

The Philippines' First Geothermal Relief Well

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ABSTRACT

Philippine National Oil Company Energy Development Corporation (PNOC-EDC) drilled Well 5R-13D, the first geothermal relief well in the Philippines. Well 5R-13D is probably the only relief well in the geothermal industry drilled using a single shot directional survey system. This well was designed to relieve the pressure of the uncompleted Well 5R-12D that blew out and toppled down the drilling rig on top of it after encountering a shallow pressurized two-phase zone at 450m estimated at about 4 MPa. Early completion of Well 5R-13D was very important to control the environmental, social and economic impact brought about by the continuous discharge. For a time, Well 5R-12D discharge contains part of the re-injected brine from the adjacent re-injection well.

In spite of the various drilling constraints like the proximity of the drilling pad against the main geologic fault prompting a revised welltrack, the non-utilization of MWD tools and time constraints, Well 5R-13D successfully intersected and quenched Well 5R-12D. As an added bonus, the completion test results suggest that this well can even be utilized as a production well. To fully seal off the formerly discharging Well 5R-12D at surface, a series of cement plugs were set through its cut-off casing.

1. INTRODUCTION

Relief well drilling is a method of blowout control that requires specialized drilling and directional skills, well-planned blowout kill methods, and a large pumping and killing system. The main objective is to pump control fluids into the bottom of a blowing well (Adams and Thompson, 1989).

Well 5R-13D is the first geothermal relief well in the Philippines drilled by PNOC-EDC. It was designed to intersect and to quench the discharging Well 5R-12D which blew out and toppled down the drilling rig on top of it after encountering a shallow pressurized two-phase zone at 450m MD with a pressure estimated at about 4 MPa. The success of this relief well drilling operation is of utmost importance to minimize the environmental, social and economic impact brought about by the continuous discharge.

Well 5R-13D is located 170m north and 31m higher in elevation from the discharging Well 5R-12D. Well 5R-13D was drilled to a total measured depth of 530m last September 17, 2003 to November 2, 2003 using the PNOC-EDC owned Romanian F200 drilling rig.

2. BACKGROUND

2.1 Well 5R-12D

Well 5R-12D was designed as a re-injection well to augment the injection capacity shortfall in the Malitbog sector (Ogena, 2003). It is located at 5R pad where two

re-injection wells had been drilled 21 years ago and accepting a total of 172 kg/sec of brine.

The well was drilled as programmed last July 19, 2003 to August 2, 2003 with the 20" casing shoe set at 106m with good cement returns. The 17-1/2" hole was drilled without problems down to 427m where the first partial loss circulation (PLC) was encountered. Two cement plugs were set to contain the total loss circulation (TLC) at 436m - 441m. On and off TLC was encountered at 441m - 447m and the well was eventually drilled blind with mud down to 450m. At this depth, the string was pulled back to the 20" casing shoe in order to build up mud volume and drill the remaining part of the hole to 455m for the total depth (TD) of casing. However, upon reaching the shoe, the well kicked. The blowout preventer was closed and fresh water was pumped through the string at 14 - 18 bpm. After 30 minutes, steam discharges came out to the surface most notably in between the substructure and shale shaker tank area. It further intensified spewing mud, soil and rock particles. In less than eight hours, the drilling mast slowly leaned and dropped towards the shale shaker tank and into the Malitbog River (Figure 1). The substructure was engulfed inside the crater-like scour measuring 12.5m x 10m at about 7.5m deep.



Figure 1: View of the blowing Well 5R-12D taken from the relief well pad

2.2 Blowout Effects

2.2.1 Environmental Effects

Well 5R-12D is located near the Malitbog River and is within an environment with vegetation and wildlife habitation. It is also located about 29m away from Well 5R-4, a re-injection well, with a casing break within 369 - 563m. It was later assessed that part of the re-injected brine at Well 5R-4 channeled to Well 5R-12D through this casing break. This was evidenced by the changing fluid chemistry of Well 5R-12D, like the increasing chloride and boron content among others.

The temporary effect of the hot and noisy discharge includes withering of the nearby vegetation and consequently affecting its wildlife routine. The change in river fluid chemistry affected the vegetation downstream. The well eventually dried up after shutting off the adjacent re-injection well and the boron impact on the Malitbog River was practically nil.

2.2.2 Social Effects

Multi-sectoral groups in neighboring communities were monitoring the cause and effect of the blowout incident. To assure these groups that the company is in control on any hazardous threats in our geothermal operation, including this unexpected blowout condition, the direction is to address this problem the soonest possible time.

2.2.3 Economic Effects

Because of its adverse effect in fluid chemistry on the discharging well, the re-injection Well 5R-4 was cut-out from the system. This minimized the environmental effect and allowed a favorable working environment on the relief well pad, particularly with the reduction in chloride content of the discharge.

However, the absence of this re-injection well to accommodate the separated brine from the Malitbog Power Plant necessitates reduction in production output. The reduction in power plant output was estimated to be about 40 MWe per day.

3. RELIEF WELL DECISION

Drilling a relief well was assessed to be the most suitable solution to the blowout problem based on the following considerations:

- The safest option since no personnel is required for direct intervention at the wellhead of the discharging well
- Direct intercept and re-entry is considered feasible with the available technology
- Dynamic kill can be initiated immediately if intercept causes surface flow
- Probability of success is acceptably high

4. RELIEF WELL CONSIDERATIONS

4.1 Pad Location

Well 5R-12D is located along the Malitbog river on one side and the foot of the mountain on the other. To save time and cost in pad preparation, the only logical location for the relief well is the area above 5R-12D. This is about 170m North and 31m higher in elevation (Figure 2). This pad however is a landslide fill and is about 35m west from the Bayabas Fault, believed to be the main conduit of the shallow pressure zone. A total of eight grout holes were drilled to 30m and about 11,000 sacks cement were used to consolidate the area.



Figure 2: Relief Well 5R-13D, located left and above Well 5R-12D

4.2 Well Track

The original well design program was to kick-off at 120m at a build-up rate of 4.8°/30m for a drift angle of 39° and an azimuth of 202°. Concerns however were raised since the Bayabas Fault, believed to be the major conduit of the shallow pressurized zone, is only 35m west of the relief well 5R-13D at surface. It is dipping towards the welltrack and runs parallel with the welltrack azimuth (Figure 3). At the programmed anchor casing shoe (ACS) depth of 330m TVD, the Bayabas fault is close at 7m from the welltrack. For safety consideration and provision for any welltrack deviation during actual drilling, the welltrack direction was revised towards the left at an azimuth of 193° up to the ACS depth to have a safe distance of about 17m from the Bayabas Fault. After setting the anchor casing, the well was turned back to the right at an azimuth of 210° to hit the target at bottom.

The well design for Well 5R-13D aims to hit Well 5R-12D at a vertical depth of 458m, equivalent to 427m at 5R-12D where the first loss circulation was encountered. This was believed to be the top of the permeable shallow reservoir.

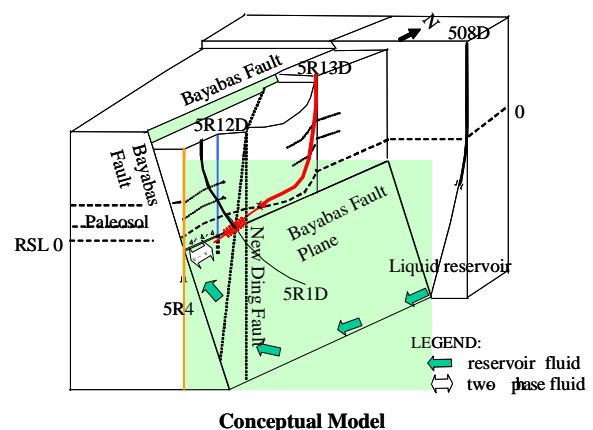


Figure 3: A conceptual model showing the Bayabas Fault dipping towards the 5R-13D welltrack (Palma, 2003)

4.3 Fault Intercepts

Geological prognosis showed that aside from the Bayabas fault, another Fault called the New Ding Fault is expected to overlap with the Bayabas Fault at bottom. It was also

assessed that a lithological contact exists at bottom, another possible source of loss circulation (Ogena, 2003).

The problem with these multiple loss circulation sources is that it would reduce the fluid flow to the blowing well reducing the effectivity of the quenching operation.

4.4 Directional Control

The complexity in executing the earlier mentioned redesigned welltrack was made more pronounced by the non-utilization of the Measurement-While-Drilling (MWD) tool due to the delay on its availability and the corresponding cost consideration. This relief well will be drilled using the single shot directional survey. The difficulties identified include:

- Extra ordinary directional control is needed to intercept the target at the required depth. Given the revised welltrack, it generally demands a continuous build and turn operation. The program requires a dogleg severity of about $4.8^{\circ}/30\text{m}$ in the 17-1/2" hole, $5^{\circ}/30\text{m}$ in the 12-1/4" hole, $2.8^{\circ}/30\text{m}$ in the 8-1/2" hole. These are theoretically on the high side of the available bent orienting subs (BOS). Moreover, with the single shot tool, the survey depth is about 16m away from the drilled depth. This means drilling about two singles before the directional driller can see the effect of his setting.
- Difficulty in attaining the desired build up rate due to massive clayey formation in the 17-1/2" and 12-1/4" hole section.
- Accuracy in hitting the target at bottom given that only Totco surveys were conducted while drilling Well 5R-12D. The cone of uncertainty has a radius of about 7m.

4.5 Casing Design

A three-string casing set-up was implemented. The 20" surface casing was programmed at 100m prior kick-off. The 13-3/8" anchor casing was programmed at 330m TVD to ensure full containment of the projected bottomhole pressure at 4MPa. The extra 9-5/8" production casing was programmed to be set close to bottom at 410m TVD, a few meters before the prognosticated intersection of the Ding Fault. This accounts for the potential formation collapse and easy access to the shoe during tripping out in case problems arise. A set of 7-5/8" slotted liners was available if deemed necessary after containing the discharging Well 5R-12D.

4.6 Rig Equipment

There were four major rig components that were modified. First was the pumping unit. Instead of the standard two slush pump compliment, a total of four slush pumps were installed. Moreover, two BJ cementing units were on line against the standard one unit compliment. The second modification was the mud and water tanks. Three additional mud tanks with agitators, one of which is complete with mud mixing hopper, were installed. These tanks served as the holding tanks for the weighted mud. A total of four water tanks were installed, instead of the standard two tanks. Two PH tanks were also available for the BJ pumping unit. The third modification was the installation of additional rig engines to accommodate the extra pumping units, agitators and mud mixing hoppers. The fourth modification was the wellhead set-up (Figure 4). A 10"

diameter banjo box, complete with 10" discharge lines and silencer, was installed on both the 21-1/4" and 13-5/8" BOPE setup. An additional drilling spool with two side ports was also incorporated to equally divide the entry ports of pumped fluid. A wellhead pressure gauge was also installed both at the wellhead directly and near the driller's console for easy monitoring by the driller.

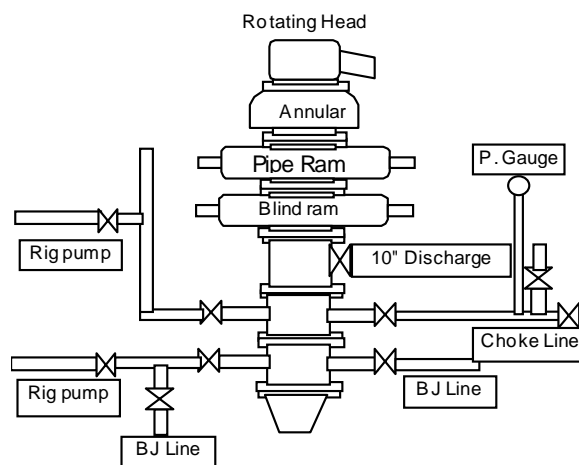


Figure 4: Diagram of the revised wellhead set-up

4.7 Kill System

A high volume kill system was designed. A minimum uninterrupted water supply of 2000 gallons per minute (gpm) was required to the rig at any given time. A reservoir pit that could accommodate 6000 barrels (bbls) of water was also available. The rig had four water tanks and the BJ cementing unit had two PH tanks for a total capacity of 880 bbls and 440 bbls respectively and were kept full at all times.

Aside from the standard mud tanks set-up filled with drilling mud, three spare mud tanks having a total capacity of 750 bbls were filled with weighted mud at 11 ppg before the start of drilling operation.

Thixotropic cement slurry at 14 ppg was specially designed for the final isolation plugging of the discharging well at bottom for quick setting.

4.8 Discharge Diffusers and Net

One of the effects of Well 5R-12D discharge was its interference with the transmission line located about 300m away. At one point, this caused the power plants to trip. To resolve this, poorboy discharge diffusers were installed to restrain the intensity of discharge (Figure 5). These are basically set of long span pipes placed on top of the discharging well. Moreover, a wide net was also installed to minimize the spread of the discharge water component to the location of the relief well.



Figure 5: View of the fabricated discharge diffuser and the net (taken when Well 5R-12D was already partially quenched)

5. RELIEF WELL PROGRAM

The general relief well drilling program was:

- Drill Well 5R-13D to intersect the blowing Well 5R-12D just above the pressurized zone
- Pump weighted mud to push the pressure back into the formation and follow it up with water to quench the well
- Cement the bottom section of the blowing well to fully contain the discharge
- With Well 5R-12D discharge fully contained, clear the pad and/or cellar from the remaining rig component and BOPE and accessories
- Assuming the fish in hole drops to bottom, set-up a longyear rig and clear to around 250m
- Plug and abandon Well 5R-12D by setting a cement plug from 250m to surface

However, due to the proximity of the Bayabas Fault with the programmed welltrack, the first objective was to ensure that the anchor casing shoe is set at the programmed depth of 330m TVD. This was to ensure that the expected bottom pressure of 4 MPa could be contained in case premature blowout is encountered.

6. ACTUAL DRILLING AND KILLING OPERATION

6.1 5R-13D Drilling Operation

Relief Well 5R-13D was spudded-in last September 17, 2003. The 20" casing was set at 94m and kick-off commenced in the 17-1/2" hole section at 120m using a 9-5/8" powerpak with 2.5° bent orienting sub (BOS). Drilling progressed to 296m but difficulty in getting the desired inclination was encountered. The welltrack however was within the desired azimuth. A 90' build up assembly was used down to 330m, still with no positive result. It was decided to cement plug and sidetrack using the then available 3.5° BOS.

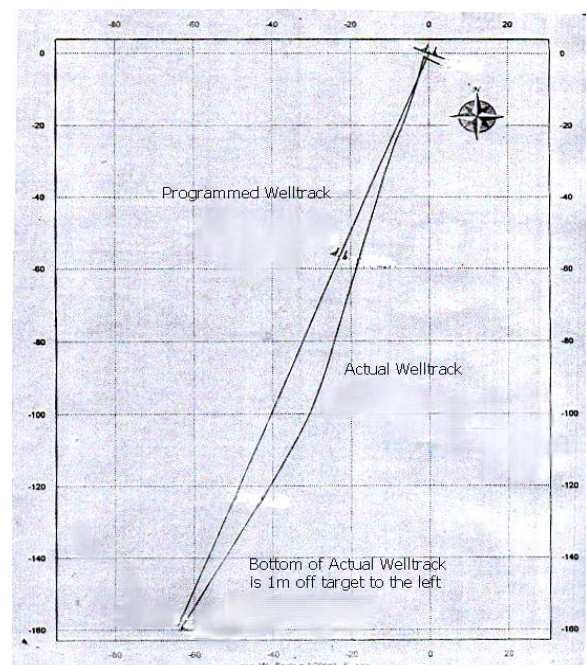
Sidetrack operation commenced at 165m and continued down to 342m, the agreed TD of the 17-1/2" hole. Drilling was slowed down by the abundant clayey formation. The drift angle was still behind program but it was decided to make it up in the 12-1/4" hole. The 13-3/8" casing was set

at 337.7m. Formation leak-off test was conducted and gave a formation gradient of 0.7696 psi / ft.

The 12-1/4" hole section was initially drilled using an 8" powerpak with 2.5° BOS down to 389m. Due to the same difficulty in getting the desired inclination, the BOS was changed to 3.5° and drilled down to the 12-1/4" hole TD at 450m. At this stage, the welltrack was within program azimuth but behind in inclination. It was assessed that the discharging well cannot be intersected at 509m MD, equivalent to the desired depth of 458m TVD where the first PLC was encountered. It was decided to intersect it at least 10m below, the section wherein massive loss circulation was encountered.

After setting the 9-5/8" casings at 446.5m, the 8-1/2" hole section was initially drilled using a 6-1/2" powerpak with 2.5° BOS down to 485m. For convenience in dealing the anticipated massive loss circulation, a 90' build up assembly was used to drill the well to TD at 530m. Total loss circulation was already encountered while reaming at 477m within the minimum intercept of the New Ding and Bayabas faults. The well was drilled blind with water at 20 bpm from 485m to 530m.

At 530m, the relief well was projected to have successfully intersected the discharging well within its welltrack at an equivalent TVD of 470m (12m below the original program). This was evidenced by the reduction in the chloride content and the change to muddy color of the discharged fluid as influenced by the mud pumped from the relief well. The last survey was at 507m at a drift angle of 44° with an azimuth of 210°. Figure 6 below shows both the top view and the vertical profile of the original against the actual welltrack.



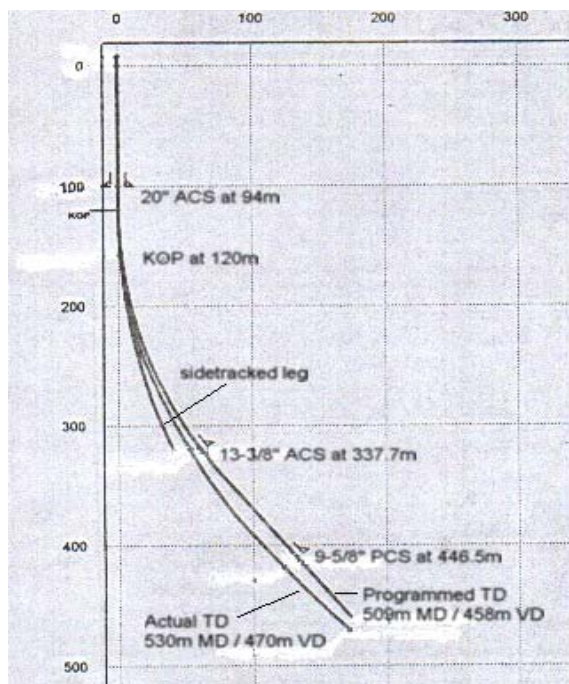


Figure 6: The top view and the vertical profile of the original program against the actual welltrack (anadrill Schlumberger Report)

As can be seen, the well was successfully directed to the left of the original program up to the anchor casing shoe depth then turned back to the right to bottom as in the revised program. It was projected to be just about 1m left of target at bottom. The difficulty was in achieving the desired inclination.

6.2 5R-13D Kill Operation

The TLC in the 8-1/2" hole section while reaming at 477m was encountered around 2115H on October 25,2003. The hole was drilled blind with water at 20 bpm from 485m and was TD'd to 530m at 0330H early the following day. Within this period, initial signs of communication with the discharging well were observed based on the chloride composition of the discharged fluid.

At 0600H of October 26,2003, killing operation commenced by pumping 240 bbls weighted mud at 11 ppg followed by water at 43 bpm with zero wellhead pressure. The pumped weighted mud came out of the discharging well minutes later. The intensity of the discharge drastically dropped after one hour of pumping but a low-level geysering type of discharge persisted even after hours of pumping water at 46 bpm. The continued reduction in chloride level however suggested an ongoing but slow quenching process (Figure 7).

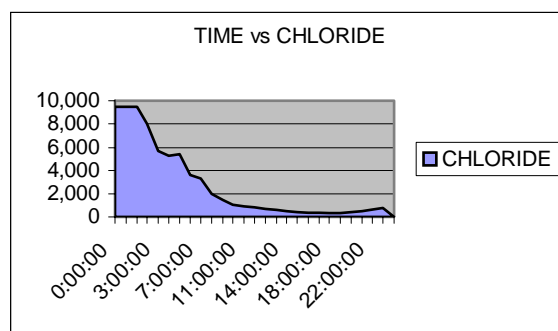


Figure 7: Graph of the reducing chloride content of 5R-12D discharge during quenching after drilling blind dated October 26,2003 (Palma,2003)

A second batch of 730 bbls weighted mud at 11 ppg was pumped followed with water at 46 bpm and eventually killed the well. Well 5R-12D was basically quenched 24 hours from the start of the total kill operation. There was no immediate significant change in wellhead pressure (WHP) of the adjacent Well 5R-4 after the quenching activity.

Water was pumped continuously while preparing to cement. A total of 285 bbls thixotropic cement slurry, composed of "G" cement and additives with sodium silicate, was pumped. This was displaced with water to bottom with the intention of leaving the relief well open in case Well 5R-12D discharges again.

A total of 5-1/2 hours were spent waiting on cement (WOC) with the pumps off for the cement to harden. No more discharge manifestations were observed on Well 5R-12D area during this period (Figure 8).



Figure 8: View of Well 5R-12D after it was totally contained

Well 5R-13D however developed a wellhead pressure of 2 MPa after only 45 minutes of WOC. With this development, it was decided to run the 7-5/8" liners and conduct a completion test. The top of cement inside the relief well was tagged at 521m (9m cement column developed) and the slotted liner was set on top of it. Pumping of water was maintained at 10 bpm while preparing for completion test.

6.3 5R-13D Completion Test

The completion test was conducted last October 29-30,2003. The test delineated the permeable zone from 480mMD to bottom. It also showed vacuum conditions

while varying the pumping rates from 10 to 22 bpm, which could mean that the injectivity index is very high (Saw, 2003). The encouraging test results suggest that Well 5R-13D is a good candidate for production well. A short term discharge was later conducted as part of the continuing evaluation on the viability of using this well for production.

7. POST KILLING ACTIVITIES

7.1 Clearing Well 5R-12D

The first set of clearing activity was the retrieval of the rig debris in the pad. A pump rate of 10 bpm water was maintained at Well 5R-13D as a safety measure while clearing Well 5R-12D.

The second set of clearing activity was the excavation of the cellar to determine the extent of damage on the 20" casing. This would determine the type of cement plugging strategy to be implemented to fully isolate Well 5R-12D at surface. After excavating about 8m from surface, it was noticed that the 20" casing was still bent at an angle of 20° from vertical. Referred to the original depth of the cellar floor, it was determined that the 30" conductor pipe and the 20" surface casing dropped by about 3.5m. Further excavation was not pursued since the excavated depth was already below the adjacent river bed level and water started to fill up the excavated hole. Moreover, a retaining wall will be required since walls of the excavated section exhibited symptoms of collapse. Figure 9 shows the excavated cut-off casing.



Figure 9: The topmost cut-off casing of Well 5R-12D

7.2 Final Isolation of Well 5R-12D

The objective was to fully seal off Well 5R-12D by establishing about 250m column of cement to surface, enough to contain any downhole pressure up to 4MPa. In as much as the 20" casing was bent, the option to initially retrieve the fish was ruled out given the difficulties that will be encountered in latching on and washing over the fish. It was also observed that the fish was plugged up with stones at surface. The remaining options considered were:

1. Pump cement through the annulus between the casing and the fish.
 - a. This will only be possible if the annulus is not clogged up with the blowout debris.
 - b. The uncertainty on this option is on where the pumped cement flows and on the controllability in establishing the required 250m column of cement to surface

2. Drill a hole adjacent to Well 5R-12D up to 250m and conduct isolation plug to surface
 - a. This would entail rehabilitating the cellar and setting up a small rig which translates to a longer time frame
 - b. This however has a greater chance of meeting the objective
 - c. This is also flexible enough such that it could be designed as a top hole for future drilling
3. A combination of both

It was decided to proceed with option 1 above and proceed with option 2 depending on the outcome.

A BJ cementing unit was mobilized and an adaptor was welded on the 20" casing to connect with the BJ lines. Water was pumped into annulus between the casing and string. Fortunately, communication to bottom through this annulus was observed thus option 1 was executed. A total of 5 cement plugs were conducted for a total cement slurry volume of 769 bbls. This is equivalent to 787m cement column to surface assuming a 17-1/2" hole. Table 1 is the tabulated cement plugging details.

Table 1: Cement Plugging Details

CP #	Slurry Volume (bbls)	Slurry Height (m)	Remarks
1	274	281	Annulus still accepting after WOC
2	210	215	Annulus still accepting after WOC
3	98	100	Annulus still accepting after WOC
4	95	97	Annulus still accepting after WOC
5	92	94	Filled up casing
Total	769	787	

After dewatering the excavated cellar of Well 5R-12D, the 20" casing was cut and was found out to be basically full of cement. Cement was also observed on the surrounding area around the casing. With the above development, pumping of water at Well 5R-13D was stopped. The pad perimeter of Well 5R-12D was monitored for days and was observed to be very stable.

7.3 Other Related Activities

Given the stable condition of the Well 5R-12D pad, it was decided to rehabilitate it and construct another cellar adjacent to Well 5R-12D (Figure 10). This will serve as a spare cellar in case another re-injection well will be needed in the area.



Figure 10: View of the cellar built to replace Well 5R-12D

8. CONCLUSIONS

- a. Well 5R-13D successfully intersected the blowing well at bottom as evidenced by the change in chloride content of the discharge fluid, the weighted mud returns to surface and eventually the quenching of the well.
- b. Though difficulty was encountered in getting the desired inclination, as aggravated by the presence of massive clay formation, the single shot survey activity was able to do the job.
- c. Success in this type of specialized operation involves a lot of extensive planning, drilling skills, flexibility in operation and close coordination with various concerned parties.
- d. The volume of cement pumped through the cut-off 20" casing was sufficient enough to fully seal off Well 5R-12D to surface as evidenced by the very stable condition of the pad after the cement plugging jobs.
- e. Well 5R-13D has the distinct honor of being the first geothermal relief well in the Philippines and possibly the first in the industry drilled using a single shot survey system

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