggregate moisture** at each of the two mines. Both plots are very similar to one another. Both show a significant interaction effect (NOTE: a close to 45 degree relationship indicates a strong interaction effect). As both, the flyash and the aggregate moisture are increased, the compressive strengths decrease dramatically. The comparatively lower compressive strengths found at the Birchtree Mine are directly related to their insufficient percentage of fines within the aggregate material.

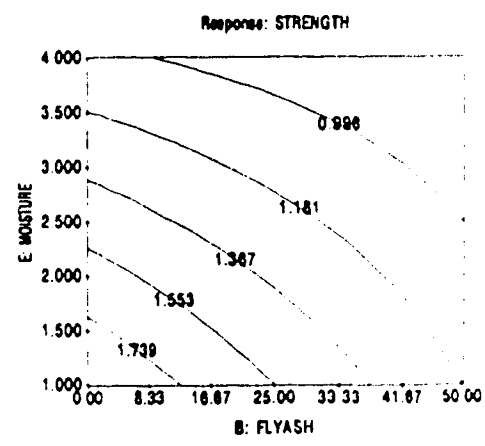
T-3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS

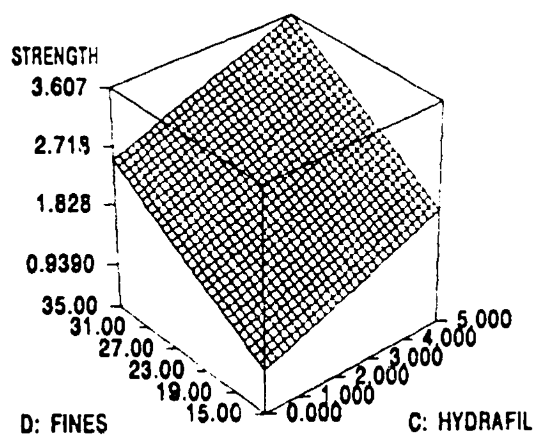


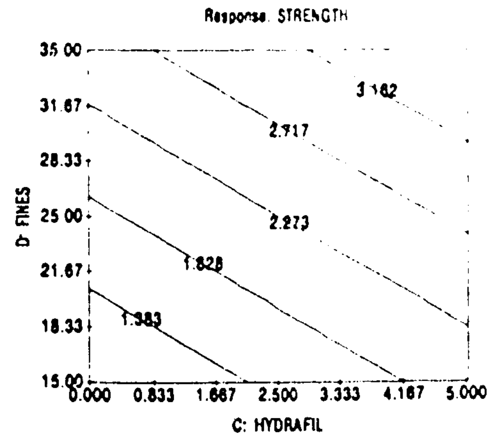


T-3 MINE versus BIRCHTREE MINE ANALYSIS
28 DAY CURING

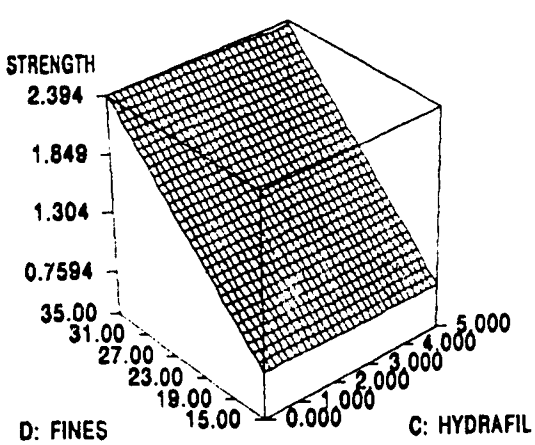
The following two-way interaction plots (page 33) compare **hydrafil versus fines** at each of the two mines. The T-3 plot contains diagonal lines (close to 45 degrees), indicating a strong two-way interaction, while the almost horizontal lines of the Birchtree plot indicate an insignificant interaction occurring. In other words the addition of hydrafil does not affect the compressive strength at the Birchtree Mine, but does greatly affect the strength at the T-3 Mine.

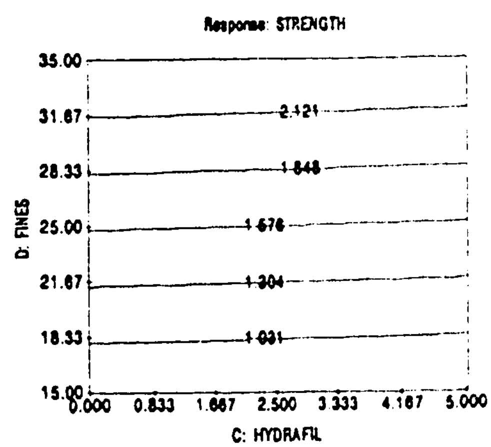
T−3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS



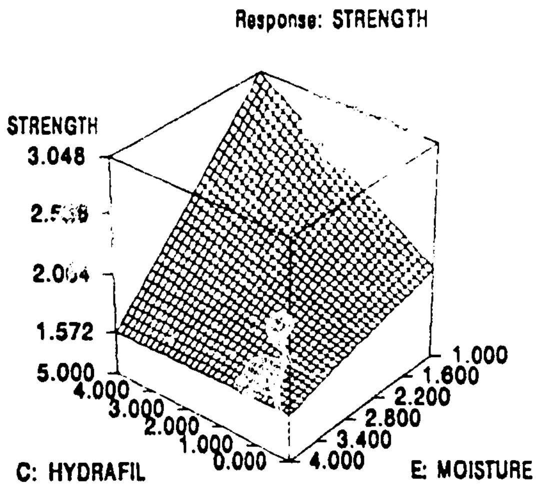


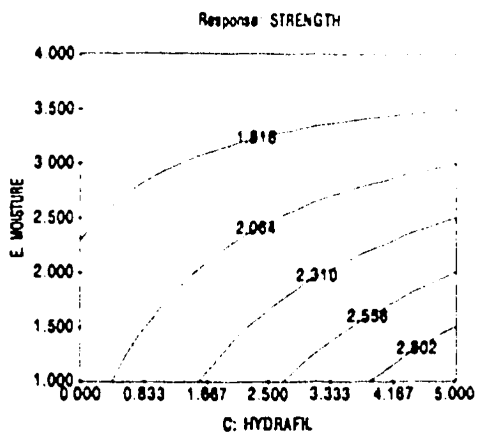
T-3 MINE versus BIRCHTREE MINE ANALYSIS

28 DAY CURING

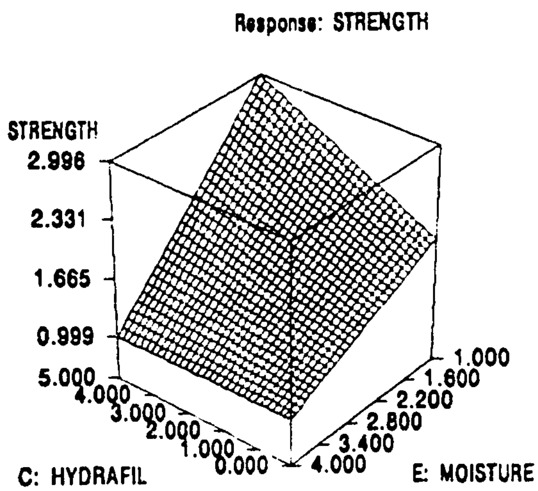
The following two-way interaction plots (page 35) compare **hydrafil versus aggregate moisture** at each of the two mines. Both plots are somewhat similar to one another. Both plots indicate that if the aggregate moisture is increased, the effectiveness of the hydrafil is decreased. The plots indicate that hydrafil is only significant in increasing the compressive strength when the aggregate moisture is low (this explains why hydrafil should only be used at the T-3 Mine where the aggregate moisture is between 1 and 2 percent moisture by weight aggregate).

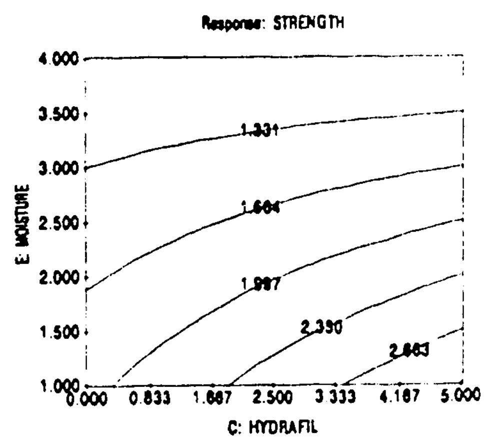
T-3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS



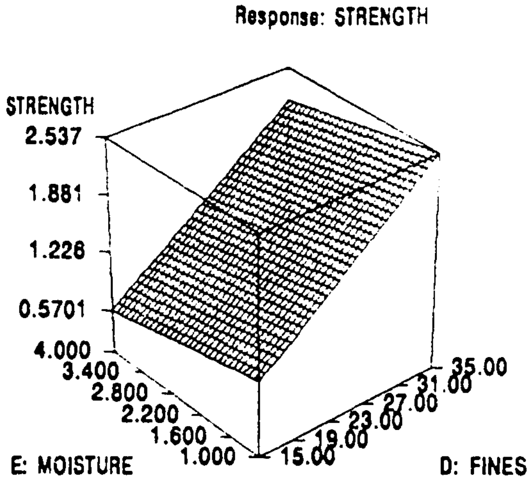


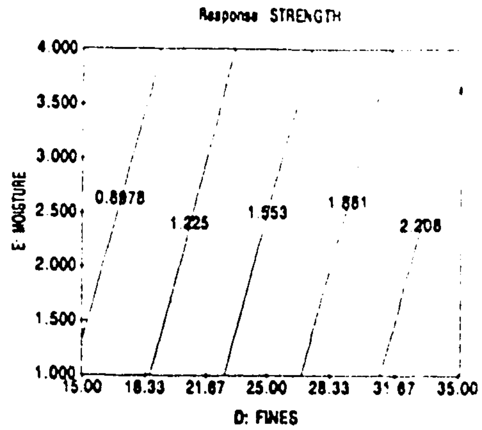
T-3 MINE versus BIRCHTREE MINE ANALYSIS

28 DAY CURING

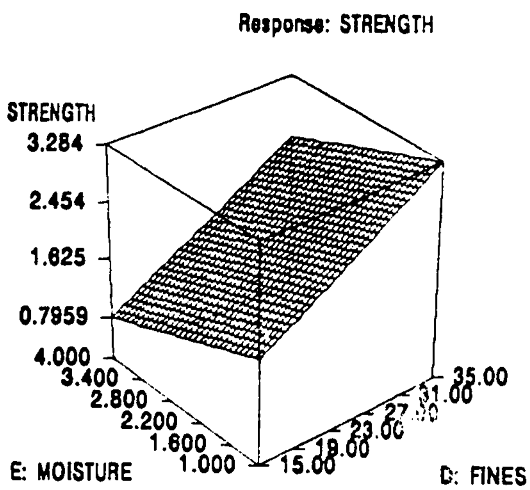
The final two-way interaction plots (page 37) compare the **fines versus aggregate moisture** at each of the two mines. Both of the plots indicate that the strength increases as the fines increase and the aggregate moisture decreases. The shallower (closer to 45 degree lines) of the Birchtree Mine represent a stronger two-way interaction effect than at the T-3 Mine. Because the fines and the moisture are the variables in this plot, the compressive strengths on the Birchtree plot are higher than those of the T-3 plot (the fines and the moisture are the usual causes for the comparitively lower Birchtree strengths). Due to the fact that Birchtree uses a slurry consisting of 100 percent portland cement and 0 percent flyash, this Birchtree plot indicates higher strengths than the T-3 plot (T-3 uses a weaker 50/50 slurry blend).

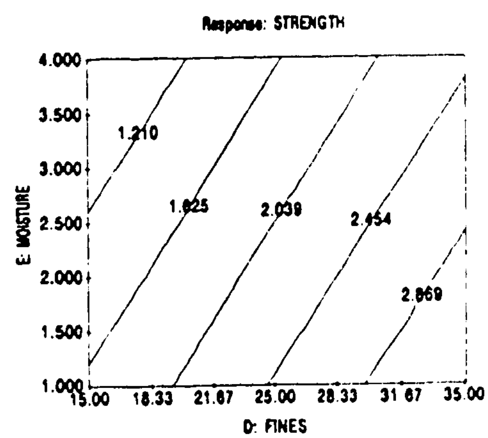
T−3 ROCKFILL @ 28 DAYS





BIRCHTREE ROCKFILL @ 28 DAYS





ROCKFILL SLURRY OPTIMIZATION

28 DAY CURING

The factorial design and the Design-ease software have enabled a strength estimation equation to be procured. By substituting a series of possible rockfill variables into the [illegible] the optimum theoretical slurry recipe can be determined. Once the optim[illegible] recipe is discovered, compressive strength cylinders can be tested to verify the reliability of the equation. If the equation proves to be accurate, the new optimum slurry recipe should be implemented at the minesite.

Four possible settings for each of the 5 factors have been chosen and substituted into the equation, they are as follows.

Binder percentage - (4.00%, 4.3[illegible], 4.66%, 5.00%),

Flyash percentage - (0%, 16.66[illegible] 33.33%, 50%),

Hydrafil addition - (0, 1.7, 3.4 [illegible] L/tonne binder),

Fines percentage - (15.0[illegible] [illegible]1.5%, 28.0%, 35.0%),

Moisture percentage - ([illegible], 2%, 3%, 4%).

The above [illegible] settings were entered into a wysiwyg spreadsheet and the estimated compressive strengths and the binder costs per tonne of rockfill were calculated for each possible slurry combination (1024 possible combinations). The 1024 slurry combinations were then sorted from highest to lowest compressive strength, allowing the cost effective slurry recipes to be determined easily.

The following 11 pages contain the 1024 ordered slurry recipes.

NOTE: When analyzing the following table for possible recipes, realize:

1) Birchtree has 4% aggregate moisture (unchangeable).

2) The minimum compressive strength from the tables (at 28 days) is **1.4 MPa**, which corresponds to a scaled strength (scaled against an OPC control mix) of 2.46 MPa at 28 days curing.

3) The current Birchtree binder cost is $6.93 per tonne of rockfill.

4) The current T-3 binder cost is $5.35 per tonne of rockfill.

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
5	0	5	36.0	1	4.32	7.43
5	16.7	5	36.0	1	4.07	6.61
5	0	3.4	36.0		3.97	7.27
5	33.3	5	36.0	1	3.82	6.38
4.66	0	5	36.0	1	3.79	6.83
5	0	5	28.0	1	3.78	7.43
5	16.7	3.4	36.0	1	3.73	6.75
5	0	5	36.0	2	3.66	7.43
5	0	1.7	36.0	1	3.61	7.10
5	50	5	36.0	1	3.57	5.86
4.66	16.7	5	36.0	1	3.53	6.44
5	16.7	5	28.0	1	3.51	6.61
5	33.3	3.4	36.0	1	3.46	6.22
5	16.7	5	36.0	2	3.46	6.61
4.66	0	3.4	36.0	1	3.43	6.78
5	0	3.4	36.0	2	3.43	7.27
5	0	3.4	28.0	1	3.41	7.27
5	16.7	1.7	36.0	1	3.38	6.56
4.66	0	5	28.0	1	3.32	6.83
4.66	33.3	5	36.0	1	3.28	5.85
5	33.3	5	36.0	2	3.27	6.38
5	33.3	5	28.0	1	3.26	6.38
4.33	0	5	36.0	1	3.25	6.44
5	0	0	36.0	1	3.25	6.83
5	0	5	21.5	1	3.24	7.43
5	16.7	3.4	36.0	2	3.24	6.75
5	50	3.4	36.0	1	3.23	5.88
4.66	0	5	36.0	2	3.19	6.83
5	0	1.7	36.0	2	3.16	7.10
4.66	16.7	3.4	36.0	1	3.18	6.29
5	16.7	3.4	28.0	1	3.17	6.75
5	33.3	1.7	36.0	1	3.11	6.06
5	0	5	28.0	2	3.08	7.43
5	50	5	36.0	2	3.08	5.86
4.66	16.7	5	28.0	1	3.07	6.44
4.66	0	1.7	36.0	1	3.07	6.82
5	0	1.7	28.0	1	3.06	7.10
5	33.3	3.4	36.0	2	3.06	6.22
4.66	50	5	36.0	1	3.03	5.45
5	50	5	28.0	1	3.01	5.86
4.66	16.7	5	36.0	2	3.00	6.44
4.33	16.7	5	36.0	1	3.00	5.88
5	16.7	0	36.0	1	3.00	6.41
5	16.7	1.7	36.0	2	3.00	6.56
5	16.7	5	21.5	1	2.99	6.61
5	0	5	36.0	3	2.98	7.43
4.66	0	3.4	28.0	1	2.98	6.78
4.66	0	3.4	36.0	2	2.97	6.78
5	0	0	36.0	2	2.95	6.83
4.66	33.3	3.4	36.0	1	2.94	5.80
5	33.3	3.4	28.0	1	2.92	6.22
4.33	0	3.4	36.0	1	2.91	6.30
5	16.7	5	28.0	2	2.90	6.61
4.66	0	5	21.5	1	2.90	6.83
4.33	0	5	28.0	1	2.90	6.44
5	0	3.4	21.5	1	2.90	7.27
5	0	3.4	36.0	3	2.88	7.27
5	0	3.4	28.0	2	2.87	7.27
5	50	1.7	36.0	1	2.86	5.35
5	50	3.4	36.0	2	2.85	5.88
5	16.7	5	36.0	3	2.86	6.61
4.66	33.3	5	28.0	1	2.82	5.86
4.66	16.7	1.7	36.0	1	2.82	6.13
4.66	33.3	5	36.0	2	2.81	5.88
5	33.3	1.7	36.0	2	2.81	6.06
5	16.7	1.7	28.0	1	2.80	6.56
4.66	16.7	3.4	36.0	2	2.78	6.29
5	0	1.7	36.0	3	2.77	7.10
5	16.7	0	36.0	2	2.76	6.41
4.33	33.3	5	36.0	1	2.75	5.35
4.33	0	5	36.0	2	2.75	6.44
5	33.3	0	36.0	1	2.75	5.88
5	16.7	3.4	36.0	3	2.75	6.75
5	33.3	5	21.5	1	2.74	6.38
4.66	[illegible]	5	28.0	2	2.74	6.83
4.66	[illegible]	1.7	36.0	2	2.73	6.60
4.66	16.7	3.4	28.0	1	2.73	6.29
4	0	5	36.0	1	2.72	5.88
5	33.3	5	36.0	3	2.72	6.38
5	0	5	15.0	1	2.72	7.43
5	33.3	5	28.0	2	2.71	6.38
4.66	0	0	36.0	1	2.71	6.44
5	0	0	28.0	1	2.69	6.83
4.66	50	3.4	36.0	1	2.69	5.30
5	16.7	3.4	28.0	2	2.68	6.75
[illegible]	50	3.4	28.0	1	2.67	5.88
4.33	16.7	3.4	36.0	1	2.66	5.84
[illegible]	0	0	36.0	3	2.66	6.80
[illegible]	16.7	5	21.5	1	2.65	6.44
[illegible]	16.7	5	28.0	1	2.65	5.86
5	16.7	3.4	21.5	1	2.65	6.75
5	16.7	1.7	36.0	3	2.63	6.56
5	0	1.7	28.0	2	2.63	7.10
4.66	50	5	36.0	2	2.62	5.46
5	50	1.7	36.0	2	2.62	5.52
4.66	0	5	36.0	3	2.61	6.80
5	33.3	3.4	36.0	3	2.61	6.22
4.66	0	1.7	28.0	1	2.61	6.82
4.66	33.3	3.4	36.0	2	2.56	5.80

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
5	50	5	35.0	3	2.58	5.85
4.66	50	5	28.0	1	2.57	5.45
5	0	5	21.5	2	2.57	7.43
4.66	33.3	1.7	35.0	1	2.57	5.84
5	33.3	0	35.0	2	2.57	5.88
4.33	0	5	21.5	1	2.57	6.44
4.33	16.7	5	35.0	2	2.56	5.88
4.66	0	3.4	21.5	1	2.55	6.78
5	33.3	1.7	28.0	1	2.56	8.06
4.33	0	3.4	28.0	1	2.56	6.30
4.66	16.7	5	28.0	2	2.55	6.44
4.33	0	1.7	35.0	1	2.54	6.15
4.66	16.7	1.7	35.0	2	2.54	6.13
5	0	1.7	21.5	1	2.53	7.10
4.33	0	3.4	35.0	2	2.53	6.30
5	16.7	0	35.0	3	2.52	6.41
5	50	5	28.0	2	2.52	5.85
4.66	0	3.4	28.0	2	2.52	6.78
4.66	0	3.4	35.0	3	2.51	6.78
4.33	50	5	35.0	1	2.50	5.07
5	33.3	1.7	35.0	2	2.50	6.06
5	50	0	35.0	1	2.50	5.36
4.66	0	0	35.0	2	2.49	6.46
5	50	5	21.5	1	2.49	5.85
5	33.3	3.4	28.0	2	2.48	6.22
4.66	16.7	5	35.0	3	2.48	6.44
5	50	3.4	35.0	3	2.48	5.88
4.66	33.3	3.4	28.0	1	2.48	5.80
4.66	0	5	15.0	1	2.47	6.83
4	16.7	5	35.0	1	2.47	5.52
4	0	5	28.0	1	2.47	5.86
5	16.7	5	15.0	1	2.47	6.81
4.66	16.7	0	35.0	1	2.46	5.87
5	16.7	0	28.0	1	2.44	6.41
5	16.7	1.7	28.0	2	2.44	6.58
5	0	5	28.0	3	2.43	7.43
4.33	33.3	3.4	35.0	1	2.41	5.36
4.66	33.3	5	21.5	1	2.40	5.86
4.33	33.3	5	28.0	1	2.40	5.53
5	33.3	3.4	21.5	1	2.40	6.22
4.66	50	3.4	35.0	2	2.40	5.30
4.33	0	5	28.0	2	2.40	6.44
4.66	0	1.7	35.0	3	2.40	6.62
5	0	0	28.0	2	2.39	6.83
5	33.3	0	35.0	3	2.39	5.88
4	0	3.4	35.0	1	2.38	5.82
5	16.7	5	21.5	2	2.38	6.81
5	50	0	35.0	2	2.38	5.36
5	0	3.4	15.0	1	2.38	7.27
4.66	16.7	3.4	35.0	3	2.37	6.78
4.33	33.3	5	35.0	2	2.37	5.53
5	50	1.7	35.0	3	2.37	5.52
4.66	16.7	1.7	28.0	1	2.36	6.13
4.66	33.3	5	28.0	2	2.36	5.86
5	0	0	35.0	4	2.36	6.80
4.66	33.3	1.7	35.0	2	2.36	5.64
4.66	33.3	5	35.0	3	2.36	5.86
5	0	3.4	21.5	2	2.36	7.27
5	0	1.7	35.0	4	2.34	7.10
4.33	16.7	3.4	35.0	2	2.34	5.84
5	0	3.4	35.0	4	2.33	7.27
4.66	16.7	3.4	28.0	2	2.32	6.29
4.66	50	1.7	35.0	1	2.32	5.15
5	0	5	35.0	4	2.32	7.43
5	0	3.4	28.0	3	2.32	7.27
4.33	16.7	5	21.5	1	2.32	5.88
4.66	0	5	21.5	2	2.32	6.80
4	0	5	35.0	2	2.31	5.85
4.66	16.7	3.4	21.5	1	2.31	6.29
5	50	1.7	28.0	1	2.30	5.32
4.33	16.7	3.4	28.0	1	2.30	5.84
4.66	16.7	0	35.0	2	2.30	5.87
5	50	3.4	28.0	2	2.30	5.69
4.33	16.7	1.7	35.0	1	2.29	5.69
5	16.7	5	28.0	3	2.29	6.81
4.33	0	1.7	35.0	2	2.29	6.15
4.66	0	0	35.0	3	2.28	6.46
5	16.7	0	35.0	4	2.28	6.41
5	16.7	1.7	21.5	1	2.28	6.58
4.66	0	1.7	28.0	2	2.28	6.62
5	16.7	1.7	35.0	4	2.27	6.58
4.66	16.7	1.7	35.0	3	2.26	6.13
5	16.7	3.4	35.0	4	2.26	6.75
5	50	0	35.0	3	2.26	5.35
4.33	0	5	35.0	3	2.25	6.44
4.66	0	0	28.0	1	2.25	6.46
5	33.3	1.7	28.0	2	2.25	6.06
5	16.7	5	35.0	4	2.25	6.81
4.66	33.3	3.4	35.0	3	2.24	5.80
4.33	0	5	15.0	1	2.24	6.44
4	0	5	21.5	1	2.24	5.85
4.66	50	3.4	28.0	1	2.23	5.30
4	33.3	5	35.0	1	2.23	5.10
4.66	16.7	5	15.0	1	2.23	6.44
4.33	0	3.4	21.5	1	2.22	6.30
4	16.7	5	28.0	1	2.22	5.52
5	33.3	5	15.0	1	2.22	6.36
4.66	50	5	35.0	3	2.22	5.45
4.66	33.3	0	35.0	1	2.21	5.48

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
5	33.3	5	35.0	4	2.21	5.88
5	0	1.7	28.0	3	2.21	7.10
4.33	16.7	5	28.0	2	2.21	5.88
5	16.7	0	28.0	2	2.20	6.41
5	33.3	1.7	35.0	4	2.20	6.05
4.66	0	1.7	21.5	1	2.19	6.62
5	33.3	5	21.5	2	2.19	6.38
5	33.3	0	28.0	1	2.19	5.88
4.33	0	1.7	28.0	1	2.19	6.15
5	16.7	3.4	28.0	3	2.19	6.75
5	33.3	3.4	35.0	4	2.18	6.22
4.33	0	0	35.0	1	2.18	6.01
4.33	50	5	35.0	2	2.18	5.07
4.33	0	3.4	28.0	2	2.17	6.30
5	33.3	5	35.0	4	2.17	6.38
5	0	0	21.5	1	2.17	6.93
4.66	50	5	28.0	2	2.17	5.45
4.33	50	3.4	35.0	1	2.16	4.83
5	33.3	5	28.0	3	2.16	6.38
4.66	50	1.7	35.0	2	2.16	5.15
4.66	0	5	28.0	3	2.16	6.83
5	16.7	3.4	21.5	2	2.16	6.75
4.66	50	5	21.5	1	2.15	5.45
4.66	16.7	0	35.0	3	2.15	5.07
4.33	50	5	28.0	1	2.15	5.07
5	50	3.4	21.5	1	2.15	5.88
4.33	0	3.4	35.0	3	2.15	6.30
4.33	33.3	3.4	35.0	2	2.15	5.38
4.66	33.3	3.4	28.0	2	2.13	5.80
5	50	0	35.0	4	2.13	5.38
4.66	0	3.4	15.0	1	2.13	6.78
4	16.7	3.4	35.0	1	2.13	5.40
4.66	33.3	1.7	35.0	3	2.13	5.84
4	0	3.4	28.0	1	2.13	5.82
5	16.7	3.4	15.0	1	2.13	6.75
4.66	16.7	5	21.5	2	2.13	6.44
4.33	16.7	5	35.0	3	2.12	5.88
5	50	1.7	35.0	4	2.12	5.52
4	16.7	5	35.0	2	2.12	5.52
4.66	33.3	1.7	28.0	1	2.12	5.84
4.66	33.3	0	35.0	2	2.11	5.48
5	0	1.7	21.5	2	2.11	7.10
4.66	50	3.4	35.0	3	2.11	5.30
5	50	3.4	35.0	4	2.11	5.88
4.33	16.7	1.7	35.0	2	2.10	5.88
5	50	5	35.0	4	2.10	5.86
5	0	0	28.0	3	2.09	6.83
4.66	0	3.4	21.5	2	2.09	6.78
4.66	16.7	1.7	28.0	2	2.09	6.13
4	0	3.4	35.0	2	2.08	5.82
5	16.7	1.7	28.0	3	2.07	6.56
4.66	0	0	35.0	4	2.07	6.48
4.33	33.3	5	21.5	1	2.07	5.53
4.33	0	5	21.5	2	2.07	6.44
4.66	0	1.7	35.0	4	2.06	6.62
4.66	33.3	3.4	21.5	1	2.06	5.80
5	50	1.7	28.0	2	2.06	5.32
4.33	33.3	3.4	28.0	1	2.06	5.38
4	0	5	28.0	2	2.06	5.86
5	33.3	3.4	28.0	3	2.06	6.22
4.66	0	3.4	28.0	3	2.06	6.78
5	0	5	15.0	2	2.05	7.43
4.33	0	0	35.0	2	2.05	6.01
4.33	33.3	1.7	35.0	1	2.05	5.24
4.66	0	3.4	35.0	4	2.05	6.78
4.66	0	0	28.0	2	2.04	6.48
4.33	0	1.7	35.0	3	2.03	6.15
5	33.3	1.7	21.5	1	2.03	6.08
4.66	0	5	35.0	4	2.03	6.83
5	50	5	28.0	3	2.03	5.80
4.66	16.7	5	28.0	3	2.03	6.44
4	0	1.7	35.0	1	2.02	5.88
4.66	33.3	0	35.0	3	2.02	5.48
4.33	33.3	5	28.0	2	2.02	5.53
4.33	16.7	3.4	35.0	3	2.01	5.84
5	0	1.7	15.0	1	2.01	7.10
5	33.3	0	28.0	2	2.01	5.86
4	0	5	15.0	1	2.00	5.86
4.66	16.7	0	28.0	1	2.00	5.87
5	50	5	21.5	2	2.00	5.86
4.66	50	1.7	35.0	3	2.00	5.15
4.66	16.7	0	35.0	4	2.00	5.87
4.33	16.7	5	15.0	1	1.99	5.88
4.33	33.3	5	35.0	3	1.99	5.53
4	16.7	5	21.5	1	1.99	5.52
4.66	16.7	1.7	35.0	4	1.99	6.13
4.33	16.7	3.4	28.0	2	1.98	5.64
4.66	33.3	5	15.0	1	1.98	5.80
4	50	5	35.0	1	1.98	4.88
4.33	16.7	3.4	21.5	1	1.98	5.24
4	33.3	5	28.0	1	1.97	5.10
5	50	5	15.0	1	1.97	5.86
4.66	16.7	3.4	35.0	4	1.97	6.29
5	33.3	3.4	21.5	2	1.97	6.22
5	16.7	0	28.0	3	1.96	6.41
4.66	50	0	35.0	1	1.96	4.88
4.66	16.7	5	35.0	4	1.96	6.44
4.33	50	3.4	35.0	2	1.95	4.80
4.66	50	3.4	28.0	2	1.94	5.30

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS	
4.66	16.7	1.7	21.5	1	1.94	6.13	
5	33.3	1.7	28.0	3	1.94	6.05	
5	50	0	28.0	1	1.94	5.35	T-3 CURREN
4.66	0	1.7	28.0	3	1.94	6.67	
4.33	16.7	1.7	28.0	1	1.94	5.89	
4.66	33.3	5	21.5	2	1.94	5.86	
4.33	0	1.7	28.0	2	1.94	6.15	
4.33	16.7	0	35.0	1	1.93	5.86	
4	33.3	5	35.0	2	1.93	6.10	
4.33	0	0	35.0	3	1.92	6.01	
4.66	33.3	0	35.0	4	1.92	5.48	
4.66	50	0	35.0	2	1.92	4.89	
5	50	3.4	28.0	3	1.92	6.88	
4.66	16.7	3.4	28.0	3	1.92	6.29	
5	16.7	0	21.5	1	1.92	6.61	
5	16.7	1.7	21.5	2	1.92	6.59	
4.66	33.3	1.7	28.0	4	1.91	5.64	
4.33	33.3	1.7	35.0	2	1.91	5.24	
5	0	5	21.5	3	1.91	7.43	
4.33	16.7	1.7	35.0	3	1.90	6.68	
4.66	16.7	3.4	21.5	2	1.90	6.29	
4.33	0	5	28.0	3	1.90	6.44	
4.66	33.3	3.4	35.0	4	1.90	5.80	
4.33	0	3.4	15.0	1	1.90	6.20	
4.66	33.3	1.7	28.0	2	1.90	6.64	
4.66	0	5	15.0	2	1.89	6.93	
4	0	3.4	21.5	1	1.89	5.82	
4.66	33.3	5	28.0	3	1.89	5.66	
4	0	5	35.0	3	1.89	5.86	
4	16.7	3.4	35.0	2	1.89	6.40	
4	33.3	3.4	35.0	1	1.89	4.98	
4.66	33.3	5	35.0	4	1.88	5.95	
4.66	50	0	35.0	3	1.88	4.99	
4.66	16.7	3.4	15.0	1	1.88	6.28	
4.33	33.3	3.4	35.0	3	1.88	5.38	
4	16.7	3.4	28.0	1	1.88	6.40	
5	33.3	3.4	15.0	1	1.88	6.22	
4.33	16.7	5	21.5	2	1.88	5.98	
5	0	0	21.5	2	1.87	6.93	
4.66	50	1.7	28.0	1	1.87	6.18	
4	16.7	5	28.0	2	1.86	6.82	
5	16.7	5	15.0	2	1.86	6.91	
4.33	0	1.7	21.5	1	1.86	6.16	
4.33	16.7	0	35.0	2	1.86	5.56	
4.33	50	5	35.0	3	1.86	5.07	
4.66	0	1.7	21.5	2	1.85	6.62	
4.66	16.7	0	28.0	2	1.85	5.87	
4.66	50	0	35.0	4	1.85	4.89	
4	0	1.7	35.0	2	1.85	5.68	
4.33	0	3.4	21.5	2	1.84	6.30	
4.66	50	1.7	35.0	4	1.83	5.15	
4	0	3.4	28.0	2	1.83	5.82	
5	33.3	0	28.0	3	1.83	5.86	
5	0	3.4	15.0	2	1.83	7.27	
4.66	0	0	28.0	3	1.83	6.46	
4.66	0	0	21.5	1	1.83	6.40	
4.33	0	0	28.0	1	1.83	6.01	
4.33	50	5	28.0	2	1.83	5.07	
4	0	5	21.5	2	1.82	5.95	
4.66	50	3.4	35.0	4	1.82	5.30	
4.33	50	5	21.5	1	1.82	5.07	
5	50	0	28.0	1	1.82	6.38	
4.66	50	5	35.0	4	1.81	5.48	
5	50	1.7	28.0	3	1.81	5.52	
4.66	50	3.4	21.5	1	1.81	5.30	
4.66	16.7	1.7	28.0	3	1.81	6.13	
4.33	50	3.4	28.0	1	1.81	4.83	
5	0	3.4	21.5	3	1.80	7.27	
5	0	0	28.0	4	1.80	5.93	
4.33	50	1.7	35.0	1	1.80	4.78	
4.33	0	3.4	28.0	3	1.79	6.30	
4.33	0	0	35.0	4	1.79	6.01	
4.33	33.3	3.4	28.0	2	1.79	5.38	
4.33	16.7	0	35.0	3	1.79	5.55	
4.66	33.3	3.4	28.0	3	1.79	6.00	
4	0	3.4	35.0	3	1.79	5.62	
5	50	1.7	21.5	1	1.79	5.62	
5	0	1.7	28.0	4	1.79	7.10	
4.33	0	1.7	35.0	4	1.78	6.16	
5	50	3.4	21.5	2	1.78	5.80	
5	16.7	5	21.5	3	1.77	6.91	
5	0	3.4	28.0	4	1.77	7.27	
4.33	33.3	1.7	35.0	3	1.77	5.24	
4.66	0	1.7	15.0	1	1.77	6.82	
4	16.7	1.7	35.0	1	1.77	5.28	
4.33	0	3.4	35.0	4	1.77	6.30	
4.33	16.7	5	28.0	3	1.77	5.86	
4	0	1.7	28.0	1	1.76	6.08	
5	16.7	1.7	15.0	1	1.76	6.94	
5	0	5	28.0	4	1.76	7.43	
4.66	50	5	28.0	3	1.76	5.45	
4	16.7	5	35.0	3	1.76	5.62	
4.33	0	5	35.0	4	1.76	6.44	
4.66	33.3	0	28.0	1	1.76	5.48	
4	16.7	5	15.0	1	1.76	5.62	
4.33	50	3.4	35.0	3	1.75	4.83	
4.66	50	5	21.5	2	1.74	5.45	
4.33	16.7	1.7	28.0	2	1.74	5.80	
4.33	33.3	5	15.0	1	1.74	5.63	

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4.33	0	5	15.0	2	1.74	5.44
4	33.3	5	21.5	1	1.74	5.10
4.66	0	5	21.5	3	1.74	6.60
4	50	5	35.0	2	1.74	4.66
5	33.3	1.7	21.5	2	1.73	6.00
4.66	50	5	15.0	1	1.73	5.46
4.33	33.3	3.4	21.5	1	1.73	5.38
4	50	5	28.0	1	1.72	4.66
5	16.7	0	28.0	4	1.72	6.41
4.33	16.7	0	35.0	4	1.72	5.55
4.33	50	1.7	35.0	2	1.72	4.78
4.66	33.3	3.4	21.5	2	1.71	5.80
5	16.7	1.7	28.0	4	1.71	6.58
4.33	16.7	1.7	35.0	4	1.71	5.66
4.66	50	1.7	28.0	2	1.70	5.15
4.66	16.7	5	15.0	2	1.70	6.44
4	33.3	3.4	35.0	2	1.70	4.66
5	16.7	3.4	28.0	4	1.70	6.75
4.33	0	0	28.0	2	1.70	6.01
5	50	0	28.0	3	1.70	5.30
4.66	16.7	0	28.0	3	1.69	5.87
4.66	33.3	1.7	21.5	1	1.69	4.84
4.33	16.7	3.4	35.0	4	1.69	5.84
4.33	33.3	1.7	28.0	1	1.69	5.24
4.33	33.3	5	21.5	2	1.69	5.53
5	0	1.7	21.5	3	1.69	7.10
5	16.7	5	28.0	4	1.68	6.81
4.33	33.3	0	35.0	1	1.68	5.09
4.33	0	1.7	28.0	3	1.68	6.15
4.33	16.7	5	35.0	4	1.68	5.66
5	16.7	0	21.5	2	1.68	6.41
4.66	33.3	1.7	28.0	3	1.67	5.64
4	33.3	5	28.0	2	1.67	5.10
4	0	1.7	35.0	3	1.67	5.66
5	33.3	5	15.0	2	1.67	6.38
5	33.3	0	21.5	1	1.67	5.26
4.66	0	3.4	15.0	2	1.67	6.78
4.33	33.3	0	35.0	2	1.67	5.09
5	16.7	3.4	21.5	3	1.67	6.75
4.66	16.7	1.7	21.5	2	1.66	6.13
4.33	16.7	3.4	28.0	3	1.66	5.64
4	0	3.4	15.0	1	1.66	5.62
4.66	33.3	0	28.0	2	1.66	5.46
4.33	33.3	0	35.0	3	1.66	5.09
4	16.7	1.7	35.0	2	1.65	5.26
4.66	50	3.4	28.0	3	1.65	5.30
4	16.7	3.4	35.0	3	1.65	5.40
4	0	0	35.0	1	1.65	5.56
4.33	16.7	3.4	21.5	2	1.65	5.84
5	33.3	0	28.0	4	1.65	5.88
5	0	0	15.0	1	1.65	6.63
4.33	16.7	3.4	15.0	1	1.65	5.64
4	16.7	3.4	21.5	1	1.64	5.40
4.33	33.3	0	35.0	4	1.64	5.09
5	33.3	5	21.5	3	1.64	6.38
4	0	5	28.0	3	1.64	5.66
4	16.7	3.4	28.0	2	1.64	5.40
5	16.7	3.4	15.0	2	1.64	6.75
4.33	50	1.7	35.0	3	1.64	4.78
5	33.3	1.7	28.0	4	1.64	6.06
4.66	33.3	3.4	15.0	1	1.64	5.80
4	50	3.4	35.0	1	1.63	4.55
4.33	33.3	5	28.0	3	1.63	5.53
4	33.3	3.4	28.0	1	1.63	4.88
4.33	33.3	1.7	35.0	4	1.63	5.24
4.66	0	3.4	21.5	3	1.63	6.78
4	16.7	5	21.5	2	1.63	5.82
5	50	3.4	15.0	1	1.63	5.88
4	33.3	5	35.0	3	1.63	5.10
5	33.3	3.4	28.0	4	1.62	6.22
4.33	33.3	3.4	35.0	4	1.62	5.36
4.66	0	0	28.0	4	1.62	6.48
4.66	0	0	21.5	2	1.62	6.48
4.33	16.7	1.7	21.5	1	1.61	5.88
5	33.3	5	28.0	4	1.61	6.38
4	0	0	35.0	2	1.61	5.88
4.33	0	1.7	21.5	2	1.61	6.15
4.33	33.3	5	35.0	4	1.61	5.53
4.66	0	1.7	28.0	4	1.60	6.62
4.66	16.7	5	21.5	3	1.60	6.44
4.33	50	3.4	28.0	2	1.60	4.83
4	0	3.4	21.5	3	1.60	5.82
4	0	1.7	28.0	2	1.59	5.88
4.66	0	3.4	28.0	4	1.59	6.76
5	0	1.7	15.0	2	1.59	7.10
4	0	5	15.0	2	1.59	5.96
4.66	0	5	28.0	4	1.58	6.83
4.66	16.7	0	21.5	1	1.58	5.87
4.33	16.7	0	28.0	1	1.58	5.56
5	0	0	21.5	3	1.58	6.83
5	50	0	28.0	4	1.57	5.35
4.33	0	5	21.5	3	1.57	6.44
4.33	50	0	35.0	4	1.57	4.83
4.33	0	0	28.0	3	1.57	6.01
4.66	33.3	0	28.0	3	1.56	5.48
4	0	0	35.0	3	1.56	5.56
5	50	1.7	28.0	4	1.56	5.52
4.33	50	1.7	35.0	4	1.56	4.78
5	16.7	1.7	21.5	3	1.56	6.28

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4.33	33.3	1.7	28.0	2	1.55	5.24
4.33	16.7	5	15.0	2	1.55	5.98
4.33	16.7	1.7	28.0	3	1.55	5.69
5	50	3.4	28.0	4	1.55	5.89
4.33	50	3.4	35.0	4	1.54	4.83
4.66	50	1.7	28.0	3	1.54	5.15
4	16.7	1.7	35.0	3	1.54	5.26
4.66	16.7	0	28.0	4	1.54	5.97
5	50	1.7	21.5	2	1.54	5.52
5	50	5	28.0	4	1.54	5.85
5	33.3	3.4	21.5	3	1.54	6.22
4	0	3.4	28.0	3	1.53	5.82
4.33	0	1.7	15.0	1	1.53	6.15
4.33	50	5	35.0	4	1.53	5.07
4	0	1.7	21.5	1	1.53	5.88
4.66	16.7	1.7	28.0	4	1.53	6.13
4.33	33.3	3.4	28.0	3	1.53	5.39
4.33	50	0	35.0	3	1.52	4.63
4	33.3	3.4	35.0	3	1.52	4.98
4	33.3	1.7	35.0	1	1.52	4.84
4.66	50	3.4	21.5	2	1.52	5.30
4.66	16.7	1.7	15.0	1	1.52	6.13
4.66	0	1.7	21.5	3	1.52	6.82
4.33	0	3.4	15.0	2	1.52	6.30
4	0	0	35.0	4	1.52	5.55
4	16.7	1.7	28.0	1	1.52	5.26
4.66	16.7	3.4	28.0	4	1.52	6.29
5	33.3	1.7	15.0	1	1.52	6.05
4.66	33.3	5	15.0	2	1.51	5.86
4	50	3.4	35.0	2	1.51	4.56
5	50	5	21.5	3	1.51	5.85
4	16.7	5	28.0	3	1.51	5.52
4.33	16.7	0	28.0	2	1.51	5.56
4	33.3	5	15.0	1	1.50	5.10
4.66	50	0	28.0	1	1.50	4.99
4.66	16.7	5	28.0	4	1.50	6.44
4	0	1.7	35.0	4	1.50	5.68
4.33	50	5	28.0	3	1.50	5.07
4.66	16.7	3.4	21.5	3	1.50	6.29
4.33	0	0	21.5	1	1.50	6.01
4.33	50	5	21.5	2	1.50	5.07
4	50	5	35.0	3	1.49	4.68
4.33	50	5	15.0	1	1.49	5.07
5	33.3	0	21.5	2	1.49	5.88
4	0	3.4	35.0	4	1.49	5.82
4	50	5	21.5	1	1.49	4.68
4	50	5	28.0	2	1.48	4.66
5	50	5	15.0	2	1.48	5.89
4.66	16.7	3.4	15.0	2	1.48	6.29
4.33	50	0	35.0	2	1.48	4.63
4.33	50	3.4	21.5	1	1.48	4.93
4	0	5	35.0	4	1.48	5.96
4.66	33.3	1.7	21.5	2	1.47	5.64
4.66	33.3	5	21.5	3	1.47	5.86
4.66	33.3	0	28.0	4	1.47	5.48
4.66	50	0	28.0	2	1.47	4.99
4.33	0	3.4	21.5	3	1.47	6.30
4	33.3	1.7	35.0	2	1.46	4.84
4.33	33.3	3.4	21.5	2	1.46	5.39
4.66	33.3	1.7	28.0	4	1.45	5.84
4	33.3	3.4	28.0	2	1.45	4.98
5	33.3	3.4	15.0	2	1.45	6.22
4.66	50	1.7	21.5	1	1.44	5.15
4.33	50	1.7	28.0	1	1.44	4.78
5	16.7	0	21.5	3	1.44	6.41
4.66	33.3	3.4	28.0	4	1.44	5.80
4	16.7	0	35.0	4	1.44	5.12
4	33.3	5	21.5	2	1.44	5.10
4.33	0	0	28.0	4	1.44	6.01
4.33	16.7	5	21.5	3	1.44	5.98
4.33	16.7	0	28.0	3	1.44	5.55
4.33	50	0	35.0	1	1.43	4.63
4.66	0	1.7	15.0	2	1.43	6.62
4.66	33.3	5	28.0	4	1.43	5.86
4.66	50	0	28.0	3	1.43	4.99
4	16.7	0	35.0	3	1.43	5.12
4	16.7	1.7	35.0	4	1.43	5.26
4.33	0	1.7	28.0	4	1.43	6.15
4.66	16.7	0	21.5	2	1.42	5.97
5	33.3	1.7	21.5	3	1.42	6.06
4	0	1.7	28.0	3	1.42	5.68
5	50	0	21.5	1	1.42	5.35
4	16.7	0	35.0	2	1.42	5.12
4.33	33.3	1.7	28.0	3	1.42	5.24
4.33	16.7	1.7	21.5	2	1.42	5.69
4	16.7	3.4	35.0	4	1.42	5.40
4.33	0	3.4	28.0	4	1.41	6.30
4	16.7	3.4	15.0	1	1.41	5.40
4	33.3	1.7	35.0	3	1.41	4.84
4	0	5	21.5	3	1.41	5.86
4	16.7	3.4	21.5	2	1.41	5.40
4.66	0	0	21.5	3	1.40	6.46
4.66	0	0	15.0	1	1.40	6.46
4	16.7	0	35.0	1	1.40	5.12
4	16.7	5	35.0	4	1.40	5.52
4	16.7	1.7	28.0	2	1.40	5.28
4.33	0	5	28.0	4	1.40	6.44
5	50	3.4	21.5	3	1.40	5.68
4	16.7	3.4	28.0	3	1.40	5.40

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4	0	0	28.0	1	1.40	5.58
5	16.7	0	15.0	1	1.40	6.41
5	16.7	1.7	15.0	2	1.40	6.58
4.33	33.3	3.4	15.0	1	1.40	5.38
4	33.3	3.4	21.5	1	1.40	4.88
4	16.7	5	15.0	2	1.40	5.57
4.33	50	3.4	28.0	3	1.40	4.91
4.66	50	0	28.0	4	1.39	4.80
4	50	3.4	35.0	3	1.39	4.55
5	0	5	15.0	3	1.39	5.43
4.66	50	3.4	15.0	1	1.38	5.30
4.66	16.7	1.7	21.5	3	1.38	6.13
4	50	3.4	28.0	1	1.38	4.55
4.66	50	1.7	28.0	4	1.38	5.15
4	33.3	5	28.0	3	1.38	5.10
4.33	0	0	21.5	2	1.37	6.0
4	33.3	0	35.0	4	1.37	4.70
4.66	50	3.4	28.0	4	1.37	5.30
4.66	33.3	3.4	21.5	3	1.36	5.80
4.33	16.7	0	28.0	4	1.36	5.50
4.33	33.3	1.7	21.5	1	1.36	5.24
4.33	50	1.7	28.0	2	1.36	4.78
4	0	3.4	15.0	2	1.36	5.82
4.33	33.3	5	15.0	2	1.36	5.53
4	0	1.7	21.5	2	1.36	5.88
4	0	0	28.0	2	1.36	5.55
4.66	50	5	28.0	4	1.36	5.45
4	33.3	1.7	35.0	4	1.36	4.84
4.33	0	1.7	21.5	3	1.35	6.15
5	0	0	15.0	2	1.35	6.93
4.33	16.7	1.7	28.0	4	1.35	5.86
4	33.3	3.4	35.0	4	1.34	4.98
4.33	16.7	3.4	28.0	4	1.34	5.84
4.66	50	5	21.5	3	1.34	5.45
4.33	16.7	3.4	21.5	3	1.33	5.84
4.66	33.3	0	21.5	1	1.33	5.64
4.33	33.3	0	28.0	1	1.33	5.08
4	33.3	5	35.0	4	1.33	5.10
4.33	16.7	5	28.0	4	1.33	5.98
4.33	16.7	3.4	15.0	2	1.33	5.84
4.66	50	5	15.0	2	1.32	5.45
4.33	33.3	0	28.0	2	1.32	5.08
4.66	0	5	15.0	3	1.31	6.83
5	33.3	0	21.5	3	1.31	5.88
4	0	0	28.0	3	1.31	5.56
4.33	33.3	5	21.5	3	1.31	5.53
4.33	33.3	0	28.0	3	1.30	5.09
4	0	3.4	21.5	3	1.30	5.82
5	50	0	21.5	2	1.30	5.36
4	33.3	0	35.0	3	1.30	4.70
4	0	1.7	15.0	1	1.30	5.88
4	50	0	35.0	4	1.29	4.28
4.33	33.3	0	28.0	4	1.29	5.08
5	50	1.7	21.5	3	1.29	5.52
4.66	33.3	3.4	15.0	2	1.29	5.80
4	16.7	1.7	28.0	3	1.29	5.28
4.33	6.7	1.7	15.0	1	1.29	5.89
4.33	50	1.7	28.0	3	1.29	4.78
4.66	50	1.7	21.5	2	1.28	5.15
4	16.7	1.7	21.5	1	1.28	5.28
5	0	3.4	15.0	3	1.28	7.27
5	0	0	21.5	4	1.28	6.83
4	50	1.7	35.0	4	1.28	4.42
4.33	0	1.7	15.0	2	1.28	6.15
4.33	33.3	1.7	28.0	4	1.28	5.24
4	50	1.7	35.0	3	1.28	4.42
4	50	1.7	35.0	2	1.27	4.42
4	16.7	5	21.5	3	1.27	5.52
4.33	50	3.4	21.5	2	1.27	4.80
4.66	16.7	0	21.5	3	1.27	5.97
4.66	33.3	1.7	15.0	1	1.27	5.64
4	50	1.7	35.0	1	1.27	4.42
4	33.3	3.4	28.0	3	1.27	4.88
4	33.3	1.7	28.0	1	1.27	4.84
5	50	1.7	15.0	1	1.27	5.52
5	0	1.7	21.5	4	1.27	7.10
4	50	3.4	35.0	4	1.27	4.56
4.33	33.3	3.4	28.0	4	1.26	5.38
4	0	0	28.0	4	1.26	5.90
4	50	3.4	28.0	2	1.26	4.56
5	50	3.4	15.0	2	1.26	5.88
4	50	5	15.0	1	1.26	4.88
5	16.7	5	15.0	3	1.25	6.81
4	50	5	35.0	4	1.25	4.88
5	0	3.4	21.5	4	1.25	7.27
4.33	33.3	5	28.0	4	1.25	5.53
4.66	33.3	1.7	21.5	3	1.25	5.64
4	0	1.7	28.0	4	1.25	5.88
4	50	8	21.5	2	1.25	4.88
4.33	16.7	0	21.5	1	1.25	5.56
4.33	0	5	15.0	3	1.24	6.44
4	50	5	28.0	3	1.24	4.88
5	0	8	21.5	4	1.24	7.43
4.66	16.7	1.7	15.0	2	1.24	6.13
4.33	0	0	21.5	3	1.24	6.01
4	0	3.4	28.0	4	1.24	5.82
4.66	33.3	0	21.5	2	1.23	5.48
4.66	50	3.4	21.5	3	1.23	5.30
4	33.3	0	35.0	2	1.23	[illegible]

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4	0	5	28.0	4	1.23	5.86
4.33	33.3	1.7	21.5	2	1.23	5.24
4.33	16.7	1.7	21.5	3	1.22	5.80
4	33.3	3.4	21.5	2	1.22	4.98
4.33	50	0	28.0	4	1.21	4.83
4	33.3	1.7	28.0	2	1.21	4.64
5	33.3	1.7	15.0	2	1.21	6.06
4.66	0	3.4	15.0	3	1.21	6.78
4	33.3	5	15.0	2	1.21	5.10
5	16.7	0	21.5	4	1.20	6.41
4.33	50	1.7	28.0	4	1.20	4.78
4.33	33.3	3.4	21.5	3	1.20	5.39
4.66	0	0	21.5	4	1.19	6.46
4.66	0	0	15.0	2	1.18	6.46
5	16.7	1.7	21.5	4	1.19	6.56
4.33	50	3.4	28.0	4	1.18	4.80
4	16.7	0	28.0	4	1.19	5.12
4	0	1.7	21.5	3	1.18	5.08
4.66	0	1.7	21.5	4	1.18	6.62
4.66	16.7	5	15.0	3	1.18	6.44
5	16.7	3.4	21.5	4	1.18	6.75
4.33	50	5	28.0	4	1.18	5.07
4.33	16.7	0	21.5	2	1.18	5.56
5	50	0	21.5	3	1.18	5.36
4	16.7	0	28.0	3	1.18	5.12
4	16.7	1.7	28.0	4	1.18	5.20
4.33	50	5	21.5	3	1.17	5.07
4	0	5	15.0	3	1.17	5.86
4	16.7	3.4	15.0	2	1.17	5.40
4.33	50	0	28.0	3	1.17	4.83
4.33	0	0	15.0	1	1.17	6.01
5	0	1.7	15.0	3	1.17	7.10
4.66	0	3.4	21.5	4	1.17	6.78
4.33	50	5	15.0	2	1.17	5.07
4	16.7	1.7	21.5	2	1.17	5.28
4	16.7	3.4	21.5	3	1.17	5.40
4	0	0	21.5	1	1.17	5.56
5	16.7	5	21.5	4	1.17	6.81
4	16.7	0	28.0	2	1.16	5.12
4	50	0	36.0	3	1.16	4.28
4	16.7	3.4	28.0	4	1.16	5.40
4	33.3	3.4	15.0	1	1.16	4.86
5	16.7	0	15.0	2	1.16	6.41
4	33.3	0	36.0	1	1.16	4.70
4	33.3	1.7	28.0	3	1.16	4.84
4.66	0	5	21.5	4	1.16	6.83
4.66	16.7	0	15.0	1	1.16	5.87
4	16.7	0	28.0	1	1.15	5.12
5	33.3	0	15.0	1	1.15	5.88
4	16.7	5	28.0	4	1.15	5.52
4.33	50	3.4	15.0	1	1.15	4.93
5	16.7	3.4	15.0	3	1.15	6.75
4	50	3.4	21.5	1	1.15	4.56
4	33.3	5	21.5	3	1.14	5.10
4.66	33.3	0	21.5	3	1.14	5.48
4.33	0	3.4	15.0	3	1.14	6.30
4	50	3.4	28.0	3	1.14	4.56
4.33	33.3	3.4	15.0	2	1.13	5.39
5	33.3	0	21.5	4	1.13	5.88
4.33	50	0	28.0	2	1.12	4.83
4	0	1.7	15.0	2	1.12	5.88
5	33.3	5	15.0	3	1.12	6.38
4	0	0	21.5	2	1.12	5.56
4.66	50	1.7	21.5	3	1.12	5.15
4.66	16.7	0	21.5	4	1.12	5.87
5	33.3	1.7	21.5	4	1.12	6.06
4.33	50	1.7	21.5	1	1.11	4.79
4	33.3	0	28.0	4	1.11	4.70
4.33	0	0	21.5	4	1.11	6.01
4.33	16.7	5	15.0	3	1.11	5.88
4.33	16.7	0	[illegible]	3	1.11	5.56
4.66	16.7	1.7	21.5	4	1.11	6.13
5	33.3	3.4	21.5	4	1.10	6.22
4	33.3	1.7	28.0	4	1.10	4.84
4.33	0	1.7	21.5	4	1.10	6.15
4.66	50	3.4	15.0	2	1.10	5.30
4.66	0	1.7	15.0	3	1.09	6.82
4.66	16.7	3.4	21.5	4	1.09	6.29
5	33.3	5	21.5	4	1.09	6.38
4	33.3	3.4	28.0	4	1.09	4.88
4.33	33.3	1.7	21.5	3	1.09	5.24
4.33	16.7	1.7	15.0	2	1.09	5.69
4.33	0	3.4	21.5	4	1.09	6.30
4.66	50	0	21.5	1	1.08	4.89
4.66	16.7	5	21.5	4	1.08	6.44
4.33	50	0	28.0	1	1.08	4.83
4	33.3	5	28.0	4	1.08	5.10
4.66	16.7	3.4	15.0	3	1.07	6.29
4	0	0	21.5	3	1.07	5.56
4.33	0	5	21.5	4	1.07	6.44
4.33	50	3.4	21.5	3	1.07	4.80
4	0	3.4	15.0	3	1.07	5.82
5	0	0	15.0	3	1.06	6.80
4	16.7	1.7	21.5	3	1.06	5.28
[illegible]	50	0	21.5	4	1.06	5.36
4.66	33.3	1.7	15.0	2	1.06	5.84
4.66	33.3	5	15.0	3	1.06	5.86
4	16.7	1.7	15.0	1	1.05	5.28
4.66	33.3	0	21.5	4	1.04	5.48

BINDER	CC FLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS	
4.66	50	0	21.5	2	1.04	5.99	
4	33.3	0	20.0	3	1.04	4.70	
5	50	1.7	21.5	4	1.04	5.52	
4.33	0	0	18.0	3	1.04	5.01	
4	16.7	0	18.0	3	1.04	5.08	
4	50	0	20.0	4	1.04	4.20	
4.33	16.7	0	21.5	4	1.04	5.55	
4	50	0	20.0	2	1.04	4.30	
4.33	33.3	1.7	18.0	1	1.04	5.24	
5	16.7	1.7	18.0	3	1.04	5.66	
4	33.3	3.4	21.5	3	1.03	4.66	
4.33	50	1.7	21.5	2	1.03	4.78	
4	33.3	1.7	21.5	1	1.03	4.64	
4.66	33.3	1.7	21.5	4	1.03	5.04	
5	0	0	21.5	4	1.03	5.66	
5	50	3.4	21.5	4	1.03	5.60	
4	50	1.7	20.0	4	1.03	4.42	
4	50	3.4	21.5	3	1.02	4.66	
4.33	0	1.7	18.0	3	1.02	5.10	
4	50	1.7	20.0	3	1.02	4.42	
4.33	16.7	1.7	21.5	4	1.02	5.00	
4.66	50	1.7	18.0	1	1.02	5.15	
4	50	1.7	20.0	2	1.02	4.42	
4	50	1.7	20.0	1	1.02	4.42	
4.66	33.3	3.4	21.5	4	1.02	5.50	
5	50	1.7	18.0	2	1.02	5.52	
5	50	0	21.5	4	1.02	5.55	
4	0	1.7	21.5	4	1.00	5.04	
5	33.3	3.4	18.0	3	1.00	6.22	
4	50	0	18.0	2	1.01	4.60	
4	50	3.4	20.0	4	1.01	4.66	
4.33	16.7	3.4	21.5	4	1.01	5.04	
4	50	0	21.5	3	1.01	4.08	
4.66	33.3	0	21.5	4	1.01	5.06	
4.66	50	0	21.5	3	1.01	4.90	
4.33	16.7	3.4	18.0	3	1.00	5.94	
4	0	3.4	21.5	4	1.00	5.02	
4.66	16.7	0	18.0	2	1.00	5.07	
4	50	0	20.0	4	1.00	4.60	
4.33	33.3	0	21.5	1	1.00	5.00	
5	0	0	18	4	1.00	5.93	STEEL CURRENT
4.33	16.7	0	21.5	4	1.00	5.00	
4	0	0	21.5	4	0.99	5.66	
5	50	0	18.0	3	0.99	6.66	
4.33	33.3	0	21.5	2	0.99	5.00	
4.66	0	0	18.0	3	0.99	6.40	
4	33.3	3.4	18.0	2	0.99	4.80	
4	33.3	1.7	21.5	2	0.99	4.94	
4.33	33.3	0	18.0	3	0.99	5.63	
4.33	33.3	0	21.5	3	0.97	5.00	
4	33.3	0	20.0	2	0.97	4.70	
5	33.3	0	18.0	2	0.97	5.60	
4.66	50	0	21.5	4	0.97	4.90	
4.66	16.7	1.7	18.0	3	0.96	6.12	
4.33	33.3	0	21.5	4	0.96	5.09	
4.66	50	1.7	21.5	4	0.96	5.16	
4.33	50	1.7	21.5	3	0.96	4.78	
4	16.7	0	21.5	4	0.96	5.17	
4	0	1.7	18.0	3	0.96	6.00	
4.33	33.3	1.7	21.5	4	0.95	5.24	
4.33	50	3.4	18.0	2	0.94	4.83	
4.66	50	3.4	21.5	4	0.94	5.30	
4.66	33.3	3.4	18.0	3	0.94	6.00	
4	16.7	0	21.5	3	0.94	5.12	
4	16.7	1.7	21.5	4	0.94	5.20	
4.33	33.3	3.4	21.5	4	0.94	5.30	
4	16.7	1.7	18.0	2	0.93	5.20	
4	16.7	3.4	18.0	3	0.93	5.40	
4	0	0	18.0	1	0.93	6.64	
4.66	50	0	21.5	4	0.93	5.45	
4	16.7	0	21.5	2	0.93	5.17	
4	16.7	3.4	21.5	4	0.93	5.60	
4.33	33.3	0	21.5	4	0.92	5.63	
5	16.7	0	18.0	3	0.92	6.41	
4	33.3	1.7	21.5	3	0.92	4.94	
4.33	16.7	0	18.0	1	0.92	5.55	
4	16.7	0	21.5	1	0.92	5.17	
4	16.7	0	21.5	4	0.92	5.52	
4.66	50	0	18.0	3	0.92	5.48	
4	50	3.4	18.0	1	0.91	4.90	
4.33	0	0	18.0	3	0.91	6.01	
4	50	0	20.0	3	0.91	4.20	
4.66	33.3	0	18.0	1	0.91	5.40	
4	50	0	20.0	1	0.91	4.20	
4	33.3	0	18.0	3	0.91	5.10	
4	33.3	0	20.0	1	0.90	4.70	
5	33.3	1.7	18.0	3	0.90	6.04	
5	50	0	18.0	1	0.90	5.34	
4	50	3.4	21.5	3	0.90	4.68	
4.33	33.3	1.7	18.0	2	0.90	5.24	
4.33	16.7	1.7	18.0	3	0.90	5.60	
4.33	50	0	21.5	4	0.90	4.63	
4	0	0	18.0	2	0.90	5.56	
5	50	3.4	18.0	3	0.90	6.00	
4	33.3	0	21.5	4	0.90	4.70	
4.33	50	1.7	21.5	4	0.87	4.78	
4.33	33.3	3.4	18.0	3	0.87	5.90	
4	33.3	1.7	21.5	4	0.87	4.84	
4.33	50	3.4	21.5	4	0.86	4.93	

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4.66	50	1.7	15.0	2	0.88	5.15
4	33.3	3.4	21.5	4	0.86	4.88
4.66	16.7	0	15.0	3	0.85	5.87
4.33	50	5	21.5	4	0.85	5.07
4.33	16.7	0	15.0	2	0.85	5.56
4.33	50	5	15.0	3	0.84	5.07
4	33.3	5	21.5	4	0.84	5.10
4.33	50	0	21.5	3	0.84	4.63
4	0	0	15.0	3	0.84	5.56
4.66	33.3	1.7	15.0	3	0.83	5.64
4	16.7	1.7	15.0	3	0.82	5.28
4.66	33.3	0	15.0	2	0.81	5.48
4.66	50	3.4	15.0	3	0.81	5.30
4	33.3	0	21.5	3	0.81	4.70
4	50	0	21.5	4	0.80	4.28
4	33.3	3.4	15.0	3	0.80	4.88
4	33.3	1.7	15.0	1	0.80	4.84
4.33	50	0	21.5	2	0.80	4.63
4	0	0	15.0	4	0.79	5.56
4	50	1.7	21.5	4	0.79	4.42
5	33.3	0	15.0	3	0.79	5.88
4	50	3.4	15.0	2	0.79	4.56
4	50	1.7	21.5	3	0.79	4.42
4	50	1.7	21.5	2	0.79	4.42
4.33	50	1.7	15.0	1	0.79	4.78
4	50	1.7	21.5	1	0.78	4.42
4	50	0	28.0	2	0.78	4.28
4.33	0	0	15.0	4	0.78	6.01
4	0	1.7	15.0	4	0.78	5.88
5	50	0	15.0	2	0.78	5.36
4	50	3.4	21.5	4	0.78	4.56
4.33	16.7	0	15.0	3	0.78	5.56
4	50	5	15.0	3	0.77	4.88
4.66	0	0	15.0	4	0.77	6.48
5	50	1.7	15.0	3	0.77	5.52
4.33	0	1.7	15.0	4	0.77	6.15
4	0	3.4	15.0	4	0.77	5.82
4	50	5	21.5	4	0.77	4.88
5	0	0	15.0	4	0.76	6.80
4.33	33.3	1.7	15.0	3	0.76	5.24
4.66	0	1.7	15.0	4	0.76	6.62
4.33	0	3.4	15.0	4	0.76	6.30
4	0	5	15.0	4	0.76	5.86
4.33	50	0	21.5	1	0.75	4.80
5	0	1.7	15.0	4	0.75	7.10
4.66	0	3.4	15.0	4	0.75	6.78
4.33	0	5	15.0	4	0.74	6.44
4	33.3	1.7	15.0	2	0.74	4.84
4	33.3	0	21.5	2	0.74	4.70
4.33	50	3.4	15.0	3	0.74	4.83
5	0	3.4	15.0	4	0.73	7.27
4.66	0	5	15.0	4	0.73	6.80
5	0	5	15.0	4	0.72	7.43
4	16.7	0	15.0	4	0.72	5.12
4.66	33.3	0	15.0	3	0.72	5.48
4.33	16.7	0	15.0	4	0.71	5.55
4	16.7	0	15.0	3	0.71	5.12
4	16.7	1.7	15.0	4	0.71	5.28
4.33	50	1.7	15.0	2	0.71	4.78
4.66	50	1.7	15.0	3	0.70	5.15
4.66	16.7	0	15.0	4	0.70	5.97
4	16.7	0	15.0	2	0.69	5.12
4.33	16.7	1.7	15.0	4	0.69	5.69
4	16.7	3.4	15.0	4	0.69	5.40
4	33.3	1.7	15.0	3	0.69	4.84
5	16.7	0	15.0	4	0.68	6.41
4.66	16.7	1.7	15.0	4	0.68	6.13
4	16.7	0	15.0	1	0.68	5.12
4.33	16.7	3.4	15.0	4	0.68	5.84
4	16.7	5	15.0	4	0.68	5.52
4	50	0	21.5	3	0.68	4.28
4.33	33.3	0	15.0	1	0.67	5.09
5	16.7	1.7	15.0	4	0.67	6.58
4.66	16.7	5	15.0	4	0.67	6.29
4.33	16.7	5	15.0	4	0.67	5.98
4	33.3	0	21.5	1	0.67	4.70
4	50	3.4	15.0	3	0.67	4.56
4.66	50	0	15.0	1	0.66	4.99
4.33	33.3	0	15.0	2	0.66	5.09
5	16.7	3.4	15.0	4	0.66	6.73
4.66	16.7	5	15.0	4	0.66	6.44
5	50	0	15.0	3	0.66	5.36
4	50	0	28.0	1	0.65	4.28
5	16.7	5	15.0	4	0.65	6.81
4.33	33.3	0	15.0	3	0.65	5.09
4	33.3	0	15.0	4	0.64	4.70
4.33	33.3	0	15.0	4	0.63	5.09
4	33.3	1.7	15.0	4	0.63	4.84
4.33	50	1.7	15.0	3	0.63	4.78
4.66	33.3	0	15.0	4	0.62	5.48
4.66	50	0	15.0	2	0.62	4.99
4.33	33.3	1.7	15.0	4	0.62	5.24
4	33.3	3.4	15.0	4	0.62	4.98
5	33.3	0	15.0	4	0.61	5.86
4.66	33.3	1.7	15.0	4	0.61	5.84
4.33	33.3	3.4	15.0	4	0.61	5.39
4	33.3	5	15.0	4	0.61	5.10
5	33.3	1.7	15.0	4	0.60	6.06
4.66	33.3	3.4	15.0	4	0.60	5.80

BINDER	CCFLYASH	HYDRAFIL	FINES	MOISTURE	STRENGTH	COSTS
4.33	33.3	5	15.0	4	0.60	5.53
5	33.3	3.4	15.0	4	0.58	6.22
4.66	33.3	5	15.0	4	0.58	5.00
4.66	50	0	15.0	3	0.58	4.66
4	33.3	0	15.0	3	0.57	4.70
5	33.3	5	15.0	4	0.57	6.38
4	50	0	15.0	4	0.57	4.28
4.33	50	0	15.0	4	0.56	4.83
4	50	1.7	15.0	4	0.56	4.42
4	50	1.7	15.0	3	0.55	4.42
4	50	1.7	15.0	2	0.55	4.42
4	50	1.7	15.0	1	0.55	4.42
4	50	0	21.5	2	0.55	4.28
4.66	50	0	15.0	4	0.55	4.66
4.33	50	1.7	15.0	4	0.54	4.78
4	50	3.4	15.0	4	0.54	4.55
5	50	0	15.0	4	0.53	5.35
4.66	50	1.7	15.0	4	0.53	5.15
4.33	50	3.4	15.0	4	0.53	4.83
4	50	5	15.0	4	0.53	4.66
5	50	1.7	15.0	4	0.52	5.52
4.66	50	3.4	15.0	4	0.52	5.30
4.33	50	5	15.0	4	0.52	5.07
4.33	50	0	15.0	3	0.51	4.83
5	50	3.4	15.0	4	0.51	5.66
4.66	50	5	15.0	4	0.51	5.45
4	33.3	0	15.0	2	0.50	4.70
5	50	5	15.0	4	0.50	5.85
4.33	50	0	15.0	2	0.47	4.83
4	50	0	15.0	3	0.44	4.28
4	33.3	0	15.0	1	0.44	4.70
4.33	50	0	15.0	1	0.42	4.83
4	50	0	21.5	1	0.42	4.28
4	50	0	15.0	2	0.31	4.28
4	50	0	15.0	1	0.19	4.28

Appendix #2

Coal Creek

Factorial Design

100 Days Curing Period

SINGLE FACTOR EFFECTS
100 DAY CURING

The single factor effect of any factor is defined as the overall average change in compressive strength produced by an increase in the level of that factor (eg. the change in compressive strength going from 4 to 5% binder).

There are 5 single factor effects:

- binder effect,
- flyash effect,
- hydrafil effect,
- fines effect,
- moisture effect.

The following page shows all 5 of the single factor effects and a chart comparing their influence on the compressive strength (MPa and %).

The order of influence on the compressive strength was as follows:

1) **fines percentage** influenced the compressive strength by **55** percent.

2) **aggregate moisture** influenced the compressive strength by **41** percent.

3) **binder percentage** influenced the compressive strength by **39** percent.

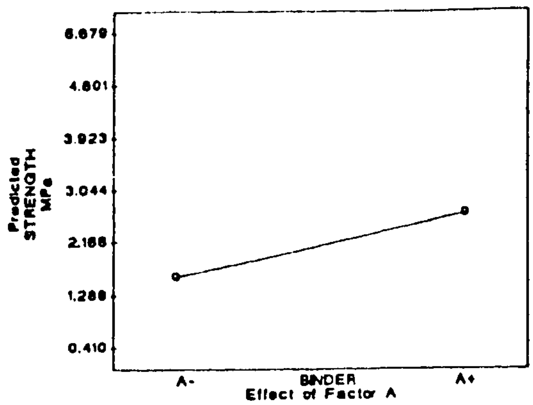
4) **hydrafil addition** influenced the compressive strength by **27** percent.

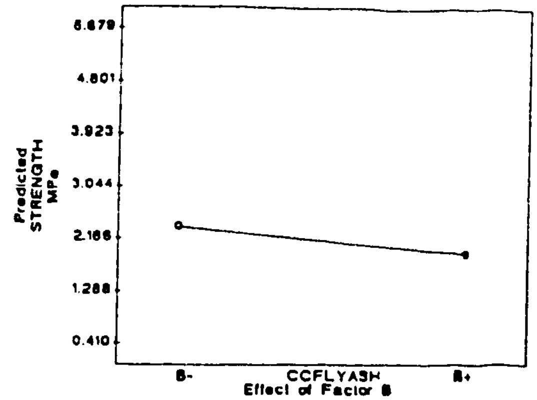
5) **ccflyash percentage** influenced the compressive strength by **20** percent.

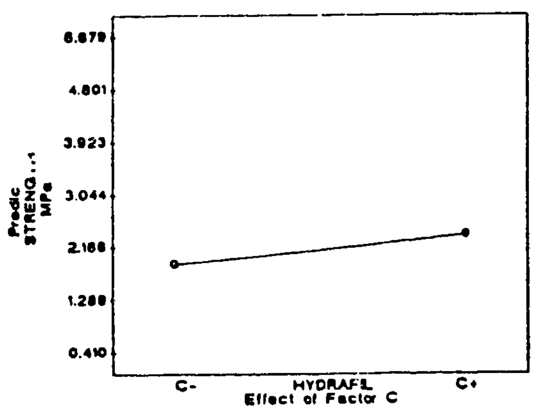
As with the 28 day test, the percentage of fines and aggregate moisture had a greater affect on the compressive strength than did the binder percentage and/or the percentage of flyash addition.

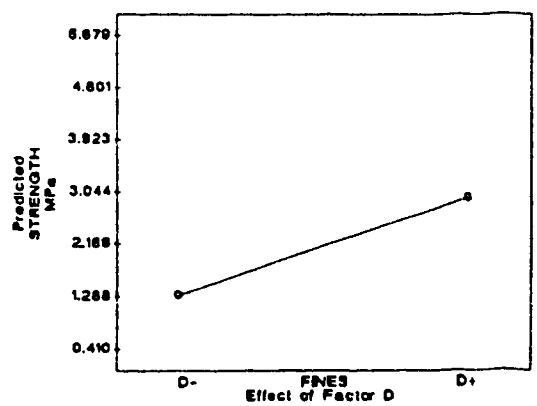
The percentage of influence on the compressive strength remained fairly similar to the 28 day test, with the exception of ccflyash which had a 6 percent decrease in strength influence. Due to the slower "hardening rate" associated with flyash, the ultimate strength of the flyash blends continue to strengthen while the 100 percent portland mixes reach their maximum strengths at a quicker rate. Given a long enough curing period, the strength of the flyash blends may eventually surpass that of the 100 percent portland blends. The table on page 57 and the graph on page 58 compare the results from the 28 and 100 day tests.

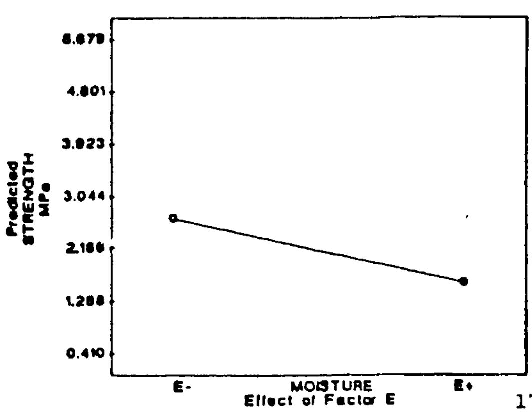
SINGLE FACTOR EFFECTS
100 DAY STRENGTH





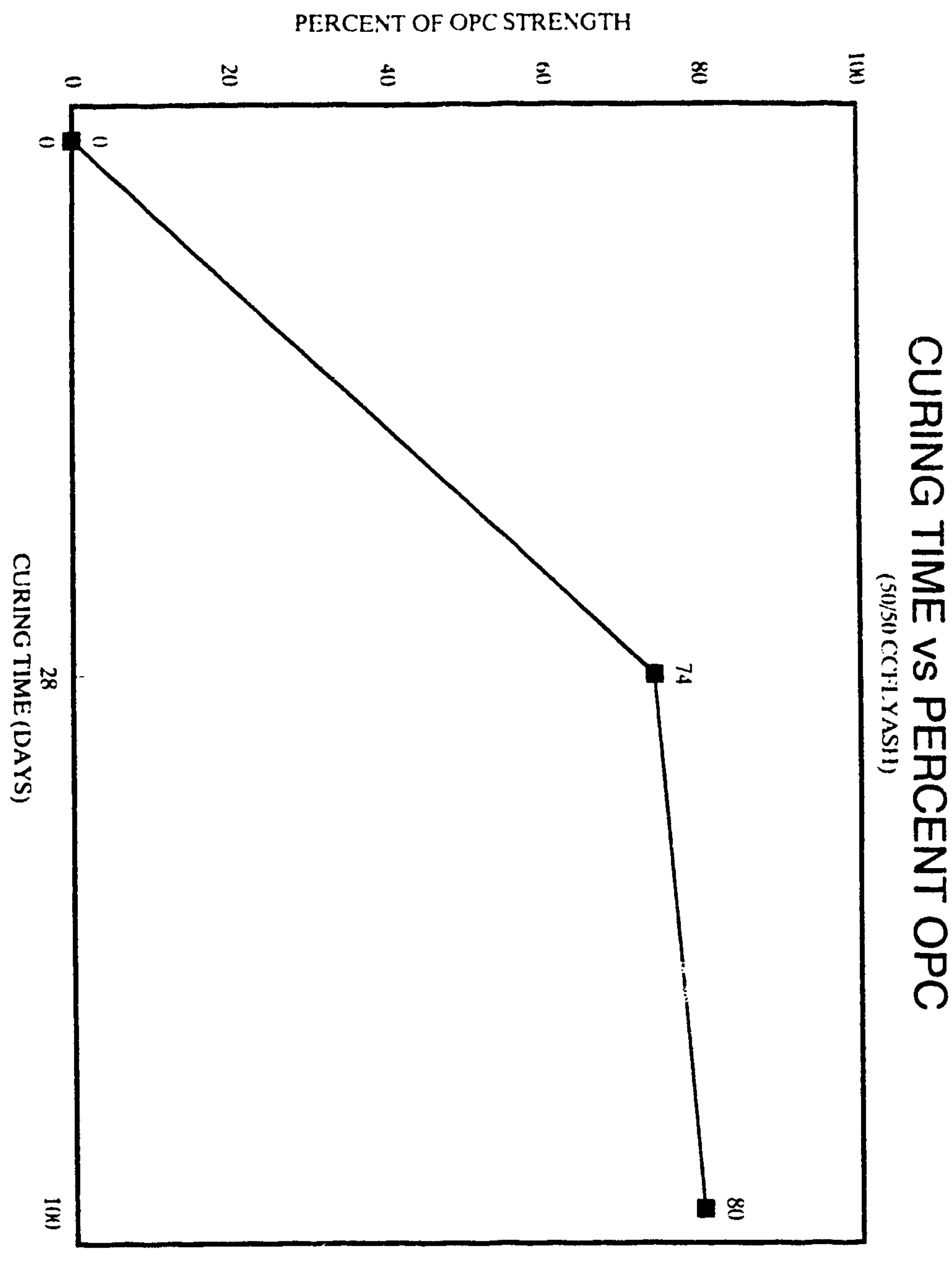






ROCKFILL FACTOR	STRENGTH INFLUENCE (MPa)	STRENGTH INFLUENCE (%)
FINES	+ 1.64 MPa	+ 55 %
MOISTURE	- 1.09 MPa	- 41 %
BINDER	+ 1.04 MPa	+ 39 %
HYDRAFIL	+ 0.52 MPa	+ 27%
CCFLYASH	- 0.47 MPa	- 20 %

ROCKFILL FACTOR	28 DAY STRENGTH INFLUENCE (MPa)	100 DAY STRENGTH INFLUENCE (MPa)	28 DAY STRENGTH INFLUENCE (%)	100 DAY STRENGTH INFLUENCE (%)
FINES	+ 1.16 MPa	+ 1.64 MPa	+ 53 %	+ 55 %
MOISTURE	− 0.81 MPa	− 1.09 MPa	− 40 %	− 41 %
BINDER	+ 0.78 MPa	+ 1.04 MPa	+ 39 %	+ 39 %
HYDRAFIL	+ 0.52 MPa	+ 0.52 MPa	+ 27%	+ 27%
CCFLYASH	− 0.49 MPa	− 0.47 MPa	− 26 %	− 20 %


CURING TIME vs PERCENT OPC
PERCENT OF OPC STRENGTH
0
20
40
60
80
100
CURING TIME (DAYS)
0
28
100
0
74
80

TWO-WAY INTERACTION EFFECTS

100 DAY CURING

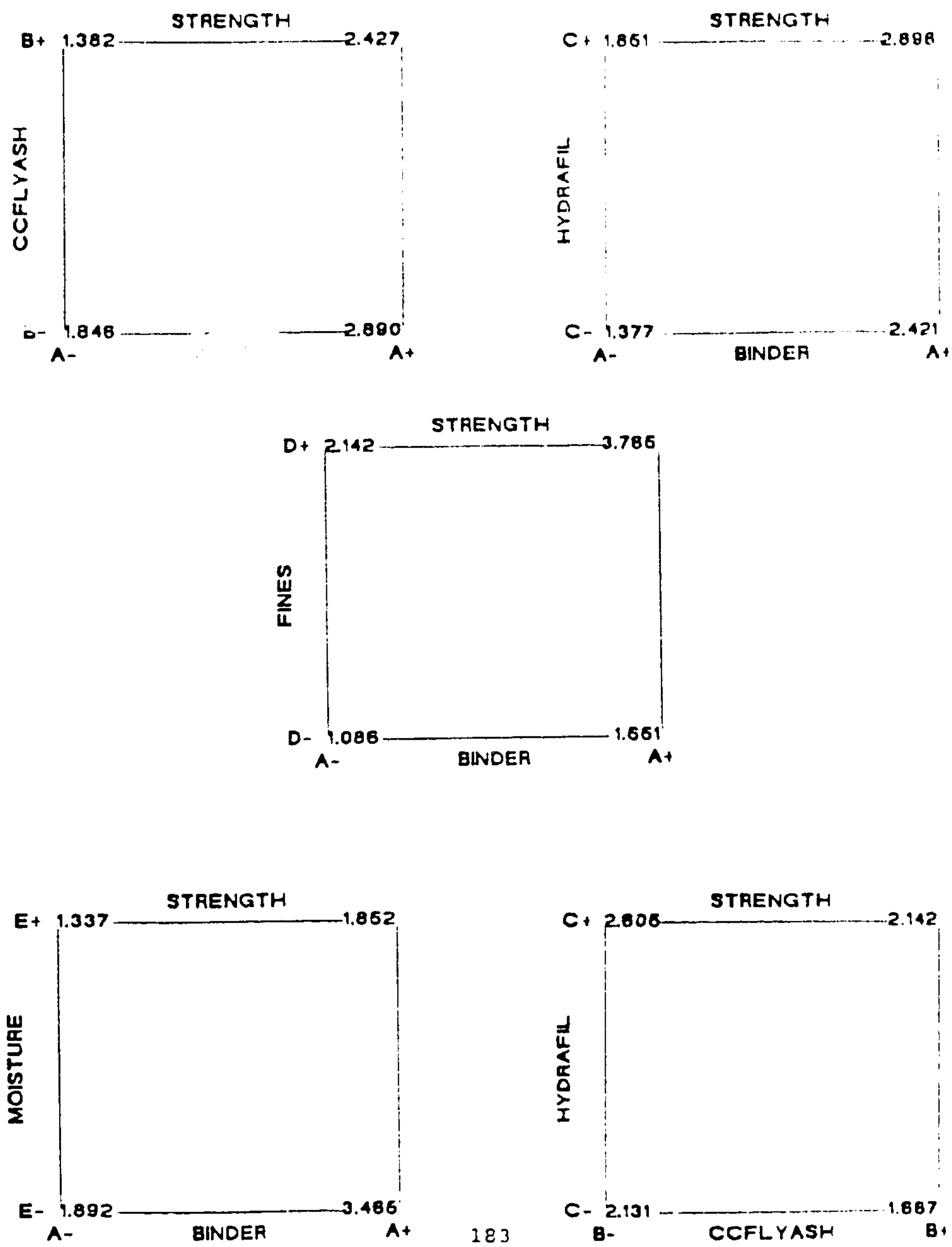
A 2-way interaction effect between two factors is the average difference between the effect of an increase in the level of the first factor at the higher level of the second factor and the effect of an increase in the level of the first factor at the lower level of the second factor.

There are 10 two-way interaction effects:

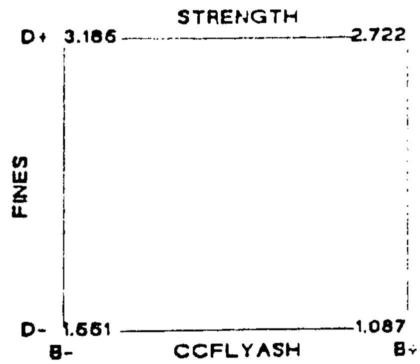
- binder/flyash,
- binder/hydrafil,
- binder/fines,
- binder/moisture,
- flyash/hydrafil,
- flyash/fines,
- flyash/moisture,
- hydrafil/fines,
- hydrafil/moisture,
- fines/moisture.

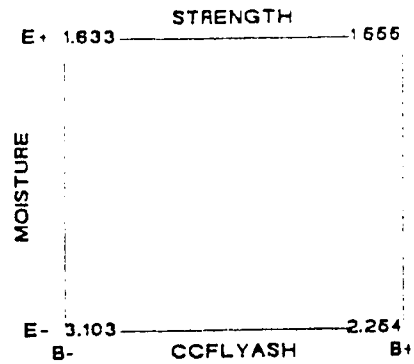
Pages 60 and 61 show all 10 two-way interaction effects.

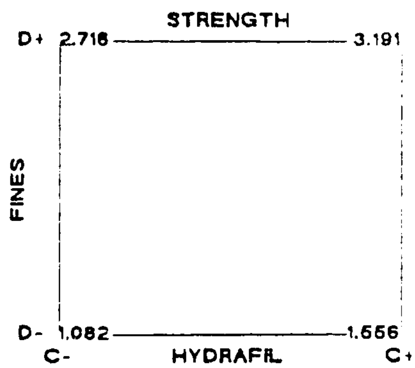
TWO FACTOR EFFECTS
100 DAY STRENGTH

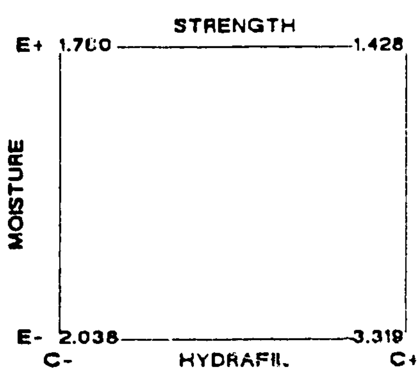


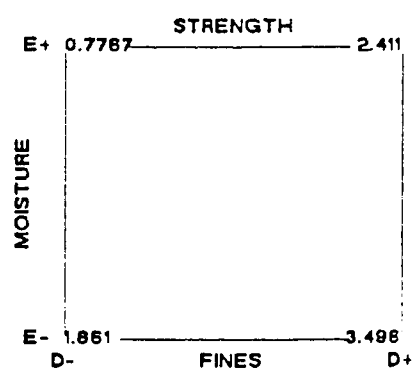
TWO FACTOR EFFECTS
100 DAY STRENGTH











THREE-WAY INTERACTION EFFECTS
100 DAY CURING

In general, an interaction which is statistically significant implies that the effect of one factor has different values at different levels of another factor.

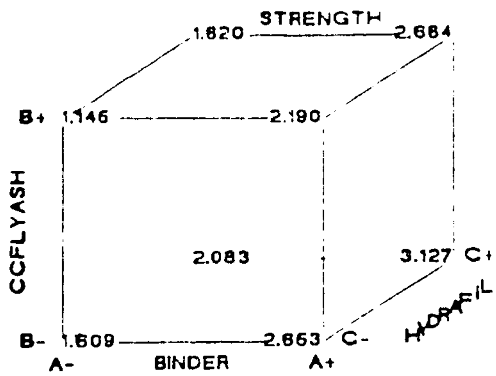
There are 10 three-way interaction effects:

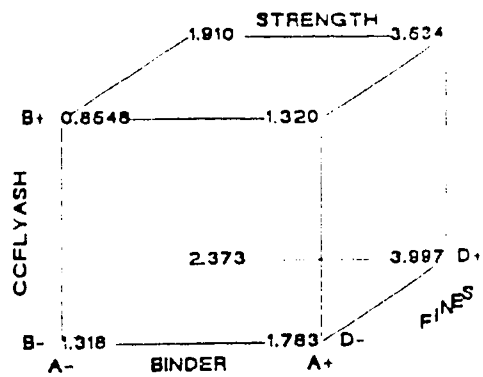
- binder/flyash/hydrafil,
- binder/flyash/fines,
- binder/flyash/moisture,
- binder/hydrafil/fines,
- binder/hydrafil/moisture,
- binder/fines/moisture,
- flyash/hydrafil/fines,
- flyash/hydrafil/moisture,
- flyash/fines/moisture,
- hydrafil/fines/moisture.

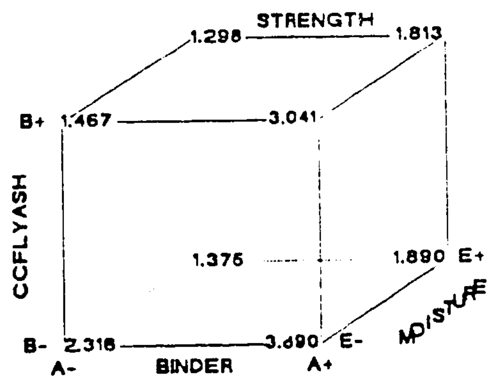
NOTE: Any interactions effects beyond three-way interaction effects (eg four-way) are considered too insignificant to be considered in an equation.

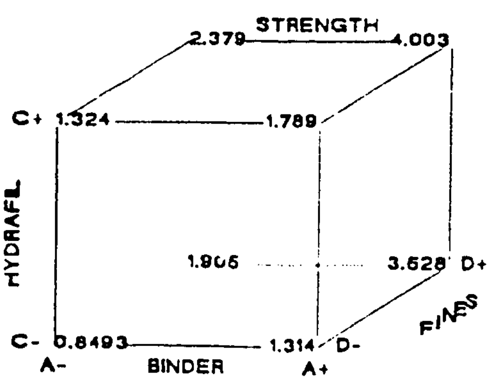
Pages 63 and 64 show all 10 three-way interaction effects.

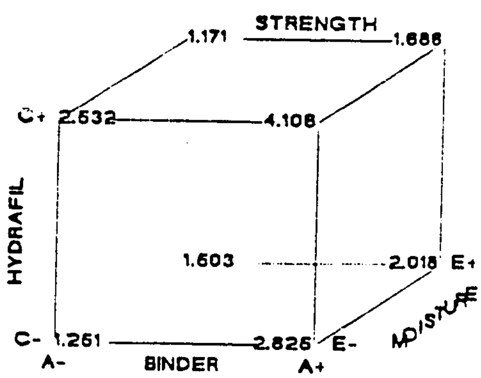
THREE FACTOR EFFECTS
100 DAY STRENGTH



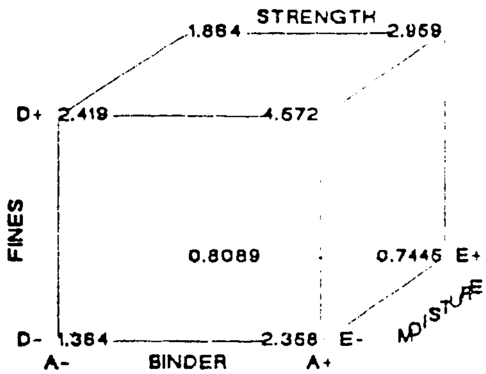


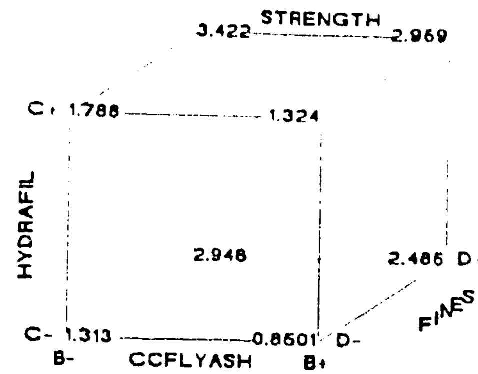


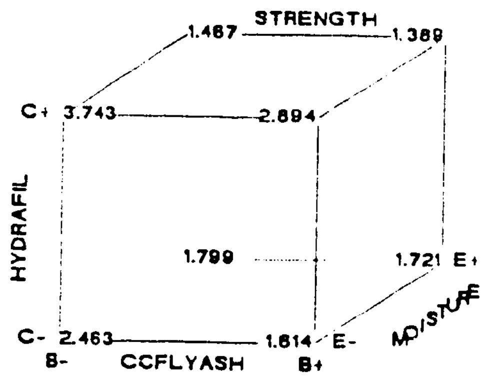


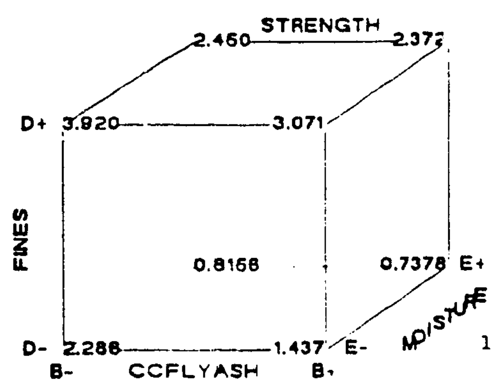


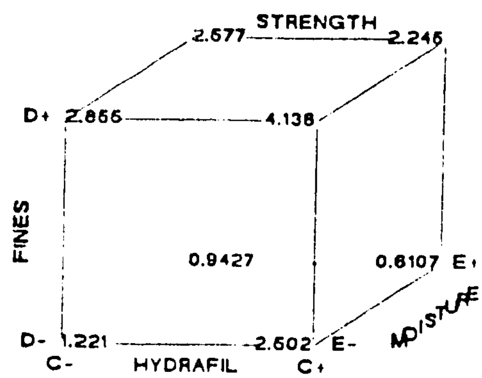
THREE FACTOR EFFECTS
100 DAY STRENGTH











D E S I G N - E A S E   A N A L Y S I S

Response: STRENGTH: File = CC100DAY   Run on 04/02/95 at 17:05:18

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	CC FLYASH	PERCENT	0.000	50.000
C	HYDRAFIL	ml/Kg	0.000	5.000
D	FINES	PERCENT	15.000	35.000
E	MOISTURE	PERCENT	1.000	4.000

VARIABLE	COEFFICIENT	STANDARDIZED EFFECT	SUM OF SQUARES
OVERALL AVERAGE	2.15422		
A	0.52475	1.04950	8.81160
B	-0.23425	-0.46850	1.75594
C	0.23781	0.47563	1.80975
D	0.81619	1.63238	21.31719
E	-0.54494	-1.08988	9.50262
AB	-0.00731	-0.01462	0.00171
AC	0.00775	0.01550	0.00192
AD	0.28838	0.57675	2.66112
AE	-0.26713	-0.53425	2.28338
BC	-0.05413	-0.10825	0.09374
BD	0.06238	0.12475	0.12450
BE	0.19263	0.38525	1.18734
CD	0.07281	0.14563	0.16965
CE	-0.40406	-0.80813	5.22453
DE	0.14306	0.28612	0.65494
ABC	0.05894	0.11788	0.11116
ABD	0.02794	0.05588	0.02498
ABE	0.03706	0.07413	0.04396
ACD	0.05288	0.10575	0.08946
ACE	-0.11413	-0.22825	0.41678
ADE	-0.08975	-0.17950	0.25776
BCD	0.04975	0.09950	0.07920
BCE	-0.03975	-0.07950	0.05056
BDE	-0.04200	-0.08400	0.05645
CDE	-0.15031	-0.30063	0.72300
ABCD	-0.03831	-0.07663	0.04697
ABCE	-0.16169	-0.32338	0.83657
ABDE	0.04856	0.09712	0.07547
ACDE	-0.05275	-0.10550	0.08904
BCDE	-0.15963	-0.31925	0.81536
ABCDE	-0.06519	-0.13037	0.13598
CENTER POINT	0.08806		0.02757

Computations done for Factorial

Model selected for Factorial:

Results of Factorial Model Fitting

ANOVA for Selected Model

D E S I G N - E A S E   A N A L Y S I S -- Page 2

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	59.45266	31	1.91783	3.297	0.1[illegible]
CURVATURE	0.02757	1	0.02757	4.74E-02	0.841
RESIDUAL	1.74508	3	0.58169		
PURE ERROR	1.74508	3	0.58169		
COR TOTAL	61.22531	35			

ROOT MSE	0.762687	R-SQUARED	0.9715
DEP MEAN	2.154222	ADJ R-SQUARED	0.6768
C.V.	35.40%		

Case(s) with leverage of 1.0000: PRESS statistic not defined

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT = 0	PROB > t
INTERCEPT	2.144438	1	0.134825		
A	0.524750	1	0.134825	3.892	0.0301
B	-0.234250	1	0.134825	-1.737	0.1807
C	0.237813	1	0.134825	1.764	0.1766
D	0.816188	1	0.134825	6.054	0.0096
E	-0.544938	1	0.134825	-4.042	0.0273
AB	-0.007312	1	0.134825	-5.42E-02	0.9602
AC	0.007750	1	0.134825	5.75E-02	0.9578
AD	0.288375	1	0.134825	2.139	0.1220
AE	-0.267125	1	0.134825	-1.981	0.1419
BC	-0.054125	1	0.134825	-0.4014	0.7150
BD	0.062375	1	0.134825	0.4626	0.6751
BE	0.192625	1	0.134825	1.429	0.2484
CD	0.072813	1	0.134825	0.5401	0.6267
CE	-0.404063	1	0.134825	-2.997	0.0578
DE	0.143062	1	0.134825	1.061	0.3665
ABC	0.058938	1	0.134825	0.4371	0.6916
ABD	0.027938	1	0.134825	0.2072	0.8491
ABE	0.037063	1	0.134825	0.2749	0.8012
ACD	0.052875	1	0.134825	0.3922	0.7211
ACE	-0.114125	1	0.134825	-0.8465	0.4595
ADE	-0.089750	1	0.134825	-0.6657	0.5532
BCD	0.049750	1	0.134825	0.3690	0.7366
BCE	-0.039750	1	0.134825	-0.2948	0.7874
BDE	-0.042000	1	0.134825	-0.3115	0.7758
CDE	-0.150313	1	0.134825	-1.115	0.3462
ABCD	-0.038313	1	0.134825	-0.2842	0.7948
ABCE	-0.161688	1	0.134825	-1.199	0.3165
ABDE	0.048562	1	0.134825	0.3602	0.7426
ACDE	-0.052750	1	0.134825	-0.3912	0.7217
BCDE	-0.159625	1	0.134825	-1.184	0.3217
ABCDE	-0.065187	1	0.134825	-0.4835	0.6618
CENTER POINT	0.088063	1	0.404476	0.2177	0.8416

Final Equation in Terms of Coded Variables:

STRENGTH =
2.144438

DESIGN-EASE ANALYSIS -- Page 3

+ 0.5[illegible] * A
- 0.[illegible] * B
+ 0.[illegible] * [illegible]
+ 0.21[illegible]88 * [illegible]
- 0.[illegible]44[illegible]
- 0.[illegible] * A * B
+ 0.[illegible] * A * C
+ 0.2[illegible] * A * D
- 0.2671[illegible] * E
- 0.0541[illegible] B * C
+ 0.0623[illegible] * B * D
+ 0.192625 * B
[illegible] 0.072813 * C D
- .404063 * C * E
+ 0.143062 * D * E
+ 0.05[illegible]38 * A * B * C
0.027938 * A * B * D
+ .037063 * A * B * E
+ 0.052875 * A * C * D
0.1[illegible]4125 * A * C * E
0.08[illegible]750 * A * D * E
0.049[illegible]50 * B * C * D
- 0.039750 * B * C * E
- 0.042000 * B * D * E
- 0.150313 * C * D * E
- 0.038313 * A * B * C * D
- 0.161688 * A * B * C * E
+ 0.048562 * A * B * D * E
- 0.052750 * A * C * D * E
- 0.159625 * B * C * D * E
- 0.065187 * A * B * C * D * E

Final Equation in Terms of Uncoded Variables:

STRENGTH =
0.550000
+ 0.236500 * BINDER
+ 0.027745 * CC FLYASH
+ 1.455883 * HYDRAFIL
- 0.334667 * FINES
- 0.692500 * MOISTURE
- 0.007133 * BINDER * CC FLYASH
- 0.245283 * BINDER * HYDRAFIL
+ 0.084100 * BINDER * FINES
+ 0.033500 * BINDER * MOISTURE
- 0.034410 * CC FLYASH * HYDRAFIL
+ 0.003706 * CC FLYASH * FINES
+ 0.018905 * CC FLYASH * MOISTURE
- 0.025063 * HYDRAFIL * FINES
0.142883 * HYDRAFIL * MOISTURE
+ 0.102167 * FINES * MOISTURE
+ 0.004883 * BINDER * CC FLYASH * HYDRAFIL
- 9.867E-04 * BINDER * CC FLYASH * FINES
- 0.004567 * BINDER * CC FLYASH * MOISTURE
+ 0.005637 * BINDER * HYDRAFIL * FINES
+ 0.008783 * BINDER * HYDRAFIL * MOISTURE
- 0.020100 * BINDER * FINES * MOISTURE
- 5.075E-04 * CC FLYASH * HYDRAFIL * FINES

```
+        0.003710 * CC FLYASH * [illegible]AFIL * MOISTURE
-        0.002416 * CC FLYASH * FINES * MOISTURE
-        0.002737 * HYDRAFIL * FINES * MOISTURE
+       2.251E-04 * BINDER * CC FLYASH * HYDRAFIL * FINES
+       2.733E-05 * BINDER * CC FLYASH * HYDRAFIL * MOISTURE
+       6.067E-04 * BINDER * CC FLYASH * FINES * MOISTURE
+       6.633E-04 * BINDER * HYDRAFIL * FINES * MOISTURE
+       4.555E-04 * CC FLYASH * HYDRAFIL * FINES * MOISTURE
-       1.391E-04 * BINDER * CC FLYASH * HYDRAFIL * FINES * MOIST
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.29000	1.29000	9.109E-12	1.000	0.000	0.000	0.000	32
2	2.52000	2.52000	-6.679E-13	1.000	0.000	0.000	0.000	27
3	1.11000	1.11000	1.002E-11	1.000	0.000	0.000	0.000	30
4	1.47000	1.47000	3.8[illegible]	1.000	0.000	0.000	0.000	9
5	2.93000	2.93000	2.288E-[illegible]	[illegible]	0.000	0.000	0.000	34
6	3.45000	3.45000	-3.169E-[illegible]	[illegible]	0.000	0.000	0.000	35
7	1.08000	1.08000	5.699[illegible]	[illegible]	0.000	0.000	0.000	28
8	2.28000	2.28000	[illegible]	[illegible]	0.000	0.000	0.000	18
9	1.76000	1.76000	[illegible]	[illegible]	0.000	0.000	0.000	20
10	4.27000	4.27[illegible]	[illegible]	1.0[illegible]	[illegible]	0.000	0.000	31
11	1.35000	1.35[illegible]	[illegible]487E[illegible]	1.000	0.[illegible]	0.000	0.000	16
12	2.61000	2.61[illegible]	[illegible]171E[illegible]	1.000	0.[illegible]	0.000	0.000	23
13	3.14000	3.14000	[illegible].8[illegible]E-12	[illegible]	0.0[illegible]	0.000	0.000	7
14	5.57000	5.570[illegible]	-1.[illegible]E-11	1.[illegible]	0.00[illegible]	0.000	0.000	17
15	2.52000	2.520[illegible]	-3.624E-12	1.000	0.00[illegible]	0.000	0.000	6
16	5.68000	5.6800[illegible]	-1.[illegible]13E-11	1.000	0.00[illegible]	0.000	0.000	36
17	0.59400	0.594[illegible]	5.[illegible]44E-[illegible]	1.[illegible]00	0.00[illegible]	0.000	0.000	12
18	1.02000	1.02000	1.[illegible]51E-[illegible]	1.000	0.0[illegible]0	0.000	0.000	26
19	0.53300	0.53300	6.608E-12	1.000	0.000	0.000	0.000	1
20	0.76900	0.76900	-1.350E-12	1.000	0.000	0.000	0.000	3
21	0.59900	0.59900	1.606E-[illegible]	1.000	0.000	0.000	0.000	2
22	0.59600	0.59600	-1.[illegible]05E-12	1.000	0.000	0.000	0.000	5
23	0.59900	0.59900	3.880E-12	1.000	0.000	0.000	0.000	19
24	0.41200	0.41200	-1.[illegible]23E-12	1.000	[illegible].000	0.000	0.000	11
25	2.37000	2.37000	1.151E-12	1.000	0.000	0.000	0.000	21
26	2.87000	2.87000	-5.443E-12	1.000	0.000	0.000	0.000	22
27	2.11000	2.11000	[illegible]833E-12	1.000	0.000	0.000	0.000	24
28	3.86000	3.86000	-3.851E-12	1.000	0.000	0.000	0.000	10
29	2.09000	2.09000	-3.396E-12	1.000	0.000	0.000	0.000	25
30	2.99000	2.99000	-8.626E-12	1.000	0.000	0.000	0.000	8
31	1.84000	1.84000	-2.601E-12	1.000	0.000	0.000	0.000	15
32	2.34000	2.34000	-9.990E-12	1.000	0.000	0.000	0.000	4
33	1.52000	2.23250	-0.71250	0.250	-1.079	0.012	-1.126	14
34	2.43000	2.23250	0.19750	0.250	0.299	0.001	0.248	29
35	1.76000	2.23250	-0.47250	0.250	-0.715	0.005	-0.641	13
36	3.22000	2.23250	0.98750	0.250	1.495	0.023	2.418	33

Case(s) with leverage of 1.0000: SRSD, DIST, T set to 0.000.

D E S I G N - E A S E   A N A L Y S I S

Response: STRENGTH; File = CC100DAY			Run on 04/02/95 at 17:06:10	
VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	CC FLYASH	PERCENT	0.000	50.000
C	HYDRAFIL	ml/Kg	0.000	5.000
D	FINES	PERCENT	15.000	35.000
E	MOISTURE	PERCENT	1.000	4.000

VARIABLE	COEFFICIENT	STANDARDIZED EFFECT	SUM OF SQUARES
OVERALL AVERAGE	2.15422		
A	0.52475	1.04950	8.81160
B	-0.23425	-0.46850	1.75594
C	0.23781	0.47563	1.80975
D	0.81619	1.63238	21.31719
E	-0.54494	-1.08988	9.50262
AB	-0.00731	-0.01462	0.00171
AC	0.00775	0.01550	0.00192
AD	0.28838	0.57675	2.66112
AE	-0.26713	-0.53425	2.28338
BC	-0.05413	-0.10825	0.09374
BD	0.06238	0.12475	0.12450
BE	0.19263	0.38525	1.18734
CD	0.07281	0.14563	0.16965
CE	-0.40406	-0.80813	5.22453
DE	0.14306	0.28612	0.65494
ABC	0.05894	0.11788	0.11116
ABD	0.02794	0.05588	0.02498
ABE	0.03706	0.07413	0.04396
ACD	0.05288	0.10575	0.08946
ACE	-0.11413	-0.22825	0.41678
ADE	-0.08975	-0.17950	0.25776
BCD	0.04975	0.09950	0.07920
BCE	-0.03975	-0.07950	0.05056
BDE	-0.04200	-0.08400	0.05645
CDE	-0.15031	-0.30063	0.72300
ABCD	-0.03831	-0.07663	0.04697
ABCE	-0.16169	-0.32338	0.83657
ABDE	0.04856	0.09712	0.07547
ACDE	-0.05275	-0.10550	0.08904
BCDE	-0.15963	-0.31925	0.81536
ABCDE	-0.06519	-0.13037	0.13598
CENTER POINT	0.08806		0.02757

Computations done for Factorial

Model selected for Factorial:

Results of Factorial Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	54.55348	9	6.06150	22.81	0.0001
CURVATURE	0.02757	1	0.02757	0.1037	0.7501
RESIDUAL	6.64426	25	0.26577		
LACK OF FIT	4.89918	22	0.22269	0.3828	0.9231
PURE ERROR	1.74508	3	0.58169		
COR TOTAL	61.22531	35			

ROOT MSE	0.515529	R-SQUARED	0.8914
DEP MEAN	2.154222	ADJ R-SQUARED	0.85[illegible]
C.V.	23.93%		

Predicted Residual Sum of Squares (PRESS) = 13.46757

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
INTERCEPT	2.144438	1	0.091134		
A	0.524750	1	0.091134	5.758	0.0001
B	-0.234250	1	0.091134	-2.570	0.0165
C	0.237813	1	0.091134	2.609	0.0151
D	0.816188	1	0.091134	8.956	0.0001
E	-0.544938	1	0.091134	-5.980	0.0001
AD	0.288375	1	0.091134	3.164	0.0041
AE	-0.267125	1	0.091134	-2.931	0.0071
BE	0.192625	1	0.091134	2.114	0.0447
CE	-0.404063	1	0.091134	-4.434	0.0002
CENTER POINT	0.088063	1	0.273401	0.3221	0.7501

Final Equation in Terms of Coded Variables:

```
STRENGTH =
             2.144438
   +         0.524750 * A
   -         0.234250 * B
   +         0.237813 * C
   +         0.816188 * D
   -         0.544938 * E
   +         0.288375 * A * D
   -         0.267125 * A * E
   +         0.192625 * B * E
   -         0.404063 * C * E
```

Final Equation in Terms of Uncoded Variables:

```
STRENGTH =
            -1.584948
   +         0.498042 * BINDER
   -         0.022212 * CC FLYASH
   +         0.364500 * HYDRAFIL
   -         0.177919 * FINES
   +         1.380417 * MOISTURE
   +         0.057675 * BINDER * FINES
   -         0.356167 * BINDER * MOISTURE
```

\+ 0.005137 * CC FLYASH * MOISTURE
\- 0.107750 * HYDRAFIL * MOISTURE

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.29000	1.15469	0.13531	0.313	0.317	0.004	0.311	32
2	2.52000	2.16169	0.35831	0.313	0.833	0.029	0.833	27
3	1.11000	0.30094	0.80906	0.313	1.893	0.148	2.004	30
4	1.47000	1.30794	0.16206	0.313	0.379	0.006	0.373	9
5	2.93000	2.43844	0.49156	0.313	1.150	0.055	1.158	34
6	3.45000	3.44544	0.00456	0.313	0.011	0.000	0.010	35
7	1.08000	1.58469	-0.50469	0.313	-1.181	0.058	-1.190	28
8	2.28000	2.59169	-0.31169	0.313	-0.729	0.022	-0.722	18
9	1.76000	2.21031	-0.45031	0.313	-1.053	0.046	-1.056	20
10	4.27000	4.37081	-0.10081	0.313	-0.236	0.002	-0.231	31
11	1.35000	1.35656	-0.00656	0.313	-0.015	0.000	-0.015	16
12	2.61000	3.51706	-0.90706	0.313	-2.122	0.186	-2.296	23
13	3.14000	3.49406	-0.35406	0.313	-0.828	0.028	-0.823	7
14	5.57000	5.65456	-0.08456	0.313	-0.198	0.002	-0.194	17
15	2.52000	2.64031	-0.12031	0.313	-0.281	0.003	-0.276	6
16	5.68000	4.80081	0.87919	0.313	2.057	0.175	2.211	36
17	0.59400	1.02194	-0.42794	0.313	-1.001	0.041	-1.001	12
18	1.02000	0.96044	0.05956	0.313	0.139	0.001	0.137	26
19	0.53300	0.93869	-0.40569	0.313	-0.949	0.037	-0.947	1
20	0.76900	0.87719	-0.10819	0.313	-0.253	0.003	-0.248	3
21	0.59900	0.68944	-0.09044	0.313	-0.212	0.002	-0.207	2
22	0.59600	0.62794	-0.03194	0.313	-0.075	0.000	-0.073	5
23	0.59900	0.60619	-0.00719	0.313	-0.017	0.000	-0.016	19
24	0.41200	0.54469	-0.13269	0.313	-0.310	0.004	-0.305	11
25	2.37000	2.07756	0.29244	0.313	0.684	0.019	0.677	21
26	2.87000	3.16956	-0.29956	0.313	-0.701	0.020	-0.693	22
27	2.11000	1.99431	0.11569	0.313	0.271	0.003	0.266	24
28	3.86000	3.08631	0.77369	0.313	1.810	0.135	1.902	10
29	2.09000	1.74506	0.34494	0.313	0.807	0.027	0.801	25
30	2.99000	2.83706	0.15294	0.313	0.358	0.005	0.351	8
31	1.84000	1.66181	0.17819	0.313	0.417	0.007	0.410	15
32	2.34000	2.75381	-0.41381	0.313	-0.968	0.039	-0.967	4
33	1.52000	2.23250	-0.71250	0.250	-1.596	0.077	-1.650	14
34	2.43000	2.23250	0.19750	0.250	0.442	0.006	0.435	29
35	1.76000	2.23250	-0.47250	0.250	-1.058	0.034	-1.061	13
36	3.22000	2.23250	0.98750	0.250	2.212	0.148	2.416	33

Appendix #3

Shand Flyash

Factorial Design

100 Days Curing Period

Statistics

D E S I G N - E A S E   A N A L Y S I S

Response: STRENGTH; File = SHAND   Run on 10/15/95 at 15:50.52

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	FLYASH	PERCENT	0.000	60.000
C	HYDRAFIL	L/TONNE	0.000	5.000
D	FINES	PERCENT	20.000	40.000
E	MOIST	PERCENT	1.000	4.000

VARIABLE	COEFFICIENT	STANDARDIZED EFFECT	SUM OF SQUARES
OVERALL AVERAGE	2.21000		
A	0.32563	0.65125	3.39301
B	0.04125	0.08250	0.05445
C	0.29688	0.59375	2.82031
D	1.11375	2.22750	39.69405
E	-0.28000	-0.56000	2.50880
AB	-0.12938	-0.25875	0.53561
AC	0.04000	0.08000	0.05120
AD	0.26437	0.52875	2.23661
AE	-0.06938	-0.13875	0.15401
BC	-0.01812	-0.03625	0.01051
BD	0.12625	0.25250	0.51005
BE	0.03125	0.06250	0.03125
CD	0.24063	0.48125	1.85281
CE	-0.10187	-0.20375	0.33211
DE	0.28500	0.57000	2.59920
ABC	-0.06875	-0.13750	0.15125
ABD	0.00813	0.01625	0.00211
ABE	0.07313	0.14625	0.17111
ACD	0.09125	0.18250	0.26645
ACE	0.02625	0.05250	0.02205
ADE	0.02312	0.04625	0.01711
BCD	-0.05562	-0.11125	0.09901
BCE	-0.15188	-0.30375	0.73811
BDE	-1.608E-13	-3.216E-13	8.272E-25
CDE	-0.10938	-0.21875	0.38281
ABCD	-0.01875	-0.03750	0.01125
ABCE	0.11750	0.23500	0.44180
ABDE	-0.07063	-0.14125	0.15961
ACDE	-0.07375	-0.14750	0.17405
BCDE	-0.16063	-0.32125	0.82561
ABCDE	0.04625	0.09250	0.06845
CENTER POINT	0.92250		3.02580

Computations done for Factorial

Model selected for Factorial:

Results of Factorial Model Fitting

ANOVA for Selected Model

D E S I G N - E A S E   A N A L Y S I S -- Page 2

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	60.31480	31	1.94564	3.715	0.15[illegible]
CURVATURE	3.02580	1	3.02580	5.777	0.0956
RESIDUAL	1.57120	3	0.52373		
PURE ERROR	1.57120	3	0.52373		
COR TOTAL	64.91180	35			

ROOT MSE	0.723694	R-SQUARED	0.9746
DEP MEAN	2.310000	ADJ R-SQUARED	0.7123
C.V.	31.33%		

Case(s) with leverage of 1.0000: PRESS statistic not defined.

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
INTERCEPT	2.207500	1	0.127932		
A	0.325625	1	0.127932	2.545	0.0843
B	0.041250	1	0.127932	0.3224	0.768[illegible]
C	0.296875	1	0.127932	2.321	0.1030
D	1.113750	1	0.127932	8.706	0.0032
E	-0.280000	1	0.127932	-2.189	0.1164
AB	-0.129375	1	0.127932	-1.011	0.3864
AC	0.040000	1	0.127932	0.3127	0.7750
AD	0.264375	1	0.127932	2.067	0.1307
AE	-0.069375	1	0.127932	-0.5423	0.6253
BC	-0.018125	1	0.127932	-0.1417	0.8963
BD	0.126250	1	0.127932	0.9869	0.3965
BE	0.031250	1	0.127932	0.2443	0.8228
CD	0.240625	1	0.127932	1.881	0.1566
CE	-0.101875	1	0.127932	-0.7963	0.4840
DE	0.285000	1	0.127932	2.228	0.1122
ABC	-0.068750	1	0.127932	-0.5374	0.628[illegible]
ABD	0.008125	1	0.127932	6.35E-02	0.9534
ABE	0.073125	1	0.127932	0.5716	0.6076
ACD	0.091250	1	0.127932	0.7133	0.5272
ACE	0.026250	1	0.127932	0.2052	0.8506
ADE	0.023125	1	0.127932	0.1808	0.8681
BCD	-0.055625	1	0.127932	-0.4348	0.6931
BCE	-0.151875	1	0.127932	-1.187	0.3206
BDE	-1.[illegible]8E-13	1	0.127932	-1.26E-12	1.0000
CDE	-0.109375	1	0.127932	-0.8549	0.4554
ABCD	-0.018750	1	0.127932	-0.1466	0.8928
ABCE	0.117500	1	0.127932	0.9185	0.4261
ABDE	-0.070625	1	0.127932	-0.5520	0.6194
ACDE	-0.073750	1	0.127932	-0.5765	0.6047
BCDE	-0.160[illegible]5	1	0.127932	-1.256	0.2982
ABCDE	0.04[illegible]	1	0.127932	0.3615	0.7417
CENTER POINT	0.9[illegible]	1	0.383797	2.404	0.0956

Final Equation in Terms of Coded Variables:

STRENGTH =
2.207500

```
+          0.325625 * A
+          0.041250 * B
+          0.296875 * C
+          1.113750 * D
-          0.280000 * E
-          0.129375 * A * B
+          0.040000 * A * C
+          0.264375 * A * D
-          0.069375 * A * E
-          0.018125 * B * C
+          0.126250 * B * D
+          0.031250 * B * E
+          0.240625 * C * D
-          0.101875 * C * E
+          0.285000 * D * E
-          0.068750 * A * B * C
+          0.008125 * A * B * D
+          0.073125 * A * B * E
+          0.091250 * A * C * D
+          0.026250 * A * C * E
+          0.023125 * A * D * E
-          0.055625 * B * C * D
-          0.151875 * B * C * F
-        1.608E-13 * B * D * E
-          0.109375 * C * D * E
-          0.018750 * A * B * C * D
+          0.117500 * A * B * C * E
-          0.070625 * A * B * D * E
-          0.073750 * [illegible] * C * [illegible] * E
-          [illegible].160625 * [illegible] * C * [illegible] * E
+          0.046250 [illegible] A * [illegible] [illegible] * D * E
```

Final Equation in Terms of Uncoded Variables:

```
STRENGTH =
          -8.006667
+          2.123333 * BINDER
+          0.195889 * FLYASH
+          2.248667 * HYDRAFIL
+          0.219167 * FINES
+          3.446667 * MOIST
-          0.043444 * BINDER * FLYASH
-          0.535333 * BINDER * HYDRAFIL
-          0.042000 * BINDER * FINES
-          0.923333 * BINDER * MOIST
-          0.008100 * FLYASH * HYDRAFIL
-          0.006936 * FLYASH * FINES
-          0.067889 * FLYASH * MOIST
-          0.103167 * HYDRAFIL * FINES
-          0.672667 * HYDRAFIL * MOIST
-          0.112667 * FINES * MOIST
+         6.111E-04 * BINDER * FLYASH * HYDRAFIL
+          0.001478 * BINDER * FLYASH * FINES
+          0.013611 * BINDER * FLYASH * MOIST
+          0.024800 * BINDER * HYDRAFIL * FINES
+          0.143333 * BINDER * HYDRAFIL * MOIST
+          0.028500 * BINDER * FINES * MOIST
+          0.001433 * FLYASH * HYDRAFIL * FINES
```

```
+        0.004633 * FLYASH * HYDRAFIL * MOIST
+        0.002694 * FLYASH * FINES * MOIST
+        0.030167 * HYDRAFIL * FINES * MOIST
-       2.556E-04 * BINDER * FLYASH * HYDRAFIL * FINES
-       3.778E-04 * BINDER * FLYASH * HYDRAFIL * MOIST
-       5.194E-04 * BINDER * FLYASH * FINES * MOIST
-        0.006400 * BINDER * HYDRAFIL * FINES * MOIST
-       5.128E-04 * FLYASH * HYDRAFIL * FINES * MOIST
+       8.222E-05 * BINDER * FLYASH * HYDRAFIL * FINES * MOIST
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.29000	1.29000	-3.411E-12	1.000	0.000	0.000	0.000	12
2	2.22000	2.22000	-8.072E-12	1.000	0.000	0.000	0.000	26
3	1.32000	1.32000	-4.206E-12	1.000	0.000	0.000	0.000	34
4	1.61000	1.61000	-6.594E-12	1.000	0.000	0.000	0.000	14
5	1.39000	1.39000	-3.297E-12	1.000	0.000	0.000	0.000	31
6	2.20000	2.20000	-1.023E-11	1.000	0.000	0.000	0.000	19
7	2.02000	2.02000	-9.322E-12	1.000	0.000	0.000	0.000	8
8	1.22000	1.22000	-5.798E-12	1.000	0.000	0.000	0.000	33
9	2.34000	2.34000	-8.527E-12	1.000	0.000	0.000	0.000	18
10	3.00000	3.00000	-1.342E-11	1.000	0.000	0.000	0.000	35
11	1.88000	1.88000	-8.413E-12	1.000	0.000	0.000	0.000	20
12	3.05000	3.05000	-1.307E-11	1.000	0.000	0.000	0.000	9
13	2.50000	2.50000	-1.069E-11	1.000	0.000	0.000	0.000	17
14	4.88000	4.88000	-1.967E-11	1.000	0.000	0.000	0.000	30
15	4.00000	4.00000	-1.398E-11	1.000	0.000	0.000	0.000	15
16	4.88000	4.88000	-1.273E-11	1.000	0.000	0.000	0.000	29
17	0.63000	0.63000	-4.206E-12	1.000	0.000	0.000	0.000	3
18	0.50000	0.50000	-1.000E-11	1.000	0.000	0.000	0.000	4
19	0.46000	0.46000	-7.049E-12	1.000	0.000	0.000	0.000	21
20	0.27000	0.27000	-6.253E-12	1.000	0.000	0.000	0.000	25
21	0.61000	0.61000	-6.594E-12	1.000	0.000	0.000	0.000	1
22	0.59000	0.59000	-1.080E-11	1.000	0.000	0.000	0.000	28
23	0.54000	0.54000	-8.981E-12	1.000	0.000	0.000	0.000	5
24	0.63000	0.63000	-6.594E-12	1.000	0.000	0.000	0.000	10
25	1.76000	1.76000	-9.322E-12	1.000	0.000	0.000	0.000	16
26	3.07000	3.07000	-1.080E-11	1.000	0.000	0.000	0.000	23
27	3.32000	3.32000	-8.299E-12	1.000	0.000	0.000	0.000	24
28	3.85000	3.85000	-8.640E-12	1.000	0.000	0.000	0.000	11
29	3.17000	3.17000	-9.209E-12	1.000	0.000	0.000	0.000	32
30	4.51000	4.51000	-7.731E-12	1.000	0.000	0.000	0.000	2
31	2.88000	2.88000	-1.160E-11	1.000	0.000	0.000	0.000	13
32	4.05000	4.05000	-9.891E-12	1.000	0.000	0.000	0.000	6
33	2.93000	3.13000	-0.20000	0.250	-0.319	0.001	-0.265	27
34	4.17000	3.13000	1.04000	0.250	1.659	0.028	4.727	36
35	2.49000	3.13000	-0.64000	0.250	-1.021	0.011	-1.032	7
36	2.93000	3.13000	-0.20000	0.250	-0.319	0.001	-0.265	22

Case(s) with leverage of 1.0000: SRSD, DIST, T set to 0.000.

=============================
Model selected for Factorial:
=============================

Results of Factorial Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	55.15925	8	6.89491	26.65	0.0001
CURVATURE	3.02580	1	3.02580	11.70	0.0021
RESIDUAL	6.72675	26	0.25872		
LACK OF FIT	5.15555	23	0.22415	0.4280	0.8998
PURE ERROR	1.57120	3	0.52373		
COR TOTAL	64.91180	35			

ROOT MSE	0.508646	R-SQUARED	0.8913
DEP MEAN	2.310000	ADJ R-SQUARED	0.8579
C.V.	22.02%		

Predicted Residual Sum of Squares (PRESS) = 12.77299

VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
INTERCEPT	2.207500	1	0.089917		
A	0.325625	1	0.089917	3.621	0.0012
B	0.041250	1	0.089917	0.4588	0.6502
C	0.296875	1	0.089917	3.302	0.0028
D	1.113750	1	0.089917	12.39	0.0001
E	-0.280000	1	0.089917	-3.114	0.0045
AD	0.264375	1	0.089917	2.940	0.0068
CD	0.240625	1	0.089917	2.676	0.0127
DE	0.285000	1	0.089917	3.170	0.0039
CENTER POINT	0.922500	1	0.269750	3.420	0.0021

Final Equation in Terms of Coded Variables:

```
STRENGTH =
                2.207500
    +           0.325625 * A
    +           0.041250 * B
    +           0.296875 * C
    +           1.113750 * D
    -           0.280000 * E
    +           0.264375 * A * D
    +           0.240625 * C * D
    +           0.285000 * D * E
```

Final Equation in Terms of Uncoded Variables:

```
STRENGTH =
                5.349167
    -           0.935000 * BINDER
    +           0.001375 * FLYASH
    -           0.170000 * HYDRAFIL
    -           0.198125 * FINES
    -           0.756667 * MOIST
    +           0.052875 * BINDER * FINES
    +           0.009625 * HYDRAFIL * FINES
```

\+ 0.019000 * FINES * MOIST

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	1.29000	1.50000	-0.21000	0.281	-0.487	0.009	-0.480	12
2	2.22000	1.62250	0.59750	0.281	1.386	0.075	1.412	26
3	1.32000	1.58250	-0.26250	0.281	-0.609	0.014	-0.601	34
4	1.61000	1.70500	-0.09500	0.281	-0.220	0.002	-0.216	14
5	1.39000	1.61250	-0.22250	0.281	-0.516	0.010	-0.509	[illegible]
6	2.20000	1.73500	0.46500	0.281	1.078	0.045	1.082	19
7	2.02000	1.69500	0.32500	0.281	0.754	0.022	0.747	8
8	1.22000	1.81750	-0.59750	0.281	-1.386	0.075	-1.412	33
9	2.34000	2.14750	0.19250	0.281	0.446	0.008	0.439	18
10	3.00000	3.32750	-0.32750	0.281	-0.759	0.023	-0.753	35
11	1.88000	2.23000	-0.35000	0.281	-0.812	0.026	-0.806	20
12	3.05000	3.41000	-0.36000	0.281	-0.835	0.027	-0.830	9
13	2.50000	3.22250	-0.72250	0.281	-1.675	0.110	-1.740	17
14	4.88000	4.40250	0.47750	0.281	1.107	0.048	1.112	30
15	4.00000	3.30500	0.69500	0.281	1.612	0.102	1.666	15
16	4.88000	4.48500	0.39500	0.281	0.916	0.033	0.913	29
17	0.63000	0.37000	0.26000	0.281	0.603	0.014	0.595	3
18	0.50000	0.49250	0.00750	0.281	0.017	0.000	0.017	4
19	0.46000	0.45250	0.00750	0.281	0.017	0.000	0.017	21
20	0.27000	0.57500	-0.30500	0.281	-0.707	0.020	-0.700	25
21	0.61000	0.48250	0.12750	0.281	0.296	0.003	0.290	1
22	0.59000	0.60500	-0.01500	0.281	-0.035	0.000	-0.034	28
23	0.54000	0.56500	-0.02500	0.281	-0.058	0.000	-0.057	5
24	0.63000	0.68750	-0.05750	0.281	-0.133	0.001	-0.131	10
25	1.76000	2.15750	-0.39750	0.281	-0.922	0.033	-0.919	16
26	3.07000	3.33750	-0.26750	0.281	-0.620	0.015	-0.613	23
27	3.32000	2.24000	1.08000	0.281	2.504	0.245	2.819	24
28	3.85000	3.42000	0.43000	0.281	0.997	0.039	0.997	11
29	3.17000	3.23250	-0.06250	0.281	-0.145	0.001	-0.142	32
30	4.51000	4.41250	0.09750	0.281	0.226	0.002	0.222	2
31	2.88000	3.31500	-0.43500	0.281	-1.009	0.040	-1.009	13
32	4.05000	4.49500	-0.44500	0.281	-1.032	0.042	-1.033	6
33	2.93000	3.13000	-0.20000	0.250	-0.454	0.007	-0.447	27
34	4.17000	3.13000	1.04000	0.250	2.361	0.186	2.612	36
35	2.49000	3.13000	-0.64000	0.250	-1.453	0.070	-1.486	7
36	2.93000	3.13000	-0.20000	0.250	-0.454	0.007	-0.447	22

D E S I G N - E X P E R T   A N A L Y S I S

Response: STRENGTH; File = SHAND			Run on 11/23/95 at 16:43:28	
FAC	FACTOR	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	FLYASH	PERCENT	0.000	60.000
C	HYDRAFIL	L/TONNE	0.000	5.000
D	FINES	PERCENT	20.000	40.000
E	MOIST	PERCENT	1.000	4.000

***** WARNING. The Cubic Model is Aliased! *****

Sequential Mo[illegible]l Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	[illegible]	1	269.75		
Linear	[illegible]	[illegible]	13.64	23.51	0.0001
Quadratic	[illegible]	[illegible]	0.98	3.080	0.0053
Cubic	[illegible]	[illegible]	0.35	1.238	0.3591
RESIDUAL	[illegible]	[illegible]	0.29		
TOTAL	[illegible]	[illegible]			

Lack of Fit Tests

MODEL	[illegible]	[illegible]	MEAN SQUARE	F VALUE	PROB > F
Linear	[illegible]	[illegible]	0.59	1.859	0.2538
Quadratic	[illegible]	[illegible]	0.32	1.010	0.5529
Cubic	[illegible]	[illegible]	0.26	0.8116	0.6240
PURE ERR	[illegible]	[illegible]	0.32		

Model Summary Statistics

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	6	42	0.745	0.7368	0.7055	29.731
Quadratic	21	27	0.564	0.9029	0.8310	30.251
Cubic	36	12	0.530	0.9619	0.8508	62.685

Response: STRENGTH; File = SHAND			Run on 11/23/95 at 16:43:55	
FAC	FACTOR	UNITS	-1 LEVEL	-1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	FLYASH	PERCENT	0.000	60.000
C	HYDRAFIL	L/TONNE	0.000	5.000
D	FINES	PERCENT	20.000	40.000
E	MOIST	PERCENT	1.000	4.000

ANOVA for Quadratic Model

D E S I G N - E X P E R T   A N A L Y S I S -- Page 2

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	79.87	[illegible]	3.994	12.56	0.0001
RESIDUAL	8.59	27	0.318		
Lack Of Fit	7.01	22	0.319	1.010	0.5[illegible]
Pure Error	1.58	5	0.316		
COR TOTAL	88.46	47			

ROOT MSE	0.564	R-SQUARED	0.90[illegible]
DEP MEAN	2.326	ADJ R-SQUARED	0.8310
C.V.	24.24%		

Predicted Residual Sum of Squares (PRESS) = 30.25

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	3.134	1	0.228	13.75	
A-BINDER	0.285	1	0.086	3.327	0.0025
B-FLYASH	-0.082	1	0.086	-0.9578	0.3466
C-HYDRAFIL	0.315	1	0.086	3.675	0.0010
D-FINES	1.084	1	0.086	12.65	0.0001
E-MOIST	-0.377	1	0.086	-4.400	0.0002
A2	-0.201	1	0.079	-2.554	0.0166
B2	-0.316	1	0.079	-4.013	0.0004
C2	-0.140	1	0.079	-1.779	0.0865
D2	-0.128	1	0.079	-1.622	0.11[illegible]
E2	-0.110	1	0.079	-1.397	0.173[illegible]
AB	-0.129	1	0.100	-1.298	0.2054
AC	0.040	1	0.100	0.4012	0.6914
AD	0.264	1	0.100	2.652	0.0132
AE	-0.069	1	0.100	-0.6959	0.4925
BC	-0.018	1	0.100	-0.1818	0.8571
BD	0.126	1	0.100	1.266	0.2162
BE	0.031	1	0.100	0.3135	0.7563
CD	0.241	1	0.100	2.414	0.0229
CE	-0.102	1	0.100	-1.022	0.3159
DE	0.285	1	0.100	2.859	0.0081

Final Equation in Terms of Coded Factors:

STRENGTH =

	3.134		
+	0.285	*	A
-	0.082	*	B
+	0.315	*	C
+	1.084	*	D
-	0.377	*	E
-	0.201	*	A2
-	0.316	*	B2
-	0.140	*	C2
-	0.128	*	D2
-	0.110	*	E2
-	0.129	*	AB
+	0.040	*	AC
+	0.264	*	AD

```
-       0.069 * AE
-       0.018 * BC
-       0.126 * BD
+       0.031 * BE
+       0.241 * CD
-       0.102 * CE
+       0.285 * DE
```

Final Equation in Terms of Actual Factors:

```
STRENGTH =
            -12.811
+            6.6354 * BINDER
+        4.339E-02 * FLYASH
-          0.11951 * HYDRAFIL
-          0.13704 * FINES
-          0.11343 * MOIST
-          0.80462 * BINDERU2
-        3.512E-04 * FLYASHU2
-        2.242E-02 * HYDRAFILU2
-        1.278E-03 * FINESU2
-        4.893E-02 * MOISTU2
-        8.625E-03 * BINDER * FLYASH
+        3.200E-02 * BINDER * HYDRAFIL
+        5.287E-02 * BINDER * FINES
-        9.250E-02 * BINDER * MOIST
-        2.417E-04 * FLYASH * HYDRAFIL
+        4.208E-04 * FLYASH * FINES
+        6.944E-04 * FLYASH * MOIST
+        9.625E-03 * HYDRAFIL * FINES
-        2.717E-02 * HYDRAFIL * MOIST
+        1.900E-02 * FINES * MOIST
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1.290	1.682	-0.392	0.450	-0.939	0.034	-0.937	47
2	2.220	2.041	0.179	0.450	0.427	0.007	0.421	31
3	1.320	1.498	-0.178	0.450	-0.427	0.007	-0.420	36
4	1.610	1.340	0.270	0.450	0.647	0.016	0.639	12
5	1.390	1.991	-0.601	0.450	-1.438	0.081	-1.468	7
6	2.200	2.510	-0.310	0.450	-0.741	0.021	-0.735	41
7	2.020	1.734	0.286	0.450	0.683	0.018	0.676	39
8	1.220	1.736	-0.516	0.450	-1.234	0.059	-1.246	9
9	2.340	2.019	0.321	0.450	0.769	0.023	0.763	25
10	3.000	3.435	-0.435	0.450	-1.040	0.042	-1.042	5
11	1.880	2.339	-0.459	0.450	-1.099	0.047	-1.103	28
12	3.050	3.238	-0.188	0.450	-0.450	0.008	-0.443	22
13	2.500	3.290	-0.790	0.450	-1.889	0.139	-1.989	14
14	4.880	4.866	0.014	0.450	0.034	0.000	0.033	18
15	4.000	3.538	0.462	0.450	1.105	0.048	1.110	29
16	4.880	4.597	0.283	0.450	0.678	0.018	0.671	30
17	0.630	0.638	-0.008	0.450	-0.020	0.000	-0.019	19
18	0.500	0.720	-0.220	0.450	-0.525	0.011	-0.518	46
19	0.460	0.579	-0.119	0.450	-0.285	0.003	-0.280	35
20	0.270	0.143	0.127	0.450	0.304	0.004	0.299	23
21	0.610	0.539	0.071	0.450	0.169	0.001	0.166	21

22	0.590	0.781	-0.191	0.450	-0.456	0.008	-0.449	24
23	0.540	0.408	0.132	0.450	0.317	0.004	0.311	8
24	0.630	0.132	0.498	0.450	1.192	0.055	1.202	11
25	1.760	2.114	-0.354	0.450	-0.848	0.028	-0.843	42
26	3.070	3.253	-0.183	0.450	-0.438	0.007	-0.432	34
27	3.320	2.560	0.760	0.450	1.817	0.129	1.904	20
28	3.850	3.182	0.668	0.450	1.599	0.100	1.6[illegible]	38
29	3.170	2.978	0.192	0.450	0.460	0.008	0.453	10
30	4.510	4.277	0.233	0.450	0.558	0.012	0.551	44
31	2.880	3.351	-0.471	0.450	-1.127	0.050	-1.133	45
32	4.050	4.133	-0.083	0.450	-0.198	0.002	-0.194	13
33	1.680	1.319	0.361	0.561	0.967	0.057	0.965	4
34	2.490	2.674	-0.184	0.561	-0.493	0.015	-0.486	32
35	2.460	1.542	0.918	0.561	2.456	0.366	2.735	16
36	0.410	1.151	-0.741	0.561	-1.983	0.239	-2.105	40
37	1.560	1.593	-0.033	0.561	-0.088	0.000	-0.086	15
38	3.300	3.090	0.210	0.561	0.561	0.019	0.554	43
39	0.120	-0.167	0.287	0.561	0.767	0.036	0.761	27
40	4.880	4.990	-0.110	0.561	-0.294	0.005	-0.289	37
41	4.150	3.408	0.742	0.561	1.984	0.239	2.107	1
42	1.050	1.615	-0.565	0.561	-1.511	0.139	-1.549	2
43	3.200	3.134	0.066	0.163	0.128	0.000	0.126	48
44	4.170	3.134	1.036	0.163	2.008	0.037	2.137	6
45	2.490	3.134	-0.644	0.163	-1.248	0.014	-1.262	17
46	3.200	3.134	0.066	0.163	0.128	0.000	0.126	33
47	2.930	3.134	-0.204	0.163	-0.395	0.001	-0.389	26
48	2.930	3.134	-0.204	0.163	-0.395	0.001	-0.389	3

Response: STRENGTH; File = SHAND   Run on 11/23/95 at 16:44:32

FAC	FACTOR	UNITS	-1 LEVEL	+1 LEVEL
A	BINDER	PERCENT	4.000	5.000
B	FLYASH	PERCENT	0.000	60.000
C	HYDRAFIL	L/TONNE	0.000	5.000
D	FINES	PERCENT	20.000	40.000
E	MOIST	PERCENT	1.000	4.000

ANOVA for Reduced Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	75.48	10	7.548	21.52	0.0001
RESIDUAL	12.98	37	0.351		
Lack Of Fit	11.40	32	0.356	1.129	0.4979
Pure Error	1.58	5	0.316		
COR TOTAL	88.46	47			

ROOT MSE	0.592	R-SQUARED	0.8533
DEP MEAN	2.326	ADJ R-SQUARED	0.8136
C.V.	25.46%		

Predicted Residual Sum of Squares (PRESS) = 25.24

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > t

Intercept	2.611	1	0.137	19.05	
A-BINDER	0.285	1	0.090	3.168	0.0031
B-FLYASH	-0.082	1	0.090	-0.9120	0.3677
C-HYDRAFIL	0.315	1	0.090	3.499	0.0012
D-FINES	1.084	1	0.090	12.05	0.0001
E-MOIST	-0.377	1	0.090	-4.190	0.0002
B2	-0.252	1	0.079	-3.183	0.0029
D2	-0.064	1	0.079	-0.8037	0.4267
AD	0.264	1	0.105	2.525	0.0160
CD	0.241	1	0.105	2.298	0.0273
DE	0.285	1	0.105	2.722	0.0098

Final Equation in Terms of Coded Factors:

```
        STRENGTH =
                          2.611
               +          0.285  * A
               -          0.082  * B
               +          0.315  * C
               +          1.084  * D
               -          0.377  * E
               -          0.252  * B2
               -          0.064  * D2
               +          0.264  * AD
               +          0.241  * CD
               +          0.285  * DE
```

Final Equation in Terms of Actual Factors:

```
        STRENGTH =
                          5.649
               -         1.0161  * BINDER
               +      1.406E-02  * FLYASH
               -        0.16279  * HYDRAFIL
               -        0.16291  * FINES
               -        0.82140  * MOIST
               -      2.799E-04  * FLYASHU2
               -      6.361E-04  * FINESU2
               +      5.287E-02  * BINDER * FINES
               +      9.625E-03  * HYDRAFIL * FINES
               +      1.900E-02  * FINES * MOIST
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1.290	1.860	-0.570	0.230	-1.098	0.033	-1.101	47
2	2.220	1.902	0.318	0.230	0.613	0.010	0.607	31
3	1.320	1.696	-0.376	0.230	-0.724	0.014	-0.719	36
4	1.610	1.738	-0.128	0.230	-0.246	0.002	-0.242	12
5	1.390	2.009	-0.619	0.230	-1.191	0.039	-1.198	7
6	2.200	2.050	0.150	0.230	0.288	0.002	0.285	41
7	2.020	1.845	0.175	0.230	0.337	0.003	0.333	39
8	1.220	1.886	-0.666	0.230	-1.282	0.045	-1.294	9
9	2.340	2.449	-0.109	0.230	-0.210	0.001	-0.207	25
10	3.000	3.548	-0.548	0.230	-1.054	0.030	-1.056	5
11	1.880	2.285	-0.405	0.230	-0.779	0.017	-0.775	28

12	3.050	3.384	-0.334	0.230	-0.642	0.011	[illegible]	[illegible]
13	2.500	3.560	-1.060	0.230	-2.040	0.113	-2.136	14
14	4.880	4.659	0.221	0.230	0.426	0.005	0.421	18
15	4.000	3.396	0.604	0.230	1.163	0.037	1.169	29
16	4.880	4.495	0.385	0.230	0.742	0.015	0.737	30
17	0.630	0.536	0.094	0.230	0.181	0.001	0.178	19
18	0.500	0.578	-0.078	0.230	-0.149	0.001	-0.147	46
19	0.460	0.372	0.088	0.230	0.169	0.001	0.167	35
20	0.270	0.413	-0.143	0.230	-0.276	0.002	-0.273	23
21	0.610	0.685	-0.075	0.230	-0.144	0.001	-0.142	21
22	0.590	0.726	-0.136	0.230	-0.262	0.002	-0.259	24
23	0.540	0.521	0.019	0.230	0.037	0.000	0.037	8
24	0.630	0.562	0.068	0.230	0.131	0.000	0.129	11
25	1.760	2.265	-0.505	0.230	-0.971	0.026	-0.971	42
26	3.070	3.364	-0.294	0.230	-0.565	0.009	-0.560	34
27	3.320	2.101	1.219	0.230	2.347	0.150	2.509	20
28	3.850	3.199	0.651	0.230	1.252	0.043	1.262	38
29	3.170	3.376	-0.206	0.230	-0.396	0.004	-0.391	10
30	4.510	4.475	0.035	0.230	0.068	0.000	0.067	44
31	2.880	3.212	-0.332	0.230	-0.638	0.011	-0.633	45
32	4.050	4.310	[illegible]	0.230	-0.561	0.007	-0.496	13
33	1.680	1.933	-0.253	0.184	-0.473	0.005	-0.468	4
34	2.490	3.289	-0.799	0.184	-1.493	0.046	-1.519	32
35	2.460	1.381	1.079	0.550	2.715	0.820	2.993	16
36	0.410	0.991	-0.581	0.550	-1.463	0.238	-1.487	40
37	1.560	1.862	-0.302	0.184	-0.565	0.007	-0.560	15
38	3.300	3.360	-0.060	0.184	-0.112	0.000	-0.110	43
39	0.120	-0.327	0.447	0.550	1.126	0.141	1.130	27
40	4.880	4.830	0.050	0.550	0.127	0.002	0.125	37
41	4.150	3.508	0.642	0.184	1.201	0.030	1.208	1
42	1.050	1.714	-0.664	0.184	-1.242	0.032	-1.251	2
43	3.200	2.611	0.589	0.054	1.022	0.005	1.023	48
44	4.170	2.611	1.559	0.054	2.706	0.038	2.980	6
45	2.490	2.611	-0.121	0.054	-0.210	0.000	-0.207	17
46	3.200	2.611	0.589	0.054	1.022	0.005	1.023	32
47	2.930	2.611	0.319	0.054	0.554	0.002	0.548	26
48	2.930	2.611	0.319	0.054	0.554	0.002	0.548	[illegible]

Appendix #4

Shand Flyash

Factorial Design

100 Days Curing Period

Cost Analysis

RATING	BINDER	FLYASH	HYDRAFIL	FINES	MOIST	DE	DX	AVG	COST	
1	5.4	30	2	30	1	3.01	3.44	3.2[illegible]	$6.[illegible]	
2	5.4	40	2	30	1	3.03	3.38	3.21	$5.[illegible]	
3	5.4	50	2	30	1	3.04	3.27	3.16	$5.[illegible]	
4	5.2	30	2	30	1	2.88	3.32	3.10	$5.[illegible]	
5	5.2	40	2	30	1	2.90	3.27	3.08	$5.7[illegible]	
6	5.4	60	2	30	1	3.06	3.10	3.08	$5.4[illegible]	
7	5.2	50	2	30	1	2.91	3.16	3.03	$5.4[illegible]	
8	5.4	30	2	30	2	2.63	3.19	3.01	$6.1[illegible]	
9	5.4	40	2	30	2	2.84	3.13	[illegible]99	$5.90	
10	5	30	2	30	1	2.75	3.21	2.98	$5.71	
11	5	40	2	30	1	2.77	3.15	2.96	$5.4[illegible]	
12	5.2	60	2	30	1	2.93	2.99	2.96	$5.2[illegible]	
13	5.4	50	2	30	2	2.86	3.02	2.94	$5.7[illegible]	
14	5	50	2	30	1	2.78	3.04	2.91	$5.2[illegible]	
15	5.2	30	2	30	2	2.70	3.07	2.88	$5.3[illegible]	
16	5.2	40	2	30	2	2.71	3.02	2.86	$5.71	
17	5.4	60	2	30	2	2.87	2.85	2.86	$5.46	
18	4.8	30	2	30	1	2.62	3.10	2.86	$5.40	
19	4.8	40	2	30	1	2.64	3.04	2.84	$5.2[illegible]	
20	5	60	2	30	1	2.79	2.88	2.84	$5.0[illegible]	
21	5.2	50	2	30	2	2.72	2.91	2.82	$5.4[illegible]	
22	4.8	50	2	30	1	2.65	2.93	2.79	$5.0[illegible]	
23	5	30	2	30	2	2.57	2.96	2.76	$5.71	
24	5	40	2	30	2	2.58	2.90	2.74	$5.4[illegible]	
25	5.2	60	2	30	2	2.74	2.74	2.74	$5.2[illegible]	
26	4.6	30	2	30	1	2.49	2.98	2.74	$5.2[illegible]	
27	4.6	40	2	30	1	2.51	2.93	2.72	$5.0[illegible]	
28	4.8	60	2	30	1	2.66	2.76	2.71	$4.[illegible]	
29	5	50	2	30	2	2.59	2.79	2.69	$5.2[illegible]	
30	4.6	50	2	30	1	2.52	2.81	2.67	$4.[illegible]	
31	4.8	30	2	30	2	2.44	2.84	2.64	$5.4[illegible]	
32	4.8	40	2	30	2	2.45	2.79	2.62	$5.2[illegible]	
33	5	60	2	30	2	2.61	2.62	2.62	$5.0[illegible]	
34	4.4	30	2	30	1	2.36	2.87	2.62	$5.0[illegible]	
35	5.4	30	2	25	1	2.39	2.81	2.60	$6.16	
36	4.4	40	2	30	1	2.38	2.81	2.59	$4.83	
37	4.6	60	2	30	1	2.53	2.65	2.59	$4.66	
38	5.4	40	2	25	1	2.40	2.75	2.58	$5.9[illegible]	
39	4.8	50	2	30	2	2.46	2.68	2.57	$5.0[illegible]	
40	4.4	50	2	30	1	2.39	2.70	2.55	$4.64	
41	5.2	30	2	25	1	2.31	2.75	2.53	$5.93	
42	5.4	50	2	25	1	2.41	2.64	2.53	$5.70	
43	4.6	30	2	30	2	2.31	2.73	2.52	$5.2[illegible]	
44	5.2	40	2	25	1	2.32	2.69	2.51	$5.71	
45	4.6	40	2	30	2	2.32	2.67	2.50	$5.0[illegible]	
46	4.8	60	2	30	2	2.48	2.51	2.49	$4.8[illegible]	
47	4.2	30	2	30	1	2.23	2.75	2.49	$4.7[illegible]	
48	4.2	40	2	30	1	2.25	2.70	2.47	$4.6[illegible]	
49	4.4	60	2	30	1	2.40	2.53	2.47	$4.4[illegible]	
50	5	30	2	25	1	2.23	2.69	2.46	$5.71	
51	5.2	50	2	25	1	2.34	2.58	2.46	$5.4[illegible]	
52	5.4	60	2	25	1	2.43	2.47	2.45	$[illegible]	
53	4.6	50	2	30	2	2.33	2.56	2.45	$4.8[illegible]	
54	5	40	2	25	1	2.25	2.63	2.44	$5.4[illegible]	
55	4.2	50	2	30	1	2.26	2.59	2.42	$4.4[illegible]	
56	4.4	30	2	30	2	2.18	2.62	2.40	$5.0[illegible]	
57	4.8	30	2	25	1	2.15	2.62	2.39	$5.48	
58	5	50	2	25	1	2.26	2.52	2.39	$5.[illegible]	
59	5.2	60	2	25	1	2.35	2.41	2.38	$5.2[illegible]	
60	4.4	40	2	30	2	2.19	2.56	2.38	$4.83	
61	4.6	60	2	30	2	2.35	2.40	2.37	$4.6[illegible]	
62	4	30	2	30	1	2.10	2.64	2.37	$4.5[illegible]	
63	4.8	40	2	25	1	2.17	2.57	2.37	$5.27	
64	4	40	2	30	1	2.12	2.58	2.35	$4.3[illegible]	
65	4.2	60	2	30	1	2.27	2.42	2.35	$4.2[illegible]	
66	4.4	50	2	30	2	2.20	2.45	2.33	$4.64	
67	4.6	30	2	25	1	2.08	2.56	2.32	$5.25	
68	4.8	50	2	25	1	2.18	2.46	2.32	$5.0[illegible]	
69	5	60	2	25	1	2.27	2.35	2.31	$5.0[illegible]	
70	4	50	2	30	1	2.13	2.47	2.30	$4.22	CURRENT T-3 RECIPE
71	4.6	40	2	25	1	2.09	2.51	2.30	$5.0[illegible]	
72	5.4	30	2	25	2	2.10	2.46	2.28	$6.1[illegible]	
73	4.2	30	2	30	2	2.05	2.50	2.27	$4.7[illegible]	
74	5.4	40	2	25	2	2.12	2.41	2.26	$5.9[illegible]	
75	4.2	40	2	30	2	2.06	2.45	2.25	$4.[illegible]	
76	4.4	30	2	25	1	2.00	2.50	2.25	$5.[illegible]	

RATING	BINDER	FLYASH	HYDRAT	FINES	MOIST	DE	DX	AVG	COST	
77	4.6	50	2	25	1	2.10	2.40	2.25	$4.65	
78	4.4	60	2	30	2	2.22	2.28	2.25	$4.45	
79	3.8	30	2	30	1	1.97	2.53	2.25	$4.34	
80	4.8	60	2	25	1	2.20	2.29	2.24	$4.66	
81	4.4	40	2	25	1	2.01	2.45	2.23	$4.63	
82	3.8	40	2	30	1	1.99	2.47	2.23	$4.17	
83	4	60	2	30	1	2.14	2.31	2.22	$4.06	
84	5.2	30	2	25	2	2.03	2.40	2.21	$5.93	
85	5.4	50	2	25	2	2.13	2.30	2.21	$5.70	
86	4.2	50	2	30	2	2.07	2.34	2.20	$4.43	
87	5.2	40	2	25	2	2.04	2.35	2.19	$5.71	
88	4.2	30	2	25	1	1.92	2.44	2.18	$4.79	
89	4.4	50	2	25	1	2.03	2.34	2.18	$4.64	
90	3.8	50	2	30	1	2.00	2.36	2.18	$4.01	
91	4.6	60	2	25	1	2.12	[illegible]	2.17	$4.66	
92	4.2	40	2	25	1	1.94	2.39	2.16	$4.61	
93	4	30	2	30	2	1.92	2.39	2.15	$4.56	CURRENT BIRCHTREE RECIPE
94	5	30	2	25	2	1.95	2.34	2.14	$5.71	
95	5.2	50	2	25	2	2.05	[illegible]	2.14	$5.49	
96	5.4	60	2	25	2	2.15	2.13	2.14	$5.46	
97	4	40	2	30	2	1.93	2.33	2.13	$4.39	
98	4.2	60	2	30	2	2.09	2.17	2.13	$4.25	POSSIBLE BIRCHTREE RECIPE
99	3.6	30	2	30	1	1.84	2.41	2.13	$4.11	
100	5	40	2	25	2	1.96	2.28	2.12	$5.49	
101	4	30	2	25	1	1.84	2.38	2.11	$4.56	
102	4.2	50	2	25	1	1.95	2.27	2.11	$4.43	
103	3.6	40	2	30	1	1.86	2.36	2.11	$3.96	
104	4.4	60	2	25	1	2.04	2.17	2.10	$4.45	
105	3.8	60	2	30	1	2.01	2.19	2.10	$3.85	POSSIBLE T-3 RECIPE
106	4	40	2	25	1	1.86	2.33	2.09	$4.39	
107	4	50	2	30	2	1.94	2.22	2.08	$4.22	
108	4.8	30	2	25	2	1.87	2.28	2.08	$5.48	
109	5	50	2	25	2	1.98	2.17	2.08	$5.25	
110	5.2	60	2	25	2	2.07	2.07	2.07	$5.26	
111	3.6	50	2	30	1	1.87	2.24	2.06	$3.80	
112	4.8	40	2	25	2	1.89	2.22	2.05	$5.27	
113	3.8	30	2	25	1	1.77	2.32	2.04	$4.34	
114	4	50	2	25	1	1.87	2.21	2.04	$4.22	
115	4.2	60	2	25	1	1.96	2.11	2.04	$4.25	
116	3.6	30	2	30	2	1.79	2.27	2.03	$4.34	
117	3.8	40	2	25	1	1.76	2.25	2.02	$4.17	
118	3.8	40	2	30	2	1.80	2.22	2.01	$4.17	
119	4.6	30	2	25	2	1.79	2.22	2.01	$5.25	
120	4.8	50	2	25	2	1.90	2.11	2.01	$5.06	
121	4	60	2	30	2	1.96	2.05	2.01	$4.06	
122	3.4	30	2	30	1	1.71	2.30	2.00	$3.88	
123	5	60	2	25	2	1.99	2.01	2.00	$5.06	
124	4.6	40	2	25	2	1.81	2.16	1.99	$5.06	
125	3.4	40	2	30	1	1.73	2.24	1.98	$3.73	
126	3.6	60	2	30	1	1.88	2.08	1.98	$3.64	
127	3.6	30	2	25	1	1.69	2.26	1.97	$4.11	
128	3.8	50	2	25	1	1.79	2.15	1.97	$4.01	
129	4	60	2	25	1	1.89	2.05	1.97	$4.05	
130	3.8	50	2	30	2	1.81	2.11	1.96	$4.01	
131	3.6	40	2	25	1	1.70	2.20	1.95	$3.96	
132	4.4	30	2	25	2	1.72	2.16	1.94	$5.02	
133	4.6	50	2	25	2	1.82	2.05	1.94	$4.85	
134	3.4	50	2	30	1	1.74	2.13	1.94	$3.59	
135	4.8	60	2	25	2	1.91	1.94	1.93	$4.86	
136	4.4	40	2	25	2	1.73	2.10	1.92	$4.83	
137	3.6	30	2	30	2	1.66	2.16	1.91	$4.11	
138	3.4	30	2	25	1	1.61	2.20	1.90	$3.88	
139	3.6	50	2	25	1	1.72	2.09	1.90	$3.80	
140	3.8	60	2	25	1	1.81	1.99	1.90	$3.85	
141	3.6	40	2	30	2	1.67	2.10	1.89	$3.96	
142	3.4	40	2	25	1	1.63	2.14	1.88	$3.73	
143	3.8	60	2	30	2	1.83	1.94	1.88	$3.85	
144	3.2	30	2	30	1	1.58	2.18	1.88	$3.65	
145	4.2	30	2	25	2	1.64	2.10	1.87	$4.79	
146	4.4	50	2	25	2	1.74	1.99	1.87	$4.64	
147	3.2	40	2	30	1	1.60	2.13	1.86	$3.51	
148	4.6	60	2	25	2	1.84	1.88	1.86	$4.66	
149	3.4	60	2	30	1	1.75	1.96	1.86	$3.44	
150	4.2	40	2	25	2	1.65	2.04	1.85	$4.61	
151	3.6	50	2	30	2	1.68	1.99	1.84	$3.80	
152	3.2	30	2	25	1	1.53	2.14	1.84	$3.65	

RAT[illegible]	BINDER	FLYASH	HYDRAFIL	FIN[illegible]	MOIST	DE	DX	AVG	CO[illegible]
15[illegible]	3.4	50	2	25	1	1.64	2.03	1.84	$3.5[illegible]
[illegible]54	3.6	60	2	25	1	1.73	1.92	1.83	$3.[illegible]
155	3.2	40	2	25	1	1.55	2.08	1.81	$3.[illegible]
156	3.2	50	2	30	1	1.6[illegible]	2.02	1.81	$3.[illegible]
157	4	30	2	25	2	1.56	2.03	1.80	$4.[illegible]
158	4.2	50	2	25	2	1.67	1.93	1.80	$4.4[illegible]
159	4.4	60	2	25	2	1.76	1.82	1.79	$4.4[illegible]
160	[illegible]4	30	2	30	2	1.53	2.05	1.79	$3.8[illegible]
16[illegible]	4	40	2	25	2	1.58	1.98	1.78	$4.[illegible]
162	[illegible]	30	2	25	1	1.46	2.07	1.77	$3.4[illegible]
163	3.2	50	2	25	1	1.56	1.97	1.7[illegible]	$3.[illegible]
164	3.4	40	2	30	2	1.54	1.99	1.76	$3.7[illegible]
165	3.6	60	2	30	2	1.70	1.83	1.76	$3.6[illegible]
166	3	30	2	30	1	1.45	2.07	1.76	$3.4[illegible]
167	3.4	60	2	25	1	1.65	1.86	1.76	$3.44
168	3	40	2	25	1	1.47	2.02	1.75	$3.29
169	3	40	2	30	1	1.46	2.01	1.74	$3.29
170	3.2	60	2	30	1	1.62	1.85	1.74	$3.24
171	3.8	30	2	25	2	1.49	1.97	1.73	$4.[illegible]
172	4	50	2	25	2	1.59	1.87	1.73	$4.2[illegible]
173	4.2	60	2	25	2	1.68	1.76	1.72	$4.[illegible]
174	3.4	50	2	30	2	1.55	1.88	1.72	$3.[illegible]
175	3.8	40	2	25	2	1.50	1.92	1.71	$4.1[illegible]
176	3	50	2	25	1	1.49	1.91	1.70	$3.1[illegible]
177	3	50	2	30	1	1.48	1.90	1.69	$3.1[illegible]
178	3.2	60	2	25	1	1.58	1.80	1.69	$3.24
179	3.2	30	2	30	2	1.39	1.93	1.66	$3.0[illegible]
180	3.6	30	2	25	2	1.41	1.91	1.66	$4.11
181	3.8	50	2	25	2	1.51	1.81	1.66	$4.0[illegible]
182	4	60	2	25	2	1.60	1.70	1.65	$4.0[illegible]
183	3.2	40	2	30	2	1.41	1.88	1.64	$3.5[illegible]
184	3.4	60	2	30	2	1.57	1.71	1.64	$3.44
185	3.6	40	2	25	2	1.42	1.86	1.64	$3.9[illegible]
186	3	60	2	25	1	1.50	1.74	1.62	$3.04
187	3	60	2	30	1	1.49	1.74	1.61	$3.04
188	3.2	50	2	30	2	1.42	1.77	1.59	$3.38
189	3.4	30	2	25	2	1.33	1.85	1.59	$3.8[illegible]
190	3.6	50	2	25	2	1.44	1.75	1.59	$3.80
191	3.8	60	2	25	2	1.53	1.64	1.58	$3.8[illegible]
192	3.4	40	2	25	2	1.34	1.80	1.57	$3.73
193	3	30	2	30	2	1.26	1.82	1.54	$3.4[illegible]
194	3.2	30	2	25	2	1.25	1.79	1.52	$3.65
195	3.4	50	2	25	2	1.36	1.68	1.52	$3.5[illegible]
196	3	40	2	30	2	1.28	1.76	1.52	$3.29
197	3.2	60	2	30	2	1.44	1.60	1.52	$3.24
198	3.6	60	2	25	2	1.45	1.58	1.51	$3.64
199	3.2	40	2	25	2	1.27	1.73	1.50	$3.51
200	3	50	2	30	2	1.29	1.65	1.47	$3.17
201	3	30	2	25	2	1.18	1.73	1.45	$3.42
202	3.2	50	2	25	2	1.28	1.62	1.45	$3.38
203	3.4	60	2	25	2	[illegible]	1.52	1.44	$3.44
204	3	40	2	25	2	[illegible]	1.67	1.43	$3.29
205	3	60	2	30	2	1.3[illegible]	1.48	1.40	$3.04
206	3	50	2	25	2	1.20	1.56	1.38	$3.1[illegible]
207	3.2	60	2	25	2	1.29	1.46	1.38	$3.24
208	3	60	2	25	2	1.22	1.39	1.31	$3.04

Appendix #5

Rockfill Cost

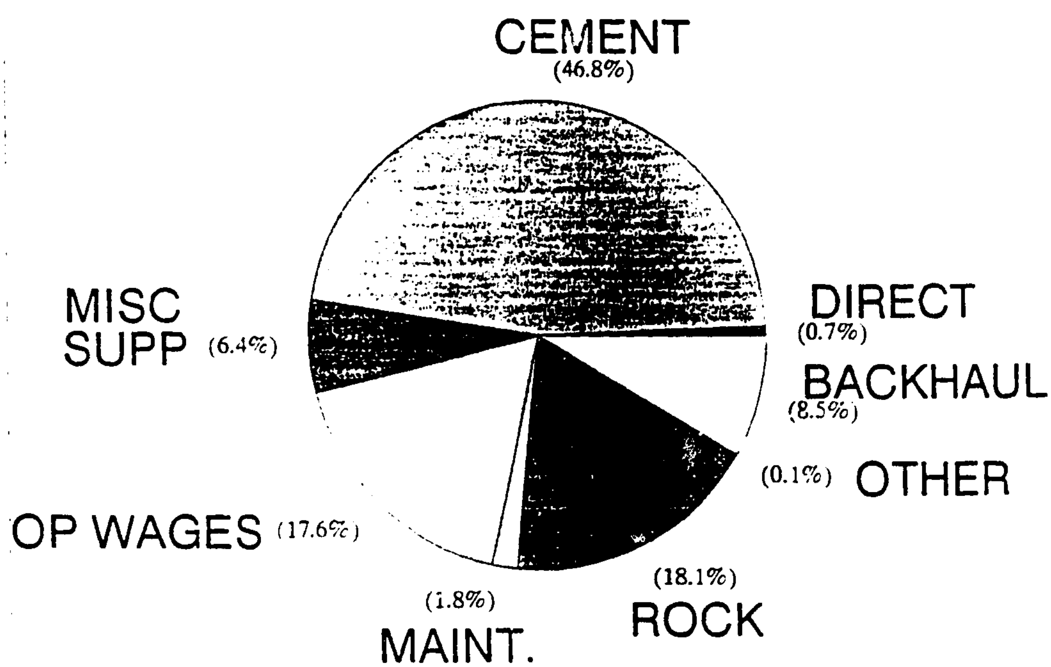
Breakdown

Cost Analysis

1994 COST ANALYSIS	TOTAL COSTS	TOTAL TON FILL	PERCENT TOTAL
DIRECT	15171	0.09	0.7
CEMENT	1001500	6.24	46.8
MISC SUPP	137867	0.86	6.4
OP WAGES	377421	2.35	17.6
MAINT.	37598	0.23	1.8
ROCK	386849	2.41	18.1
OTHER	1389	0.01	0.1
BACKHAUL	181052	1.13	8.5
TOTAL	2138847	13.33	100.00
TOTAL TONS PLACED	160395		

ROCKFILL ANALYSIS

(1994 ROCKFILL COSTS)



TOTAL COSTS = $13.33/TON FILL PLACED

Appendix #6

Rockfill Fill Raise

Orientation Figures

Cost Analysis

FIGURE #1

OPTIMUM RAISE ORIENTATION FOR DOUBLE RAISE FILLING

MINING ON TWO SIDES OF THE FILL BLOCK - L,W < 30 METERS

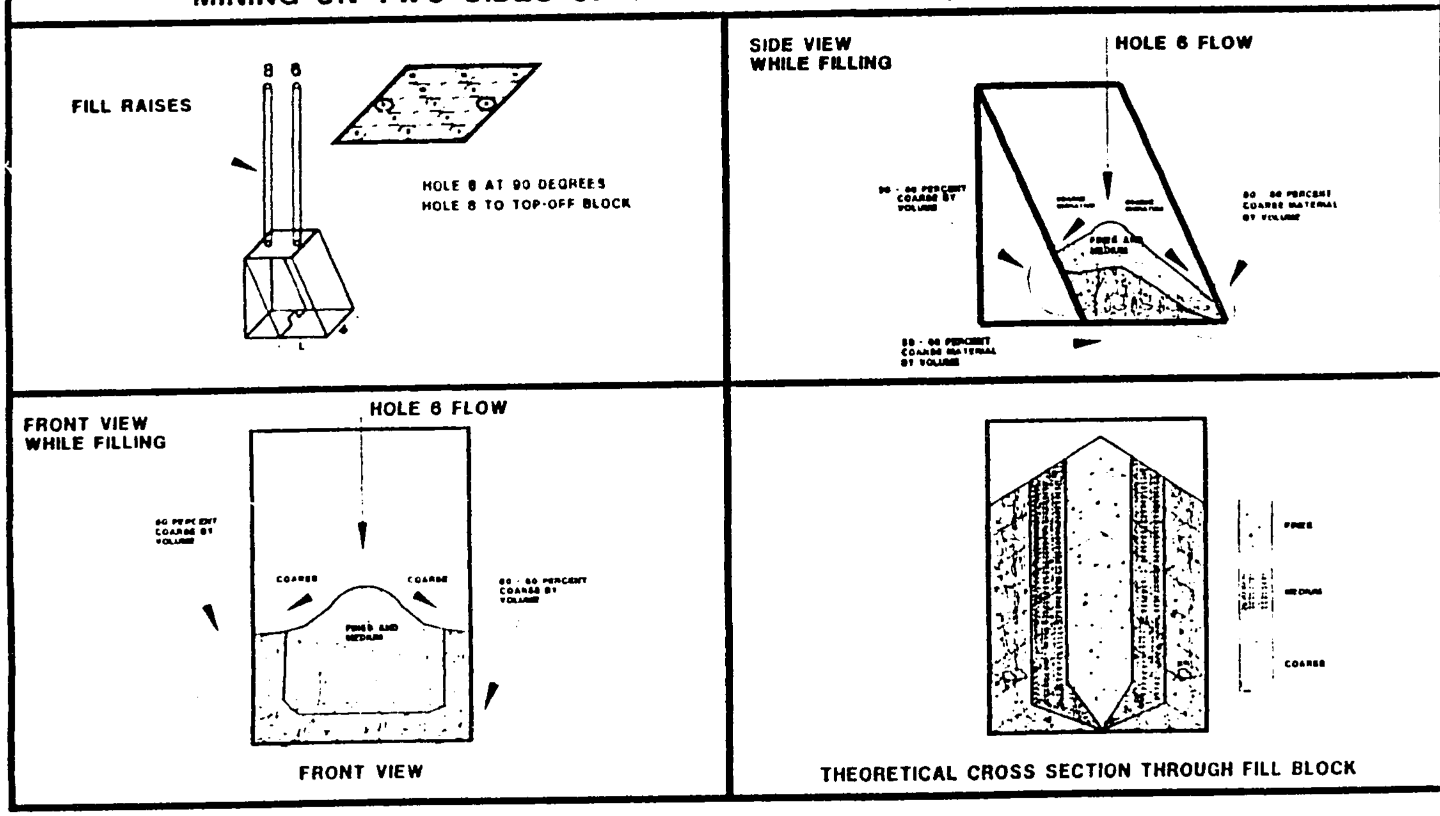


FIGURE #2

OPTIMUM FILL RAISE ORIENTATION FOR TRIPLE RAISE FILLING MINING ON TWO SIDES OF THE FILL BLOCK - L › 30, W ‹ 30 METERS

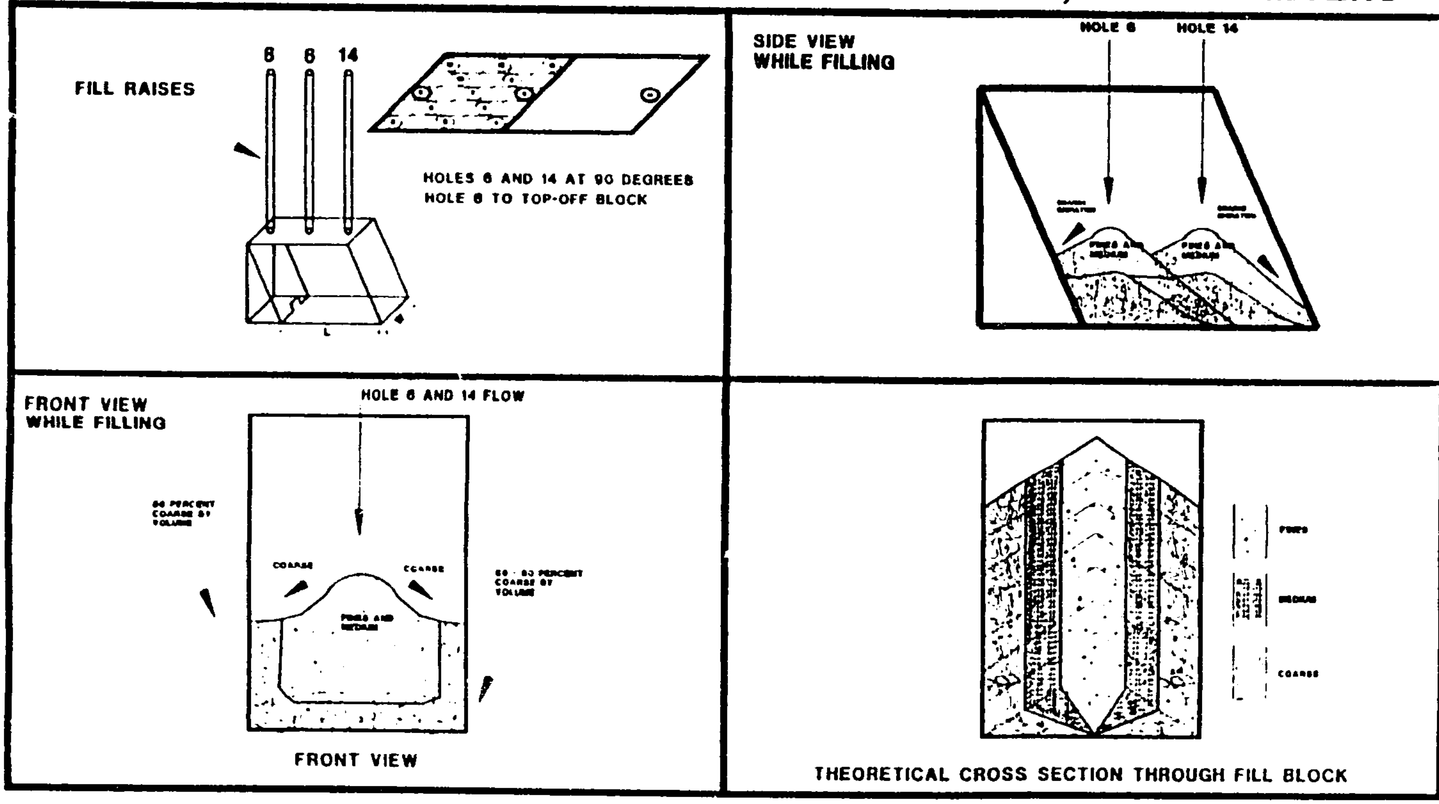


FIGURE #3

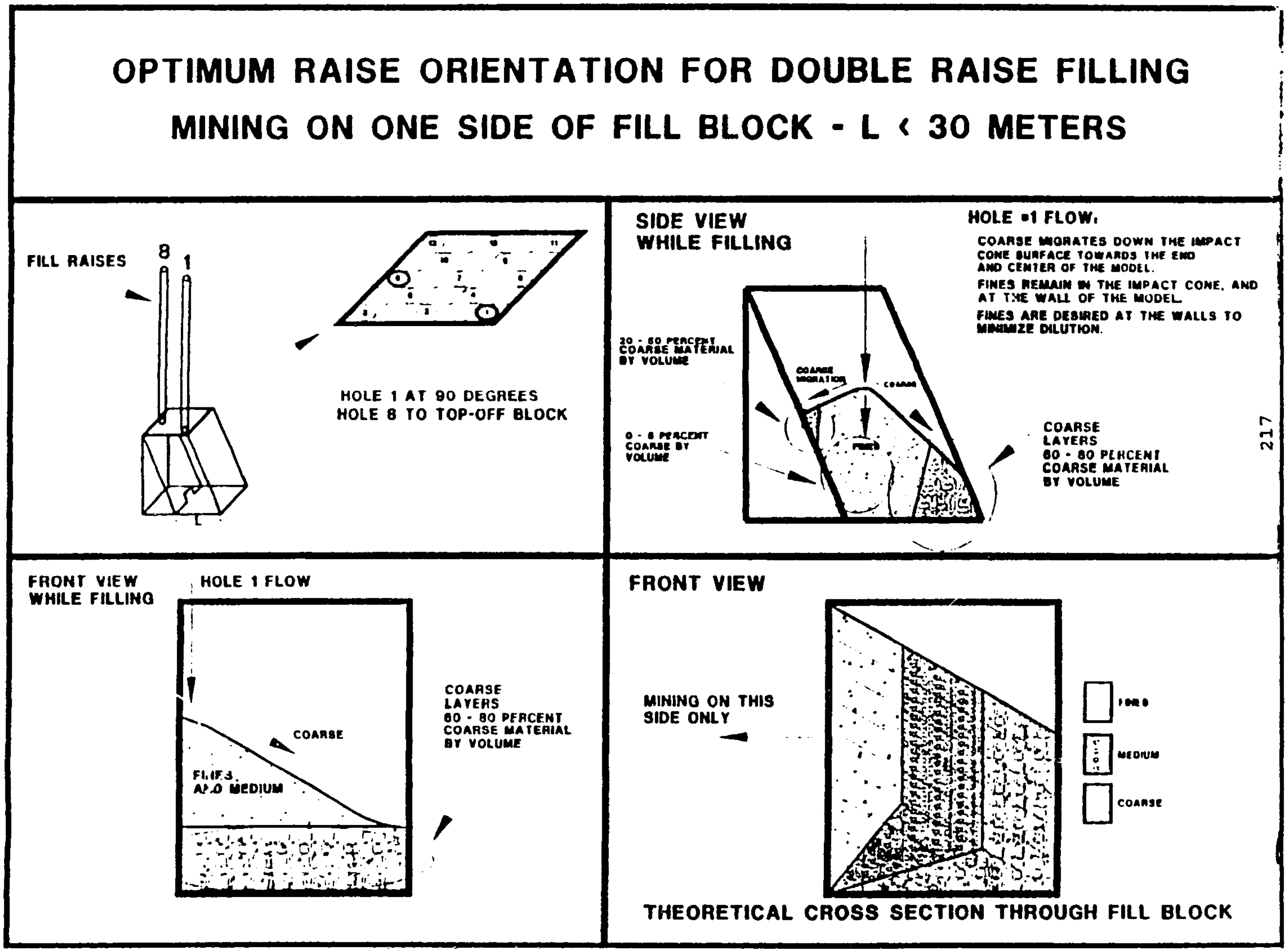
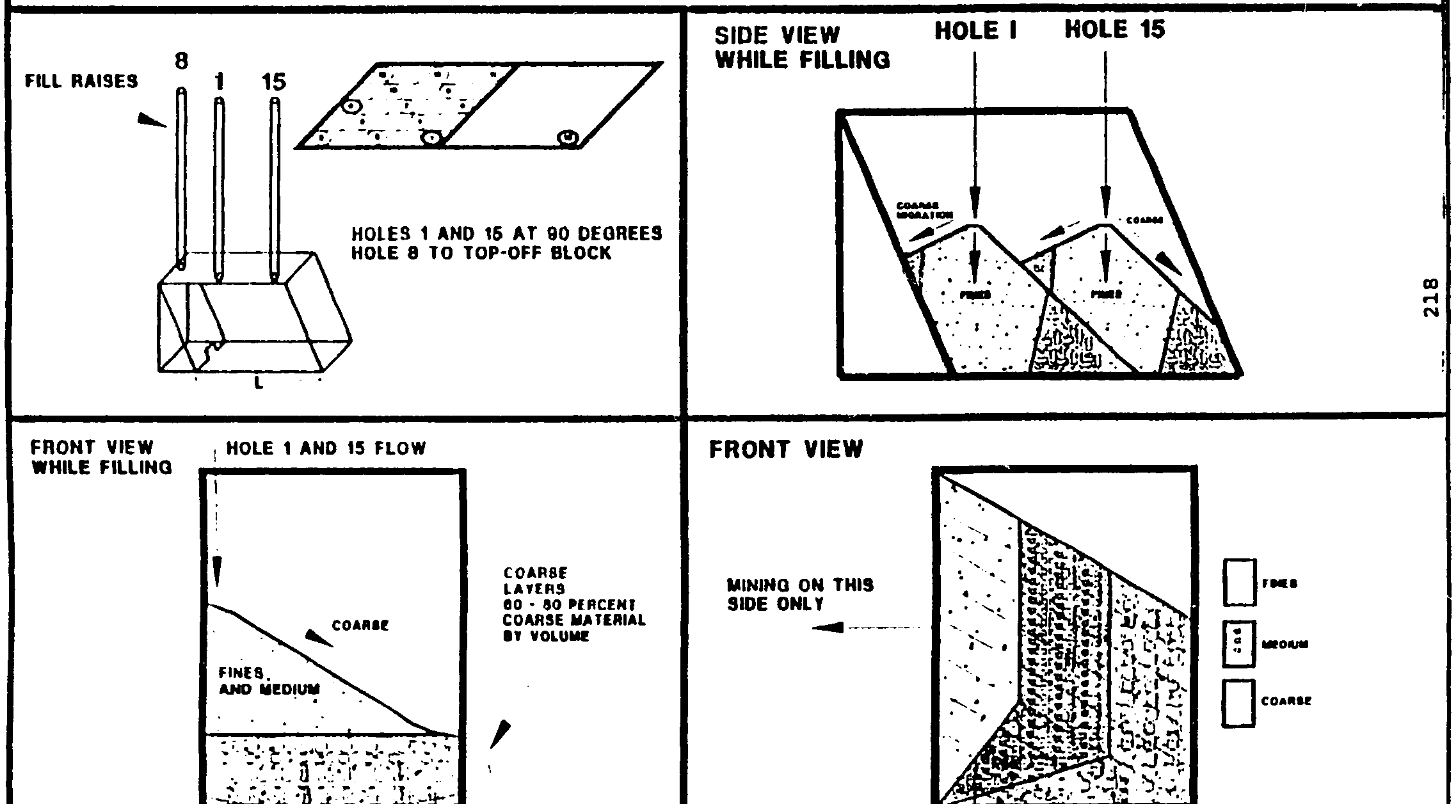

OPTIMUM RAISE ORIENTATION FOR DOUBLE RAISE FILLING
MINING ON ONE SIDE OF FILL BLOCK - L ‹ 30 METERS
FILL RAISES
8
1
L
HOLE 1 AT 90 DEGREES
HOLE 8 TO TOP-OFF BLOCK
SIDE VIEW
WHILE FILLING
HOLE #1 FLOW:
COARSE MIGRATES DOWN THE IMPACT CONE SURFACE TOWARDS THE END AND CENTER OF THE MODEL.
FINES REMAIN IN THE IMPACT CONE, AND AT THE WALL OF THE MODEL.
FINES ARE DESIRED AT THE WALLS TO MINIMIZE DILUTION.
20 - 80 PERCENT COARSE MATERIAL BY VOLUME
0 - 8 PERCENT COARSE BY VOLUME
COARSE MIGRATION
COARSE
FINES
COARSE LAYERS 60 - 80 PERCENT COARSE MATERIAL BY VOLUME
FRONT VIEW
WHILE FILLING
HOLE 1 FLOW
COARSE
FINES AND MEDIUM
COARSE LAYERS 60 - 80 PERCENT COARSE MATERIAL BY VOLUME
FRONT VIEW
MINING ON THIS SIDE ONLY
FINES
MEDIUM
COARSE
THEORETICAL CROSS SECTION THROUGH FILL BLOCK

FIGURE #4

OPTIMUM RAISE ORIENTATION FOR TRIPLE RAISE FILLING MINING ON ONE SIDE OF THE FILL BLOCK - L › 30 METERS



THEORETICAL CROSS SE.TION THROUGH FILL BLOCK

FIGURE #5

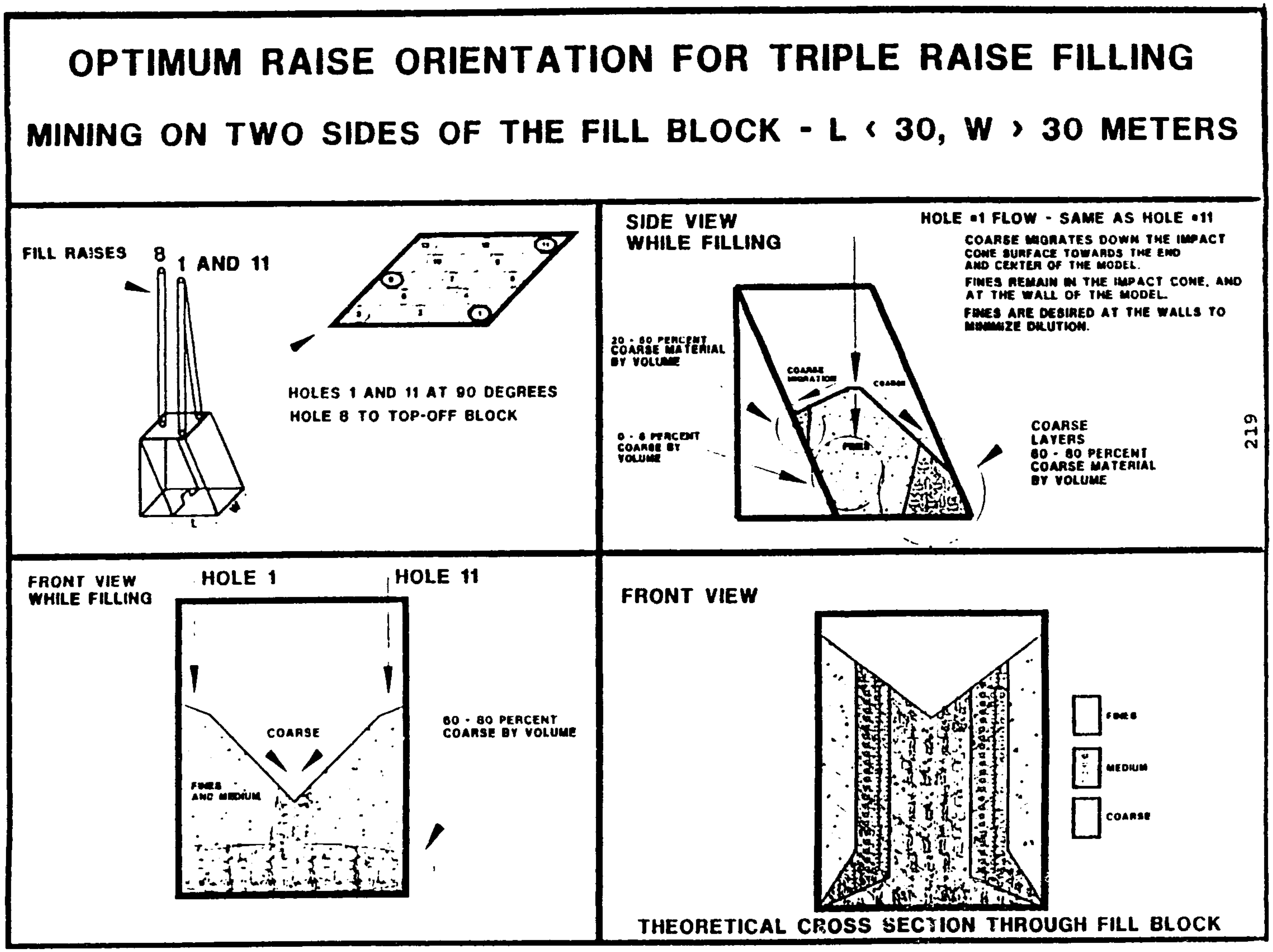
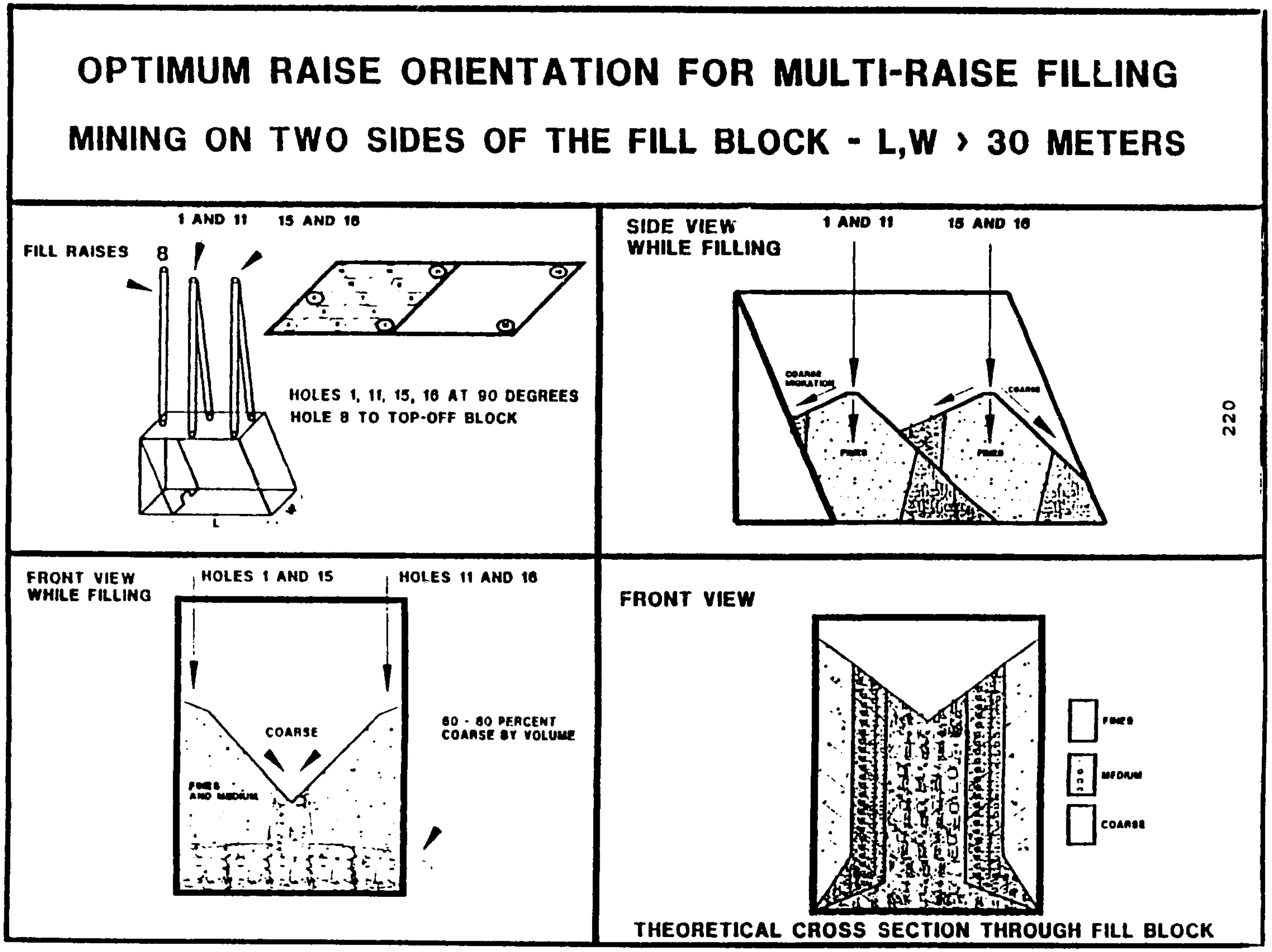

OPTIMUM RAISE ORIENTATION FOR TRIPLE RAISE FILLING
MINING ON TWO SIDES OF THE FILL BLOCK - L < 30, W > 30 METERS
FILL RAISES 8 1 AND 11
HOLES 1 AND 11 AT 90 DEGREES
HOLE 8 TO TOP-OFF BLOCK
SIDE VIEW
WHILE FILLING
HOLE #1 FLOW - SAME AS HOLE #11
COARSE MIGRATES DOWN THE IMPACT CONE SURFACE TOWARDS THE END AND CENTER OF THE MODEL.
FINES REMAIN IN THE IMPACT CONE, AND AT THE WALL OF THE MODEL.
FINES ARE DESIRED AT THE WALLS TO MINIMIZE DILUTION.
20 - 60 PERCENT COARSE MATERIAL BY VOLUME
0 - 6 PERCENT COARSE BY VOLUME
COARSE LAYERS
60 - 80 PERCENT COARSE MATERIAL BY VOLUME
FRONT VIEW
WHILE FILLING
HOLE 1
HOLE 11
COARSE
FINES AND MEDIUM
60 - 80 PERCENT COARSE BY VOLUME
FRONT VIEW
FINES
MEDIUM
COARSE
THEORETICAL CROSS SECTION THROUGH FILL BLOCK

FIGURE #6


OPTIMUM RAISE ORIENTATION FOR MULTI-RAISE FILLING
MINING ON TWO SIDES OF THE FILL BLOCK - L,W › 30 METERS
FILL RAISES
8
1 AND 11
15 AND 16
HOLES 1, 11, 15, 16 AT 90 DEGREES
HOLE 8 TO TOP-OFF BLOCK
L
SIDE VIEW
WHILE FILLING
1 AND 11
15 AND 16
FRONT VIEW
WHILE FILLING
HOLES 1 AND 15
HOLES 11 AND 16
COARSE
60 - 80 PERCENT
COARSE BY VOLUME
FRONT VIEW
THEORETICAL CROSS SECTION THROUGH FILL BLOCK