INTERN EXPERIENCE AT

BECHTEL PETROLEUM INCORPORATED

An Internship Report

by

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Major Subject: Chemical Engineering

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ABSTRACT

This report describes the internship performed in the slurry group of the pipeline and production facilities division of the Bechtel Corporation in San Francisco, during the period February, 1981 to January, 1982.

The intern worked as a slurry engineer in the slurry systems group of the pipeline and production facilities division. The intern supervisor was Mr. Ramesh L. Gandhi, chief engineer for the slurry systems group.

The intership objectives included two aspects; tangibles and intangibles. In the tangible phase,the intern participated in the development of slurry technology-related projects. The intangible aspects of the internship were more subjective, yet were invaluable. These included such things as learning to see engineering problems as a whole and translating this knowledge to obtain specific technical objectives whenever it was appropriate.

Almost half of the internship time was spent in the technical development projects pertaining to the design and development of slurry pipelines, and the other half of the time was spent doing feasibility studies, engineering studies, and preparing cost estimates for slurry pipelines-related projects. In addition to this, the intern reviewed design work done by other engineers and made recommendations to improve the quality of designs and studies.

During the technical development phase of the internship, two major projects were performed. First, a computer program was developed

for the optimum economic design of slurry pipelines. Second, a study was performed wherein various slurry thinners were evaluated to transport a very highly concentrated limestone slurry. In addition, feasibility and engineering studies were performed to evaluate different alternatives to transport coal, copper and phosphate slurry pipelines.

ACKNOWLEDGEMENT

The author would like to express his gratitude to Dr. Ronald Darby for his worthy advice during the course of this program, for his efforts in handling the many details associated with a doctoral program and, above all, instilling a sense of professionalism. My sincere appreciation goes to Mr. Ramesh Gandhi, intern supervisor, for his guidance and encouragement throughout various assignments I undertook during the course of my internship which has helped me become a better engineer. I would like to give my special thanks to Mr. Peter Snoek for his leadership and understanding which helped me conclude this internship successfully.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Tables | Page

CHAPTER 1

INTRODUCTION

OBJECTIVES:

The purpose of this report is to document the accomplishment of the following general internships objectives:

1. To demonstrate the ability to carry out planning, organizing, executing, reporting and correcting the procedures encountered during the course of an engineering problem.
2. To perceive a specific engineering problem in a systems approach as a whole and see its interaction with other components of the system.

INTERNSHIP ORGANIZATION:

History of the Organization:

Bechtel Corporation is a leading Engineering-Construction Company which is also involved in investment activities. The Bechtel Company was founded by W.A. Bechtel in 1898. Initially it started as a small railroad construction firm but in 1906, became a full contracting construction firm, with work on highways, bridges and water tunnels. Under the guidance of Steve Bechtel, Sr., president from the mid 1930's to 1960, the company grew rapidly. Engineering was added to its capabilities, and new fields included refinery and chemical plants. In 1940, the company began its first international project when it began work on a pipeline system in Venezuela. In the late 1950's, Bechtel began building commercial scale nuclear plants. Near the end of 1960, the third generation of the Bechtel family assumed the leadership of the company when Steve Bechtel, Jr. was named president. During this period, Bechtel moved into many new fields; rapid transit, master planning and urban development, underground hydro power stations, slurry pipelines, airports, hotels and water treatment plants, among others.

Types of Services:

Bechtel companies provide three types of services:

(1) Engineering: Complete engineering and design services are performed through technical staffs within different divisions. Services include:

a. Project Evaluation and Preliminary Planning
b. Preliminary Engineering
c. Process Planning and Design
d. Plant Layout
e. Final Detailed Engineering

(2) Construction: Bechtel companies perform construction for clients under either of two basic arrangements:

a. As part of an overall contract, including engineering design and furnishing materials.
b. As a separate assignment, based upon engineering plans, specifications and materials supplied by the owner, by the contractor or partly by both. The companies provide a complete construction service with all or major portion of the work performed by Bechtel.

(3) Management: The Bechtel companies provide three kinds of management services:

a. Engineering Management
b. Construction Management
c. Total project Management

Structure of the Organization:

Bechtel is structured to provide its services through three principal operating companies:

a. Bechtel Civil and Minerals, Inc.

This company offers services for projects including hydroelectric power, water projects, community facilities, and all types of mining and metals projects.

b. Bechtel Power Corporation

All Bechtel activities involving nuclear, fossil fuel and geothermal power plants, and electrical transmission and distribution facilities around the world, are the responsibility of the Bechtel Power Corporation.

c. Bechtel Petroleum Inc.

The full range of engineering, construction and management services for projects in petroleum, oil field, pipelining, petrochemical, LNG, tar sands and synthetic fuels fields is provided by Bechtel Petroleum, Inc.

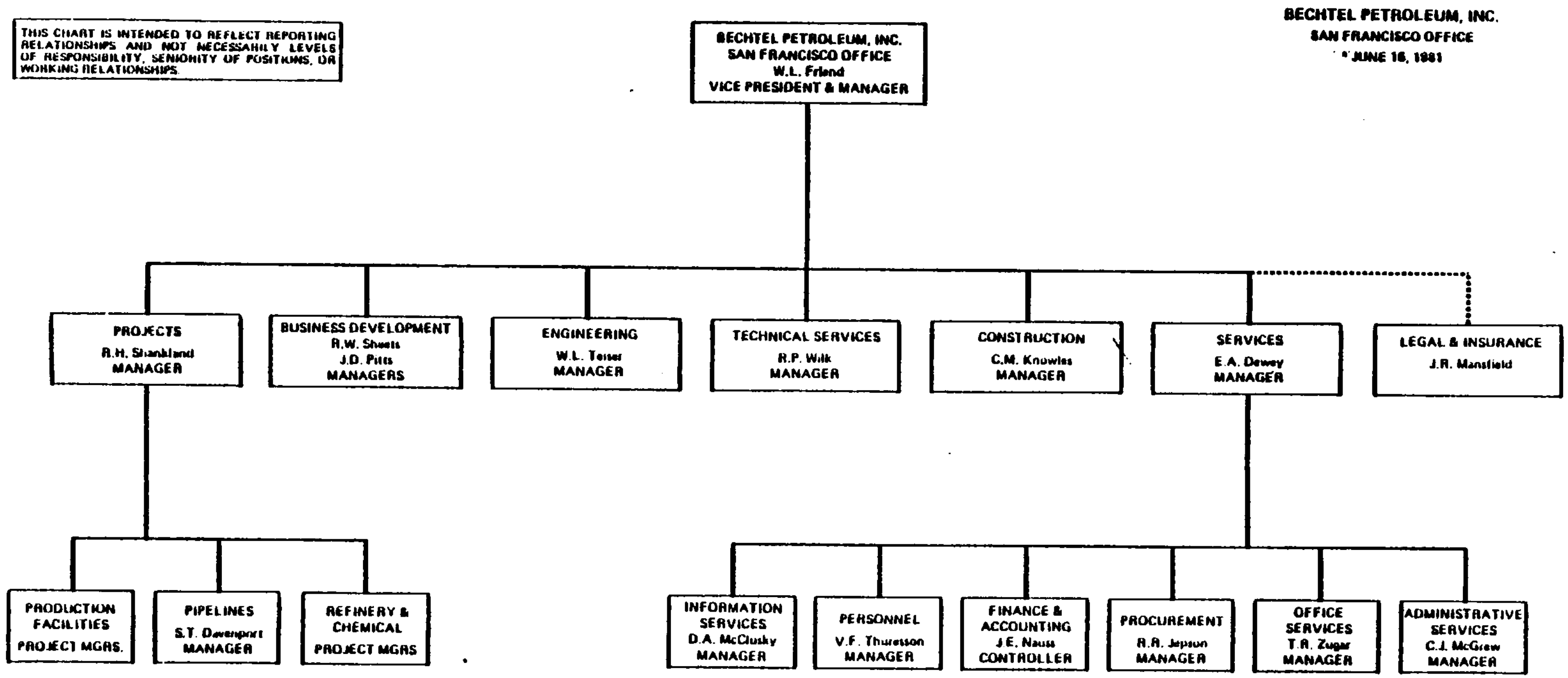
In addition the Bechtel Group, Inc., through its Research and Engineering operation, offers engineering services in advanced and emerging technologies. Bechtel's investments are handled by a wholly owned subsidiary, Bechtel Investments, Inc.

INTERNSHIP POSITION:

The intern was employed by the slurry systems group in San Francisco. The slurry department is a part of the pipeline and production facilities division which is headquartered in Houston. This in turn is one of the divisions of Bechtel Petroleum, Inc., with the home office in San Francisco. Bechtel has two slurry systems groups, one in San Francisco and another in Houston. The San Francisco office of the slurry systems group is the head office with a well equipped laboratory, data base for slurry pipelines and various computer design programs.

Figure 1 shows the hierarchy of management with reporting relationships of Bechtel Petroleum's San Francisco office. Figure 2 shows the reporting relationship of the Pipeline and Production Facilities Division. Figure 3 shows the relationship of slurry systems group and the position of the intern to the P&PF Division.

The intern supervisor was Mr. Ramesh L. Gandhi who is the chief engineer of the slurry systems group. Mr. Gandhi has extensive experience in slurry pipeline systems design. He has supervised many feasibility studies, engineering studies, conceptual designs and is in charge of technical development projects. He has co-authored a book with E.J. Wasp which is considered a major source book for slurry pipeline technology.



.... ACCEPTS ASSIGNMENTS FROM BECHTEL PETROLEUM, INC. – SAN FRANCISCO OFFICE BUT REPORTS TO S.F. HOME OFFICE

** RECEIVES FUNCTIONAL GUIDANCE FROM THE APPLICABLE SAN FRANCISCO SERVICE ORGANIZATION

* REPLACES CHART DATED JANUARY 5, 1981

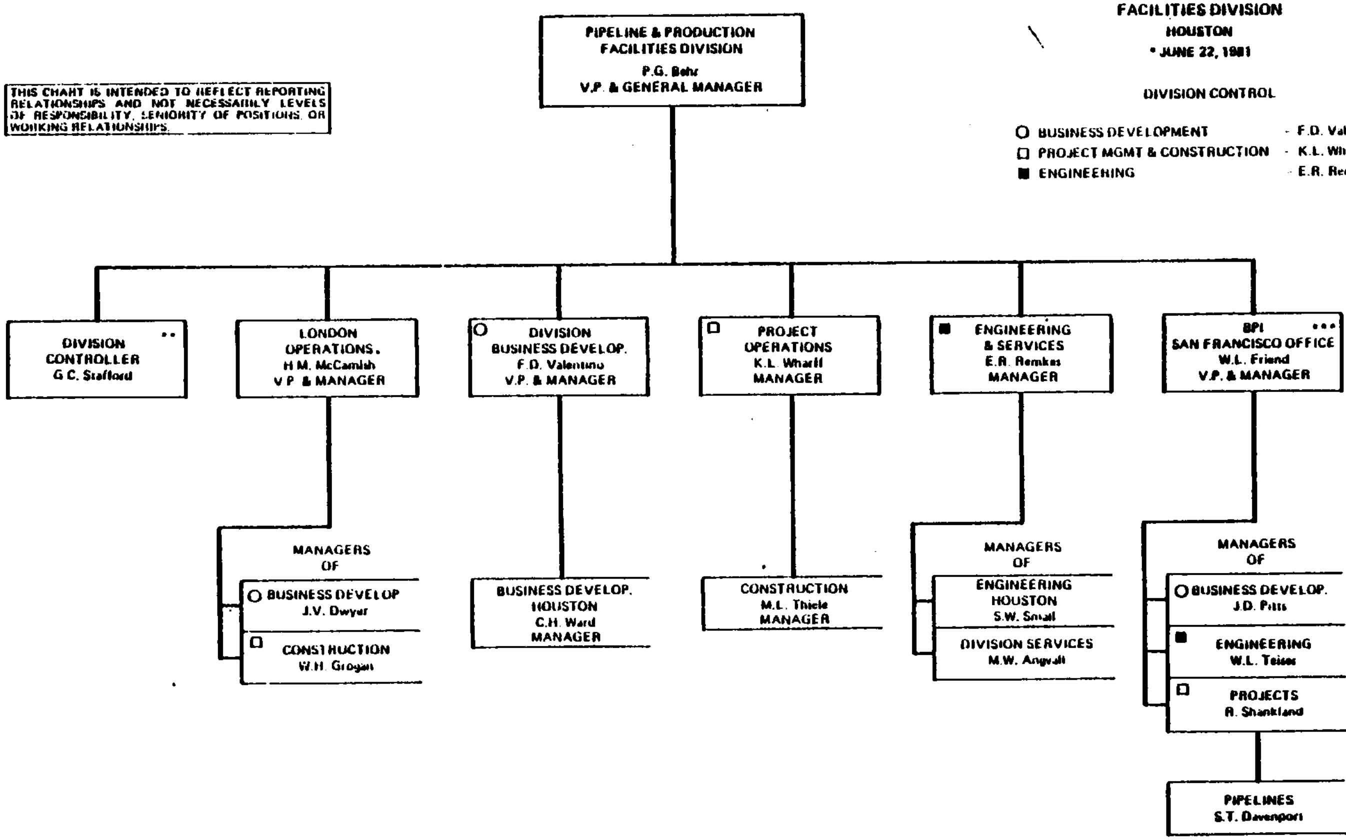
REPORTING RELATIONSHIP IN BECHTEL PETROLEUM
SAN FRANCISCO OFFICE

Figure 1

PIPELINE AND PRODUCTION FACILITIES DIVISION
HOUSTON
*** JUNE 22, 1981**

DIVISION CONTROL

- O BUSINESS DEVELOPMENT - F.D. Valentino
- □ PROJECT MGMT & CONSTRUCTION - K.L. Wharff
- ■ ENGINEERING - E.R. Remkes



NOTE
ALL PERSONNEL BASED IN DIVISION HOME OFFICE UNLESS OTHERWISE INDICATED

*** AS REGARDS P&PF DIVISION BUSINESS
** RECEIVES FUNCTIONAL GUIDANCE FROM THE APPLICABLE SAN FRANCISCO SERVICE ORGANIZATION
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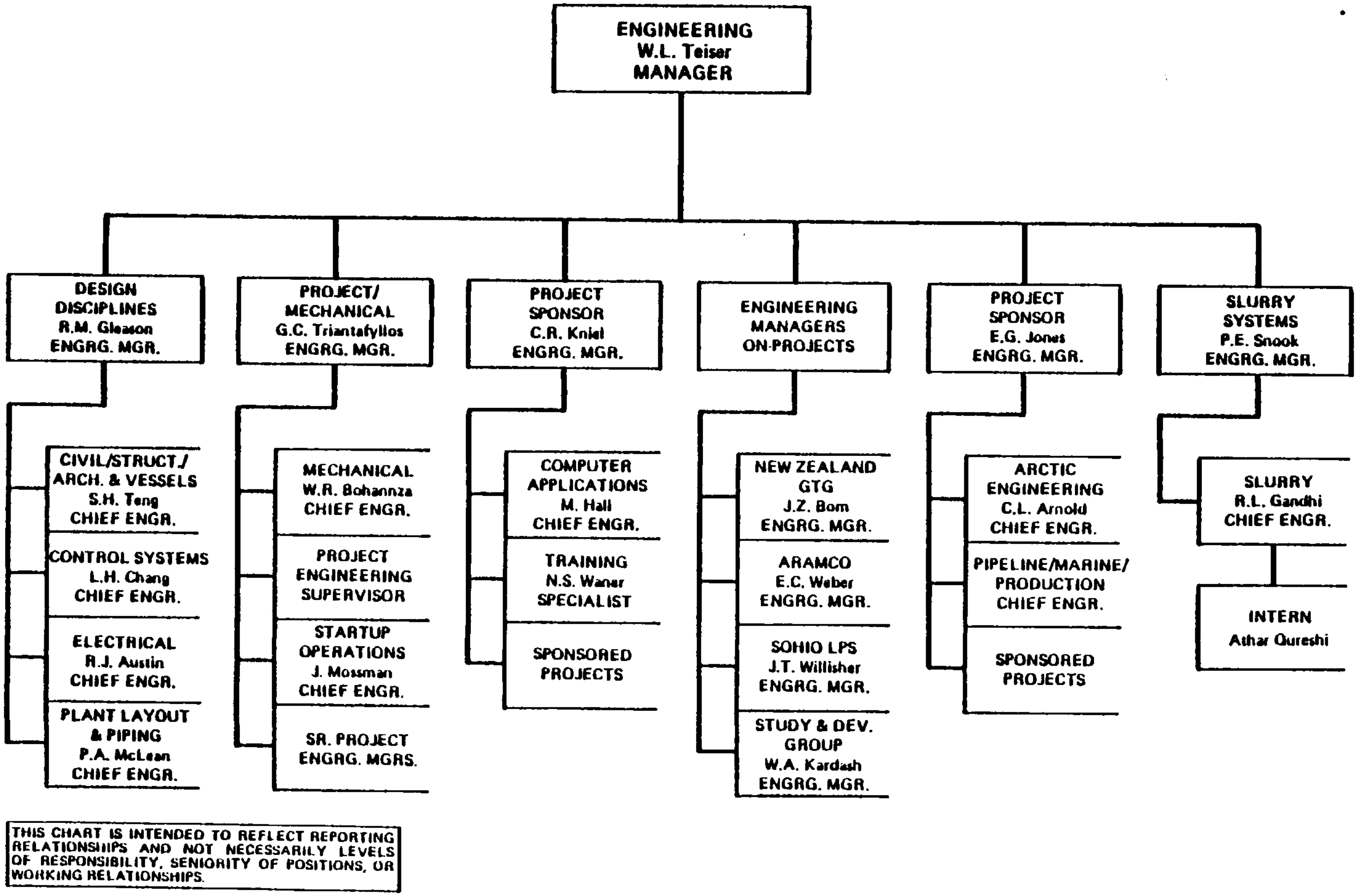
REPORTING RELATIONSHIP IN PIPELINE AND PRODUCTION FACILITIES DIVISION

Figure 2



SLURRY SYSTEMS POSITION IN PIPELINE AND PRODUCTION FACILITIES DIVISION

Figure 3

The intern, in the capacity of slurry engineer, participted in five projects during the internship period, starting February, 1981 and lasting through January, 1982. These are described in detail later.

The specific objectives which were established for this Internship were:

1. Learn and practice route location of slurry pipelines.
2. Learn and practice laboratory testing of slurry samples.
3. Learn and practice hydraulic design of the pipelines based on the laboratory results.
4. Learn and practice sizing of major equipment involved in slurry pipeline systems. This equipment includes:
    a. Selection and sizing of pipelines.
    b. Selection and rating of pumps.
    c. Rating of flanges.
    d. Sizing of agitated storage tanks.
    e. Rating of pump motor h.p. and agitator motor h.p.
    f. Sizing of slurry ponds.
    g. Sizing of orifice station.
5. Perform operating cost estimates on slurry pipeline systems.
6. Perform order of magnitude capital cost estimates on slurry pipeline systems.
7. Write, debug, modify, and test a preliminary optimization computer program for slurry pipeline systems.

CHAPTER 2

Technical Development Projects

Development of Computer Program for the Optimum Economic Design of Slurry Pipelines

INTRODUCTION

As a part of the technical development programs of the slurry systems group, a computer program was developed for the preliminary optimum design of pseudo-homogeneous solid-liquid pipelines. A preliminary logic chart of the computer program was provided initially.

The logic was coded in Fortran V programming language, and the program was run on Univac 1100/80 computer system for an iron ore slurry pipeline. Hand calculations were performed to diagnose the syntax and logical errors. The logic was then modified and extended to increase the flexibility and capacity of the program.

The program development work was later discontinued due to the depletion of funds allocated to the project for the year 1981-1982. However, the computer program was developed to the stage that it can be used to optimize a conventional slurry pipeline, and it was used to optimize an iron ore slurry pipeline for an arbitrary pipeline route. The program has been documented for other users.

OBJECTIVE:

For a slurry pipeline, when a feasibility study, engineering study or conceptual design of a project is undertaken, many technical alternatives are available, and the final selection of an alternative depends upon the economics. Thus the objective of this computer program is to select a technical design which yields minimum transportation cost.

Basis of the Program:

This computer program deals with the pipeline aspect of slurry systems. Table 1 shows the input variables fed into the program. The slurry is assumed to behave as psuedo-homogeneous suspensions and follows the Bingham-Plastic rheological mode. For a given concentration (by wt.) of the desired slurry, the yield stress and viscosity are measured in a concentric cylinder type viscometer, and is input into the program.

The program also contains a separate subroutine for commercial pipeline diameter selection. Normally the commercial pipe sizes are available in even sizes (nominal sizes; 4, 6, 8 inches, etc.); however, sometimes hydraulic design dictate the selection of the odd size pipes (nominal sizes; 5, 7, 9 inches, etc.). Odd pipe sizes are not readily available commercially, and are relatively expensive compared to even pipe sizes. This program incorporates both odd and even pipe sizes.

The pipeline route profile is supplied in a separate subroutine. It is added by the user, outside the main program as a separate data file. It lists elevation of the pipeline as a function of distance, as the pipeline traverses from the mine site to the slurry pipeline dewatering facility.

TABLE 1

System Input Parameters for Optimization Program

Technical Input Parameters

pipe roughness = inches

number of pipeline route profile points
slurry concentration in weight percent
viscosity for given concentration = centipoise
particle size below which 95 percent of particles lie = in micron
equilibrium moisture content = %
specific gravity of solid
specific gravity of carrier liquid

maximum pump discharge pressure = PSI
minimum slurry concentration by wt. = %
maximum slurry concentration by wt. = %
increment in concentration = %
minimum pipe wall thickness = inches
pressure safety factor =
flow safety factor =

number of pump station cases to be considered
number of diameter cases to be considered
pipe grade = PSI
solids throughput = Tons/hr.
pipeline operating time/year = hours
maximum velocity = ft/sec.
pump efficiency = in fraction
maximum horsepower/pump = Hp
first length of the pipe = mile or kilometer
corrosion allowance for first length of pipe = inches
corrosion allowance for remainder pipe length = inches

Economic Input Parameters

steel cost = $/Ton
construction cost = $/in-ft.
base cost of pump station = $
cost/pump/station = $
cost per Hp = $/Hp
labor cost/pump station/year = $
supplies cost/pump/year = $
power cost = $/kwh

cost premium factor for odd pipe size
amortization period = years
cost of debt = %
fraction of capital financed by debt
corporate tax = fraction
advalorem tax = percentage of capital
average inflation rate = %
cost of equity = %

A corrosion allowance, which is also fed into the program as an input, is measured in the laboratory using a corrosometer. The maximum velocity limit is set by the corrosion - erosion characteristics of the slurry and is also determined through data on corrosion - erosion.

Analysis of the alternative designs revealed an optimum design which is presented in Table 2.

Logic Description

Figure 4 shows a very generalized flow chart for the optimization program. For a chosen concentration, rheological properties are calculated. The deposition velocity is calculated using rheological properties and concentration. Bechtel's model for deposition velocity prediction was used in the program. An operating velocity is selected above the deposition velocity but below maximum velocity which depends on the abrasivity of the slurry. Then a commercial size pipe diameter is selected. The selection of the pipe size is based on outside diameter since inside diameter changes for tapered wall pipe. The friction losses are calculated by a model developed by Bechtel. The hydraulic gradient is checked for slack flow conditions. Typically slack flow occurs when the pipeline operating pressure is less than atmospheric pressure, and is usually encountered at the peaks of the pipeline route profile. Slack flow is avoided by lifting the hydraulic gradient line above the peak of the pipeline profile as shown in Figure 5. Sometimes avoiding slack flow results in excess head at the terminal, which

TABLE 2

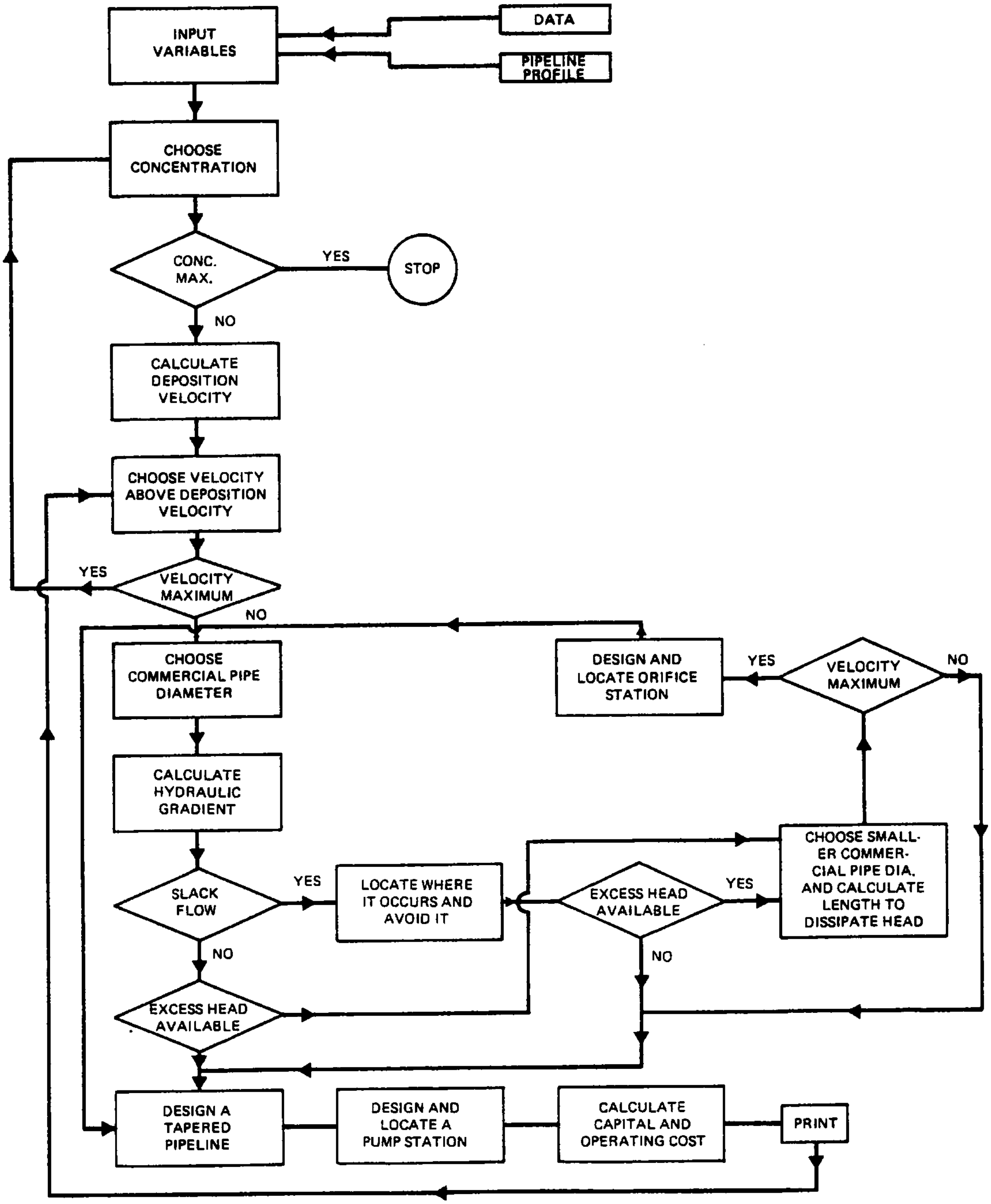
Optimum economic Design of Iron Ore Pipeline

concentration by wt. = 54%
outside pipe diameter = 9.625 inches
slurry flow rate = 1325 gpm
average operating velocity = 6.5 ft/sec.
number of pumps/station = 2 (1 operating, 1 spare)
total required horsepower = 6367 Hp

number of pump stations = 3
horsepower/pump = 1061 Hp
power consumption = 15 million kwh/yr
steel weight for API-5LX52 = 2062 Tons
direct capital cost of pipeline = 15.615 million dollars
operating cost of pipeline = 0.907 million dollars/year
transportation cost = 1.1294 $/Ton

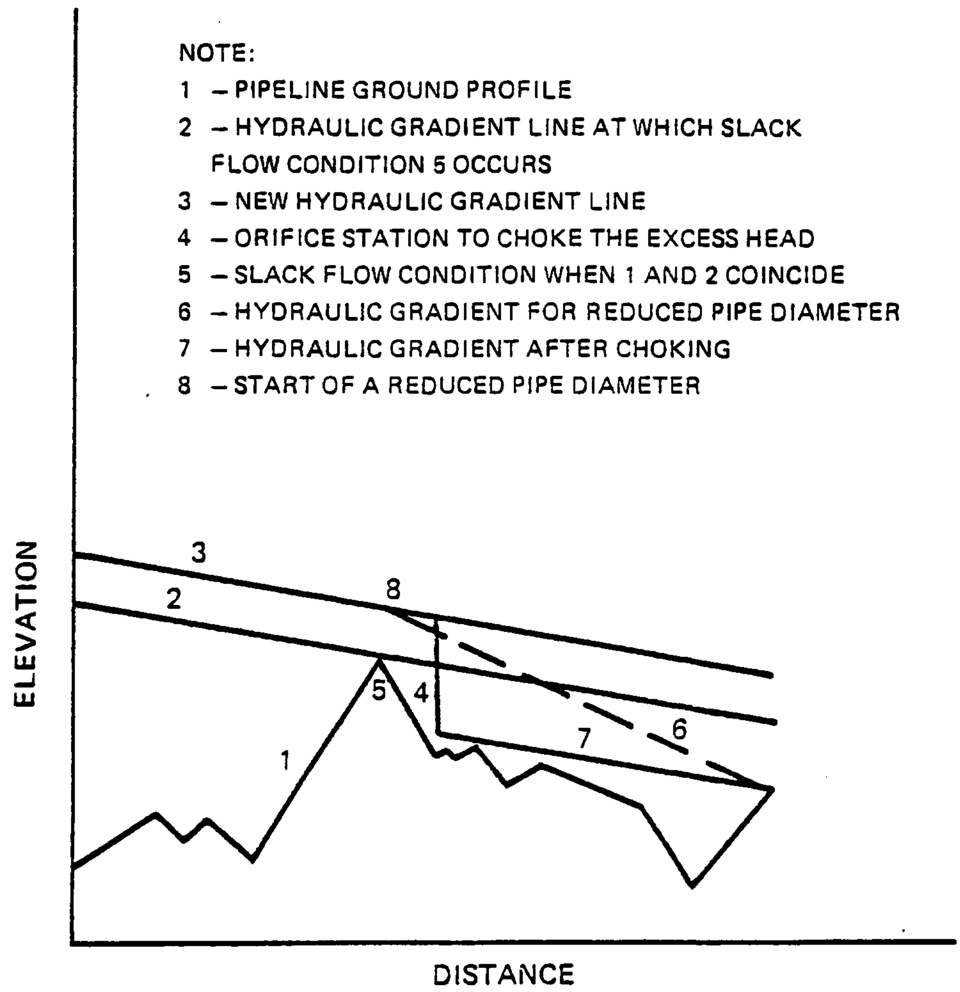
Pump Station Location:

Pump Station	Elevation (ft.)	Distance From Pipeline Mouth (1000 ft.)
1	1345	0
2	2414	36.27
3	1368	225.98



GENERALIZED LOGIC OF OPTIMIZATION PROGRAM

Figure 4



GENERAL PIPELINE ROUTE PROFILE
WITH HYDRAULIC DESIGN CONSTRAINTS

Figure 5

should be dissipated either by a selection of a smaller diameter pipe or an orifice station. If the reducer diameter is selected to dissipate the excess head, the resulting operating velocity should be such that it does not exceed maximum velocity, since at higher velocities the wear rate of the pipe increases at an increasing rate.

Once the hydraulic design criteria has been established, the tapered wall pipe is designed along with pump stations. Finally, capital and operating costs are calculated. The procedure is repeated for different concentrations.

Capabilities of the Program:

The program has been developed primarily to compare several technical alternatives available within given design limits, so that the most economical technical design could be selected. Following are some major features performed by the program:

(1) For different concentrations, it selects a commercial pipe diamater for a tapered wall pipeline.

(2) For the number of stations as specified in the input, it sizes up pump stations and establishes their exact location.

(3) It avoids slack flow and makes necessary design changes to avoid it during operation.

(4) It considers both regular (e.g., nominal pipe sizes 4, 6, 8 inches, etc.) and premium (e.g., nominal pipe sizes 5, 7, 9 inches, etc.) pipe sizes.

(5) It sizes orifice station and establishes the location.

(6) If a hydraulic design criteria establishes slack flow condition somewhere along the pipeline route, it selects a lower diameter pipe for the remaining length of the pipe. Thus, it can calculate two diameters for one pipeline system with the exact location and length for each pipe size.

(7) It considers different economic parameters for the calculation of transportation cost, e.g., time value of money, cost of debt and equity, income tax, advalorem tax, capital financing structure, rate of inflation, amortization period, etc.

(8) It calculates installed capital cost of the tapered pipeline.

(9) It calculates power cost, labor cost, cost of supplies and maintenance.

(10) It can be used to perform sensitivity analysis on any input technical parameter or economic parameter.

(11) The major variables which can be optimized are concentration, diameter, number of pump stations, pipeline route, pipe grade, etc. The optimum values are obtained at minimum transportation cost.

Example Case: A previously designed iron ore slurry pipeline was tested on the optimization program. The input pipeline route profile data is given in Appendix I. Appendix II shows the various alternate designs for this pipeline.

Shortcomings:

Two kinds of shortcomings were encountered during the development of the optimization program. The first was due to personal limitations and the second was program related.

Personal Limitations:

I first joined the slurry group of the Bechtel petroleum's pipeline and production facilities division on February 9, 1981, and was assigned the responsibility for the development of the slurry pipeline optimization program. Most of the computer programs in Bechtel are developed and used on Univac 1100/80 Computer System with Fortran V Compiler. I had marginal familiarity with the Fortran V Compiler and none on the operation aspects of Univac 1100/80 Computer System. The deficiency was corrected through the following:

1. Self Study
2. Bechtel sponsored computer courses
3. Computer services group
4. Users support group

1. Self Study:

Through self study the use of Fortran V as a programming language and operation of Univac Computer System was made possible. The books used were: Bechtel Reference Manual for the Univac Computer System, an introduction to Bechtel Data Processing Service and Fortran V (level 4R1) local inventions.

2. Bechtel Sponsored Courses:

To learn the operation of the Univac Computer System, computer program generation on it and the Text editor, four certificate courses were completed. Copies of the certificates are given in Appendix III.

3. Computer Services Group:

The Computer Services Group typically does production runs on existing computer programs for the slurry group. Also during the development of any computer program, they are responsible for coding the program in Fortran V language and loading it on the Univac Computer System. Frequent interaction with the Computer Services Group during the development of the optimization computer program was necessary.

4. Users Support Group:

The Users Support Group services were sought during the debugging of the program. The intern learned to diagnose different system related and program related error messages through their help.

In addition to this, occasional interaction with the Time-Share support services group and Engineering Support services group was necessary.

Program Related:

When the intern was assigned the responsibility for the development of the computer program, there was no separate allocation of funds for the project. The development cost incurred was charged to another ongoing technical development project. After the depletion of funds, the work on the program development was discontinued.

The program has been documented with appropriate instructions to help the user to use it. The computer program is developed to the stage that it can be used to optimize a conventional slurry pipeline. There are still some bugs left in it so that slack flow calculations, orifice station calculations and two diameters case for one line cannot be handled by it at the moment.

Recommendations have been made for future work on the program.

DEVELOPMENT OF A SLURRY THINNER:

Long distance slurry pipelines are designed to transport solids under turbulent flow conditions. In the case of a limestone slurry, the yield stress increases quite rapidly as the solids content is increased. The laminar-turbulent transition velocity increases as the slurry yield stress increases. Dispersing agents can be used to reduce the yield stress of a slurry. In cement plants, it is advantageous to deliver a limestone slurry at the maximum possible solids concentration. Dispersing agents (slurry thinners) are used to reduce the yield stress and make the slurry pumpable at high concentrations.

A client-sponsored research program was carried out by Bechtel to evaluate the effectiveness of various types of slurry thinners on a limestone slurry, shale slurry and clay slurry.

Objectives:

(1) Evaluate the effectiveness of various slurry thinners on limestone, shale and clay slurries.

(2) Produce the maximum concentration pumpable slurries with the aid of the most effective thinner.

Duration of Study:

The slurry thinner study took about 5 months to complete. The study was divided into two parts:

(1) Lab Testing and Engineering Analysis

(2) Field Testing.

Both lab testing and field testing had to be repeated. The initial results obtained through lab testing and engineering analysis was found to be encouraging. Recommendation for field testing was made to the client. However, the results obtained during field testing were not as encouraging as the laboratory results. More extensive laboratory tests were performed to determine the effect of variations in slurry properties on the effectiveness of slurry thinners. A subsequent field test under more controlled conditions confirmed the predictions based on laboratory evaluations.

Types of Experiments:

Five types of experiments were performed on slurries in Bechtel's slurry laboratory.

1. Size Analysis: Particle size distribution was measured on limestone solids using Tyler mesh screen. The original design particle size was -65 Tyler mesh. For the current study, the same particle size was maintained.
2. Specific Gravity of Solids: Specific gravity was determined for limestone, shale and clay solids using

pycnometer method, where the specific gravity is measured by weighing the material in the air, compared to the weight in the water.

3. Penetration Tests: Penetration tests were performed on the limestone slurry to determine the extent of settled bed compaction. This is done by dropping a previously weighed conical bob on the settled slurry. The weight required to penetrate the bed is the measure of slurry packing characteristics. This indicates the relative difficulty which may be encountered in attempting to resuspend a slurry which has settled in a pipeline during shut down.

4. Settling Rate: Settling tests were performed on limestone slurry. This determines the slurry-liquid interface settling rate and terminal solids concentration under static conditions. This helps to eatablish a safe shut down period, also this is an indirect measure of slurry packing density, i.e., if the slurry-liquid interface is closer to the top of the pipe, the slurry is less compact and easier to resuspend during start-up of the pipeline.

5. Rheology Tests: Rheology tests were the most important tests and they were performed extensively on the three slurries using a concentric cylinder type viscometer. This viscometer consists of a cylindrical bob and a cylinder. The bob rotates inside the cylinder containing the slurry. For a preset shear rate the shear stress is

recorded. The data are used to characterize the rheological model. The limestone slurries obey the Bingham plastic rheological model, which is

$$\tau = \tau_0 + \mu\infty \dot{\gamma}$$

where τ_0 = yield stress of the slurry

$\mu\infty$ = viscosity at infinite shear rate

$\dot{\gamma}$ = shear rate

τ = shear stress

The rheological parameters τ_0 and $\mu\infty$ are used to predict transition critical velocities and friction losses in the pipe. The transitional velocity is an important criteria, which is used to define the laminar and turbulent flow regions. An operating velocity below critical transition velocity means the slurry will operate in laminar flow. Similarly, an operating velocity above the critical transition velocity indicates a slurry flow regime in the turbulent region. Almost all the pipelines are designed in the turbulent region.

Types of Thinners:

Seven different thinning agents were evaluated during this study. These will be designated as A, B, C, D, E, F and Orzan AL-50.

Evaluation of Thinners:

Since the limestone slurry contributed the major portion of the solids going to kiln for cement production, the selection of thinner was based on the sole criteria of its effectiveness in reducing the yield stress and viscosity of limestone slurry. The same thinner was used for the determination of rheological properties for shale and clay slurries.

The thin limestone slurry was filtered and various samples in concentration range from 74-75 percent by weight were prepared using the filtrate. The thinners were added to the samples on the weight basis (lb. of thinner per ton of dry limestone) as recommended by the suppliers. The rheological measurements were made in the viscometer at room temperature. Table 3 shows the effect of various thinners on the rheological properties of limestone slurries. It shows that the thinner E was the best among all the thinners evaluated. For a 75 percent weight limestone slurry the yield stress was found to be 20 dynes/cm^2 and limiting viscosity, 120 centipoise. Further rheological measurements were made on limestone, shale and clay slurries with this thinner.

Establishment of Maximum Concentration Limestone Slurry:

The maximum concentration for the limestone slurry was determined for pumping purposes using 2 pounds of thinner E per ton of dry limestone. For comparison purposes rheological measurements were made for limestone slurry without any additive and with 3 pounds Orzan per ton of dry limestone which is currently being used for the production of 70 percent weight limestone slurry. The concentric cylinder type viscometer was used to measure the rheological properties at room temperature. Several samples of

TABLE 3

Effect of Thinners on Limestone Slurry Rheology

Thinner	Slurry Conc. Wt. %	Yield Stress Dynes/cm^2	Viscosity CP	Dosage Rate lb/Ton	Additive Cost $/Ton Limestone
A	75.5	544	377	1	0.56
B	75.5	462	316	1	0.56
C	74.25	721.4	411	1.4	0.59
D	74.25	334	190	1.2	0.59
E	75	20	120	2	0.60
F	75.5	721	571	6	0.15
ORZAN AL-50	75	200	425	3	0.20

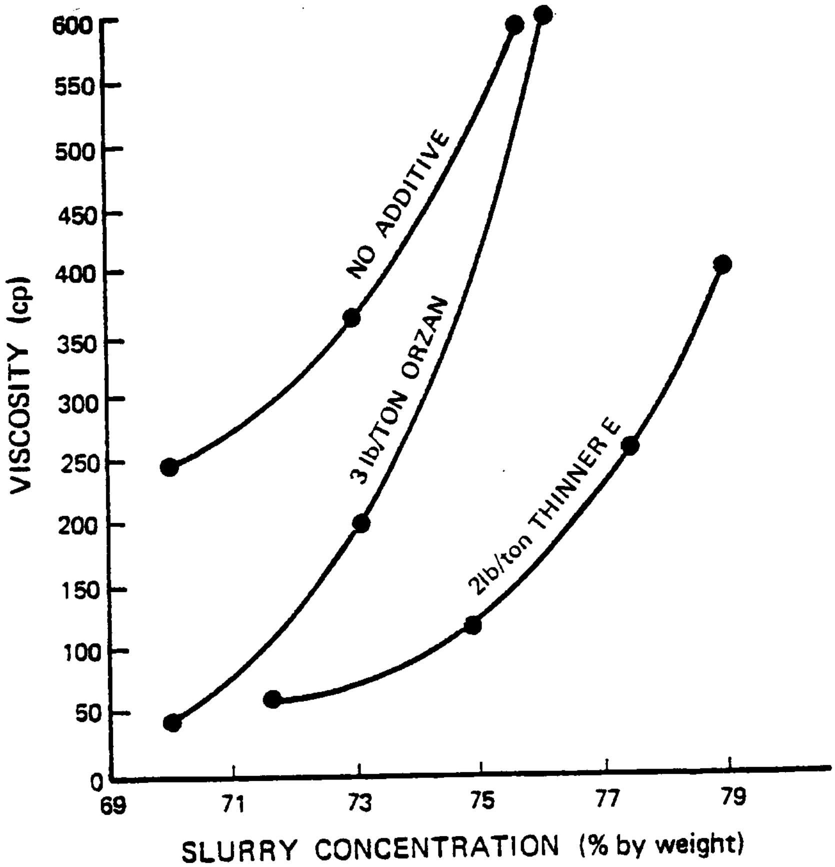
limestone slurries were prepared in the concentration range of 70-79 percent by weight of solids. Figure 6 shows the variation in viscosity of the slurry with the concentration of limestone solids in a slurry. The limestone slurry without any additive had the highest viscosities and the lowest viscosities were observed with 2 pounds of thinner E per ton of limestone. The Orzan treated limestone slurry had an intermediate viscosity.

Figure 7 shows the change in yield stresses of limestone slurries as a function solids concentration. The limestone slurry without any additive had the highest yield stresses while the thinner E treated slurry shows the lowest yield stresses.

The existing limestone slurry pipeline system had been designed to transport solids in the turbulent region. Bechtel's computer model was used to predict the minimum operating velocity in the turbulent region. Analysis of the results revealed that a maximum of 75 percent limestone slurry is possible without over-pressuring the existing pipeline and pump.

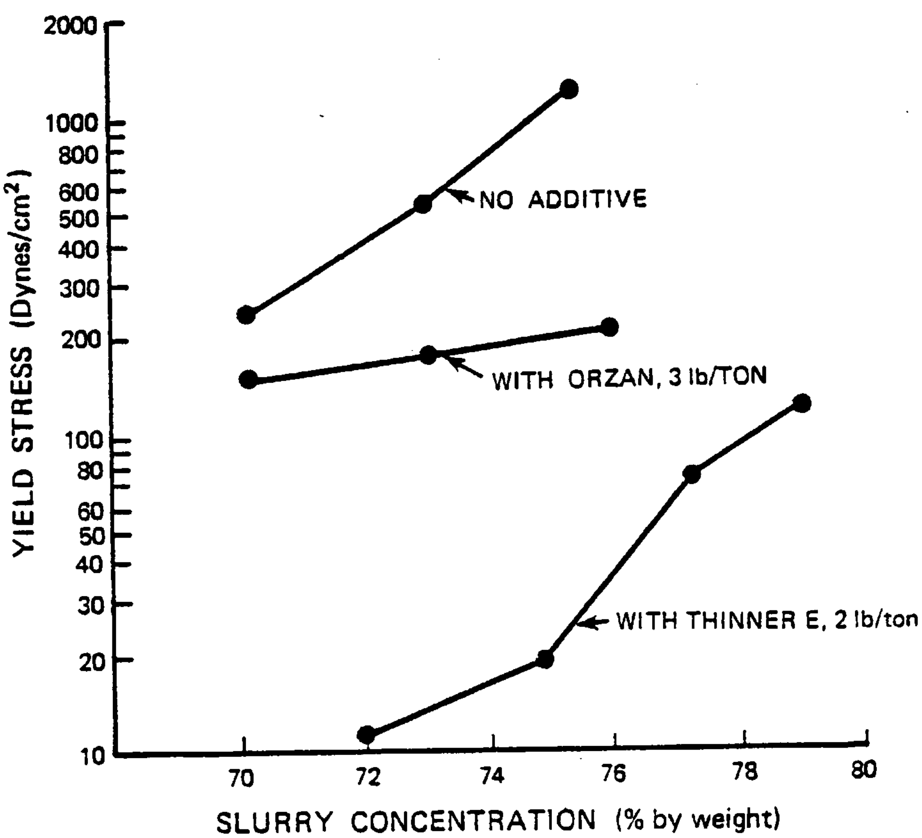
<u>Establishment of Maximum Concentration for Shale Slurry</u>:

The thin shale slurry sample was filtered. Various samples of different concentrations were prepared. For comparison purposes, a base concentration of 50 percent by weight was selected. Figure 8 shows the viscosity and yield stress versus shale slurry concentration relationship for 2 lb/ton, 4 lb/ton thinner E and without any additive. It was decided that a higher maximum concentration can be achieved by increasing the thinner E dosage. Thus a 60



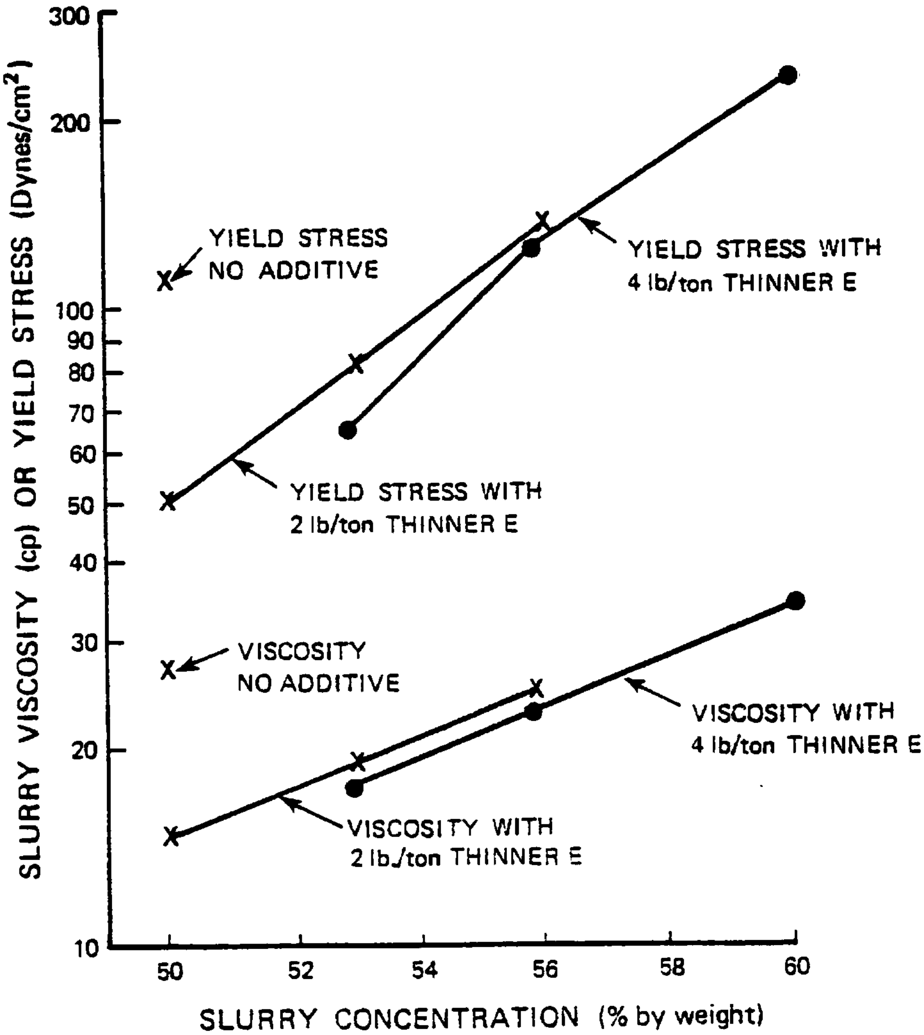
EFFECT OF LIMESTONE SLURRY CONCENTRATION
ON VISCOSITY

Figure 6



LIMESTONE SLURRY YIELD STRESS VS. CONCENTRATION

Figure 7



RHEOLOGICAL PROPERTIES OF SHALE SLURRY
TREATED WITH THINNER E

Figure 8

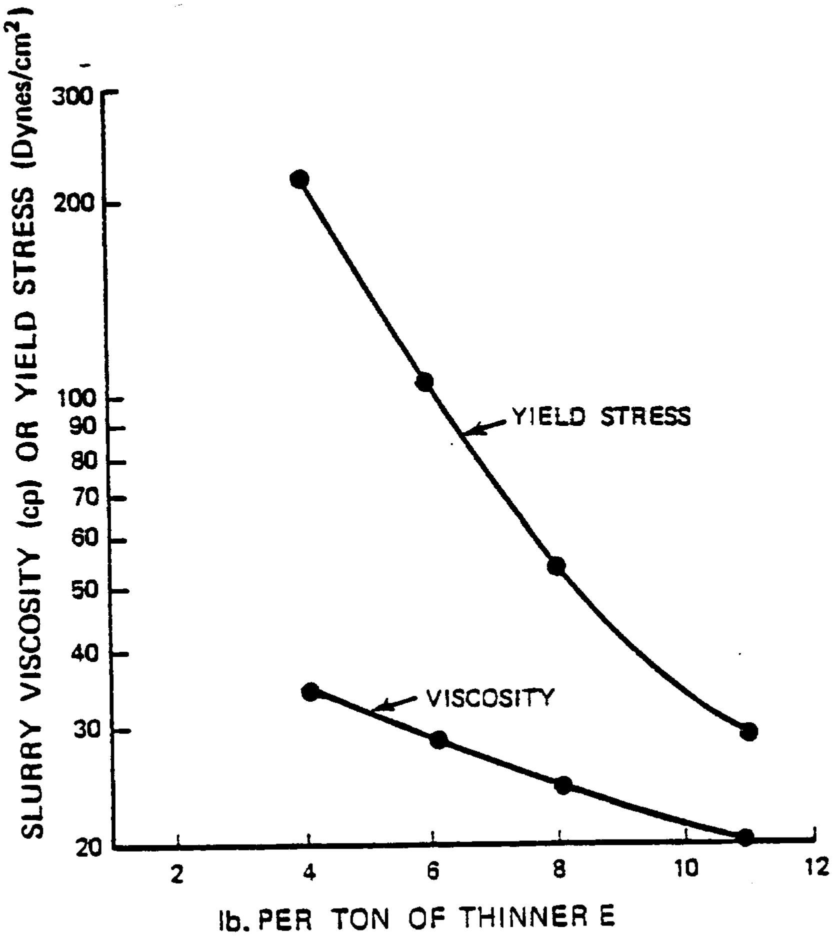
percent maximum concentration was selected and rheological properties were measured for various thinner E dosages. Figure 9 shows the effect of change in thinner E dosages on viscosity and yield stress of a 60 percent weight shale slurry. At about 6 lb/ton of thinner E, the desired viscosity and yield stress were obtained.

Establishment of Maximum Concentration for Clay Slurry:

Figure 10 shows the variation in yield stresses and viscosities of the clay slurry as a function of concentration of thinner E. However, at the request of the client, additional tests on the clay slurry were discontinued.

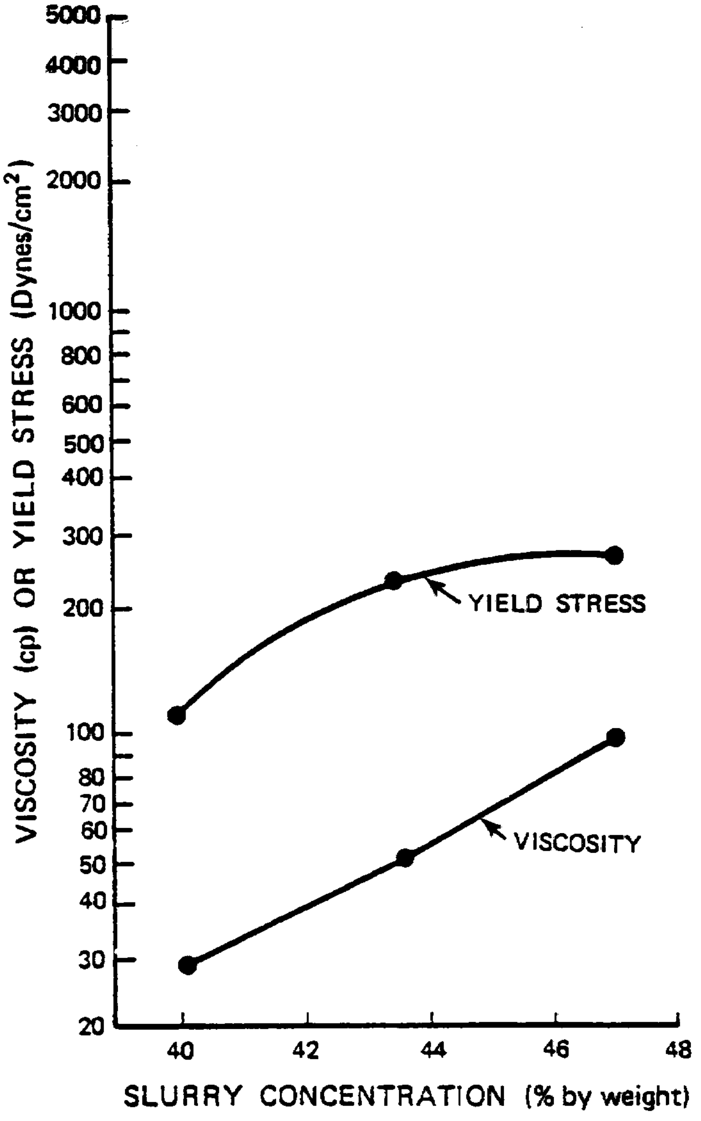
Field Test:

A field test was carried out at the client's slurry preparation and pump station facility, to demonstrate the feasibility of the project. However, due to some unavoidable circumstances, which will be discussed later, only 74 percent weight limestone slurry could be produced through the mills. The diaphragm pressure cell at the test loop was not functioning, so a mercury monometer was installed for pressure drop measurement at the test loop. For various flow rates pressure drop measurements were recorded. Figure 11 shows the change in friction losses in psi/mile for various flow rates. It had been observed in the past that the slope of the pressure drop vs. velocity line in a logarithmic plot for turbulent region was about 1.75; however, analysis of Figure 11 revealed that all the data points lie in laminar region. Rheological tests were performed at the test site on slurry samples collected



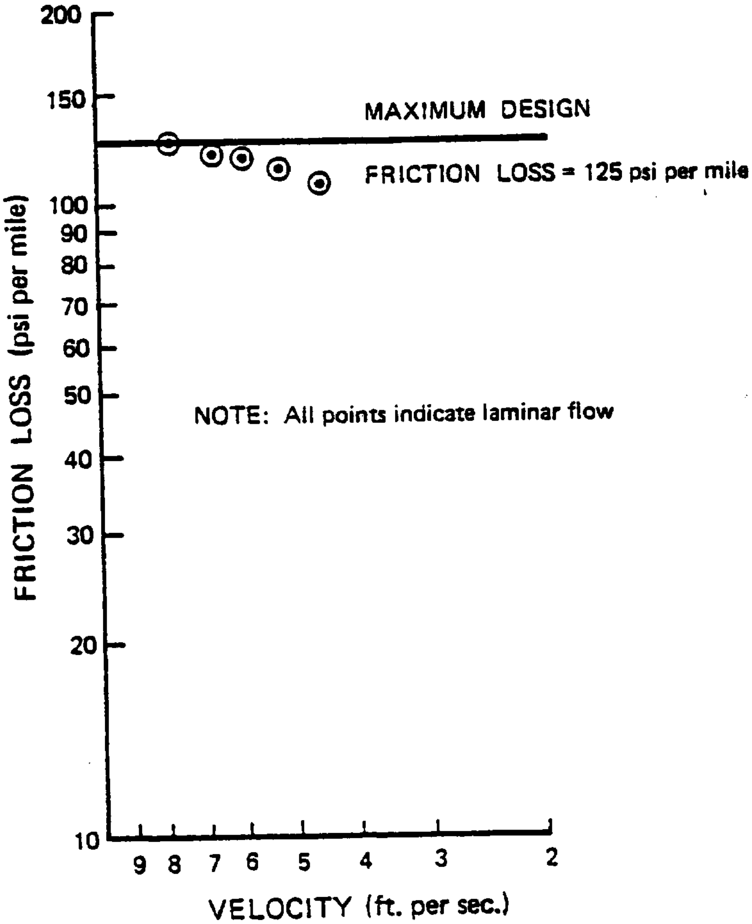
EFFECT OF THINNER E ON THE
RHEOLOGICAL PROPERTIES OF 60% Wt. SHALE SLURRY

Figure 9



RHEOLOGICAL PROPERTIES OF CLAY SLURRIES
TREATED WITH 2 lb/ton THINNER E

Figure 10



FRICTION LOSS VS. VELOCITY TEST LOOP DATA
FOR 74% Wt. LIMESTONE SLURRY

Figure 11

from the ball mill, storage tank and test loop at various concentrations. Table 4 shows the rheological properties and laminar-turbulent transition velocity at various concentrations. The Bechtel model was used to predict the transition velocity.

The slurry was diluted to about 73.5 percent concentration and rheological properties measured as shown in Table 4. The slurry could have been pumped at 73.5 percent concentration. However, since the mainline pump speed reducer was not working, the slurry was further diluted to about 71 percent concentration and pumped.

Effect of Thinner on Varying Rock Properties:

Additional tests were carried out on limestone slurry to determine the effect of thinner on changing limestone rock properties. Rheological tests were performed on different batches of limestone slurries collected on different dates at the mine. Table 5 shows the rheological properties, transition velocities and minimum and maximum flow rates for different batches of limestone slurries. Batches 1, 2, 3 could be pumped at 75 percent concentration with pounds of thinner E per tone of dry limestone, whereas for Batch 4 only 73.5 percent concentration limestone slurry could be pumped with 2 pounds of thinner E per tone of dry limestone. However, it was noted that by varying the thinner amount to 10 lb/ton, it was possible to pump the 75 percent concentration limestone slurry.

Figure 12 shows the effect of cnanging thinner dosages on yield stress of a 75 percent weight limestone slurry for Batches

TABLE 4

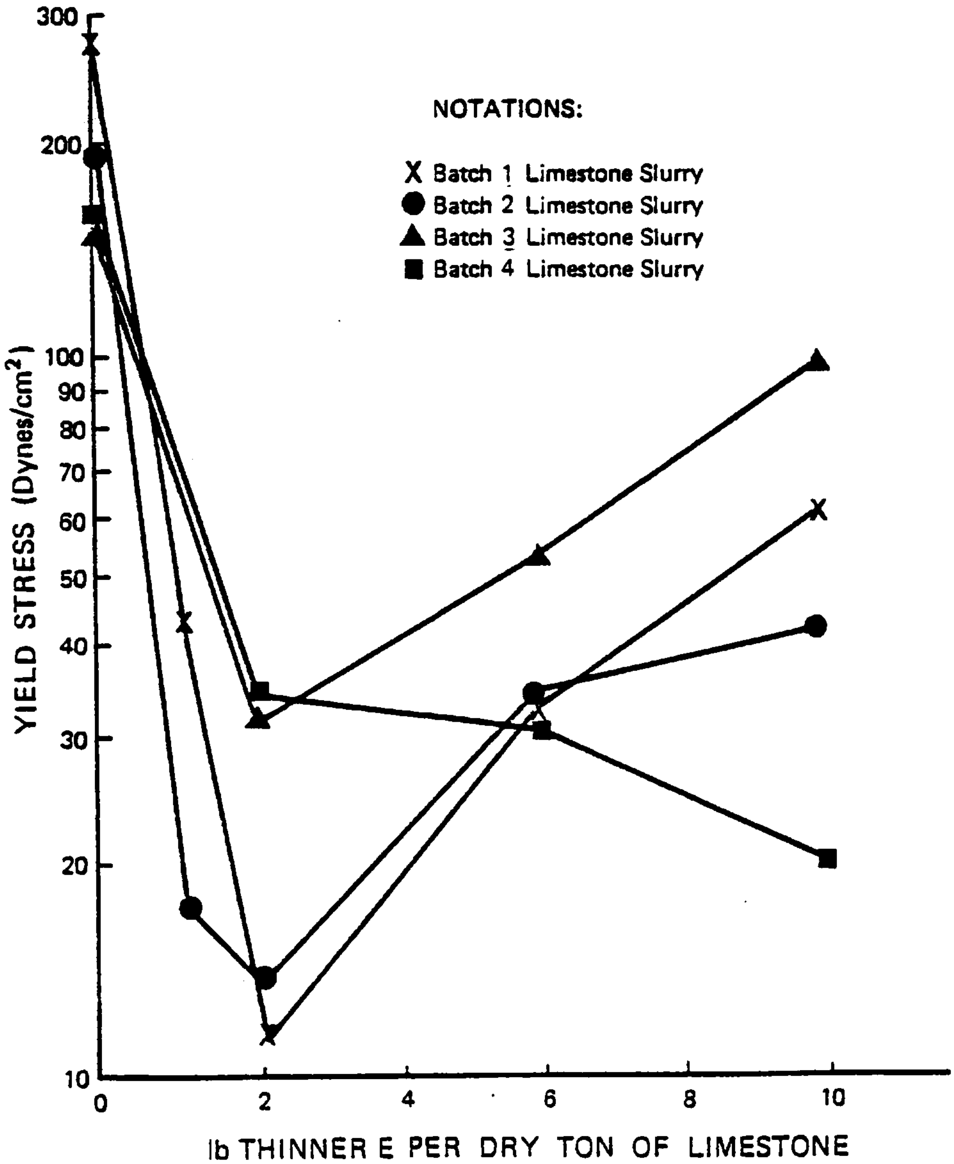
Rheology of Limestone Slurry During Field Tests

Material	Slurry Conc. Wt.%	Viscosity CP	Yield Stress Dynes/cm^2	Calculated Laminar-Turbulent Transition Velocity Ft/S.
Mill Product	75.5	300	160	11.2
Storage Tank	74	240	74	8.0
Test Loop	73.8	190	110	8.6
Test Loop-Mainline	73.6	150	60	6.5
Test Loop-Mainline	71.0	100	50	5.4

TABLE 5

Operating Limits Chart for Limestone Slurry

Batch	Wt% Solids	Thinner E (lb/Ton)	Yield Stress (Dynes/cm^2)	Viscosity CP	Lami-Turb Transition Velocity (ft/sec)	Flowrate Min. (GPM)	Flowrate Max. (GPM)	Throughput Min. Flow (Ton/hr)	Throughput Max. Flow (Ton/hr)
1	75	2	12.13	62.45	2.8	722	820	260	296
2	75	2	13.48	54.46	2.8	734	820	265	296
3	75	2	32.02	83.2	4.4	712	795	257	287
4	75	10	18.54	218.2	4.8	572	665	206	240
4	73.5	2	27.7	134.9	4.8	645	722	229	256



EFFECT OF THINNER E ON
THE YIELD STRESS OF 75% Wt. LIMESTONE SLURRY

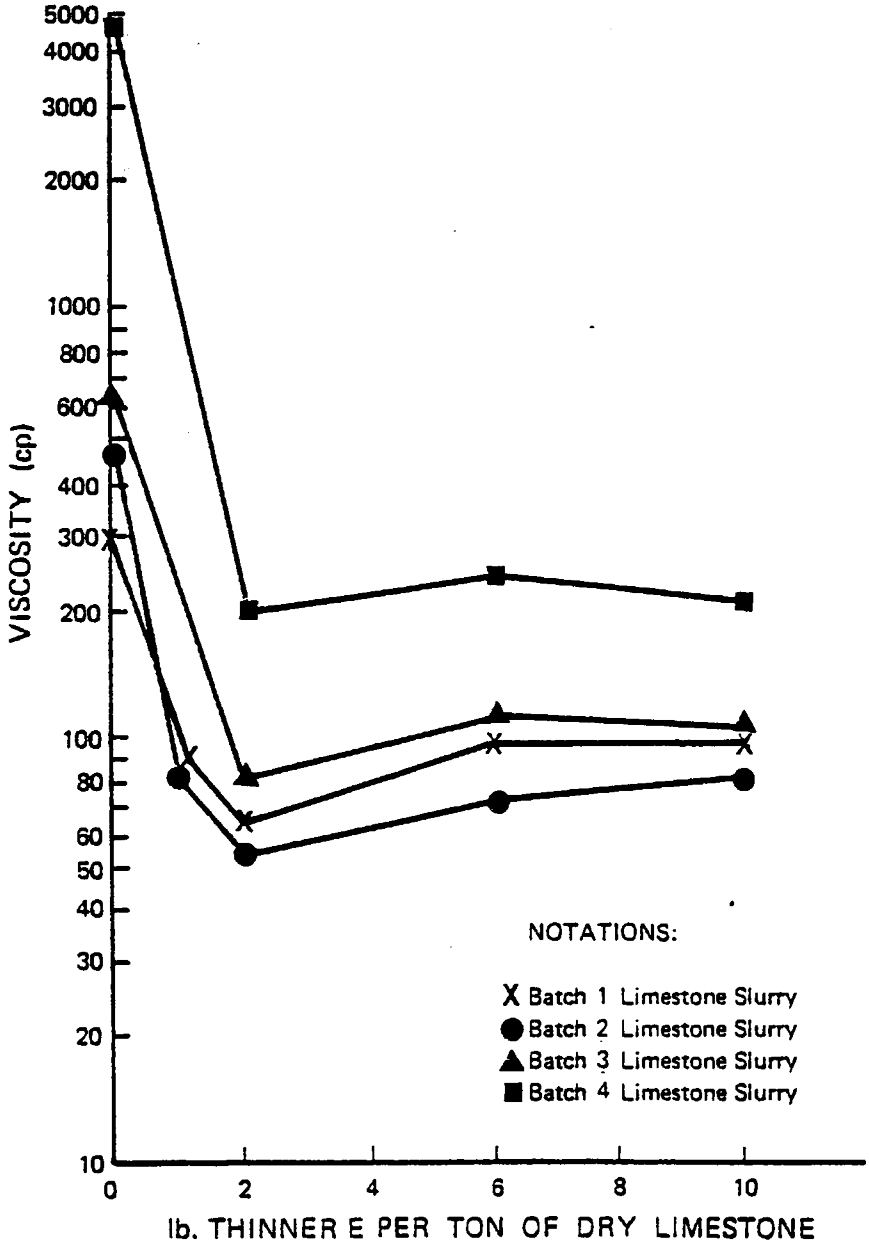
Figure 12

1, 2, 3 and 4. For Batches 1, 2, 3 it can be seen that 2 lb/ton of thinner produced a minimum yield stress for a 75 percent weight of limestone slurry. However, for Batch 4 the yield stress of the slurry decreased as the thinner dose in the slurry was increased. Similarly, Figure 13 shows the viscosity variation in a 75 percent weight limestone slurry as the thinner dosage was changed. It can be seen that for 2 pounds thinner/ton of dry limestone, all the four batches exhibited minimum viscosity.

The pH of the slurry was also found to be an effective measure of changing limestone rock properties. Figure 14 and Figure 15 show the viscosity and yield stress of slurry respectively for all four Batches 1, 2, 3, and 4 as the pH was increased. Between pH 9.5-10 all the batches appeared to have lowest yield stresses and viscosities except for Batch 4, which showed a significant drop in viscosity as the pH increased from 7.5-8. However, further increase in pH did not produce any significant change in the viscosity of Batch 4 slurry. Thus, the effect of varying dosages of thinner E on the changing rock properties was established. The recommendations were made to the client for field testing.

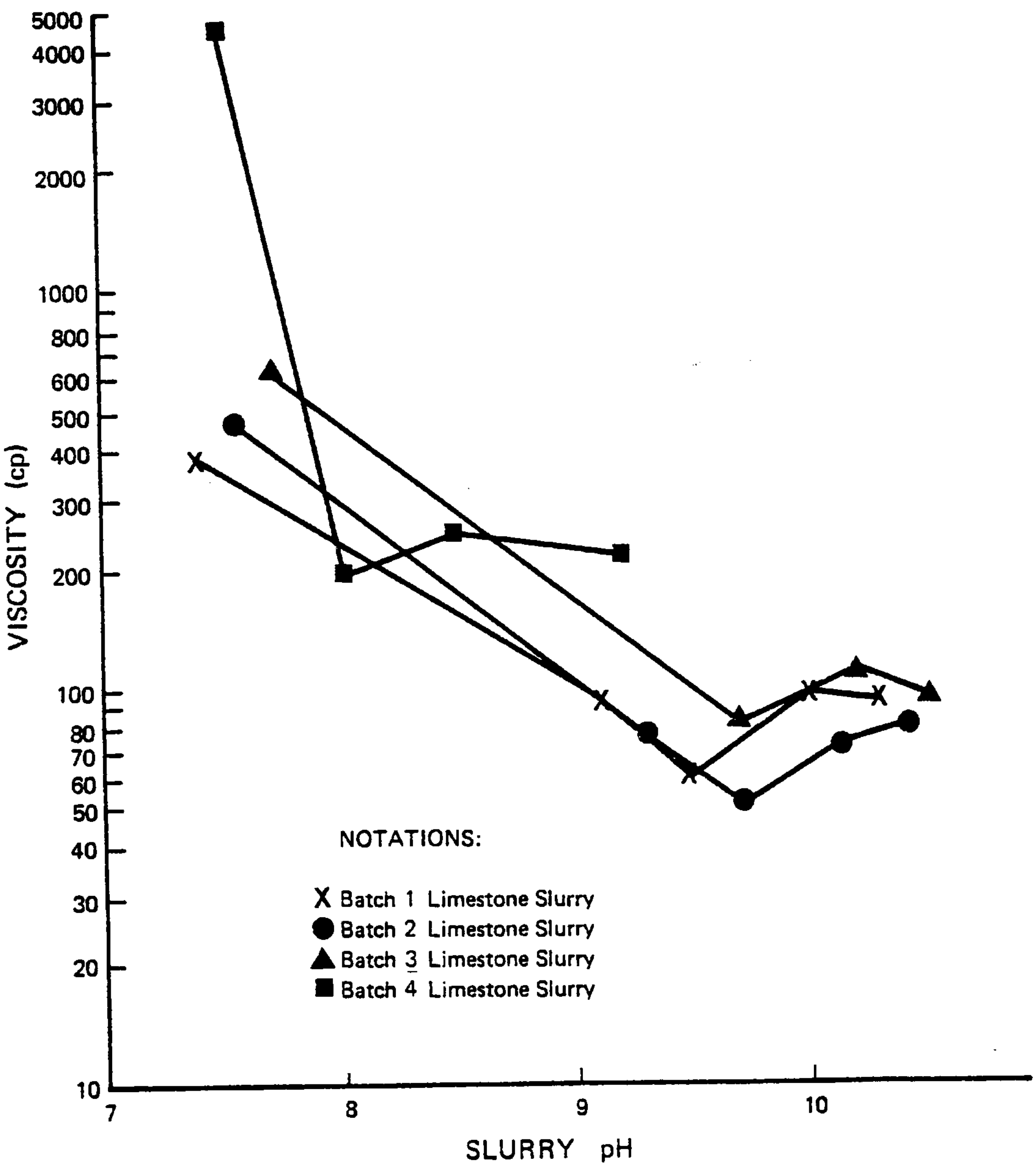
<u>Field Test</u>:

About 3500 tons of limestone was processed through the ball mills and stored in slurry holding tanks. The thinner was added in the mill, initially at a lower rate. The pH of the ball mill processed slurry was about 8-8.5 at 75 percent concentration during the thinner addition rate of 1.6 lb/ton. The rheology of the



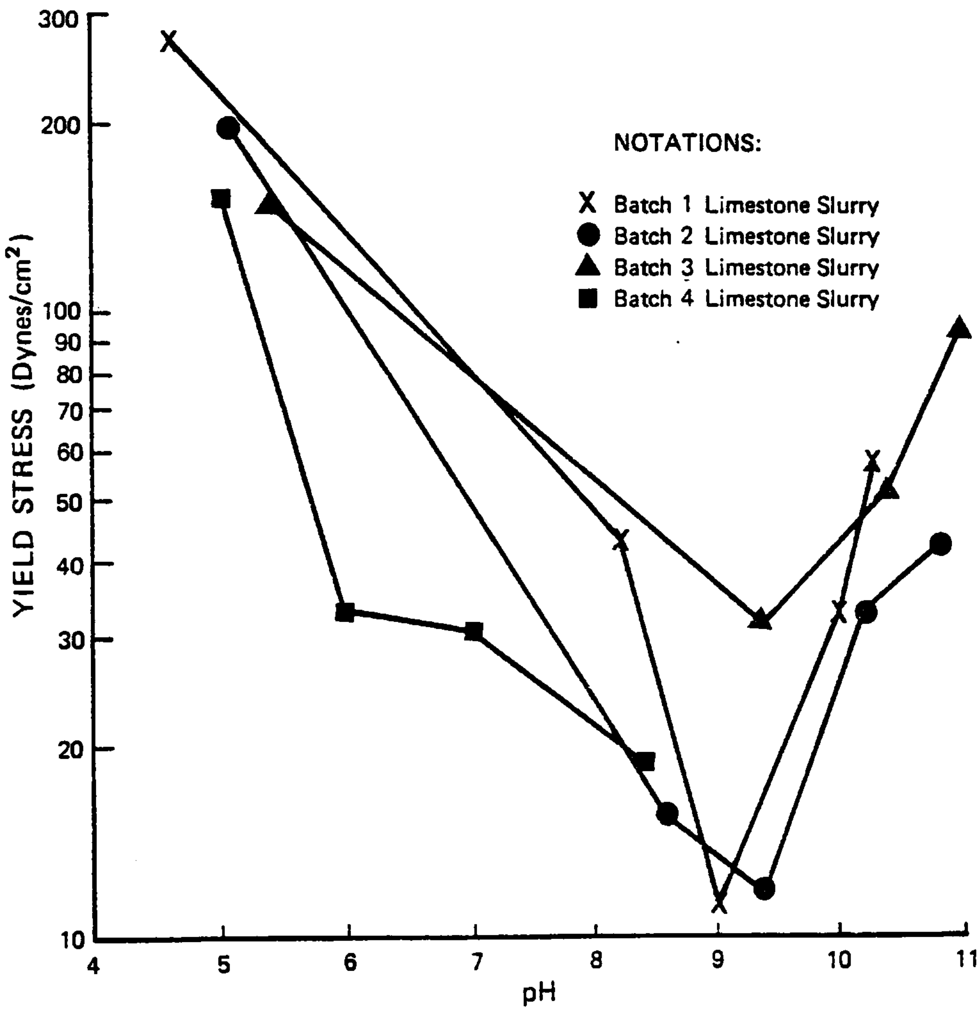
EFFECT OF THINNER E ON VISCOSITY
OF 75% Wt. LIMESTONE SLURRY

Figure 13



EFFECT OF pH ON VISCOSITY OF
75% Wt. LIMESTONE SLURRY

Figure 14



EFFECT OF pH ON THE YIELD STRESS OF
75% Wt. LIMESTONE SLURRY

Figure 15

slurry indicated that the yield stress and viscosity of the slurry was high at this pH. The estimated laminar-turbulent transition velocity was also found to be quite high so that the 75 percent weight slurry could not have been pumped in turbulent region. The thinner rate was increased to about 2.5 lb/ton of limestone. The pH of the slurry at this thinner rate was found to be 9-9.5. The rheological properties were measured which indicated lower transition velocity.

When the processing of the limestone slurry was complete, it was pumped through the pipeline test loop. The differential pressure transducer cell on the test loop was out of service, so a mercury monometer was installed to measure the friction losses. The friction losses of the slurry were measured at various flow rates. The critical transition velocity was calculated using Bechtel's model for transitional velocity.

Table 6 shows the rheological properties at different pH for processed limestone slurry at various concentrations. Based on the test loop data, engineering calculations were made to pump the 75 percent weight limestone slurry at a flow rate such that it did not exceed the maximum design discharge pressure of the pump station.

Based on the data collected during the test loop operation and mainline pumping of the slurry, operating charts were prepared to account for the variable rheological properties of the limestone rock. Figure 16 shows the minimum operating velocity, maximum flow rate and the maximum discharge pressure as a function of

TABLE 6

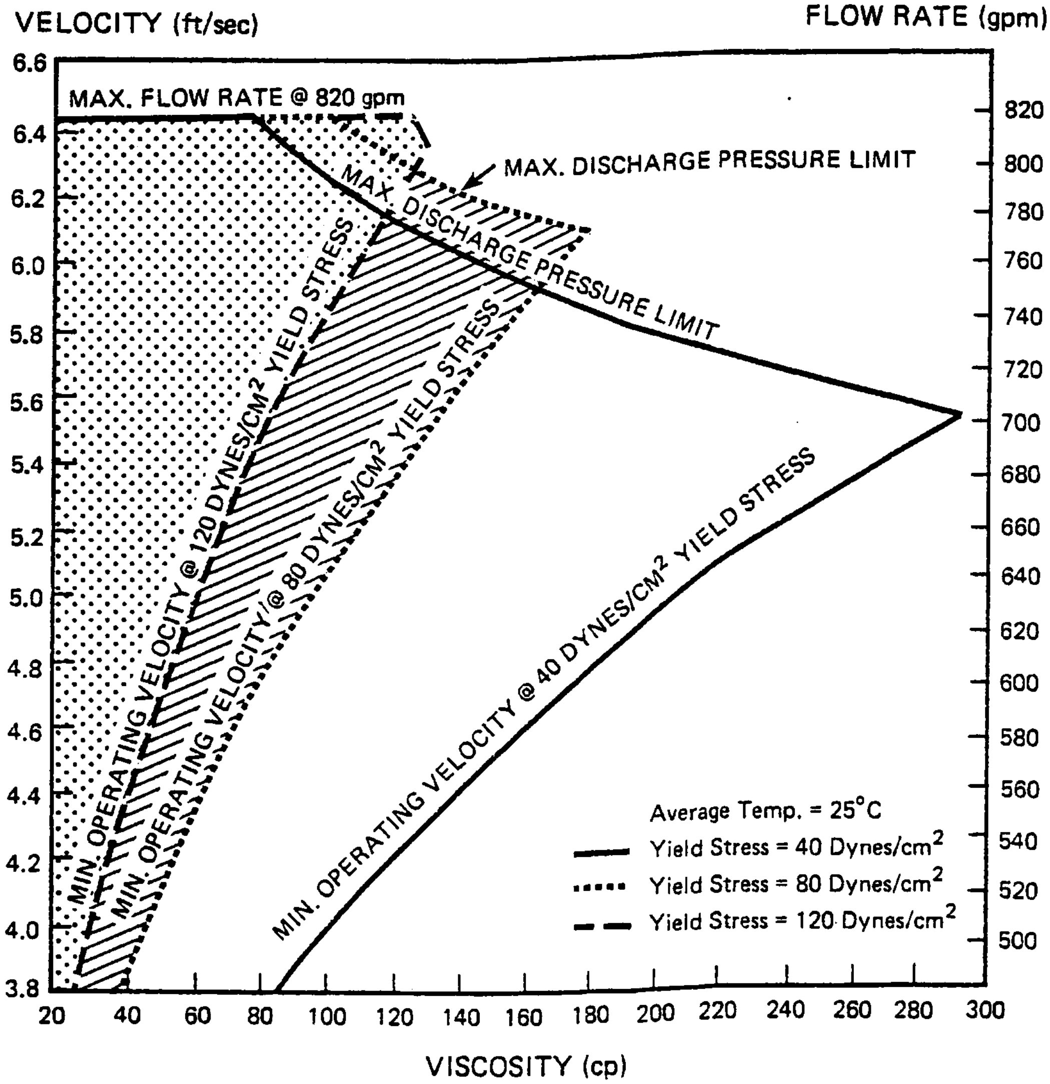
Rheology of Limestone Slurry During Field Test

Average Temperature = 26° C

Material	Slurry Conc. Wt.%	pH	Viscosity CP	Yield Stress $Dynes/cm^2$	Laminar-Turbulent Transition Velocity ft/s
Mill Product	(A) 76.3	8.0	237	94	6.9
		9.5	181	64	5.6
	(B) 75.5	8.0	194	305	9.7
		9.5	206*	95	6.7
Holding Tank	75	8.5	102	47	4.3
		9.0	111	47	4.4
		9.5	77	12	2.5
Mainline Pump	75	9.0	125	54	4.7

* Viscosity and yield stress higher than 76.3 wt.% due to variation in limestone rock properties.

SLURRY CONCENTRATION RANGE = 73 to 75 PERCENT WT.

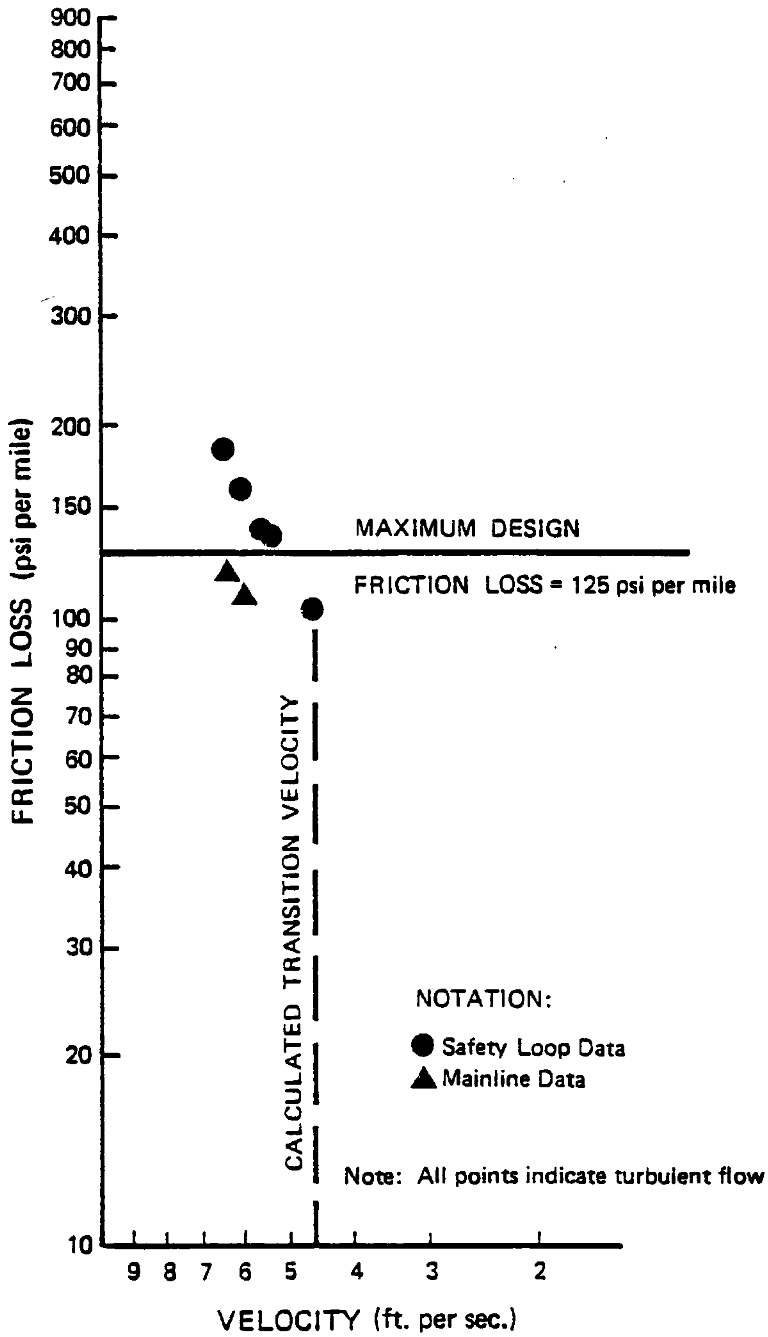


Note: Min. Operating Velocity = Laminar - Turbulent Transition Velocity.

OPERATING CHART FOR LIMESTONE SLURRY

Figure 16

rheological properties for the limestone slurry in the concentration range of 73-75 percent weight. Figure 17 shows the friction losses for safety loop and mainline as the operating velocity was varied in the pipeline.



FRICTION LOSS VS. VELOCITY DATA
FOR 75% Wt. LIMESTONE SLURRY

Figure 17

CHAPTER 3

Engineering Projects

Feasibility of a Phosphate Slurry Pipeline

INTRODUCTION:

A feasibility study of a phosphate slurry pipeline was undertaken. The original study was performed by Bechtel in 1979 for the client. The pipeline was designed for an 8 inch nominal size pipe with design concentration of 65 percent by weight and top particle size of -65 mesh. The original study was performed for a pipeline route length of about 25.58 miles. Table 7 shows the major hydraulic design parameters for the original study.

At the request of the client, hydraulic design was performed with a 10 inch pipeline on the original pipeline route. The original study on 8 inch pipe had recommended a positive displacement pump, it was anticipated that a 10 inch pipe size might result in the selection of a centrifugal pump which is quite cheap compared to the positive displacement pump. To realize this design change, the design velocity was reduced by adjusting the particle size. The particle size was decreased from minus 65 mesh to minus 100 mesh which resulted in a decrease in operating velocity from 5.3 feet per second to about 5 feet per second. However, it was found that a lower pump discharge pressure could not be achieved because the pipeline system has a large static head to overcome. The ground elevation rises from 7430 feet at the pump station site to about 8450 feet elevation at mile post 8. The client further

TABLE 7

Major Hydraulic Parameters for the

Phosphate Slurry Pipelines (Original Study)

Nominal Pipeline Diameter	8 inches
Slurry Concentration	65 percent by weight
Particle Size Distribution	-65 mesh
Flow Velocity	5.3 feet per second
Throughput	2.0 million short tons per year
Pump Discharge Pressure	1613 PSI
Choke Pressure	1082 feet

asked for a sensitivity of the 10 inch pipe design to solid concentration to determine any possible economy of scale. This was done by relaxing the 2 million ton per year design throughput constraint. Table 8 shows the sensitivity of pump station discharge pressure to various solid concentrations for a 10 inch size pipeline. The results were discussed with the client who has taken them under consideration. No operating and capital cost estimates were performed.

An additional sensitivity analysis was performed on both 8 inch and 10 inch pipe size design with respect to two route changes from the original route profile. The length of the changed routes were approximately the same as the original route length, but the elevation profiles were different. Table 9 shows the sensitivity of both 8 inch and 10 inch pipe hydraulic design to route changes. For an 8 inch pipeline the route changes did not result in any significant changes in the hydraulic design, except for route change 1, where the slack flow choke pressure requirement is only 736 feet compared to 1082 feet for both the original route and route change 2. Similarly for a 10 inch diameter pipe the hydraulic design for route change 1 differed from the original profile, whereas route change 2 did not affect the hydraulic design at all compared to original profile. The result of this study was also forwarded to client.

Later on, the client came up with a new terminal station site which was about seventy miles away from the terminal site used in the original study. Four routes were analyzed to reach

TABLE 8

Evaluation of Throughputs for Phosphate Slurry Pipeline

Concentration by weight	50	55	60	65
Design Parameters				
Particle Size (Mesh)	-100	-100	-100	-100
Operating Velocity (ft/sec)	5.0	5.0	5.0	5.0
Flow rate (gallon/minute)	1,286	1,286	1,286	1,286
Solids Throughput (million tons per year)	2.0	2.3	2.6	3.0
Pump Station Discharge Pressure (PSI)	924	1010	1090	1190

TABLE 9

Sensitivity of Both 8 Inch and 10 Inch Pipe Hydraulic Design to Route Changes

Parameters	Original Profile	Route Change 1	Route Change 2	Original Profile	Route Change 1			Route Change 2
Pipe Nominal Diameter (inches)	8	8	8	10	10			10
Slurry Concentration (% by weight)	65	65	65	50		50	65	50
Particle Size Distribution (mesh)	-65	-65	-56	-100	-65	-100	-65	-100
Flow Velocity (feet per second)	5.3	5.3	5.3	5.0	5.17	5.0	5.3	5.0
Throughput (million tons per year)	2.0	2.0	2.0	2.0	2.05	2.0	3.15	2.0
Pump Discharge Pressure (PSI)	1613	1613	1613	924	950	924	1280	924
Choke Pressure (ft.)	1082	736	1082	1424	1040	1100	820	1424

the new terminal site from the old terminal site. The client requested Bechtel to perform a sensitivity analysis of the 8 inch pipeline system to these new routes. The pipeline was designed for a throughput of 240 tons of solid phosphate per hour (2 million short tons per year) as used in the original design. The design concentration was selected to be 65 percent by weight and particle size -65 mesh as used in the original design. The design operating velocity was selected to be about 5.2 feet per second based upon the estimated deposition velocity. Table 10 shows the hydraulic design parameters for an 8 inch pipeline system, obtained through the Bechtel's computer program. The pump discharge pressure, pump station horsepower, number of pump stations and the steel requirement for the API-5LX60 grade pipe with tapered wall thickness were also calculated by the Bechtel computer program. The difference between the design and operating discharge pressure is due to the fact that an 8 percent design flow safety factor had been used, i.e. the operating flow rate is 8 percent less than the design flow rate. After consultation with the client, two routes were selected for additional study. Routes B and D were selected based on fewer required pump stations, lower horsepower, and lower steel tonnage requirement. Routes B and D were each combined with the original route length of about 25.58 miles. An engineering analysis was performed on these combined routes for a 10 inch pipeline at the request of the client. Table 11 shows the hydraulic design for a 10 inch pipeline system for the combined routes.
For the combined route B plus the original route, it was calculated

TABLE 10

Evaluation of Routes for Phosphate Slurry Pipeline

Routes Design Parameters	A	B	C	D
Length, miles	77.8	66.6	67.3	68.9
Throughput, TPH	240	240	240	240
Slurry conc. Wt%	65	56	65	65
Flow rate, gpm	920	920	920	920
Pipe Diameter, inch	8	8	8	8
Average Velocity	5.3	5.3	5.3	5.3
Number of pump stations	3	2	2	2
Discharge Pressure				
Design	1477	1827	1627	1950
Operating	1196	1479	1318	1579
HP required per station				
Design	933	1154	1027	1231
Operating	755	934	832	997
Tons of Steel	3891	3585	4050	3932

TABLE 11

Evaluation of Combined Routes

For a 10 Inch Pipe Size Phosphate Slurry Pipeline

Design Parameters	Original Route + Route B	Original Route + Route D
Length of the pipeline (miles)	92.18	94.48
Throughput (million short tons per year)	3.22	3.22
Slurry concentration (percent by weight)	65	65
Particle size distribution (mesh)	-65	-65
Flow rate (gallons per minute)	1480	1480
Pipe Diameter (inches)	10-88 miles 8-4.18 miles	10
Number of pump stations	2	2
Pump discharge pressure (PSI)		
(1) pump station one	1600	1600
(2) pump station two	1230	634
Choke station (feet)	300	---

that slack flow will occur at mile post 88. An 8 inch pipe size was selected for the remaining length (4.13 mile) of the pipe to avoid slack flow. The choke requirement for this station was found to be about 300 feet. Following instructions from the client, further work on the 10 inch pipe system was discontinued.

Equipment Sizing:

A detailed design was performed for an 8 inch pipeline system for both the original route plus route B and original route plus route D.

Table 12 shows the quantity, size and description of the major components of the 8 inch pipeline system for combined route B and original route.

Similarly, Table 13 shows the listing of major components of the pipeline system for route B plus the original route.

Operating Cost:

The operating cost estimates were made for the 8 inch system for both the combined routes, following sizing of equipment. The capital cost estimates were performed by the capital estimating group and they are not reported here.

The operating cost was estimated using Bechtel's in-house information. Table 14 shows the operating cost for Routes B and D for an 8 inch system. The components of the operating costs are power, labor, maintenance supplies, and corrosion inhibitor. The operating cost comprises power required to operate the mainline pumps at the pipeline mouth and intermediate stations as well

TABLE 12

Major Equipment Listing for Phosphate

Slurry Pipeline for Route B Plus Original Route

LOCATION	EQUIPMENT	QUANTITY	SIZE	DESCRIPTION
Pump station at mill site	Slurry tanks	2	32'x32' dia. x ht.	4600 bbl. each
	Agitators	2	125 ph each	
	Mainline pumps	2	1700 p	Piston pumps
	Variable speed drive	2		With gear reducer
	Motor	2	1400 hp each	
	Centrifugal pumps and driver	2	75 hp each	920 gpm @ 80 ft.
	Station building	1	60'x150'	Heated and ventilated
	Control room	1	15'x40'	Heated and ventilated
	Corrosion inhibitor system	1		
Pump Station No. 2	Slurry Tank	1	32'x32' dia. x ht.	4600 bbl. each
	Agitator	1	125 hp	
	Mainline	2	1700 p	Piston pumps
	Variable speed drive	2		With gear reducer
	Motors	2	1000 hp each	
	Centrifugal pump and driver	1	75 hp	920 gpm @ 80 ft.
	Water pond	1	102'x102'x13.5'	
	Station Bldg.	1	60'x90'	Heated and ventilated

LOCATION	EQUIPMENT	QUANTITY	SIZE	DESCRIPTION
Pump Station No. 3	Slurry tank	1	32'x32'	4600 bbl. each
	Agitator	1	125 hp	
	Mainline pumps	2	1700 p	Piston pumps
	Variable speed drive	2		With gear reducer
	Motors	2	1200 hp each	
	Centrifugal pumps and driver	1	75 hp	920 gpm @ 80 ft.
	Water pond	1	85'x85'x13.5'	
	Station Bldg.	1	60'x90'	Heated and ventilated
Terminal at Dewatering plant site	Slurry tanks	4	56'x48'	2200 bbl. each
	Agitators	4	250 hp each	
	Slurry emergency pond	1	132'x132'x13.5'	
	Choke Station	1	2 chokes	Ceramic-Design Head Drop 230 ft.
Communication System	Leased telephone lines	1		
	Microwave radio system	1		
Pipeline (Externally Coated)	Steel Tonnage	5608 tons	O.D. = 8.625"	API-5LX60
			pipelength = 95.8 miles	
	Plug Valves	13	900	ANSI
		8	600	ANSI
		3	300	ANSI
	Ball Valves	3	900	ANSI
		2	600	ANSI
		1	300	ANSI

TABLE 13

Major Equipment Listing for Phosphate
Slurry Pipeline for Route D Plus Original Route

LOCATION	EQUIPMENT	QUANTITY	SIZE	DESCRIPTION
Pump Station at mill site	Slurry tanks	2	32'x32'	4600 bbl. each
	Agitators	2	125 hp each	
	Mainline pumps	2	1700 p each	Piston pumps
	Variable speed drive	2		With gear reducer
	Motors	2	1300 hp each	
	Centrifugal pumps and driver	2	75 hp each	920 gpm @ 80 ft.
	Station Bldg.	1	60'x150'	Headed and ventilated
	Control Room	1	15'x40'	Heated and ventilated
	Corrosion inhibitor System	1		
Pump Station No. 2	Slurry tank	1	32'x32'	4600 bbl. each
	Agitator	1	125 hp each	
	Mainline pumps	2	1700 p each	Piston pumps
	Variable speed drive	2		With gear reducer
	Motors	2	1000 hp each	
	Centrifugal pump and driver	1	75 p each	920 gpm @ 80 ft.
	Water tank	1	93'x93'x13.5'	
	Station Bldg.	1	60'x90x	Heated and ventilated

(Table 13 continued)

LOCATION	EQUIPMENT	QUANTITY	SIZE	DESCRIPTION
Pump Station No. 3	Slurry tank	1	32'x32'	4600 bbl. each
	Agitator	1	125 hp	
	Mainline pumps	2	1700 p	Piston pumps
	Variable speed drive	2		With gear reducer
	Motors	2	1000 hp each	
	Centrifugal pumps and driver	1	75 hp	920 gpm @ 80 ft.
	Water tank	1	85'x85'x13.5'	
	Station Bldg.	1	60'x90'	Heated and ventilated
Terminal at plant site	Slurry tanks	4	56'x48'	22000 bbl. each
	Agitators	4	250 hp each	
	Slurry emergency pond	1	134'x134'x13.5'	
Communication System	Leased telephone lines	1		
	Microwave radio system	1		
Pipeline Externally Coated	Steel tonnage	5708 tons	O.D. = 8.625" Pipelength = 98.3 miles	Grade API-5LX60
	Cathodic protection system	1		
	Plug Valves	13	900	ANSI
		8	600	ANSI
		3	300	ANSI
	Ball Valves	3	900	ANSI
		2	600	ANSI
		1	300	ANSI

TABLE 14

Annual Operating Cost for Phosphate Slurry Pipeline
(Thousand Dollars)

ITEM	ROUTE B Plus Orginal Route	ROUTE D Plus Original Route
Power	370.0	384.0
Labor	451.0	451.0
Maintenance Supplies	501.0	501.0
Corrosion Inhibitor	16.5	16.5
SUB-TOTAL	1338.5	1352.5
CONTINGENCY	201.0	203.0
	1539.5	1555.5

BASIS: 1st quarter 1981

as agitated slurry tanks, and charge pumps, skilled and semiskilled people to operate and maintain the pipeline and pump stations and the central control system at the pipeline mouth. Lime is used for corrosion inhibition inside the pipeline. The maintenance and supplies include the pump parts and other parts annually to keep the pump station and pipeline running smoothly. Finally, a contingency allowance of 15 percent is added.

FEASIBILITY OF A COAL SLURRY PIPELINE:

A short feasibility study was undertaken for the design of a coal slurry pipeline for throughputs of 3 million short tons per year and 5 million short tons per year.

The pipeline was designed for a flat terrain.

Hydraulic Design:

Table 15 shows the major hydraulic design parameters and equipment sizing. Due to the very preliminary nature of the study, no rheological tests or tests to determine the operational characterictics of the slurry were performed. The rheological data used was from inhouse data.

Capital Cost Estimate:

Table 16 shows the capital cost for the major components of the pipeline systems. It gives rough order of magnitude capital cost estimates and no input was sought from the cost estimating group.

Feasibility of a copper concentrate slurry pipeline:

A preliminary feasibility study was undertaken for the design of a copper concentrate slurry pipeline. The pipeline was designed to transport three thousand tons per day of copper concentrate along a 52 kilometer long route.

Hydraulic Design:

Table 17 shows the hydraulic design parameters and major

TABLE 15

Hydraulic Design for Coal Slurry Pipeline

Throughput (million tons/year)	5	3
Design Parameters		
Length (miles)	250	250
Specific gravity of slurry	1.184	1.184
Concentrating solids (wt%)	50	50
Outside diameter (inches)	18	14
Number of pumps (including 1 spare)	4	3
Number of pump stations	4	5
Horsepower per pump	1300	1350
Average wall thickness (inch) (including corrosion allowance)	0.50	0.45
Type of pumps	Positive Displacement	Positive Displacement
Grade of pipe	API-5LX60	API-5LX60
Weight of steel (tons)	61794	43062

TABLE 16

Capital Cost Estimates for Coal Slurry Pipeline

(Million Dollars)

Throughput (million tons/year)	3	5
Installed pipeline	63.0	86.0
Installed pump stations	38.0	41.0
Slurry preparation and Dewatering facilities	45.0	60.0
Indirect costs	49.0	60.0
Total	195.0	247.0

TABLE 17

Hydraulic Design Parameters for

Copper Concentrate Slurry Pipeline

Throughput (metric tons per day)	3000
Length of the line (kilometers)	52
Particle size distribution	-65 mesh, 80% through -325 mesh
Solid concentration (wt%)	60
Outside diameter (mm)	168.275
Average wall thickness (mm)	6.35
Number of pumps (including one spare pump)	2
Pump discharge pressure (kgm/square cm.)	115
Type of pump	Plunger type reciprocating pump
Grade of pipe	API 5LX-52
Weight of steel (tons)	1455
Number of slurry tanks	4
Size of slurry tanks	10 m diameter 8 m high

equipments listing for this study. The slurry enters at an elevation of 400 meters and discharges at an elevation of 45 meters. The pipeline has been designed as a tapered wall pipeline taking into account the changing operating pressure due to friction losses and changing static heads along the pipeline route.

Capital and operating costs:

The major equipment listing for capital cost estimates are given in Table 18. Some of the cost figures were acquired from the vendor over the telephone. The other cost figures were developed through in-house information without getting a detailed input from the cost estimating group. The labor cost and power cost have not been included in the operating cost Table 19 due to the nonavailability of unit cost for labor and power at the time of the study. However, the total power requirement was calculated to be 7.2 million kwh per year, and the labor requirements were estimated to be 8 operators and one pipeline superintendent.

TABLE 18

Capital Cost for Copper Concentrate Slurry Pipeline

(Million Dollars)

Installed Pipeline	2.9
Installed Pump Station	3.8
Indirect Costs	3.3
Total	10.0

TABLE 19

Operating Cost for Copper Concentrate Slurry Pipeline
(Dollars Per Year)

Pump Maintenance Supplies	$ 52,000
Other Maintenance Supplies	93,000
TOTAL	$145,000

PREDICTION OF FRICTION LOSSES FOR A COAL SLURRY PIPELINE

Friction losses were calculated for a coal slurry for various concentrations. The information was needed by a project group to size the pumps for the under flow slurry obtained from the slurry thickener in the separation plant. A 2-inch diameter pipe was supposed to be used. The coal slurry obtained from the bottom of the thickener was observed to be highly stable and homogeneous. The calculated transitional velocity was estimated to be higher than the desired operating velocity. Thus the concerned auxiliary equipments were designed to pump the slurry in the laminar region. The rheological data were obtained through laboratory testing and indicated that slurry behaved as a Bingham plastic slurry. Theoretical equations given in Govier and Aziz were used to predict theoretical friction losses.

Table 20 shows the measured Bingham viscosities, yield stresses, calculated transitional velocities and predicted friction losses for different concentrations of slurry.

The procedure used to estimate friction losses is given as follows:

(1) Calculate Bingham Reynold number

$$NRe = \frac{\rho v D}{\eta}$$

(2) Calculate Hedstrom number

$$NHd = \frac{D^2 \rho \tau_o}{\eta^2}$$

TABLE 20

Prediction of Friction Losses for Coal Slurry

Slurry Concentration (% by weight)	Specific Gravity of Slurry	Limiting Viscosity (CP)	Yield-Stress (Dynes/cm^2)	Transitional Velocity (ft/sec)	Friction Losses (psi/mile)
25	1.078	28	40	5.7	209
30	1.095	52	240	12.8	758
35	1.112	140	1000	28.1	2792

(3) Get $\Psi = f(\varepsilon_o)$ using

$$N_{Re} = \frac{1}{8} \quad \frac{He\Psi}{\varepsilon_o}$$

(4) Calculate ε_o using Newton-Raphson technique

$$\Psi = 1 = 4/3 \quad \varepsilon_o + 1/3\ \varepsilon_o^4$$

where N_{Re} = Bingham Reynold number

v = Slurry velocity

D = Pipe diameter

η = Bingham viscosity

ρ = Slurry density

τ_o = Yield stress

N_{Hd} = Hedstrom number

CHAPTER 4

SUMMARY AND CONCLUSIONS

This report serves the purpose of explaining the various aspects of my internship at Bechtel Petroleum Inc. at San Francisco. The internship was served in the slurry systems group of the pipeline and production facilities division.

The specific objectives outlined in Chapter One have been met. The requirements for internship in the Doctor of Engineering program are two fold: first, an intern is supposed to make an identifiable technical contribution to the company; second, to enable the student to work in a nonacademic environment where he can see the organizational approach to the industrial problems. It was the second objective which I believe proved most beneficial to me. I think the training I have received in the Doctor of Engineering program, especially one pertaining to economics, business law, systems engineering, communications, management, human interaction, reward-punishment motivation, conflict resolution in a project environment has helped me understand and perceive things during my internship in a logical manner.

APPENDIX - I

Pipeline Route Profile Data for Iron Ore Pipeline.

PIPELINE ROUTE PROFILE DATA

LOCATION (kilometers)	ELEVATION (meter)	LOCATION (kilometers)	ELEVATION (meter)	LOCATION (kilometers)	ELEVATION (meter)
0	410.0	17.66	300.0	28.0	185.0
1.81	235.0	17.87	250.0	29.0	178.0
2.0	250.0	18.0	200.0	30.0	178.0
3.55	230.0	18.18	150.0	31.0	165.0
5.85	255.0	18.46	108.0	32.0	168.0
8.0	250.0	18.82	150.0	33.0	140.0
9.42	570.0	19.08	195.0	33.12	135.0
9.97	590.0	19.28	150.0	34.0	155.0
10.3	600.0	19.58	100.0	34.77	165.0
10.45	645.0	20.0	95.0	35.0	150.0
11.15	750.0	21.0	110.0	36.0	120.0
11.70	700.0	21.2	150.0	37.0	102.0
12.28	650.0	22.0	145.0	38.0	105.0
12.35	600.0	23.0	155.0	39.0	115.0
12.82	550.0	24.0	155.0	40.0	80.0
14.00	550.0	25.0	205.0	40.45	65.0
16.0	450.0	25.7	295.0	40.55	65.0
16.74	400.0	26.0	270.0	41.0	75.0
17.13	350.0	27.0	190.0	42.0	90.0

PIPELINE ROUTE PROFILE DATA CONTINUED

LOCATION (kilometers)	ELEVATION (meter)	LOCATION (kilometers)	ELEVATION (meter)	LOCATION (kilometers)	ELEVATION (meter)
43.0	100.0	62.0	322.0	79.0	595.0
44.0	130.0	63.0	375.0	80.0	592.0
45.0	195.0	64.0	365.0	81.0	612.0
46.0	190.0	65.0	328.0	82.0	615.0
47.0	140.0	65.72	275.0	83.0	615.0
48.0	155.0	66.0	318.0	84.0	620.0
49.0	190.0	67.0	375.0	85.0	628.0
50.0	242.0	68.0	395.0	86.0	652.0
51.0	262.0	69.0	420.0	86.28	655.0
52.0	275.0	70.0	440.0		
53.0	282.0	71.0	512.0		
54.0	278.0	72.0	525.0		
55.0	310.0	73.0	528.0		
56.0	355.0	73.7	550.0		
57.0	272.0	74.0	540.0		
58.0	270.0	75.0	545.0		
59.0	330.0	76.0	575.0		
60.0	365.0	77.0	585.0		
61.0	330.0	78.0	595.0		

APPENDIX - II

Optimization Output for Iron Ore Pipeline

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
50.00	9.625	1512.	7.417	2	8170.	3	1362.	20.	2051.	15827.	1036.	1.2808

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	520.	157.82
3	1292.	222.92

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	DPERAT COST 1000$	TRANSP COST $/TON
50.00	9.625	1512.	7.417	2	8320.	4	1040.	20.	2051.	19225.	1197.	1.4841

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2169.	34.63
3	1060.	181.42
4	1610.	231.97

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
50.00	9.625	1512.	7.417	2	8470.	5	847.	20.	2051.	22624.	1357.	1.6873

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	1923.	32.37
3	792.	164.02
4	1202.	206.17
5	1753.	240.16

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
52.00	9.625	1415.	6.940	3	5283.	2	881.	17.	2056.	13977.	1005.	1.2363

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	1115.	182.64

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
52.00	9.625	1415.	6.940	2	7188.	3	1198.	17.	2056.	15711.	966.	1.1984

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	602.	160.15
3	1331.	224.50

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
52.00	9.625	1415.	6.940	2	7333.	4	917.	18.	2056.	19109.	1126.	1.4011

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2108.	34.26
3	1115.	182.64
4	1639.	232.39

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
54.00	9.625	1325.	6.500	3	4671.	2	778.	15.	2062.	13906.	947.	1.1678

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	1040.	192.86

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
54.00	9.625	1325.	6.500	2	6367.	3	1061.	15.	2062.	15615.	907.	1.1294

STATION/ NO.	ELEVATION (FT)	OISTANCE (1000FT)
1	1345.	.00
2	2414.	36.27
3	1368.	225.98

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
54.00	9.625	1325.	6.500	2	6506.	4	813.	16.	2062.	19012.	1067.	1.3317

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2052.	34.07
3	1040.	192.86
4	1666.	232.76

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
56.00	8.625	1241.	7.682	2	8803.	3	1467.	21.	1831.	15008.	1081.	1.3298

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	492.	145.37
3	1206.	219.41

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
56.00	8.625	1241.	7.682	2	8937.	4	1117.	21.	1831.	18405.	1241.	1.5317

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2319.	35.64
3	943.	178.13
4	1538.	230.98

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
56.00	8.625	1241.	7.682	2	9071.	5	907.	22.	1831.	21801.	1401.	1.7336

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2005.	33.92
3	622.	160.74
4	1080.	203.86
5	1729.	238.28

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
58.00	8.625	1164.	7.201	2	7811.	3	1302.	19.	1836.	14890.	1010.	1.2464

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	576.	146.66
3	1247.	220.68

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
58.00	8.625	1164.	7.201	2	7940.	4	993.	19.	1836.	18286.	1169.	1.4479

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2252.	35.19
3	991.	179.65
4	1569.	231.42

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
58.00	8.625	1164.	7.201	2	8069.	5	807.	19.	1836.	21681.	1329.	1.6494

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	1963.	33.59
3	696.	162.17
4	1133.	204.87
5	1732.	239.39

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
60.00	8.625	1091.	6.753	2	6975.	3	1162.	17.	1841.	14790.	950.	1.1762

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	634.	148.89
3	1279.	222.25

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
60.00	8.625	1091.	6.753	2	7100.	4	887.	17.	1841.	18186.	1109.	1.3773

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	2192.	34.79
3	1039.	180.95
4	1598.	231.81

CONC WT %	PIPE DIAM INCHES	FLOW GPM	VELOCITY FT/SEC	NO PUMP /STN	TOTAL HP	NO STN	HP/ PUMP	MKWH	TON	CAPITAL COST 1000$	OPERAT COST 1000$	TRANSP COST $/TON
60.00	8.625	1091.	6.753	2	7225.	5	722.	17.	1841.	21581.	1268.	1.5785

STATION/ NO.	ELEVATION (FT)	DISTANCE (1000FT)
1	1345.	.00
2	1936.	32.70
3	764.	163.48
4	1182.	205.79
5	1746.	239.95

APPENDIX - III

Computer Certificate Courses

Certificate of Completion

This is to certify

ATHAR J. QURESHI

has satisfactorily completed the requirements of the Data Processing Education course in

INTRODUCTION TO EXEC

on

APRIL 6, 1981

and is hereby awarded this Certificate

David L. Spalding
Supervisor

Data Processing

Data Processing Education
Bechtel Group of Companies
San Francisco

Certificate of Completion

This is to certify

ATHAR J. QURESHI

has satisfactorily completed the requirements of the Data Processing Education course in

INTRODUCTION TO EXEC USING DEMAND

on

MAY 26, 1981

and is hereby awarded this Certificate

Supervisor

Data Processing

Data Processing Education
Bechtel Group of Companies
San Francisco

Certificate of Completion

This is to certify

ATHAN J. QURESHI

has satisfactorily completed the requirements of the Data Processing Education course in

USING THE EXEC OPERATING SYSTEM

on

JUNE 22, 1981

and is hereby awarded this Certificate

Supervisor

Data Processing

Data Processing Education
Bechtel Group of Companies
San Francisco

Certificate of Completion

This is to certify

ATHAR J. QURESHI

has satisfactorily completed the requirements of the Data Processing Education course in

COMPUTER PROGRAM GENERATION

on

JUNE 29, 1981

and is hereby awarded this Certificate

D K Spalding
Supervisor

DeDe Gurley
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This report was typed by Virginia Woods and Dianne Wauters