

## Design and Construction of the Kawerau Steam Field

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### ABSTRACT

The steam field design and construction at the MRP Kawerau Geothermal Project in New Zealand is unique in many ways. The location of one well pad is unusual in that it is in the middle of an industrial complex. The steam field two-phase piping system runs uphill, downhill and under culverts, which is against the recommended practice. The Steam field has 11 culvert crossings under access roads. It crosses a major state highway twice; once using a bridge and a second time using a long tunnel. It also runs through a railway yard. A single pipe carrying 67% of the two-phase fluid runs through the industrial complex occupied by multiple owners. The construction access inside this industrial complex was restricted and the pipeline was built over known and unknown services installed over the last 50 years. This pipe line had to be routed to avoid damaging trees and to squeeze through narrow corridors inside the industrial complex and the main access road to it. The other 33% of this two-phase fluid also flowing inside a single pipe crosses mostly farm land, rises up on a bridge to cross the state highway and runs through a log yard area.

During construction, the underground services in the plant were located using ground penetrating radar and hand digging. The pipeline route was altered in several places and some of the pipe supports were redesigned to avoid the rising water table and unknown underground obstacles.

The steam field was successfully completed on time without damage to any services and minimal damage to trees.

### 1. INTRODUCTION

Mighty River Power (MRP), Putauaki Trust and Norske Skog Tasman co-operated to develop the 90 MW Kawerau Geothermal Power Plant. The double flash Power Plant was constructed by Sumitomo- Fuji Electric. Tenix Robt Stone, one of New Zealand's largest and most experienced mechanical engineering companies specializing in project management, mechanical design, fabrication, site construction and maintenance, won the contract to design and construct the Steam field.

The Steam field consists of three production well pads, each with two wells and 3.5 kilometers of large bore two-phase lines. There are also three reinjection wells on two well pads and 3.2 kilometers of brine piping. The condensate runs in a buried HDPE pipe for 2.6 kilometers to a single reinjection well.

The pipe lines cross over the state highway on a bridge and underneath it at another point inside an 80 meter long culvert which also included a section crossing underneath a railway line. In places, it runs along public roads and through industrial plant and private farm land.

MRP is an environmentally friendly and safety conscious company. They were very aware of the impact of this project on the environment, the industrial complex and the community. Each of the industrial plants involved has their own health, safety and environment (HSE) plan and permitting systems.

Therefore, the planning and management of HSE issues was an integral part of this project. Great care was taken by MRP and the contractors to cause no disruption to services and operations in the industrial operations.

The Steam field was designed, built and commissioned in 12 months with no loss time injuries or operational impact to the existing plants. In this regard, the project was both interesting and challenging

### 2. THE SITE

The site is located in Kawerau, a town built around the Pulp & Paper industrial plants. Approximately half of the steam field is located on farm land. The other half is located inside the industrial complex which is more than 50 years old. This complex accommodates a few independent industrial companies. The New Zealand State Highway 34 runs through the middle of the town dividing the farm land from the industrial complex. A small airfield is located on the northern side of the complex and a railway line runs parallel to the airfield to deliver raw products and remove finished products from the complex. There is a steady stream of logging and articulated trucks servicing the industrial complex. The chemical waste produced by the Pulp and Paper mills runs inside a large fiberglass pipe across the industrial site to a treatment pond. In the farm area a natural gas line and a power transmission line crossed the construction site. The Tarawera River runs along the western side of the complex. Therefore the part of the site containing the industrial complex is "ring fenced" on the north by an airfield, on the east by the state highway and a rail track, and on the west by the Tarawera River. The Kawerau Township is in the south.

#### 2.1 Property Owners

The companies that occupy the industrial complex are:

- Norske Skog Tasman (NST)
- CHH Wood Products
- Carter Holt Harvey
- SCA Hygiene Australia Ltd
- Ontrack/Tolls
- Ngati Tuwharetoa Geothermal Assets Limited (NGTA)

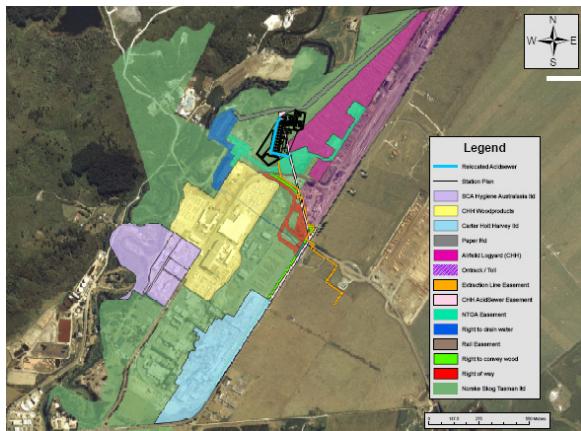
Putauaki Maori Trust owns the farm land east of the industrial complex.



**Figure 1A: The steam field site**



**Figure 1B: The industrial complex site**



**Figure 2: The properties owned by various parties**

## 2.2 Other Interested Parties

Transit New Zealand owns State Highway 34 which runs through the town and it is an important highway that links the inland towns to the coast. Transit has specific requirements for overhead height, minimum cover for under road crossings and strict traffic management.

Toll Rail, which own the railway line going into the industrial complex, also has minimum cover requirements

for tunnels and has a tight operating schedule. A lengthy interruption to their service was not acceptable.

Kawerau District Council owns the main road going into the industrial complex and the domestic water main running along side the road. Trees line the grass strip along side this road where the pipeline route was intended. Underneath the grass strip were existing fire mains, domestic water supply, drainage lines, telephone and power cables plus a few other unknown services.

The Bay of Plenty District Council owns some of the other access roads where pipe crossings were required.

Telecom's telephone cables are buried along the sides of the public roads and in the industrial complex.

Natural Gas Corporation operates a gas line which runs through the farm side of the site. Transpower own the power transmission lines in the vicinity. These lines created limited interference to the project as they ran through the farm side only.

## 3. THE STEAM FIELD

There are only three well pads in the steam field. Each well pad has two production wells. The first well pad is located in the Putauaki Farm. The two phase fluid from this well pad flow inside a single header pipe to the industrial plant site. It goes through several road culverts, crosses over a state highway on a bridge and runs through a log yard area.



**Figure 3: The two-phase lines from the three well pads**

The second well pad is located on the south side of the industrial complex. The single two-phase header pipe from this well pad runs over a long, straight and narrow strip of land next to Fletcher Avenue. A row of trees is planted in the middle of it and the fence of the NST plant runs along one side. After the long straight run, it crosses underneath the main access road to the NST plant and then enters the plant. Inside the plant area it goes through the third well pad located in the middle of the industrial complex. The two wells from the well pad stab into the header. Then the header threads its way through a narrow corridor beside a busy road carrying trucks removing wood chips from the process plant. After that, the header runs over existing pipes and crosses underneath the main access road to another industrial plant before joining up with the two-phase header from the farm side. The combined line runs underneath a plant railway line, over a pond and under another access road before arriving at the power plant.



**Figure 4: The Brine and Condensate Reinjection Lines**

The brine line from the power plant runs along an airfield, crosses underneath a couple of access roads to other industrial plants and Ontrack rail yard. It then crosses underneath the railway yard and the state highway inside an 80 meter long tunnel. After the under road crossing it enters the farm and then runs on for another 1.5 kilometer avoiding the natural gas line and power pylons. The brine is then reinjected into three wells located on two well pads on the farm.

The condensate flows down a buried HDPE pipe to a condensate reinjection well located another 500m from the brine reinjection well.

## 4. DESIGN

### 4.1 Process Design

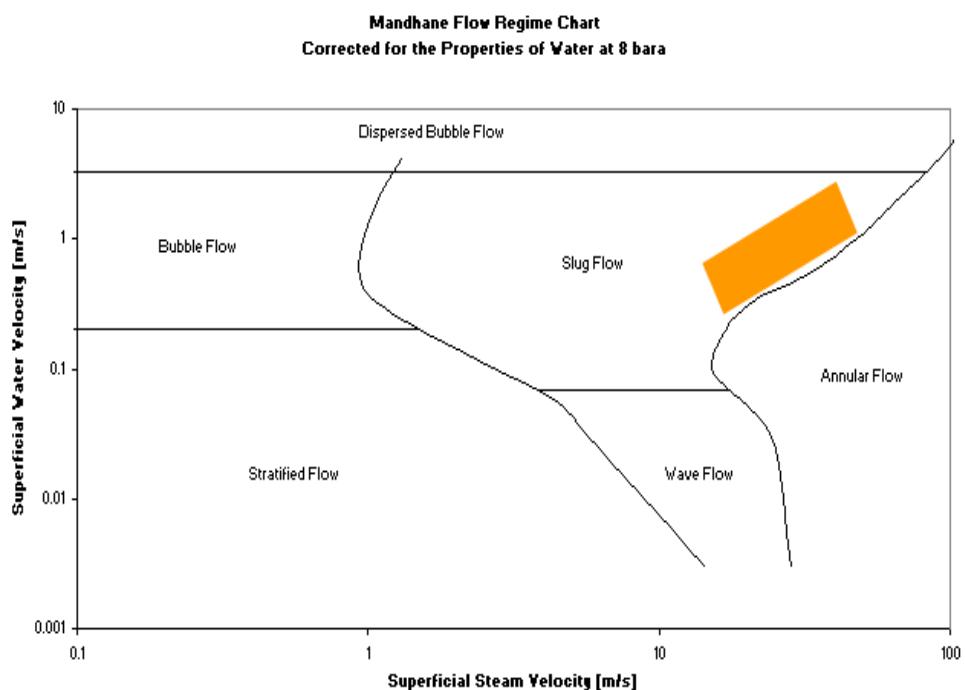
The steam field process design was provided by MRP. The enthalpy of the fluid is approximately 1300 kJ/kg which would classify it as a wet system. The difficulty in running a two-phase line is the risk of slugging, especially when it starts to slope uphill. Running it at high velocity will push

the flow into the annular flow regime reducing the risk of slugging but it increases the line losses. Running at low velocity requires a large diameter pipe and it pushes the flow into the wave and slug flow regimes. It was obvious that a compromise between slug risk and pressure losses needed to be made. The uncertainty in the enthalpy of the fluid made this balancing act more difficult. This was further compounded with the pipe running uphill, downhill, inside culverts under the roads and on a bridge over the state highway.

The theoretical flow regime for the design conditions would place it near the boundary of slug and annular flow regime of the Mandhane diagram. There is uncertainty in that area as most of the research on two-phase flow was carried out on small diameter pipes of less than 12". The steam field cross country pipe diameter is normally larger. Some literature suggested that it is unlikely that a slug can form in a large diameter pipe because the waves that initiate it cannot bridge the diameter of the pipe. MRP have many years of experience in running two-phase fluid up hill and had experienced the occasional slug. Due to the uncertainty of slug formation, the designers were required to consider slug flow in their analysis.

### 4.2 Mechanical Design

The routing of the pipe was the biggest concern. Not only it is required to keep the slope of the two phase line low, it has to be sloped in a direction to minimize low point drains as there are not many places available to dispose of the fluid. The routing of the pipe in the industrial area needed to avoid trees, a memorial plaque and also to avoid all the known and unknown underground services. To make this even more difficult, the location of these services on plans was not exact and therefore the services had to be located by careful hand digging during the route design stage. There was also a restriction on space and the pipe route needed to thread through narrow pipe corridors.

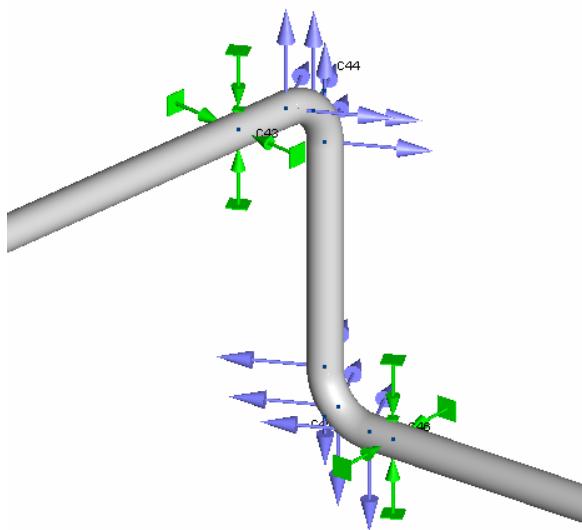


**Figure 5: The two-phase flow regime is close to the slug-annular flow boundary**



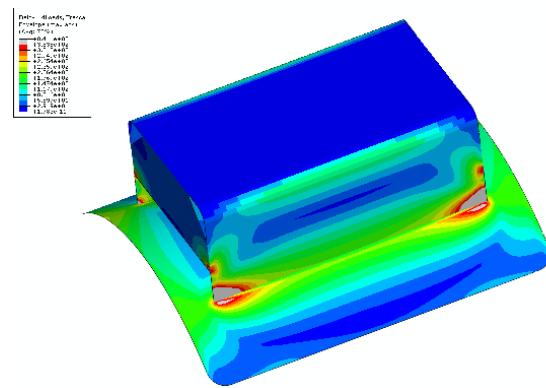
**Figure 6: The known underground services in the industrial complex**

The pipe stress analysis for the Steam field was done to ASME B31.1 code for Power Piping using the AutoPipe software. The slug load was entered as random occasional load acting on the bends in the pipeline to make use of the higher allowable load margins permitted by the code. In the analysis, the addition of slug loads increased the stresses in the pipe and the pipe support system was tightened up to resist the slug load.



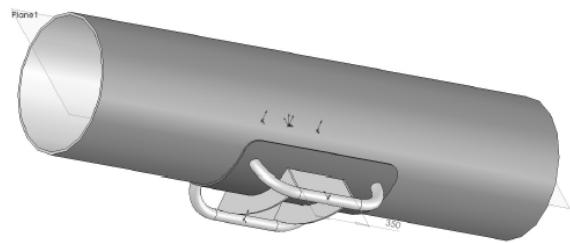
**Figure 7: Slug loads modeled on the bends of a pipe**

The pipe support local stresses were checked using finite element analysis (FEA) on sample supports to ensure that the stresses were not too high. The results were peer reviewed by several engineers. Figure 8 shows a sample of the analysis.

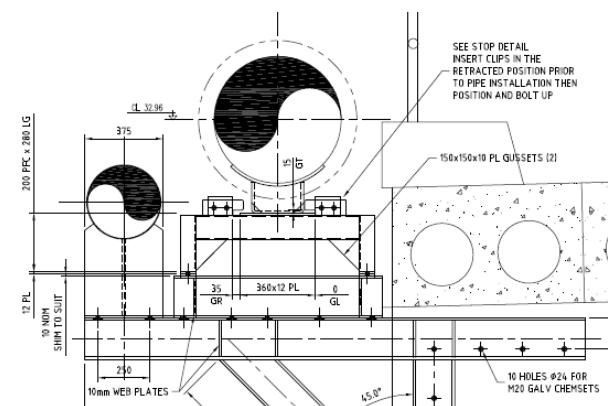


**Figure 8: Finite Element Analysis on pipe support saddle**

The construction team was consulted on the location and the design of the supports used to thread the pipe through the culverts. Special supports were also designed for the installation of the pipe on the bridge. These supports were designed to reduce the installation time which minimize the interruption to the traffic on the State Highway. The support system allowed the 55m pipe to be lifted in one piece onto the supports.



**Figure 9: Support designed to skid pipe into the pipe culverts**



**Figure 10: Removal support clips to allow for lifting the pipe straight onto the bridge support**

The brine line flows over a flat area and needed to be pumped to prevent it from flashing. A water hammer analysis was carried out on the brine line.

The steam condensate was disposed off inside plant drains where one can be found. Some ponds were also used to temporary store the fluid from the drains during the start up

of the steam field. Where no plant drains or pond is available, deep soakage holes were used.

#### 4.3 Structural and Civil Design

The development site is filled with pumice soil which goes down quite deep. While it offers good drainage, it has poor soil strength.

The pipe support foundation designs used are the standard pile and pad design. Pile design was preferred because of the smaller foot print which allows it to utilize the small gaps between the buried service lines. For each support in the difficult areas, a pile and a pad design was prepared so that the construction team could use either to suit the conditions.

During construction, the rising water table during winter and unknown buried cavities often necessitated a quick redesign to allow construction to proceed.

The underground culverts were constructed using standard pre-cast wing walls and round culverts.

The bridge supports took some time to work through as several parties had vested interests. The loading on the bridge was re-calculated and a risk assessment on the installation of the high pressure hot pipe across the bridge was performed. The high pressure hot pipe was subsequently required to be installed with a single lift. Methodical planning was required as this was a one-chance-one-off operation.

The construction of the tunnel underneath the railway yard and the state highway presented a different challenge. The minimum over burden requirement and the water table level needed to be considered. The tunnel had to be installed between these two limits.

The civil work involved in this project was minimal.

#### 4.4 Electrical and Instrumentation Design

The E & I is standard design. The power supply in the farm site comes from overhead cables and in the industrial site it comes from some switch boards. Two fiber optics cables clipped to the side of the pipe communicates data to the Power Plant as the steam field is remotely controlled from it.

### 5. CONSTRUCTION

The land occupied by the project site was controlled by several companies, each with their own specific HSE and work permit systems. The construction teams needed to be cognisant of these HSE requirements as they moved through these locations. This was discussed each morning at a tool box meeting before the team commenced work.

The schedule allowed 8 months for the construction of the 9 kilometers of pipes. The commencement of construction was delayed due to late delivery of pipe supports, materials and design work. Therefore the construction work had to be spread over several fronts to meet the deadline and initially the work force was moved around these work fronts as materials and details became available.

With delay in construction in the low lying areas, it was winter before the construction started in earnest. By then, the water table in the construction area had risen and the support foundation design had to be changed quickly to allow construction to go ahead.

The designs took the known underground services into account but many of these services were not indicated in the service drawings and were only discovered during the digging for the foundations. Minor changes were made to the location of the supports along the pipe where possible. Where this could not overcome the problem, the foundation was redesigned or the pipe route was changed. In one location underground cavities formed by an old plant room or similar was unearthed.

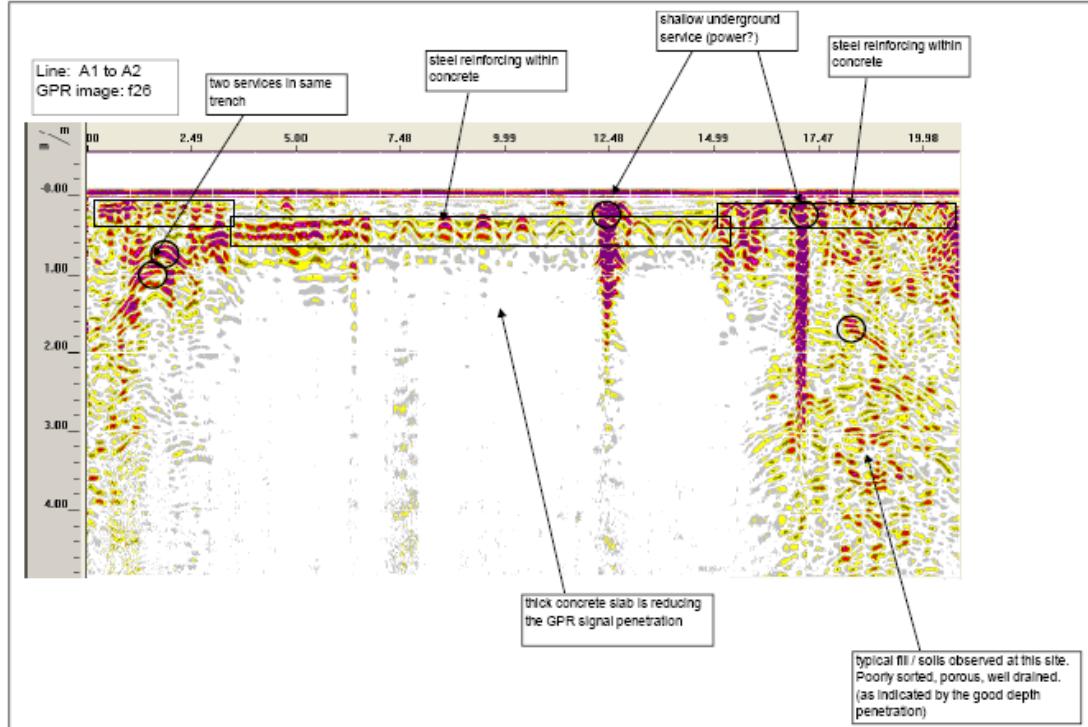


Figure 11: Ground Penetrating Radar results

A lot of the work was carried out in heavy traffic areas and a traffic management plan was required for each location. This was especially important on the State Highway where the road had to be closed for the lifting of the pipe onto the overhead bridge.



**Figure 12: The 80m tunnel underneath the State Highway and the railway line**

The State Highway could only be closed for a short period of time. Discussions were carried out with the crane operators, welders and fitters to work out a plan for the single one-chance-one-lift operation. The operation went smoothly with limited disruption to traffic.

Similarly, the construction of the 80m long tunnel needed to be timed to suit the railway operation in the yard.

The prefabricated spools for the well pads were welded and predominantly post weld heat treated (PWHT) in the workshop keeping onsite PWHT to a minimum.

The piping installed through the culverts was pre-insulated and 100% of radiography was carried out on the welds before they were skidded into place.



**Figure 13: Lifting the 55m pipe onto the bridge over the State Highway**

There were many low point drains in the system and the condensate was removed to these drains via a flash tank during the start up of the steam field. These were constructed on site to suit, as unknown underground services did not allow for pre-engineered draining systems. There were many issues around the locations of the flash tanks and the route of the drain pipes. In some places, the drain did not work as well as envisaged because of the limited capacity of the soakage holes.



**Figure 14: Running new pipes over old in a tight spot**

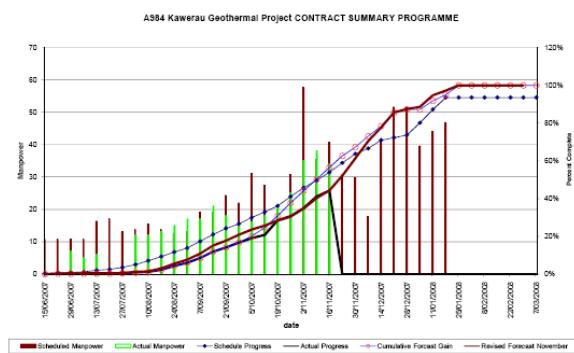
## 6. PROJECT MANAGEMENT

The project wouldn't have been completed on time without the cooperation and assistance from various individuals in the different companies. Mighty River Power took an honest and cooperative approach and provided invaluable assistance during the design, construction and commissioning phases. This included underground radar survey results to assist in locating some of the underground services.

The ASME B31.1 code does not require radiography of welds but the Client stipulated 10% radiography for quality assurance. Even though Tenix Robt Stone is certified to perform weld inspections, independent third party inspectors were used to radiograph and certify the welds to give greater quality assurance to the client.

The project schedule was monitored using Microsoft Project which was constantly updated and uploaded into the MRP overall project control system.

The S curve was used to monitor the progress of the work. Initially the project was running behind schedule and additional resources were employed. These quick corrective actions brought the project back on schedule.



**Figure 15: The S Curve used to monitor progress**

During the construction, a "3 day look ahead" work forecast was used for planning and scheduling work. This assisted the construction team to avoid delays in obtaining work permits and ensuring that the materials are available. This added considerable value to the project delivery.

Toolbox sessions were held daily to discuss work sites, work fronts, specific HSE and permitting requirements and potentially problematic areas. These sessions also provided workers the opportunity to give feedback to management.

## 7. PROJECT COMPLETION

Originally, the pipes were to have “in-service” testing but this would have delayed the completion of the project so hydrostatic testing was carried out instead. The early completion of the hydrostatic tests allowed thermal insulation around the pipe welds and the mounting of the fiber optic cables on the insulation cladding to be completed.

Mighty River Power operators from another geothermal power plant carried out the steam blow and commissioned the steam field. Although there were initial concerns regarding slug flow during start up, slug flow did not occur. However, a few plant items were worn out during the commissioning.

Full credit must be given to the MRP team whose assistance and speed in resolving issues meant that the work could be carried out at pace.

Not a single service line in the industrial complex was disrupted and no property was damaged. All the trees along the public road were saved. The fast track project was completed on time, within budget and without a single loss time incident.



**Figure 16: Commissioning – Steam Blow**

## 8. LESSONS LEARNED

The delays in receiving accurate, relevant surveys hampered progress in both design and construction work. Inaccuracies delayed the completion of design and in some cases; the design was repeated as accuracy is paramount when running pipes through tight spots and narrow corridors. In places the corridors narrowed to barely 1.2 meters between the row of trees and the boundary fence of the process plants. The interface connection points with the Power Plant were not pegged out correctly and had led to reworked. In hindsight, many design and construction

hours could have been saved by spending more time on survey and site work. It is recommended that more resources be allocated to survey work.

In the process of reducing construction cost, maximum pipe spans were calculated to reduce the number of supports for the pipe. This increased the load on the local supports and the local stresses around the pipe support. Also, in attempting to reduce the number of anchors required, the distance between anchors was stretched. This has resulted in huge anchor loads and foundation size. It is still not clear whether this is a beneficial approach.

The soakage hole for the low point drain was modeled on an existing one using well liners. The design was later changed as the pores in the liners were thought to be too small and could clog up quickly by fine particles or worse, the deposition of calcite. This was changed to a deep soakage hole filled with scoria with a centralised slotted pipe running to the bottom of the hole. The idea was to get the fluid to the bottom of the well as quickly as possible and utilise the hydrostatic head to drive the fluid out of the scoria into the porous pumice soil. The hole size was determined after soakage rate testing was carried out in the field. This concept did not achieve the desired result as the calcite in the fluid did not block up the scoria but blocked up the pumice soil around it instead resulting in low flow. Similar problems were encountered in the drainage ponds but here the surface could be scraped off.

The interpretations of the design code by the verifiers varied. Despite independent assessments from the stress analysis software company and a consulting engineer, some engineers still did not agree with the interpretation of the code. Currently the ASME committee has been requested to give a clear ruling. It is important to get agreement on the interpretation of the design code with the ruling authority, no matter how obvious before starting the design process.

## CONCLUSION

The steam field process moved into a relatively uncharted territory with the two-phase flow design. There was an element of risk but this was well managed. With careful start up procedures, the steam field is now operating successfully.

This particular fast track project had a lot of obstacles to overcome during the design and construction phase. However, with careful planning, cooperation and honest collaboration at all levels and in all phases, the project was completed on time, within budget and with no loss time incidents. It was a team effort.

## ACKNOWLEDGEMENTS

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