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PLANNING OF A SLIM WELL FOR GEOTHERMAL EXPLORATION IN VIETNAM

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ABSTRACT

Slim wells are commonly used for the exploration of geothermal resources. This paper deals with the planning of slim wells for geothermal exploration in Vietnam. In the discussion on well planning, emphasis is put on some practical aspects, such as the drilling depth limit of the drilling rigs available in Vietnam, casing design, cementing calculations, selection of blowout prevention equipment, and estimated drilling costs.

1. INTRODUCTION

In Vietnam the geothermal energy resources have been researched for many years. As a result of several reconnaissance surveys, two target areas, Le Thuy and Mo Duc, have been selected (Gianelli, 1997). The research results indicate that the thermal water temperature may reach upto 150-200°C. Exploration wells will be drilled in these areas in the near future. The principal objectives of the programme are obtaining samples and cores for geological studies, delineating the stratigraphic structure, and determination of the existence of a production zone of geothermal fluid and its characteristics (pressure, temperature, permeability).

Taking into account the technical and economic conditions of Vietnam, a programme with some exploration slim wells may be the most sensible. Compared to conventional large-diameter wells the drilling cost of slim holes is relatively low, and the drilling equipment available in Vietnam can be used for the job. Slim holes can provide high quality cores and samples, and also establish the underground temperature distribution and presence of a geothermal resource. The discharge characteristics of a future production well may also be estimated based on results from flow testing of slim wells (Pritchett, 1993).

The most powerful drilling rig available in the Department of Geology and Minerals of Vietnam is ZIF-1200 MR. The maximum drilling depth of this rig for geothermal exploration and how to construct a well with minimum cost are discussed in this report.

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2. DETERMINATION OF THE RIG'S DEPTH LIMIT

2.1 Determination of drilling depth limits

The Russian drilling rig ZIF-1200 MR is a stationary rig driven by synchronic electric motors. In Table 1 are the main technical characteristics of the rig. Figure 1 shows the line string up.

TABLE 1: The main characteristics of the drilling rig ZIF-1200 MR

Mast	Four-legged bolted mast, 25 m high; total gross capacity of 330,000 kN; maximum hook load of 200,000 kN
Hoisting drum	Line capacity of 120 m (for ¾" line), maximum single line pull of 50,000 kN (at the third layer of line)
Drill motor	55 kW synchronic electric motor
Mud pump	Two pumps of duplex reciprocating type, with 40 kW synchronic electric motor, each one with an output of 300 l/min at a pressure of 60 bars

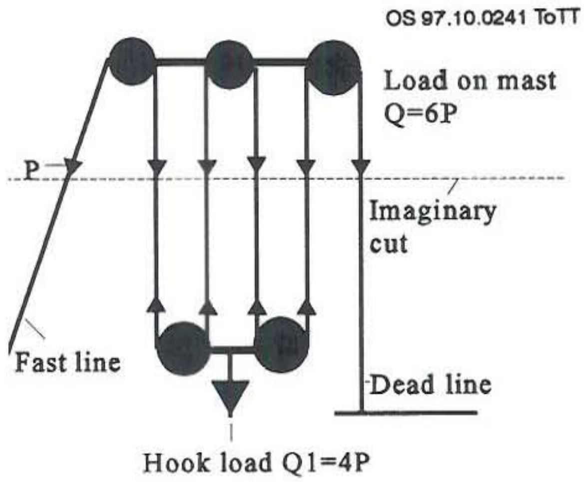

FIGURE 1: Line string up

TABLE 2: Drilling string components

String	Bit size (")	Drill collar size	Drill pipe size (")
A	6-6¼	NC 44-60	3½
B	4½-4¾	NC 31-41	2⅞
C	3⅞	NC 26-35	2⅜

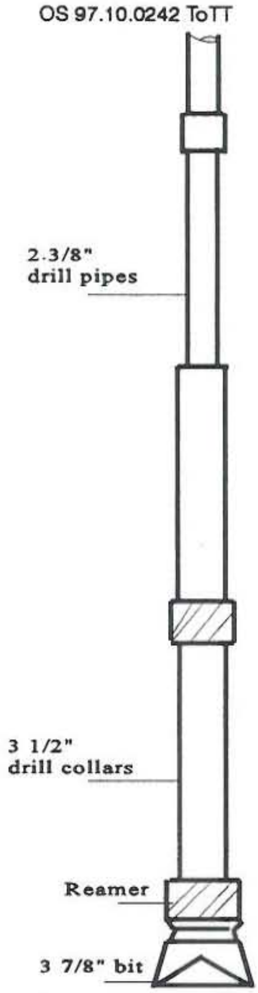

FIGURE 2: Drilling string

The drilling depth limits are determined based on the principle that the total dry weight of the entire drilling string should not exceed 75% of the hook load (L'Espoir, 1984). The slim wells will be drilled with 6¼"; 6"; 4¾"; 4½" and 3⅞" bits, the drilling strings (Figure 2) will be made up of the components shown in Table 2.

The maximum depth drilled with these strings is calculated with an average load on bit of 10,000 kN per inch of bit diameter, and the total weight of the drill collars is equal to 1.1 times the load on bit. The data and the calculation results are presented in Tables 3-6 and in diagrams in Figures 3 and 4.

TABLE 3: Rock bit characteristics

Bit size (")	Bit size (mm)	API pin shank (")	Weight (kg)	Load on bit (kN)
3⅞	98.4	2⅜	4.5	3800
4½	114.3	2⅜	5.4	4500
4¾	120.6	2⅞	7.3	4500
6	152.4	3½	13.6	6000
6¼	158.7	3½	13.6	6000
8½	215.9	4½	39.0	8500
8¾	222.2	4½	41.7	8500
11	279	6⅝	72	-

TABLE 4: Drill collar sizes

Type	Min. outer diam. (")	Min. outer diam. (mm)	Calc. weight (kg/m)	Total weight (kg)	Total length (m)
NC 26-35(2⅜ IF)	3½	88.9	39.74	4,100	103
NC 31-41(2⅞ IF)	4⅛	104.8	51.6	4,950	96
NC 44-60	6	152.4	122.9	6,600	54
NC 44-60	6	152.4	122.9	9,600	78

TABLE 5: Drill pipe sizes

Size (")	Outer diameter (mm)	Tool joint	Tool joint, outer diam. (mm)	Calc. weight (kg/m)
2⅜	60.3	NC26, IF	85.7	10.57
2⅞	73.0	NC31, IF	104.8	16.22
3½	88.9	NC38, IF	127	21.31

TABLE 6: Drilling depth limits

Bit size (mm)	Drill collar		Drill pipe		Depth limit (m)
	Outer diameter (mm)	Length (m)	Tool joint, outer diameter (mm)	Total length (m)	
98.4	89.9	88	85.7	1088	1176
114.3-120.6	104.8	96	104.8	697	793
158.7	152.4	54	127	394	448
215.9-222.2	152.4	78	127	253	331

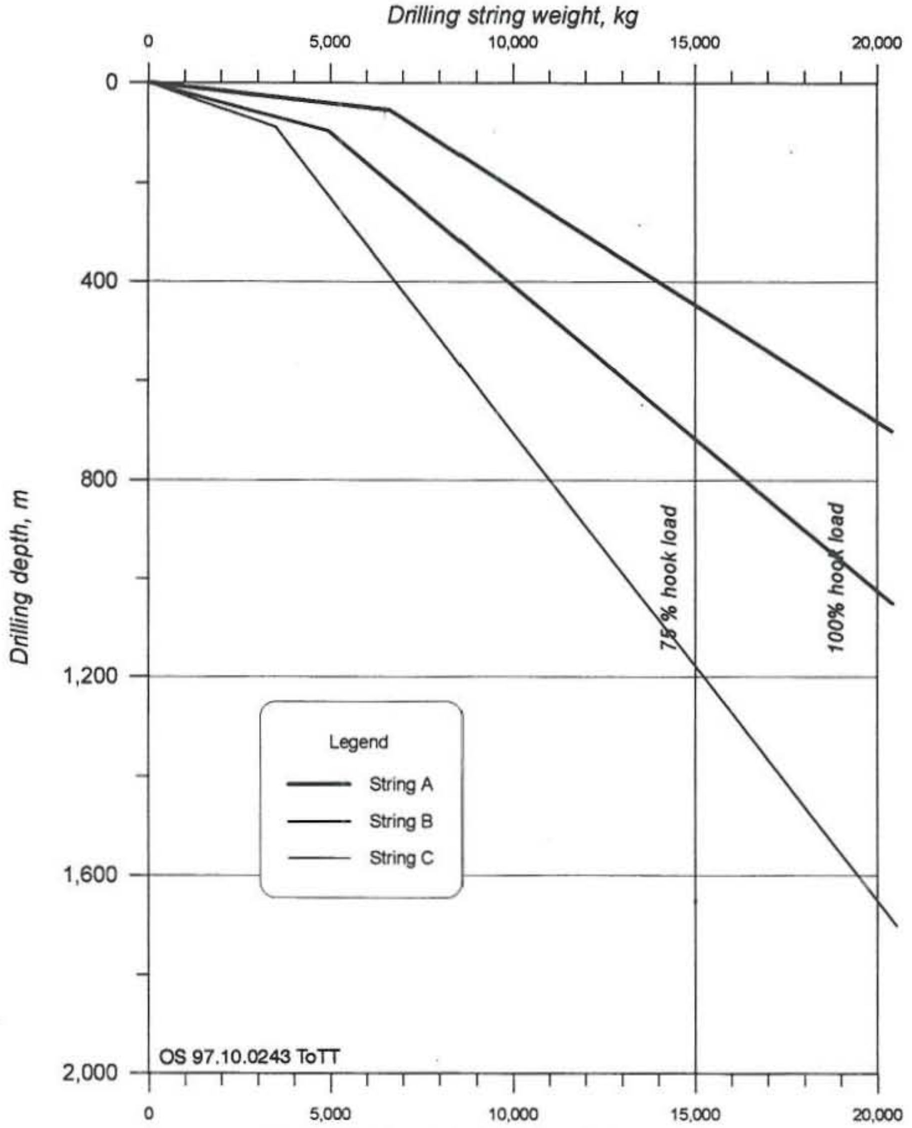

FIGURE 3: Drilling depth limits

2.2 Determination of casing depth limits

Similar to the drilling string, the total weight of the casing string should not exceed 75% of hook load capacity, Q_s. Calculation results are presented in Table 7.

TABLE 7: Casing depth limits

Casing size outer diam.		Internal diameter	Coupling outer diameter	Nominal weight	Total length limit
(")	(mm)	(mm)	(mm)	(kg/m)	(m)
5	127.0	114.1	141.3	19.36	775
5½	139.7	124.2	153.7	25.32	592
7	168.3	145.1	194.5	43.64	344
7⅝	193.7	171.8	215.9	50.19	299
9⅝	244.5	230.2	-	59.58	252

Based on the above mentioned calculation results, a typical casing diagram is proposed (Figure 5).

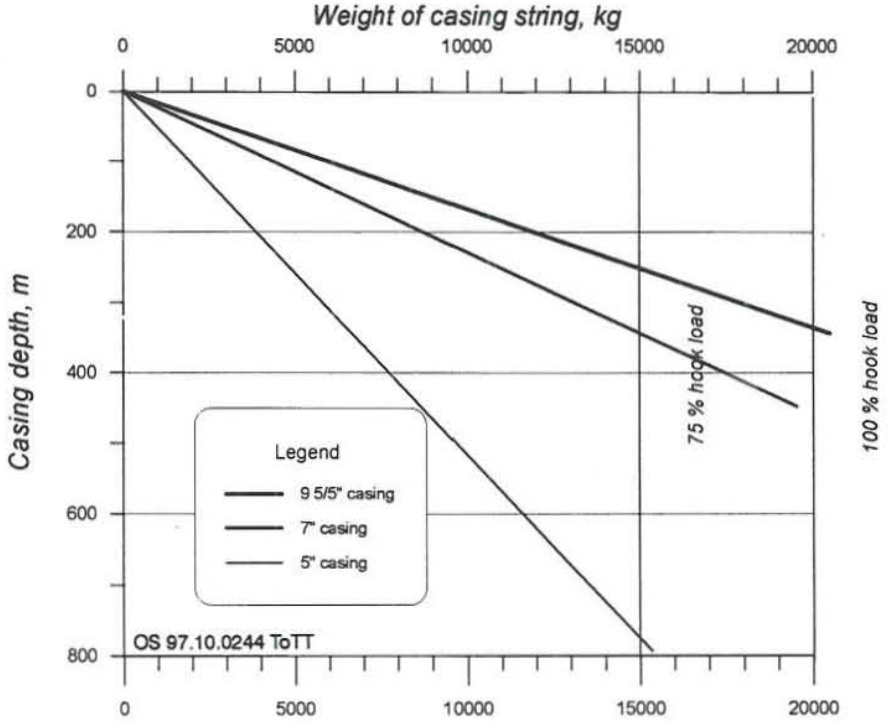

FIGURE 4: Casing depth limits

2.3 Determination of mud pump capacity required for drilling

Discharge capacity

For removing cuttings from the borehole, the pump discharge capacity must be enough to obtain an annular upflow velocity of 30-50 m/min (Preston, 1965). The required pump output (Q, l/min) is calculated based on the annular volumes and the required upflow velocity.

$$Q = (V_h - V_p)v \tag{1}$$

where V_h = Volume of the well (l/m);
V_p = Volume of the drill pipe (l/m);
v = Annular velocity (m/min).

For drilling of the 6" hole with a 2⅞" drill pipe, the minimum output of pump needed to obtain the annular velocities of 30 and 50 m/min are 420 and 700 l/min.

Pressure

The pump pressure rating must be more than 1.5 times the total pressure losses. These pressure losses are comprised of

$$p = p1 + p2 + p3 + p4 \tag{2}$$

where $p1$ = Losses through surface equipment;
$p2$ = Losses through drill pipe and drill collar bore;
$p3$ = Losses through the rock bit (ignored in the case presented here);
$p4$ = Losses between the outer diameter of the drill pipe and drill collar, and the wall of hole.

For this case (with the drill string as shown in Figure 2 and with circulation rate of 250 l/min), the above mentioned losses are determined as follows (diagrams from Gabolde and Nguyen, 1991, pp. 290-300):

$$p = 1.5 + 13.3 + 1.7 = \mathbf{16.5\ bar}$$

The pressure losses are proportional to the square of circulation rate. If the circulation rate is raised to 400 l/min the losses will increase 2.6 times (to 42 bar).

Pumping power

The engine power, P_e (kW) required to produce p and Q is calculated by the following formula:

$$P_e = \frac{pQ}{60000\, f_1\, f_2} \qquad (3)$$

where

p = Discharge pressure (p = 6000 kPa);
Q = Flowrate (Q = 300 l/min);
f_1 = Mechanical efficiency of pump (0.85);
f_2 = Compound efficiency (0.95).

This gives

P_e = 6,000 x 300 / 60,000 x 0.85 x 0.95 = **37 kW**

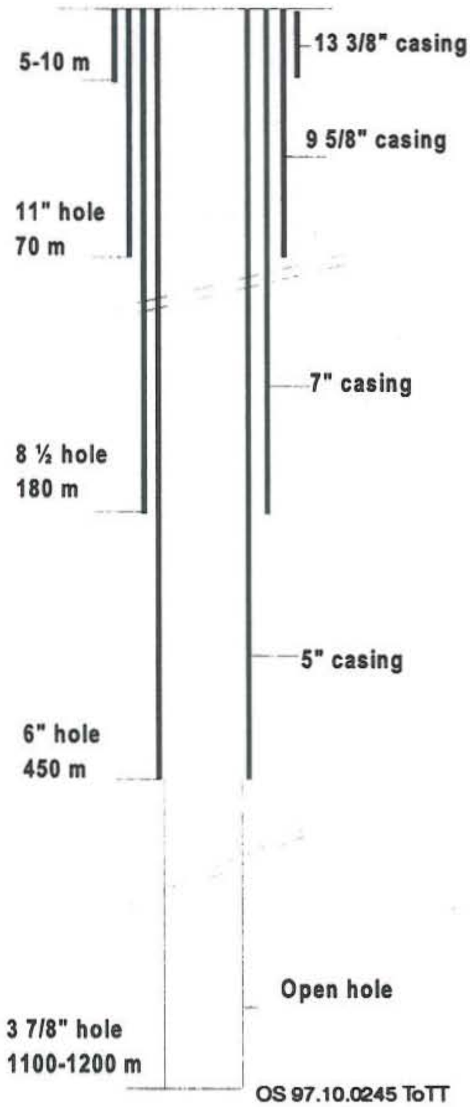

FIGURE 5: Typical casing programme

3. CASING PROGRAMME DESIGN

3.1 The importance of casing programme design

The casing design ensures longer life of the well and a successful drilling activity. The casing programme is designed to satisfy the safety and economic requirements. The main consideration in designing a casing programme for high-temperature geothermal production wells is to have sufficient strength to resist all tensile, compressive, collapse and bursting forces to which the casing may be subjected.

- The conductor casing is set to prevent caving around the mouth of the well and conduct drilling fluid to a sufficient height.
- Surface casing is set to protect fresh water zones, to prevent cave-in of near-surface formations and for installation of blowout preventers.
- The anchor casing is set to prevent caving of the well during drilling and to anchor the blowout preventer and the wellhead equipment (master valve).
- The production casing is set to isolate the upper aquifers to protect the prospective producing formations, to provide a means of controlling blow-out and to provide a transmission line for geothermal mass.

In comparison with production wells the slim wells have a similar casing programme but of smaller casing sizes.

3.2 Determination of minimum casing depth

The minimum safety casing depth is determined by the pressure and the temperature expected in the well. For design of high-temperature exploration wells, it is frequently assumed that the temperature and the pressure at depths follow the boiling point curve. This is the "worst possible case". Actual temperature and pressure conditions or estimates thereof should be used where available.

The maximum expected pressure in the well is obtained by the method given by Karlsson (1978). When a flowing well is shut off, the pressure profile in the well is given by

$$\frac{dp}{dz} = g\rho_m \tag{4}$$

where

p	= Pressure;
z	= Depth;
g	= Acceleration of gravity;
ρ_m	= Steam-water mixture density.

The minimum casing depth is determined by setting the overburden pressure at casing depth, p_{ov}, equal to the corresponding pressure in the well, p_w

$$p_{ov} = \rho_f g z = p_w \tag{5}$$

where

z	= Minimum casing depth;
ρ_f	= Density of formation (assumed ρ_f = 2000 kg/m^3).

The casing minimum depths are determined by the diagram of pressure variation in a shut-in-well (Figure 6) and are as follows:

- The minimum depth of production casing of a 1,200 m deep well is 350 m; assume that the casing depth is defined at 450 m (depends on the actual formation conditions).
- The minimum depth of the anchor casing is 170 m; assume the anchor casing depth to be 180 m.
- Surface casing depth is 70 m.

The casing depths can be selected by the diagram shown in Figure 7 (New Zealand Standard, 1991).

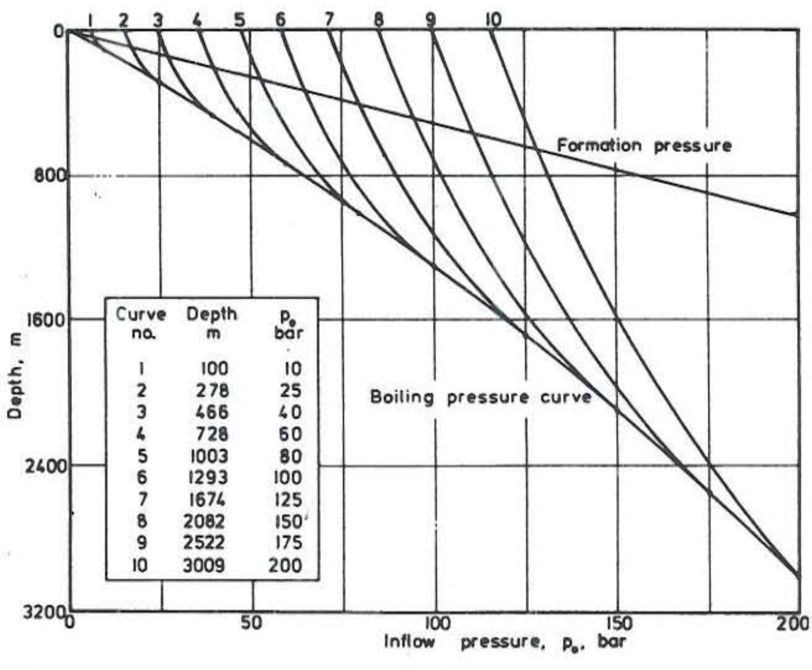

FIGURE 6: Pressure profile in shut-in wells (Karlsson, 1978)

3.3 Casing design calculations

During installation and operation, the geothermal well casings are subjected to significant conditions affecting their stresses. Some of these conditions are discussed below.

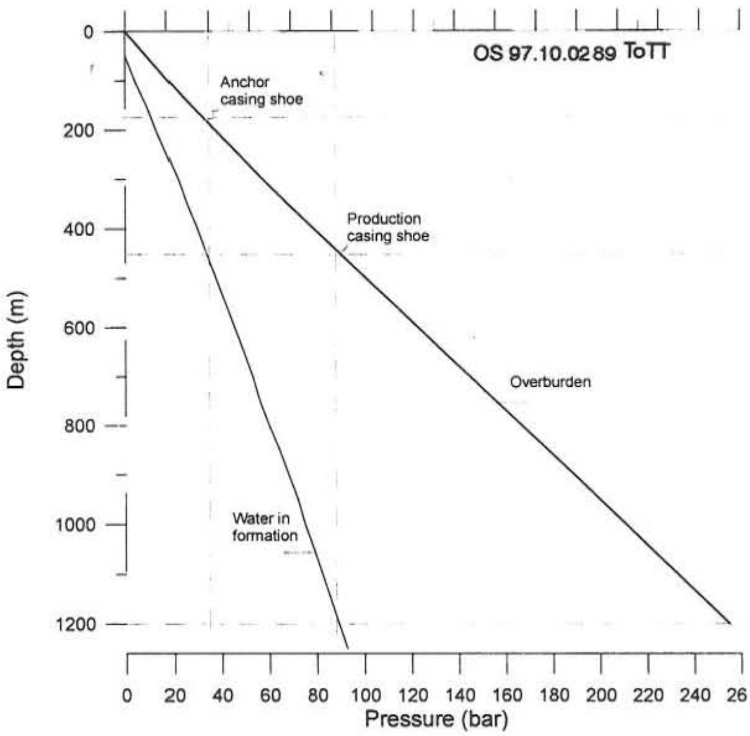

FIGURE 7: Casing depth selection

Stress caused by internal pressure

The internal pressure causes tangential and radial stress in the pipe wall. According to the ASME code (1974) the analysis is based on the average values of these stresses:

$$\sigma_1 = \frac{pD_i}{2t_{min}}; \quad \sigma_2 = 0.5p \qquad (6)$$

where

p = Internal pressure;
D_i = Internal diameter;
t_{min} = Minimum casing wall thickness.

The stress intensity, S_p, is defined as

$$S_p = (\frac{D_i}{t_{min}} + 1)\frac{p}{2} \qquad (7)$$

The internal pressure reaches the highest level when a blow out well is shut off. Assuming that temperature and pressure in the well correspond to boiling condition, the well pressure at a depth of 450 m (casing shoe) in a 1200 m shut-off-well can be defined by diagram (Figure 6). It is about 60 bar. The minimum casing wall thickness is 6 mm. The internal diameter of the production casing is 114.1 mm. Hence, the stress intensity becomes

S_p = (114.1/6 + 1) x 60/2 = **49kg/cm²**

Stress caused by external pressure

During the casing cementing operation, the maximum differential external pressure occurs near the bottom when the annulus is filled with dense cement slurry and the inside is filled with water. This pressure P_e (MPa) is defined as

$$P_e = Lg(G_c - G_w)\times 10^{-3} \qquad (8)$$

where L = Depth below liquid level (for production casing, L = 450 m);
g = Acceleration due to gravity (g = 9.81 m/s²);
G_c = Cement slurry density (G_c = 1.8 kg/l);
G_w = Water density (for cold water, G_w = 1 kg/l).

This gives

$$P_e = 450 \times 9.81 \times (1.8 - 1) \times 10^{-3} = \mathbf{3.53\ MPa} \text{ or } \mathbf{35.3\ bar}$$

The casing collapse strength must be higher than 1.2 P_e.

Effect of temperature

The axial thermal stress caused by heating a pipe which is not free to expand is given by the expression:

$$\sigma = E\alpha\Delta T \tag{9}$$

where

- E = Elasticity modulus of steel, which is $2\text{x}10^5$ N/mm^2;
- α = Thermal expansion coefficient of steel, taken as $1.2\text{x}10^{-5}$ m/m.°C;
- ΔT = Temperature rise from initial temperature of pipe, which is taken as 40°C.

This gives

$$\sigma = 2\text{x}10^5 \times 1.2\text{x}10^{-5} \times 160°\text{C} = \mathbf{384\ N/mm^2} \text{ or } \mathbf{3840\ kg/cm^2}$$

If the temperature through the pipe wall is assumed to be constant, the maximum allowed temperature as prescribed by the Code is given in Table 8 for the standard API casing (Karlsson, 1978).

TABLE 8: Maximum allowable temperature for API casing based on axial expansion

Casing grade	H-40	J-55	C-76	N-80	P-110
Temperature (°C)	222	270	320	340	340

In the case of exploration wells with expected temperatures of about 200°C, casings of lower grade can be used.

Casing selection

Based on the results of the design calculation given above, the casings are selected as follows:

- The production casing string should consist of API 5" casing of J55 grade, with a thickness of 5.59 mm (17.1 kg/m).
- The anchor casing string should consists of API 7" casings of H40 or J55 grade, with a thickness of 6.91 mm, (28.8 kg/m).
- The surface casings are of 9⅝" pipes of H40 grade, with thickness of 7.92 mm, without couplings. (The pipe will be welded together during inserting into the borehole). The conductor is 13⅜" pipe of H40 grade, without couplings.

4. CEMENTING

Cementing of the casing is a crucial operation. Failure of proper placement of the cement slurry usually results in expensive remedial work or even loss of the well. The successful cementing of a geothermal well requires careful planning for the job. The higher the temperature the more crucial each aspect is of the planning and implementing a cement job (Shryock and Smith, 1985).

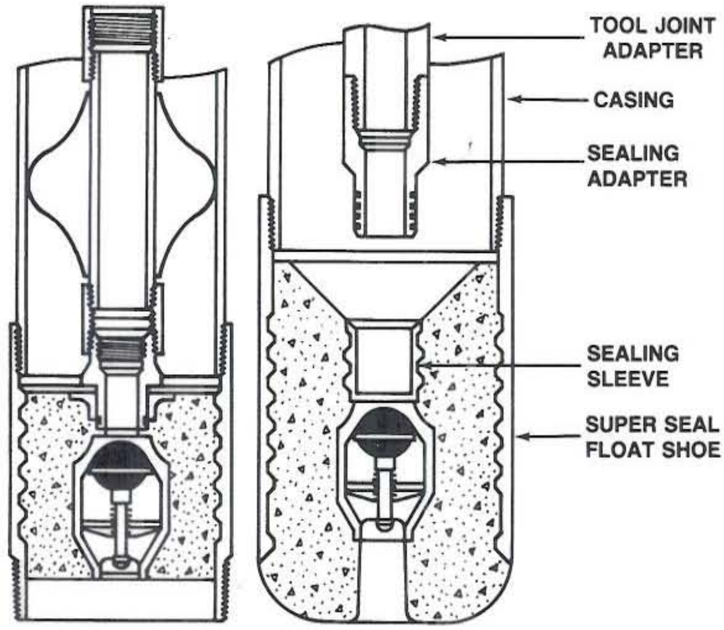

FIGURE 8: Stab-in cementing equipment (Shryock and Smith, 1985

4.1 Casing cementing methods

There are three primary cementing methods; the conventional two plug, the inner string method (stab-in method) and the stage method.

The stab-in cementing method has many advantages, the cement is pumped down through the drill pipe, reducing pumping time, no plug is required, high accuracy of displacement, mixing cement can be continued until cement slurry returns and terminated at any time, cementing pressure is confined to the drill pipe (Figure 8).

4.2 Cementing materials

The cementing composition must be selected to fit the well conditions and to satisfy the requirements of the cementing job. According to the American Society for Testing Materials (ASTM), portland cement is classified into five types. For general use, cement of type 1 should be selected. The first property of cement slurry that should be considered is the pumping time or thickening time. The cement slurry must remain fluid for a sufficient length of time to allow it to be pumped down the string and up the annular space behind the pipe. Secondly, the cement must set in a reasonable period of time and should develop sufficient strength to allow continuation of normal drilling operation. The minimum strength required to support the pipe is about 100 psi (7 kg/cm^2) compressive strength.

To obtain the cementing mixture of required properties, various kinds of cementing additives are used. These additives include accelerators (calcium chloride, sodium chloride, sodium silicate, etc.), dispersants (organic acid, organic polymer, etc.), heavyweight additives (barite, hematite, etc.), lightweight additives (perlite, bentonite, diatomite, glass microspheres, etc.).

The following list gives the cementing composition popularly used in Iceland.

API class G cement:	100 kg
Silica flour	35-40 kg
Perlite	4-5 kg
Bentonite	2 kg
Retarder	0.4-0.5 kg

In this project the slurry of class A cement will be used for cementing all casings.

4.3 Cementing calculations

Determination of quantity of cementing materials

The cementing material requirements are calculated on the basis of the cemented volume (annular volume). A more accurate annular volume calculation is based on the calliper log data. In the case of a lack of such data, double the theoretical volume is used (100% excess), see Table 9.

TABLE 9: Quantity of cement and water for cementing slurry

Hole size (")	Casing outer diameter (")	Annular volume (l/m)	Length (m)	Total volume (l)*	Cement quantity (kg)**	Water volume (l)
13½	11¾	22.19	10	444	543	272
11	9⅝	14.37	70	2,012	2,460	1,231
8½	7	11.73	170	3,988	4,878	2,441
6	5	5.55	450	4,995	6,109	3,057
Total				11,439	13,990	7,001

* The approximate cementing slurry volume is defined by two times the theoretical annular volume, taking into account the slurry loss during cementing.
** The cement slurry density is 1.83 g/cm^3, the cement density is 3.15 g/cm^3

Cementing pressure
The pump discharge pressure will reach the highest level at the end of pumping the water following the cement slurry. The pressure represents the total amount of different pressure losses

$$p = p_1 + p_2 + \Delta p + p_3 \tag{10}$$

where

- p_1 = Losses through surface equipment;
- p_2 = Losses through drill pipe and drill collar;
- Δp = Differential hydrostatic pressure between the column of cement slurry and the column of water;
- p_3 = Pressure losses in the annular space between the casing and borehole.

These losses are defined by monogram, assuming a pumping rate of 300 l/min as:

$$p = 1.5 + 6.5 + 38 + 5 = \mathbf{51\ bar}$$

4.4 Measures to improve cementing quality

The success of a cementing operation depends on completely filling the annular space between the casing and the well with cement slurry of most suitable properties. The successful cementing of a geothermal well requires careful planning for the job, selection of down-hole equipment, pre-testing of cement slurry and competent implementation of cementing operations. The higher the temperature, the more crucial each aspect of planning and implementing is for a successful cement job. Prior to performing the cementing operations, information about depth, hole and pipe size, bottom static temperature, drilling mud properties and hole condition (the wick and water loss zones) is needed. The following techniques should be kept in mind:

- The well must be cleaned and cooled down before cementing.
- The casing needs to be equipped with centralizers to assure adequate centralizing of the casing and removal of mud cake from the walls.
- Cementing slurry must be pumped in a state of turbulence to increase the percentage of mud.

5. DRILLING FLUID PROGRAMME AND CIRCULATION SYSTEM

5.1 Drilling fluid programme

The drilling fluid is a major factor in the success of the drilling program. The principal functions of the drilling fluid are:

- To remove the cuttings from the bottom of the hole and carry them to the surface.
- To cool and lubricate the drilling string and bit.
- To exert sufficient hydraulic pressure to control formation pressures.
- To support and protect the walls of the hole.
- To keep the cuttings in suspension when circulation is temporarily stopped.

The performance of these functions depends upon various properties of the mud. The mud properties are measured by tests. Tests commonly made are density, viscosity, gel strength, filtration, sand content and pH. The main functions of mud and their related properties are presented in Table 10.

TABLE 10: Main functions of drilling mud

Function	Property to control
Cuttings transport	Viscosity
Pressure control	Density
Hole protection	Filtration, gel strength
Lubrication	Co-efficient of friction

Commonly used drilling fluid systems are water only, drilling mud, air or foam, aerated water or mud.

The selection of mud program is based upon several factors such as type of formation to be drilled, characteristics of aquifers and reservoir, and materials available for mixing the mud. The expected collapse zones, water loss zones, and bottom well temperatures should be given critical attention. The high temperature contributes to the degradation of some mud products, speeds up some of the chemical reaction and causes changes in mud behaviour.

In this project, mud will be used to drill to the depth of production casing (about 450 m). In this section of the well the formations are loose with a tendency to cave in, and there are some water loss zones. In addition, the hole size of this section is relatively large, the up flow velocity is low; it is, thus, necessary to use a drilling fluid with high cutting lifting capacity. Typical properties of mud for geothermal drilling are shown in Table 11 (Polk, 1985):

TABLE 11: Typical properties of mud for geothermal drilling

Mud density (lb/gal)	9.0-9.4
Funnel viscosity (s/qt.)	38-42
Plastic viscosity (cp)	5-10
10-min gel strength ((lb/100 sqft.)	5-10
API fluid loss (cc)	10-20
pH	9-10

After inserting the production casing, water or low solid content mud will be used to complete the borehole in order to limit the sealing effect of the fluid.

5.2 Circulation system

The drilling fluid circulation system components are represented in Figure 9. The mud system is equipped with a shale-shaker or cyclone for mud cleaning and sample collection. The mud tank is usually equipped with a hopper and jets for the mixing of mud and additives.

The designed well's volume is about 10 m³; the mud tank volume should be about 15-20 m³.

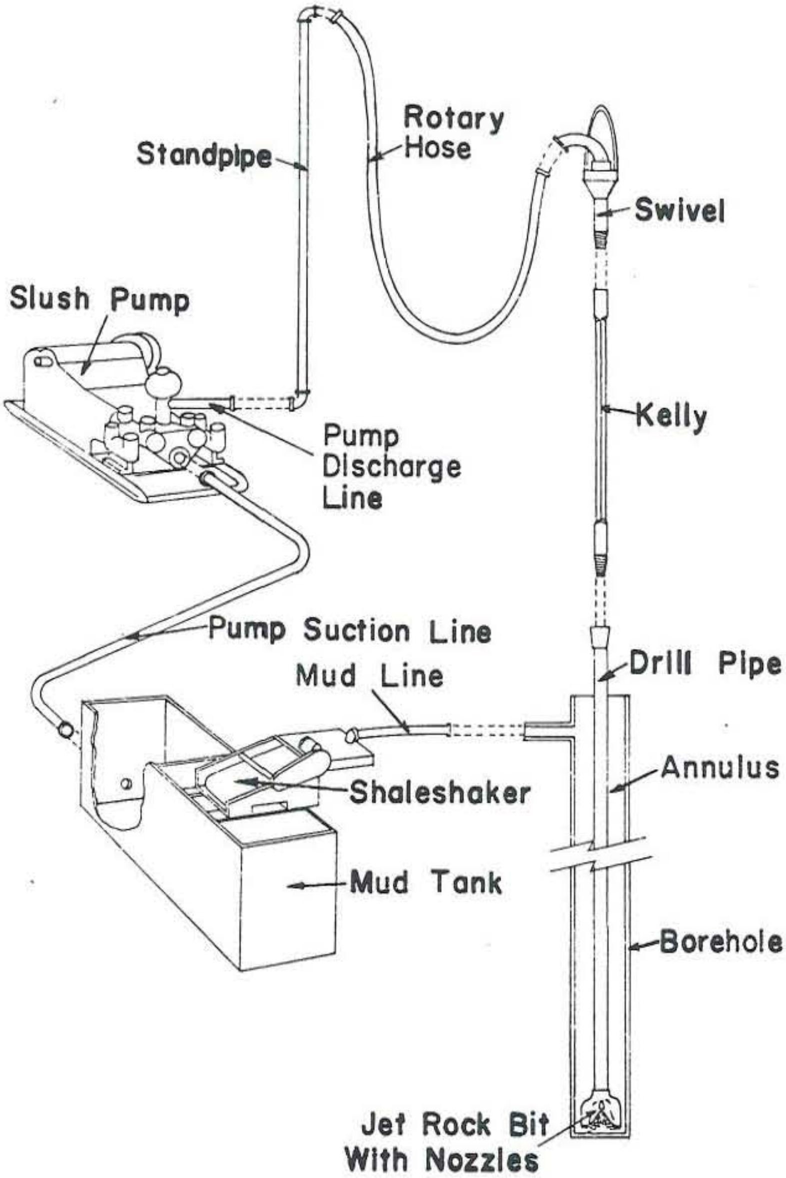

FIGURE 9: Drilling fluid circulation system components (IADC, 1980)

6. WELLHEAD EQUIPMENT AND BLOW OUT PREVENTION MEASURES

Geothermal blowouts are caused by an unbalance of pressure which permits formation fluids to enter the borehole. The imbalance of pressure may result from one or more of the following situations:

1. Formation pressure gradient is higher than drilling fluid pressure gradient;
2. Failure to keep hole adequately filled with drilling fluid;
3. Reduction of hydrostatic pressure by loss circulation or by "swabbing".

Blowout can cause losses of life, lost well, and serious damage to the drill rig. The blowout can be controlled by installation of properly rated blowout preventers (BOP) and use of appropriate drilling fluid.

6.1 Selection of blowout preventer

The blowout preventer (BOP) is selected on the basis of expected wellhead pressure. This pressure can be defined as the maximum anticipated surface pressure to which the equipment may be exposed.

In this project, the anticipated maximum wellhead pressure is about 55 bar (assuming the saturated condition in a shut-in well). A simple blowout preventer stack can be applied (Figure 10). The stack components consist of two ram preventers (or one double ram preventer) and a drilling spool with two outlet connections for choke and kill lines. The preventer should be of the hydraulic operation type. An annular preventer is also used that can close around any object.

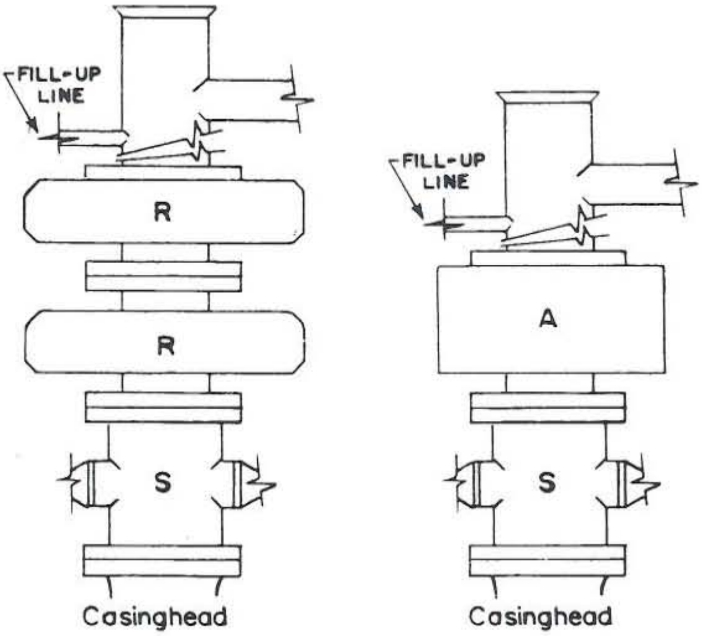

FIGURE 10: IADC class 2 blowout preventer stacks (IADC, 1980)

6.2 Measures to prevent blowout

The following items should receive special attention to prevent blowouts in geothermal wells:

- Keep the well cool by flushing, especially after long drilling break time.
- Keep the well full with drilling fluid.
- Limit the pulling out velocity of the drilling string to decrease "swabbing effect".
- Apply a sensible drilling fluid programme, using heavyweight additives for drilling in formations with high hydrostatic pressure.
- Seal off circulation loss zones in potentially dangerous zones.

7. DRILLING PROGRAMME

The upper part of the borehole consists of soft and loose formations, so the spudding hole and 11" hole are drilled with milled steel tooth bits. The load applied on bit is usually smaller than normal load on the bit because it is impossible to install the required number of drill collars. The mud flowrate is at maximum for the pumps (500-600 l/min). The estimated penetration rate is about 10-20 m/day. This hole could also be drilled with a cable tool rig.

The 8½" and 6" holes are drilled with steel tooth bits or tungsten carbide insert bits (IADC 2-1-1, 2-2-1 and 5-1-1, 5-2-1 etc), with bentonite mud. The circulation loss zones are to be sealed with a loss of circulation material (sawdust, cotton seed, etc) and cementing. The estimated penetration rate is about 25-20 m/day.

After installation of 5" casing, drilling is continued down to 1100-1200 m with 3⅞" bits. At selected intervals, the hole is drilled with a core barrel to obtain cores for geological studies (about 3 m of core per 50 m of borehole). The estimated penetration rate is about 15 m/day. Water or low solid content fluids are used to drill this section of the hole to avoid plugging of production zones.

The drilling progress plot presented in Figure 11 is constructed based on the estimation of drilling penetration rates and casing time.

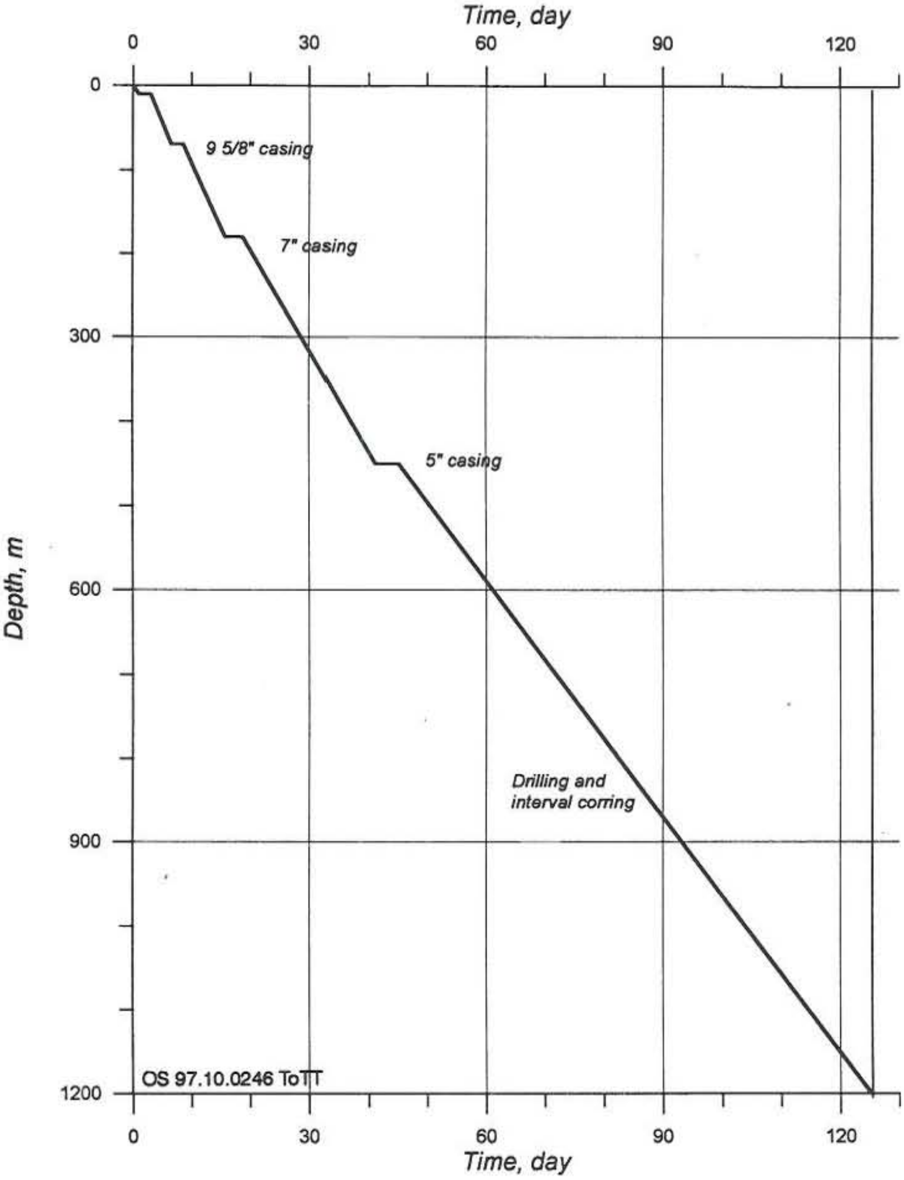

FIGURE 11: An estimated drilling progress plot for a slim hole

8. COMPLETING THE WELL

The completion operations are done to determine as accurately as possible the productivity of the well. Generally, there is a loss of circulation during drilling, and a certain hydrostatic level is established to satisfy equilibrium between the weight of the liquid column in the well and the reservoir pressure. As long as water is being pumped into the well, it prevents the formation of steam. Thus, when it is necessary to put the well into production, the water pumping must be stopped. The effect of temperature rise together with the emulsion caused by the presence of gas may start the well flowing. When the rising temperature reaches the corresponding saturation pressure, the vaporization conditions can trigger a blowout, with violent expulsion of a water column from the well. On the other hand, when the action of gas and temperature is not sufficient to cause the well to flow, various techniques can be applied to bring it about.

Methods to bring about a well blow out

The followings methods are commonly used to put a well into production (Giovannoni, 1970):

- Taking water from the well by means of a plunger piston. The piston inserted in the tubing is powered by cable of sand reel.
- Emulsifying foaming agents as well as a "gas lift" system by an air compressor are used to decrease the density of the water column in the well and to expel it from the well.
- Decompression method: The well is closed so that it will be subjected to pressure buildup by the effect of pumping air into the well with an air compressor. This pushes the colder water down into the hole where it will be heated by the hotter rock. When a certain pressure level has been reached, the well is allowed to stand under pressure for 1-2 days and then opened suddenly, causing sudden decompression at the water level causing boiling in the well and expulsion of the water to the surface.

Killing a well

A well in production can be killed by closing the master valve and pumping water into it through the kill line (Figure 12).

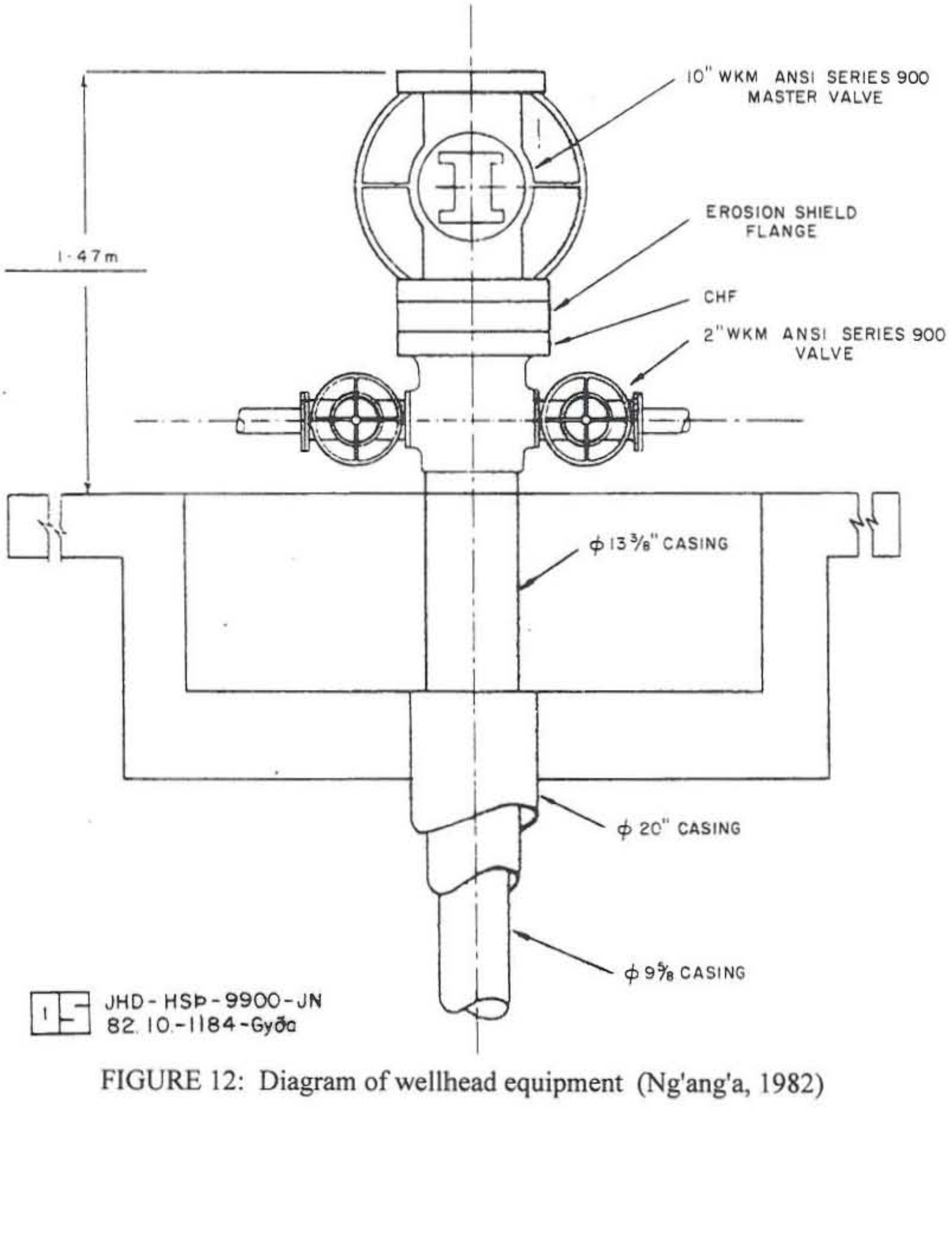

FIGURE 12: Diagram of wellhead equipment (Ng'ang'a, 1982)

9. ESTIMATED DRILLING COSTS

The estimated costs of the designed slim hole are presented in Table 12. The calculated costs are based on approximate rates in Vietnam.

TABLE 12: Estimated drilling costs in Vietnam, 1200 m deep well

Item	Quantity	Rate	Amount (USD)	% of total
Rig charge	130 days	40 USD/day	5,200	3.3
Down-hole equipment charge	130 days	20 USD/day	2,600	1.6
Fuel and lubricant	120 days	78 USD/day	9,360	5.9
Materials and instruments	1200 m	35 USD/m	42,000	26.5
Casing and cementing	710 m	5.5 USD/m	3,905	2.5
Transportation	30,000 ton km	1 USD/ton km	30,000	18.9
Labour cost	130 days	300 USD/day	39,000	24.6
Sub total			132,065	83.3
Indirect cost		20% subtotal	26,413	16.7
Total cost			158,478	100
Cost per metre (USD/m)			**132**	

10. CONCLUSIONS

1. The drilling rig ZIF-1200MR can be used to drill a geothermal exploration well up to a depth of 1200 m. The top section of the hole (13⅜" and 11" casings) can be drilled with cable tool rig if the formations consist of hard rocks or loose rocks with components like coble, gravel, etc.

2. Because of the limited capacity of the mud pumps, the upper section of the hole (5" casing) should be drilled with mud with high cutting carrying capacity. After installation of the production casing, drilling should be continued with water or low solid drilling fluid.

3. For the exploration hole and for medium-enthalpy geothermal water, the casings should be of low grade steel (API H40, K55, or J55).

4. Many things in the above plan are defined as typical examples. They should be modified to meet the actual conditions.

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