DESIGN OF A HIGH HEAD, HIGH VOLUME UNDERGROUND PUMP STATION

by
E.R. Hogg and P. Taylor
Techpro Mining & Metallurgy
Dover Place
Ashford
Kent TN23 1EX, England

Introduction

This paper discusses the main problems encountered in the design of a high volume, high head underground pump station.

It also identifies the areas where advances have been made and tries to establish the current "state of the art".

For the purposes of this paper the pump station at the 1360m level at ZCCM's Mufulira Mine is used as a case study.

For a pumping installation such as this it is necessary to establish a design which achieves the correct balance between capital and operating costs and maintenance costs that is acceptable to the client.

Techpro

Techpro have been involved with the development of the Zambian Mining Industry for over 20 years and have designed most of the main underground pump stations that have been installed in recent years at Nkana, Nchanga, Mufulira and Konkola Divisions of ZCCM.

Design Brief

The design brief for the 1360m level pump station is as follows:-

Settling of mine water with overflow to clearwells. The clear water to contain less than 50 ppm solids with a particle size of less than 25 microns.

- Installed pumping capacity of approximately $70m^3$/min and sustained capacity of $52m^3$/min.

- Water discharge from the pump station to feed the 430m level pump station and thence to surface.

- Removal of mud from the settlers and transport to surface.

- the pump chamber to be protected by a watertight door and the escape exit to be at 1240 metre level.

- for ease of maintenance an overhead travelling crane will be installed.

- a railtrack to be installed along the length of the chamber.

Although not stated, implicit in the design brief is that ease and cost of operation and maintenance has a high priority in the design and that capital costs must be kept to a minimum commensurate with good design and ZCCM's specifications and standards.

Settling

Introduction

In general before a successful pumping scheme can be designed the following basic information on the water must be established:-

- source and quantity
- location to where it will report
- the quality as it is received and although difficult to predict, thoughts on how consistent this will be over the life of the pumping installation

Settling tests must be carried out on representative dirty water samples taken throughout at least one 24 hour period, to establish water turbidity over the three operating shifts and the entrained solids settling characteristics.

This information must be as accurate as possible prior to design work starting as a pumping facility is a large investment and if wrong decisions are made it could be expensive in both capital and operating costs.

ZCCM personnel have much experience in establishing such parameters and the relevant information was provided to Techpro by Mufulira Division.

The sizing of settlers and clearwells was undertaken by Mufulira Division and Techpro's Project Manager Mr G M Gale, who also carried out research into this problem and prepared a report titled "Study on Mine Water Clarification using Underground Settlers" (Ref 1). This report is referred to in this paper.

Due to a number of constraints his investigations were limited to particular settler types however for the sake of completeness the authors have included the range of settlers currently in use.

Settling Efficiency

The wear within a pump is directly related to the amount of suspended solids in the water, the particle size and hardness of the solids present and the head being pumped against.

It has been shown by the South African CSIR that wear within a pump with a suspended solids count of 1000 ppm in the water is of the order of ten times the wear at 250 ppm.

A ZCCM Ltd Technical Services Report on Multi-Stage Underground Dewatering Pumps (Ref 2) shows that life in hours between pump overhauls at different divisions within ZCCM ranges between 3,000 and 30,000 hours, generally reflecting the varying settling conditions that exist.

The minimum clearance within large clear water multi-stage centrifugal pumps of the type used extensively on ZCCM mines is of the order of 25-75 microns, therefore to prevent bridging by two particles ideally all particles above 25 microns should be removed before water is fed to the clearwell.

From the above it is clear that in order to keep maintenance costs down, the desired settling efficiency to aim for is a suspended solids clarity as low as possible and removal of all particles above 25 microns while keeping the capital and operating costs of the necessary installation within acceptable economic limits.

Types of Settlers

The types of settlers used underground fall into one of the following categories:-

- Horizontal flow
- Vertical flow
- Proprietary

Horizontal Flow. This type of settler is generally long and narrow with dirty water being introduced at one end and clean water overflowing at the other (Fig 1).

It was generally assumed that the distribution of flow across its cross section is uniform and that particles above the required size fall to the bottom as they travel along the settler.

Measurements taken in models and working settlers (Ref. 3, 4 and 5) suggests this analysis to be incorrect. Solids bearing water, on entering the settler, sinks to a layer of water of equal density. The water then flows along the settler in a relatively narrow layer at velocities up to seven times the average predicted velocity. Consequently, solids deposition is considerably less than that predicted and is unevenly spread throughout the length of the settler.

To try and improve the performance of this type of settler a variety of modifications have been tried.

These have mainly been associated with the addition of baffle plates to make the water flow change direction and also travel a longer path.

A typical modified settler is shown in Fig 1a.

<u>**Vertical Flow.**</u> There are two basic types of vertical flow settler used in the mining industry the first of conical design and the second rectangular.

Conical Type

Over the past twenty years the vertical flow conical settler with varying types of internals has been popular in South Africa and is the accepted best design on the Zambian Copperbelt. In the original design (Fig.2) solids bearing water enters the settler from a cross-cut and is evenly distributed to the outside of a vertical conical baffle. The water flows down the outside before rising in the cental cone shaped region to overflow into concentric V notched launders. The larger size fraction solids drop out readily while the smaller size fraction solids (less than around 80-100 microns) rise up the centre of the cone until the vertical velocity is less than the particle settling velocity. It is thought that they then form a type of 'floc' blanket 'filtering' much finer particles before agglomerating and sinking.

This particular design is installed at ZCCM's Nchanga and Konkola mines and have proved to be very effective over many years. Reports from Nchanga Division show consistently good results in the overflow and a pump operating life of some 20,000 hours.

One variation on the type of internal used is shown on Fig 3. The principle of operation is basically the same as above and the results comparable.

Rectangular Type

The excavation of this type is basically the same shape as the conventional horizontal settler. However in this design the settler is fitted with twin long baffle plates which are arranged at an angle of approximately 15^{0} as shown in Fig 4. and sealed at each end to the settler walls. Raw water is distributed along the length of the settler by channels and weirs on either side of the settler. The water overflows the weirs and flows downward in two streams before rising in the centre to overflow into discharge launders. In all respects the principle of operation and settling characteristics are the same as for the conical vertical flow settlers.

Settlers of this type were installed and commissioned at Broken Hill, N.S.W Australia (ref.4) in 1964 and it is reported that they have operated very satisfactorily producing water of good clarity with no particles greater than 25 microns. The pumps installed run at high speed (3,000 rpm) and it is reported that after 25,000 hours of operation the wear due to abrasion is negligible. Another installation in America using upward flow settlers (Ref. 6) reports a settling efficiency of 155 ppm clarity from a raw water inflow of 1,103 ppm, 92% of the sludge formed being less than 43 microns.

In general this type of settler should be of interest where smaller volumes of water are handled as the required excavation is smaller and easier to mine.

Depending upon the configuration it should be possible to retro fit a set of baffle plates and launders to change a conventional horizontal flow settler to vertical flow and thereby improve settling efficiency.

Proprietary. Although underground settling would seem to be an area where equipment suppliers could have a significant input, by providing high rate thickeners that require relatively small excavations, little impact appears to have been made on the underground mining scene over the past 20 years.

One solution, to the settling problem, which has been developed is the lamella plate thickener. The lamella principle utilizes a series of closely spaced inclined plates to increase the settling area available per unit of plan area and shortens the settling path to be covered by each particle on its way into the sediment.

It would appear that currently there are only two companies that provide this type of equipment.

A third company has developed a design using the conical vertical flow principle, with mechanically activated rakes to squeeze the settled mud and push it to the bottom of the cone. They make the claim that throughputs of 200% - 300% higher than conventional cone settlers can be achieved.

A search through the literature has revealed sparse information on the use of proprietary thickeners in underground applications. In fact at Vaal Reefs it is reported (Ref 7) that after an unsuccessful trial period the Delta-Stak components (lamella type) which had been installed were removed and a modified cone design fitted.

The authors would be pleased to learn of the use of proprietary settling equipment, installed underground, whether it has been successful or not.

__Selection.__ Invitations to tender for the supply of proprietary equipment for Mufulira were sent to three suppliers, however only two tendered.

With the knowledge of the successful operation of the Nchanga design conventional cone type settler, described previously, it was chosen as the best of the in-house non-proprietary designs to compare with proprietary designs.

It is not intended to detail the adjudication which was carried out however the relative capital cost comparison which is obviously important is as follows:-

Nchanga design	-	1
Lamella design	-	6
Mechanical Rake Design	-	2

Which ever type of settler is chosen there will always be some element of risk as over the passage of time the quality and volume of the incoming water may change significantly. It is clear that it is desirable to have some confidence that the settler selected would be capable of handling at least some change and continue to maintain the required quality of water being fed to the pumps.

Neither of the proprietary designs were pursued for the following reasons;-

- they are relatively unproven in an underground environment
- both have a number of potential problem areas associated with operating and maintenance. In particular the rake mechanism and associated drive of the mechanical rake type.
- the relatively high cost

It was decided therefore to recommend the Nchanga design of settler with the total settling capacity sized to operate without flocculant addition. This provides the comfort that if the parameters of the raw water alter it would be possible to add a flocculant and maintain the required performance.

Clearwells. The clean water from the settlers will report to clearwells which in turn feed the pumps.

Clearwells should be sized to provide adequate surge capacity to ensure stable pump operations. Mufulira will have two clearwells, one operational one on standby, each with a capacity of around 3100 m^3.

Sludge Disposal

Introduction

The method of removing settled sludge from a settler depends upon the design and is either removed manually after the build up becomes excessive or is removed through valved drain pipes.

If the latter method is used removal can either be continuous or on a batch basis and is dependent upon which method of disposal to surface is used. As it contains some potential mineral value almost invariably settler sludge is introduced into the concentrator feed. Where this occurs is dependent upon the method used.

Methods

The two basic ways to get sludge out of the mine are to either pump it as a slurry or dewater it and feed the resulting "dried" material into the ore hoisting system.

Pumping. A number of different pumps have been used to pump sludge to surface ranging from multiple "in series" slurry pumps through the various types of positive displacement pumps specifically designed for this duty. ZCCM has used all of these methods over the years although the recent trend has been for the reciprocating piston type.

This type of pump works on the principle of a large slow speed reciprocating duplex piston working in oil and displacing slurry via vertical oil/slurry pressure chambers. No slurry comes into contact with the piston although the suction and discharge valves work in the abrasive slurry. Pumps of this type are used for this application at Nchanga and for hoisting of ore at the Val Reefs gold mine in South Africa.

A more recent development of this style of pump is the piston diaphragm type which is reported as finding favour in similar installations.

It should be noted that the capital and maintenance costs of such pumps with associated pipelines in deep mines are quite significant.

Displacement Chamber. An alternative to straight forward pumping is to use some form of displacement chamber. This comprises of a vertical excavation which is plugged at the top.

The operation is:-

- sludge is either pumped or gravity fed to fill the excavation

- high pressure water from a pump on surface is fed through the plug and displaces the sludge which is forced through a rising main to surface.

- after the mud is displaced the water is emptied using compressed air after which the cycle is repeated.

This method is simple to install however the solids throughput capacity is limited also valve wear is high.

Filtering. The alternative to pumping is to filter the sludge to remove as much water as possible and transport the resulting "dried cake" to surface via the hoisting system.

Selection. Mufulira Division have extensive experience in transporting sludge to surface and over the years have operated almost all of the above systems.

The possibilities which were considered for this installation were displacement chamber, positive displacement pumps and filtering.

The filtering route was chosen as the capital cost of this system is approximately one third of that of the pumping route and was also considered to be better and cheaper to operate. The chosen system comprises two pressure filters and a conveyor belt to transport the dried cake to the ore pocket under the 1360L crusher.

The filter duty specification used is for the treatment of 110 tonnes per day of solids in 16 hours through one filter with a complete standby unit.

Pump Station

Pumps

Before work can start on the layout of a pump station a decision must be made on the type of pump sets to be used.

There are many reputable suppliers of high head, high volume pumps and the choice is dependent upon a number of factors which include:-

- cost
- delivery
- previous experience in similar installations
- spares availability
- service arrangements

Although most pump makers have some units installed on ZCCM's mines, by far the largest population is the Sulzer HPH 54-25W-27° and it is understood ZCCM have standardised on this model for main underground pumping installations. This is a multi-stage centrifugal pump which can accommodate a wide range of delivery heads. The variation in head requirements being accommodated by varying the number of stages accordingly.

It is always beneficial for both operators and suppliers to work together by exchanging information to overcome problems and wherever possible "develop" the pump to suit the particular application with the objectives of increasing operating life.

For example at Nkana and at Konkola Divisions they have been modifying the standard bronze impellers by hard chroming, for many years and more recently have also experimented with stainless steel.

From Konkola experience the life of the stainless steel impeller was seen to be between 200% and 300% longer than a chrome plated one. Although the price of the stainless steel impeller is around 150% to 200% greater than the chromed impeller there is still an obvious advantage.

In light of this experience it is understood that ZCCM have standardised on stainless steel impellers for their Sulzer 54-25W-27^{o} type pumps.
From the design brief the required installed pumping capacity for Mufulira of approximately 70m^3/min against a static head of 930 m can be met by seven off 10 stage Sulzer HPH 54-25W-27^{o} pump sets. Under normal operating conditions this allows for five sets running one on standby and one under maintenance.

The other half of a pump set is the motor which because of the differing duties of pump stations must be specified separately.

The basic specification for the Mufulira Station is 3000 kw, 11 kv, 3 phase, 50\hz cage rotor induction motors. A major consideration for motors of this power is that their physical size must be such as to permit transportation from surface to the pump chamber.

As there are usually no limitation on supplier they are normally purchased from the lowest bidder who meets the technical specification.

Pump Station Layout

Once the dimensions of the pump sets are known and the suction and delivery piping within the pump chamber sized, the layout design can begin.

Probably one of the biggest advances in engineering design over the past ten to fifteen years has been the general development of computer aided design and draughting.

Techpro uses a 3D computer based design management system to aid engineers in the design of the complete range of facilities from complex process plants through to underground installations.

It enables multi-discipline design teams to simultaneously build a 3D model on screen from the engineering information available and has replaced the need to build hard models.

The computerised model ensures accuracy of design and automatically checks for interference clashes and consistency and interfaces to stress analysis.

As well as producing the standard isometrics, plans, elevations and section drawings it also produces material take-offs.

Figures 5, 6 and 7 are typical of the type of drawing which can be produced.

Views can be generated from any point and in the pump chamber case by "walking" around the chamber it is easy to see if there is adequate clearance around pump sets and valves to ensure ease of operation and maintenance. It also establishes the most space effective excavation, thereby keeping mining costs down.

Piping

From a design point of view the piping separates into two sections. The piping in the chamber itself and the pipe column up the shaft.

Pump Chamber Piping. This piping again divides into two - the suction pipes and the delivery pipes.

The suction piping must be designed for the head to the level to which the station is protected (plus a generous safety margin) when the watertight door is closed and the delivery piping of course must be designed for the head to the discharge point.

Over recent years computer based programmes have been developed which assist the design engineer and Techpro uses a package which carries out the complex calculations for the static and dynamic forces on piping systems as well as their supporting structural steelwork.

The associated graphics shows displaced shapes, forces, stresses and motions and gives a comprehensive picture of the behaviour of the complete piping system. For example, Fig 8 illustrates the piping layout from the pump sets to the bottom of the raise bored hole with no external forces acting. Fig 9 shows the exaggerated movement of the piping under various loads ranging from normal operating conditions through to surge conditions after a trip out. This assists the design engineer to identify areas which should be examined in more detail, where he should locate the thrust blocks and guides to prevent pipe movement, where pipes should be strengthened, or a higher material specification used.

Fig 10 shows the piping arrangement from a pump set to the discharge pipe, identifying the nodes to be analysed.

The computer then provides a printed stress report for all types of stress for every node.

Shaft Piping. Pipe columns up a shaft are traditionally in flanged lengths which are installed by either hanging them from a bearer set and adding lengths downwards or starting at the bottom at a thrust block and building them upwards. Both methods are time consuming and costly as the pipe length must be slung into position and then bolted together. The operation is also quite dangerous as it involves working in an open shaft.

An alternative to this is to install a free hanging column with threaded connections such as those used in the oil and gas industry. Although this method is reported as having been used for a number of years in the German mining industry it has not yet achieved universal popularity. There is however a recent report that a 1000 m column has been installed at Broken Hill Mine in Australia. The original estimated time to run the complete pipe string down the shaft was 80 hours but in fact it was completed in 36 hours. The advantages claimed are space saved in the shaft as there are no pipe flanges, no need for intermediate supports, column assembly takes place on the surface and is therefore safer, the installation time is significantly less than for a conventional column.

Raise Bored Holes. The use of raise bored holes for rising mains instead of piped columns has become an accepted method for the transfer of water underground. This raisebore method also referred to as 'Rock Rising Main' was selected for use at Mufulira Mine in view of:-

- the existence of raisebore machines on site
- the purchase cost of a high pressure rising main column
- restrictions in installing additional services inside the Musombo Subvertical Shaft
- the negligible maintenance and replacement costs

The Rock Rising Main, when complete, will run from 430 to 1360m level, passing through 500, 730, 810, 960, 1140 and 1240 metre intermediate levels. The raisebore holes will have a nominal diameter of 0.66m and will be connected at each intermediate level with steel piping grouted and concreted into place.

Pumping will occur through one Rock Rising Main although a standby hole is being simultaneously developed. The raisebore holes have been designed to pass through competent rock and avoid unnecessary proximity to existing underground excavations, to reduce any leakages that may occur.

Conclusion

It would appear that the changes within a High Head, High Volume Pump Stations complex, in the past twenty years, have been limited to minor variations in settlers and in improved materials used by pump manufacturers.

In the actual design area the speed of advance has been quite dramatic with the use of computer aided design and draughting. This in fact has made the use of pencil and paper on a drawing board virtually obsolete.

Acknowledgements

The authors wish to thank ZCCM Ltd and Techpro Mining & Metallurgy for granting permission to use internal reports and information and to publish this paper.

They also wish to thank their colleagues at ZCCM Ltd and Techpro for their assistance.

References

1. Gale G. M., Study on Mine Water Clarification using Underground Settlers".

2. ZCCM Ltd Technical Services., "Report on Multi-Stage Underground Dewatering Pumps". (May 1989)

3. de Villiers J.W., "An Investigation into the Design of Underground Settlers". Journal South African I.M.M (June 1961)

4. Goninan E.K., "The Development of Mine Dewatering Installations at Broken Hill South Ltd". (1968)

5. Symposium of Papers on Pumping - various authors, reprinted from the Journal of the Institution of Certificated Engineers, South Africa. (June 1952 - January 1955)

6. Monroe H.L., "Design of a Mine Water Settler at Pea Ridge". Mining Engineering (December 1965)

7. Perry G.D., The Excavation and Equipping of Large Vertical Dams and Settlers at Depth on Vaal Reefs East Division. International Deep Mining Conference SAIMM (1990)

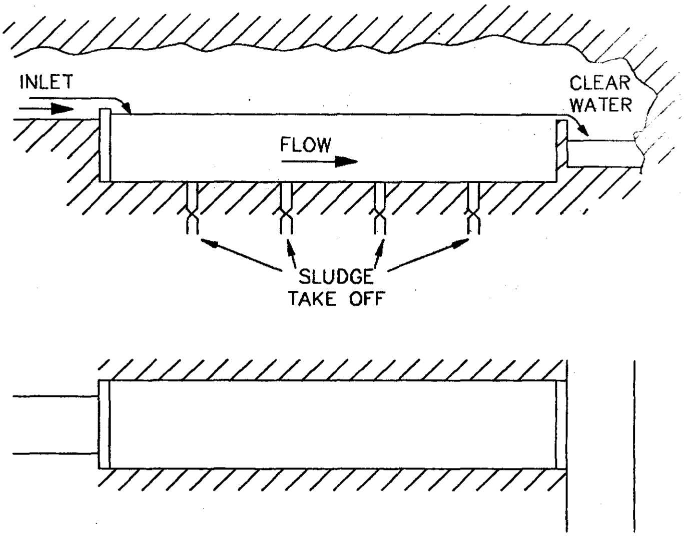


FIG. 1 RECTANGULAR HORIZONTAL FLOW SETTLER

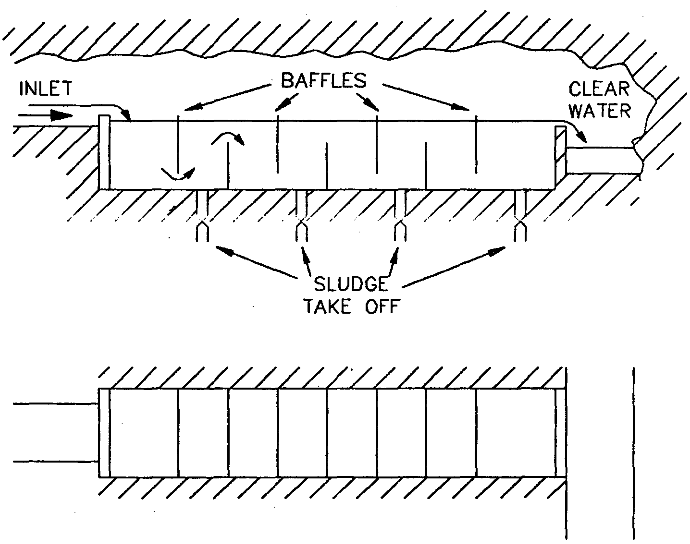


FIG. 1a MODIFIED RECTANGULAR HORIZONTAL FLOW SETTLER

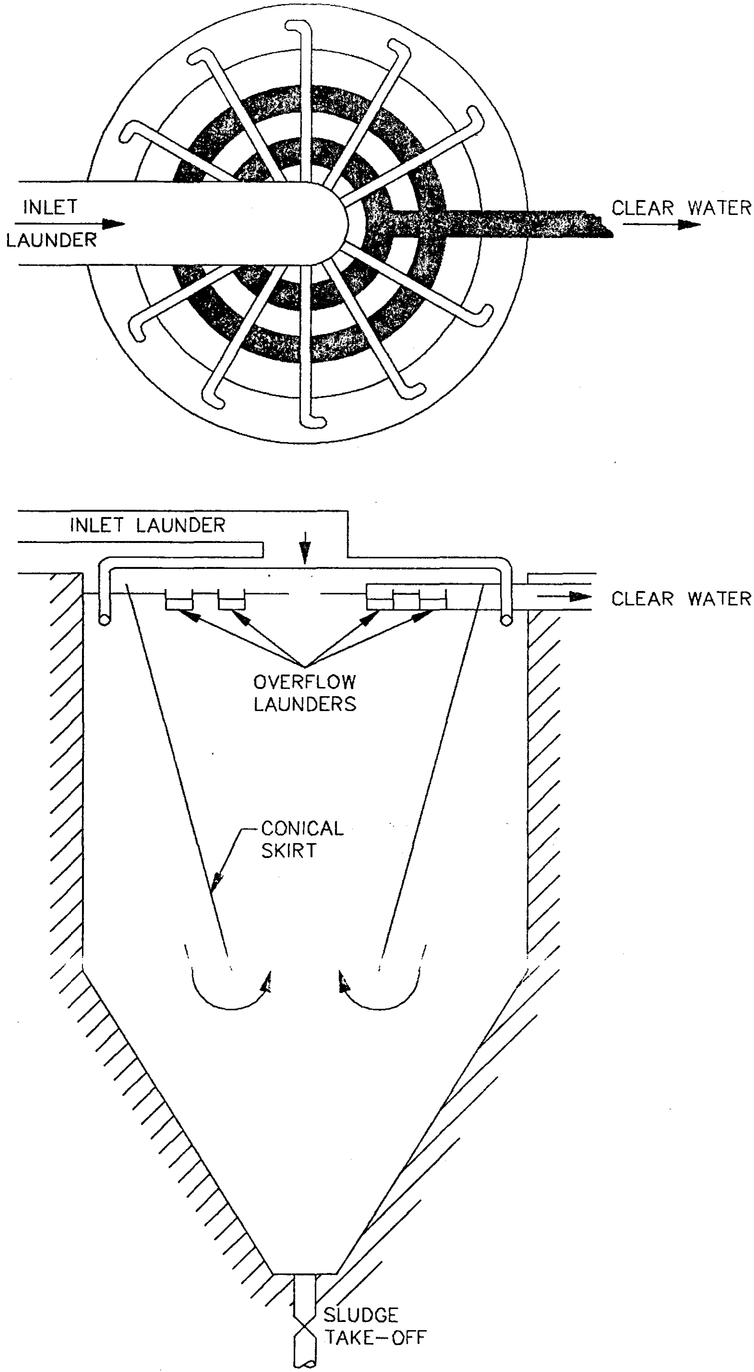


FIG. 2 VERTICAL FLOW CONICAL SETTLER

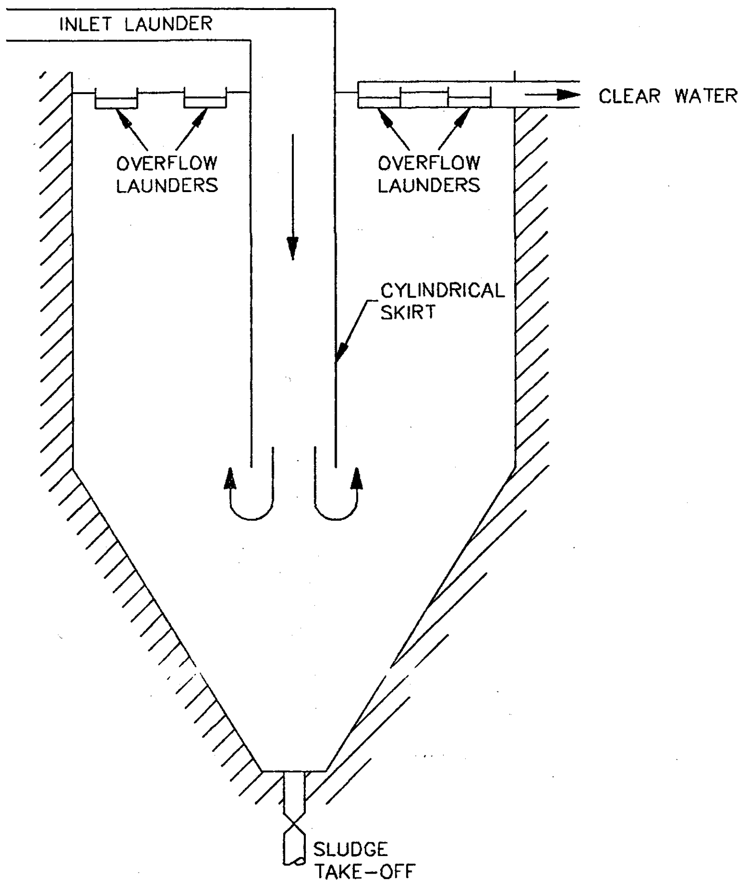


FIG. 3 MODIFIED VERTICAL FLOW CONICAL SETTLER

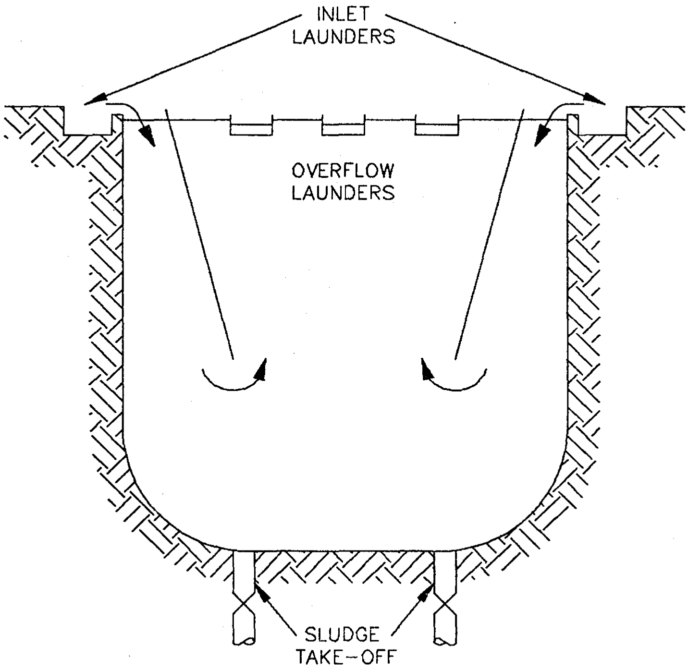
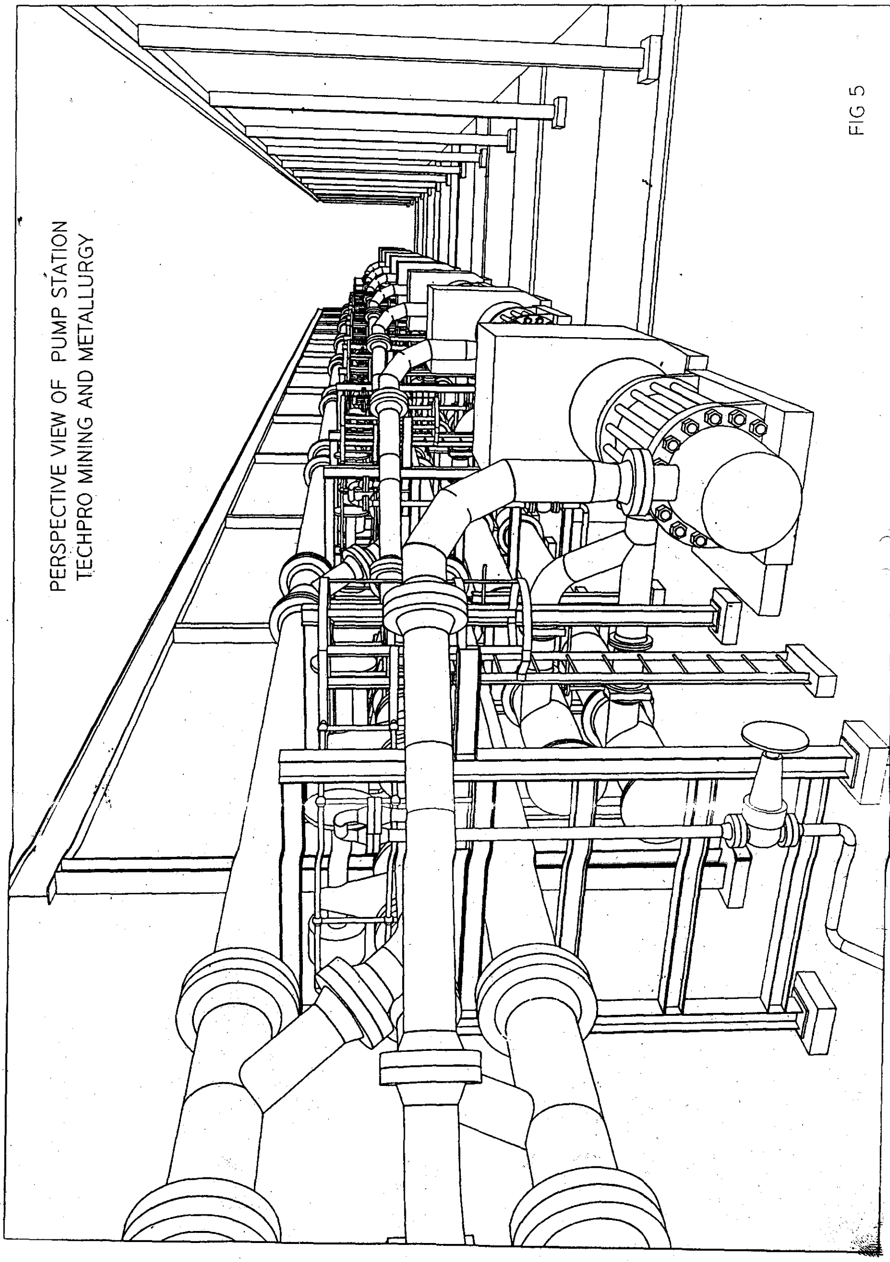
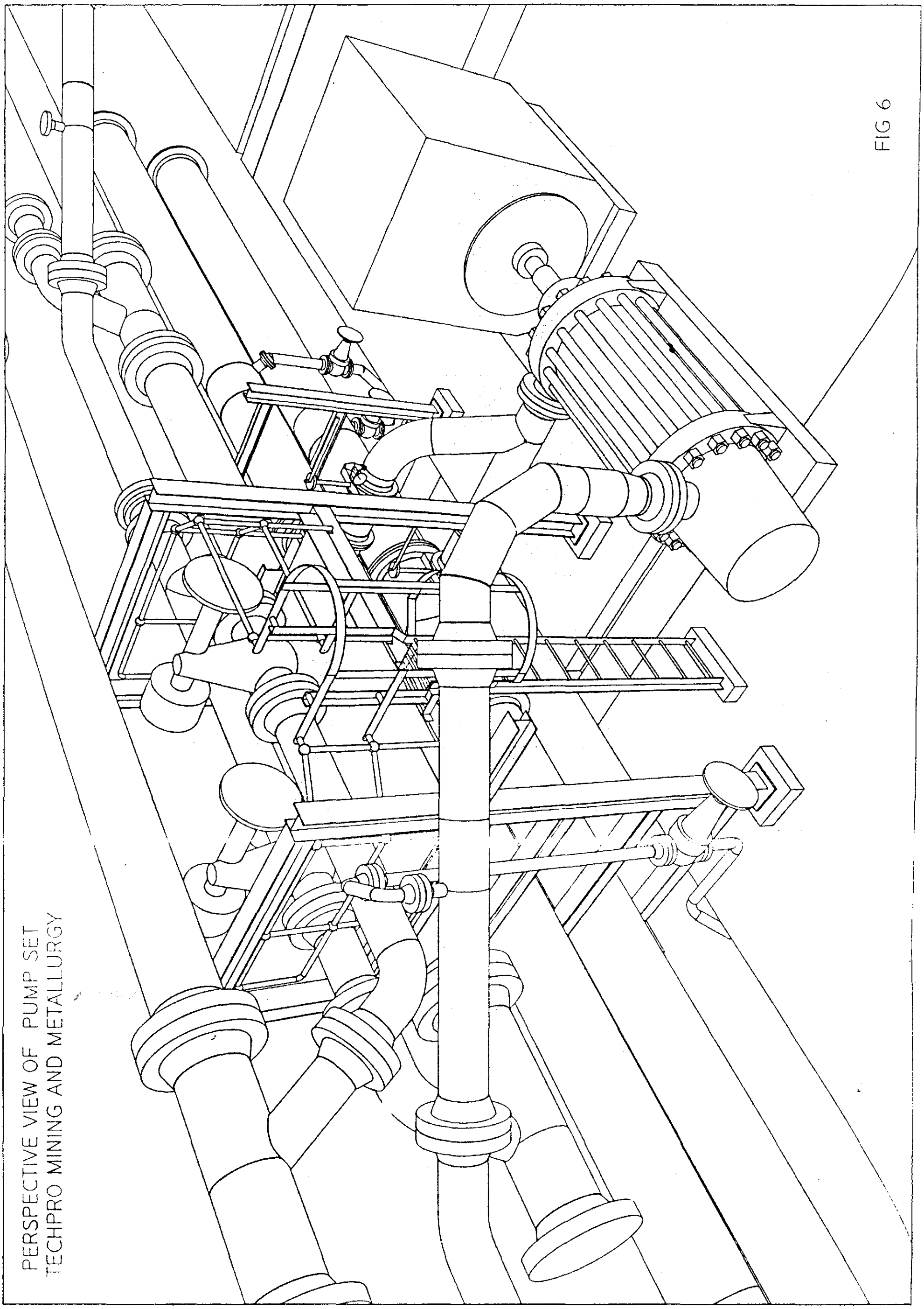


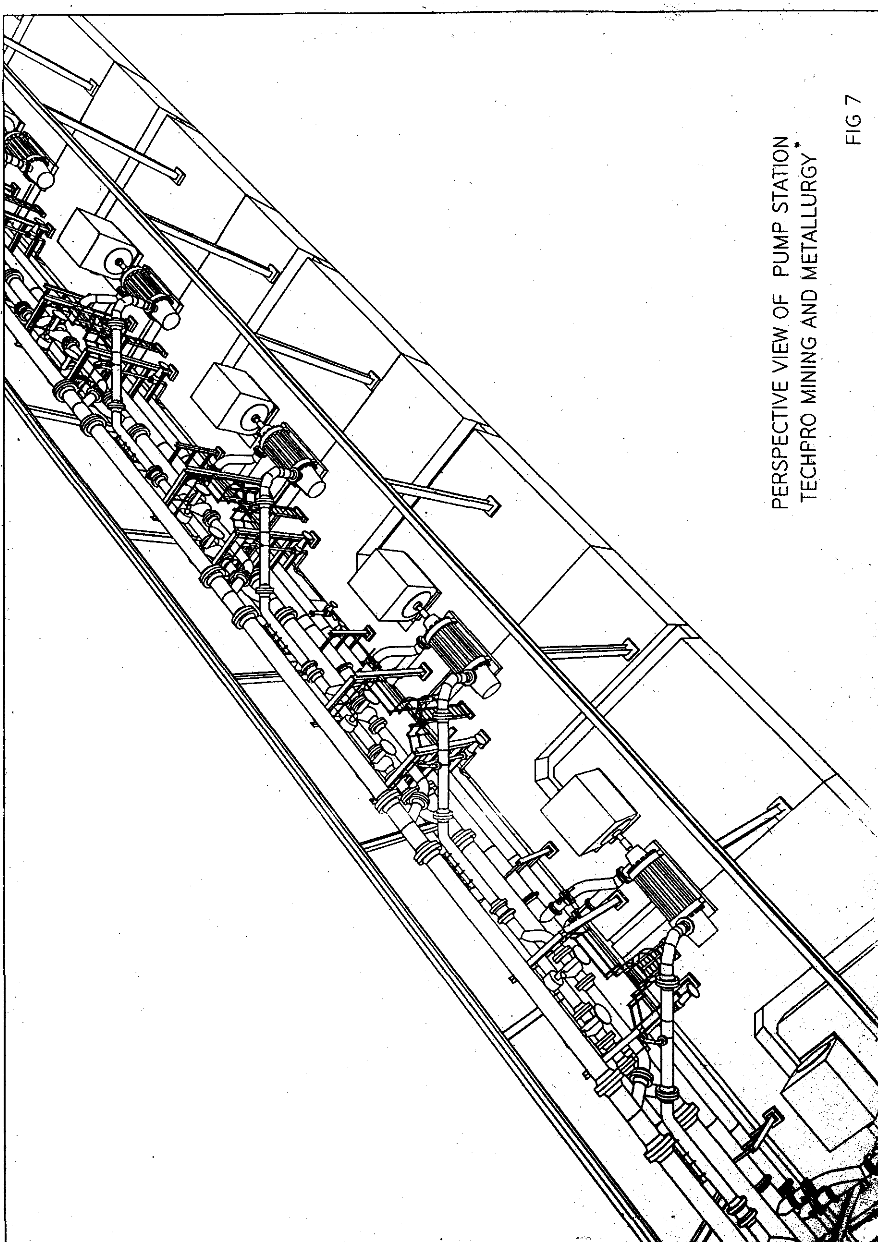
FIG. 4 VERTICAL FLOW
RECTANGULAR SETTLER


PERSPECTIVE VIEW OF PUMP STATION
TECHPRO MINING AND METALLURGY
FIG 5



PERSPECTIVE VIEW OF PUMP SET
TECHPRO MINING AND METALLURGY

FIG 6



PERSPECTIVE VIEW OF PUMP STATION
TECHPRO MINING AND METALLURGY

FIG 7

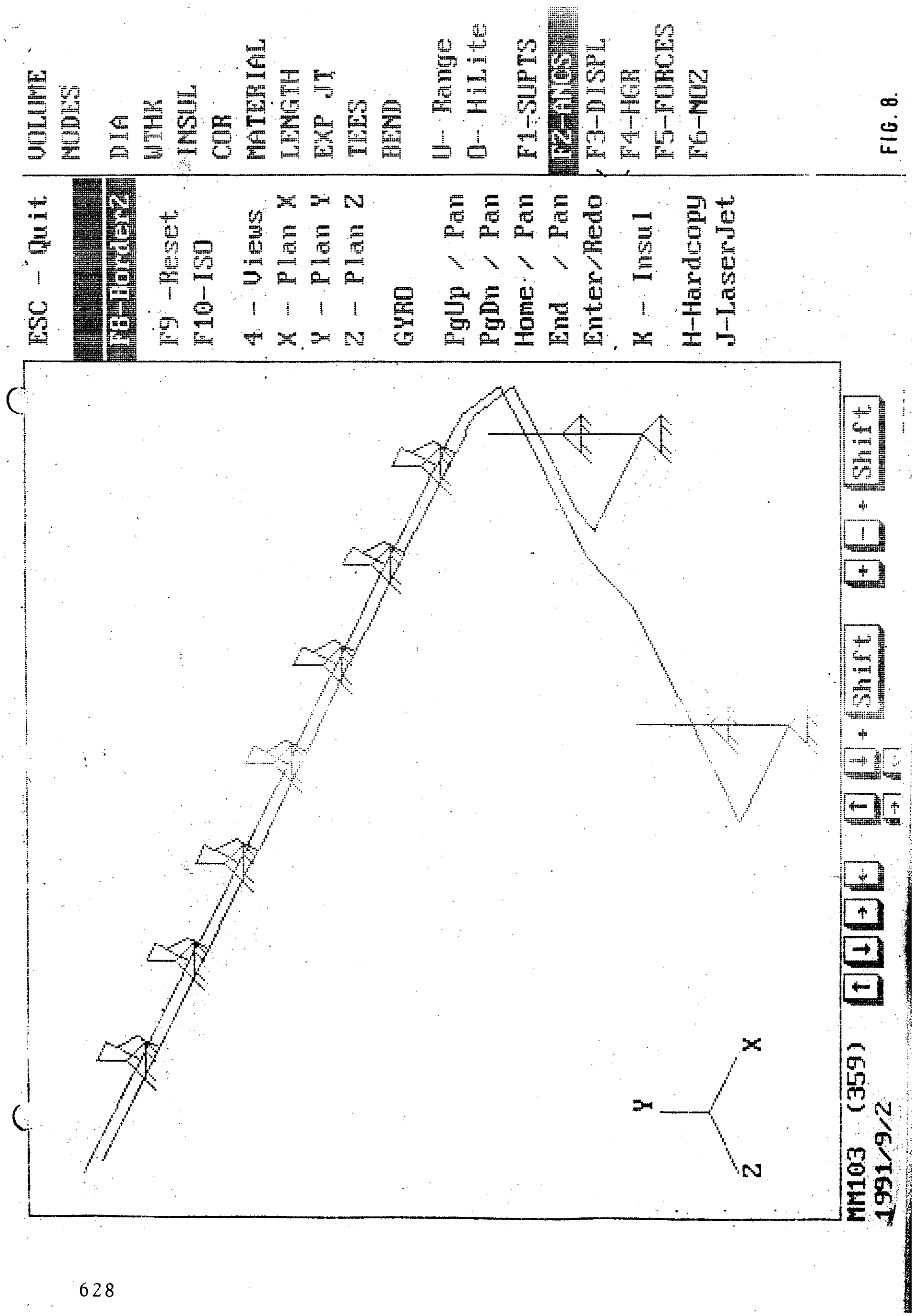

ESC - Quit
F8-Border 2
F9 -Reset
F10-ISO
4 - Views
X - Plan X
Y - Plan Y
Z - Plan Z
GYRO
PgUp / Pan
PgDn / Pan
Home / Pan
End / Pan
Enter/Redo
K - Insul
H-Hardcopy
J-LaserJet
VOLUME
NODES
DIA
WTHK
INSUL
COR
MATERIAL
LENGTH
EXP JT
TEES
BEND
U- Range
O- HiLite
F1-SUPTS
F3-DISPL
F4-HGR
F5-FORCES
F6-NOZ
Shift
Shift
MM103 (359)
1991/9/2
X
Y
Z

FIG. 8.

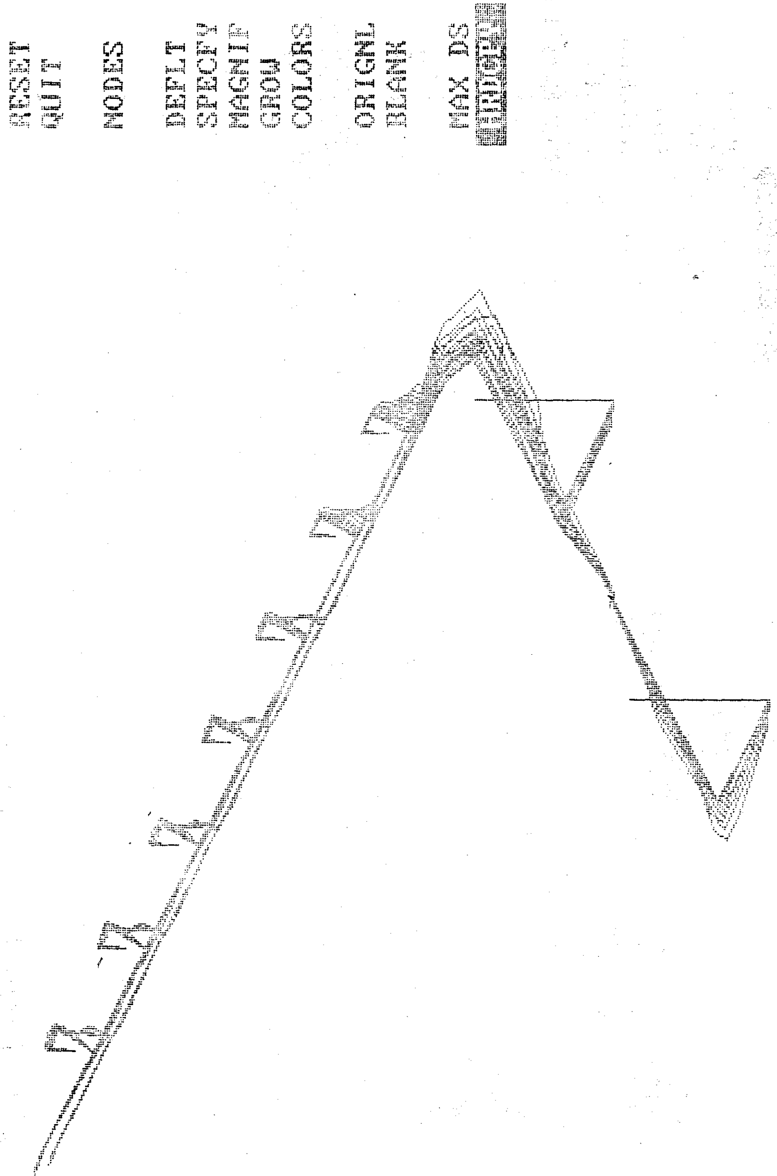

RESET
QUIT
NODES
DEFLT
SPECFY
MAGNIF
GROW
COLORS
ORIGNL
BLANK
MAX DS

FIG 9

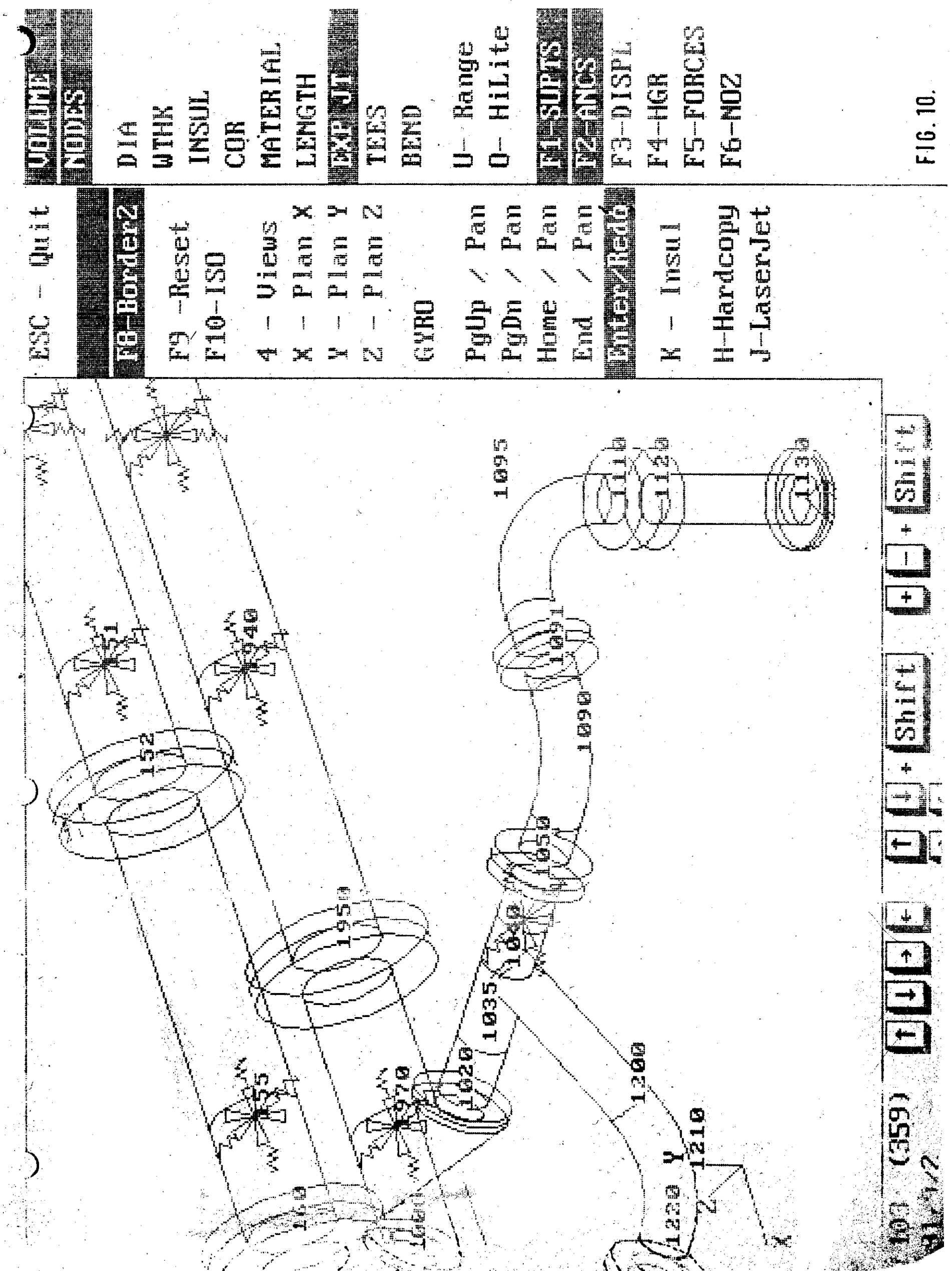

ESC - Quit
F8-Border2
F9 -Reset
F10-ISO
4 - Views
X - Plan X
Y - Plan Y
Z - Plan Z
GYRO
PgUp / Pan
PgDn / Pan
Home / Pan
End / Pan
Enter/Redo
K - Insul
H-Hardcopy
J-LaserJet
VOLUME
NODES
DIA
WTHK
INSUL
COR
MATERIAL
LENGTH
EXP JT
TEES
BEND
U- Range
O- HiLite
F1-SUPTS
F2-ANCS
F3-DISPL
F4-HGR
F5-FORCES
F6-NOZ
1095
1090
1050
1035
1020
970
152
1200
1210
1220
Shift
Shift

FIG. 10.