

# OHAAKI GEOTHERMAL STEAM TRANSMISSION PIPELINES

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## ABSTRACT

This paper describes the main steam transmission pipelines of Ohaaki Power Station, a project undertaken by DesignPower New Zealand Ltd, and Works and Development Services Corporation (NZ) Ltd, (WORKS). Two HP pipelines and one IP pipeline from the steamfield interface with the station steam pipework at a point about 75 m from the powerhouses. The station steam pipework includes steam pressure control valves, extensive condensate drains pipework, and steam vent silencers.

## INTRODUCTION

The Broadlands geothermal field consists of two steam production zones separated by the Waikato River. The two sides of the field (the West and East steamfields) possess slightly different steam characteristics and are expected to exhibit different rundown characteristics. There are three separation plants on the West field and two on the East field, and the flows from these, in conjunction with the turbine steam demands, governed the steam mains design.

The Ohaaki Power Station powerhouses are located a few kilometres from the steam production zones, sited on a ridge above the West steamfield. The steam transmission system has two pipe networks, one from each steamfield, that do not meet until about 350 metres from the powerhouses. It is the purpose of this paper to describe the link between the steamfields and the powerhouses.

DesignPower New Zealand Ltd and its predecessors were responsible for the overall design philosophy and coordination of the total project. Works and Development Services Corporation (NZ) Ltd, Consultancy Services Division, then the Ministry of Works and Development, undertook the design and construction of the steamfield fluid transmission system on their behalf.

To enable the concurrent development of the steamfield and the powerhouses to proceed independently a construction interface was designated in the steam transmission pipelines at anchor A1, a point about 75 m downhill from the IP powerhouse (see Diagrams 1 & 2, and Photo 1).

Although the steam transmission pipeline system was separately developed by the two organizations, some common features have been adopted. For example, the drain pots and steam trap assemblies are the same in both pipework systems.

There are many unique design features in the Ohaaki steam transmission pipelines, including combined venting and over-pressure protection control valves, very efficient drain pots, standardised steam trap assemblies, and acoustic and thermal insulation systems. Some of these design features are described in Ref 1.

## OPERATING

The field and power station will initially operate at two steam pressures (Refs 1 & 2):

- (a) High pressure (HP); 12.5 bars gauge at the HP turbine inlet, and
- (b) Intermediate pressure (IP); 3.5 bars gauge at the IP turbine inlet.

The HP machines are back-pressure sets and their exhaust HP steam will initially supply the major part of the steam supply to the IP inlet manifold.

However, as field pressures decline with continued fluid extraction, so too will the HP operating pressure. When pressures have declined to a point where the HP inlet pressure is about 5.5 bars gauge, the HP sets will be removed from service and the HP steam mains converted to IP steam transmission. The steam swallowing capacity of the HP turbines decreases as the inlet pressure drops so an increasing quantity of IP steam must be supplied to the station to maintain station output.

The IP transmission system is designed to have some initial surplus capacity to supply the extra IP steam but as HP pressures continue to decline and HP wells are derated to IP to meet the shortfall from the HP turbines, the single IP line will reach the limit of its capacity. To meet this and other possible changes in operating conditions during the life of the fields, blanked off tees are provided on the steam mains at Anchor A3. This provision will enable a cross-over to be installed to enable one of the original two HP lines downstream of A3 to serve as a second IP line handling the increasing IP flow resulting from HP well derating. The cross-over may also be required for:

- (a) Pressure flow balancing.
- (b) Enabling the HP mains to run at different pressures,

(It is probable that the East and West bank fields will rundown in pressure at the different rates, and an alternative strategy may be to run the two HP turbines at different pressures.)

Ultimate derating of all HP steam mains to IP steam transmission will, in any case, be required when the HP turbines are finally decommissioned.

## STEAM FLOW RATES

Design flow rates for the various pipe segments are governed by the turbine steam demands and the separation plant outputs:



Photo 1: Aerial View of Station showing part of steam transmission pipelines.

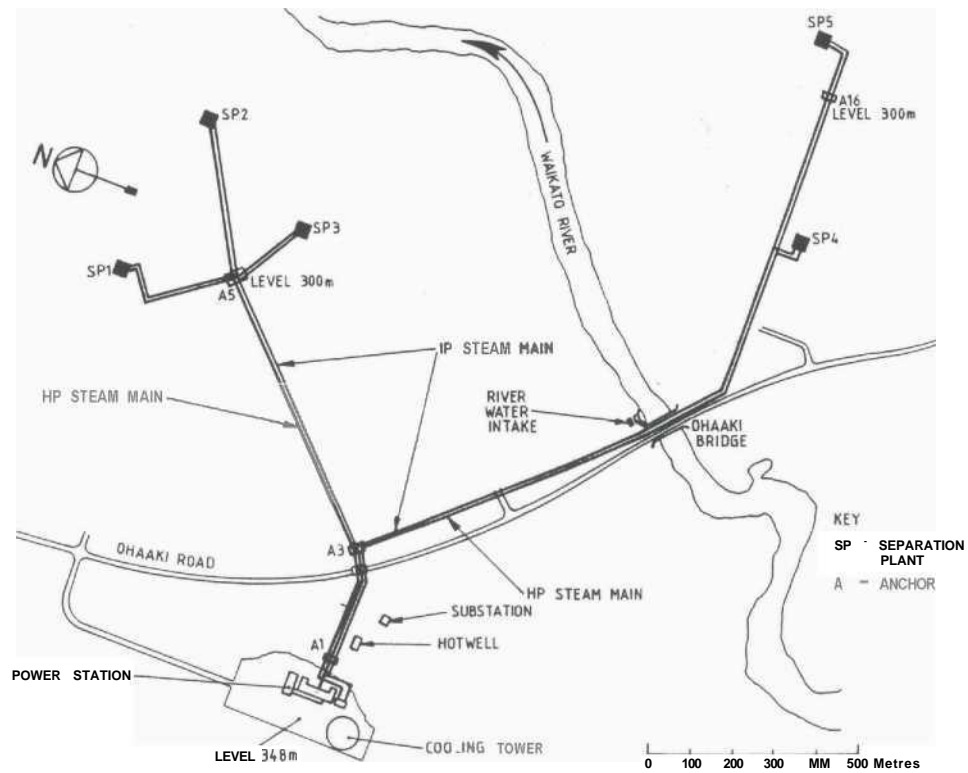


Diagram 1: Overall Layout of Main Steam Transmission Pipelines.

## (i) Turbine steam demand:

- HP      **520** t/h @ 12.5 bars g. (max)  
200 t/h @ **5.5** bars g. (min)
- IP      **680** t/h @ 3.5 bars g. (max)

(There is 30 steam condensate loss through the HP turbines because the HP exhaust steam is 3% wet).

## (ii) Separation plant outputs:

- HP      Peak output                      140 t/h  
Normal output                      110 t/h
- IP      Peak output                      120 t/h  
Normal output                      90 t/h  
Derated HP Peak output           80 t/h

Because of the HP pressure rundown and the consequent decrease in swallowing capacity of the HP turbines, there is a range of operating conditions for the HP mains. The design condition is the initial operating period when pressures and flow rates are highest.

A difficulty in assessing design flows for the steam mains is the possibility of imbalance of steam supply between the West and East steamfields. Indications are that the West steamfield will rundown in pressure faster than the East steamfield.

A small allowance for imbalance of supply between the East and West fields is included in the design flow rates.

The design flow rates adopted for the HP and IP steam mains (Ref 2) are summarized in Table 1.

	Steam Main Junction A1-A3		Steam Main West (A3-A5) & East (A3-A16)		Branch Lines	
	Initial	Derated	Initial	Derated	Initial	Derated
HP Stem	520	0	260	0	140	80
IP Stem	190	680	160	340	120	120
Condensate + Gas Loss	HP 30 IP 10	0 40	15 5	0 20	0 0	0 0
Imbalance Allowance	HP 0 IP 130	0 0	25 10	0 110	0 0	0 0
Total Flow Rate t/h	HP 550 IP 330	0 720	300 175	0 470	140 120	0 200

Table 1: Design Steam Flow Rates (tomes/hwr)

## STATION STEAM CONTROL VALVES

The HP bypass valves and the IP vent valves incorporate feed forward sensors in their control systems. If an HP turbine trips the HP bypass valve assigned to the HP turbine will automatically open to maintain the HP pressure by diverting HP steam directly into the IP manifold. In the event of an IP turbine trip the two IP vent valves assigned to the IP turbine will open rapidly to discharge the IP steam directly to atmosphere via the steam vent silencers.

The IP vent valves also have modulating and safety functions. Under normal operation the vent valves are controlled by a pressure controller that either opens or closes the valves to control IP steam

pressure within set limits. However, flows will normally be in balance to avoid venting.

The IP pipework is protected from over-pressure by means of a "1 out of 3" pressure switch system. These IP vent valves are fail-safe in that loss of electric or hydraulic power will cause the valves to open.

## PRESSURES AND TEMPERATURES

The design pressures for the steam mains are greater than the maximum attainable operating pressures by a margin that ensures satisfactory operation of the safety valves. The design pressures (Ref 2) and temperatures are shown in Table 2.

The adopted design pressures for the steam mains are the same as respective design pressures for the HP and IP separators. Consequently, the safety valves installed in the branchlines immediately downstream of the separation plant are sufficient to protect against over-pressure in both separation plant and the steam mains.

The Station HP steam pipework has the same design pressure of 17 bar g as that of the steamfield pipework. Over-pressure protection of the Station HP pipework is provided by the safety valves in the steamfield. The IP pipework has a design pressure of 5 bar g and it is protected against over-pressure by the IP vent valves at the station. Some of the Station IP steam pipework is protected against vacuum condition by rupture discs

	HP	IP
Maximum TSV pressure	12.5	4.0
Maximum pressure losses		
• inlet manifolds	0.5	0.5
• steam mains	1.0	1.5
• branches (include 0.15 bar loss for flow metering devices)	0.35	0.35
- separators	0.5	0.5
Sub-total	14.85	6.85
Margins for bypass/vent valves	0.5	0.5
Sub-total	15.35	7.35
Margin for safety valves (10%, or 1.0 bar minimum)	1.5	1.0
Minimum design pressure	16.85	8.35
Adopted design pressure	17.0	8.5
Corresponding design temperatures	187 °C	

TABLE 2: Steamfield Design Pressures (bars gauge) and Temperatures.

## STEAM VELOCITIES AND PRESSURE LOSSES

The HP steam mains will operate under a range of conditions. The design conditions were identified as the initial condition before HP rundown commences and the final condition when HP rundown is complete and the HP system is operating at IP pressures. The worst design condition for the IP steam mains is just prior to the final derating of the HP system.

K.C. Lee, D.G. Jenks

The design velocities for HP and IP steam transmission are limited to a maximum value of 50 m/s (Refs 3 & 4).

Maximum pressure losses are governed by the maximum allowable operating pressure (ie design pressure and safety valve lifting pressure). Velocities are restricted to ensure that these pressure losses are not excessive.

#### CORROSION ALLOWANCE

A corrosion allowance has been provided in the steam mains pipework according to the requirements of the design code. A minimum allowance of 3.0 mm is provided in the wall thickness of the IP steam mains, but a lower corrosion allowance (1.0 mm minimum) is provided in the HP steam mains. The justification for this is the intended derating of the HP steam mains for IP steam transmission. After final derating to IP pressures, safety valves will be reset to lower lifting pressures to ensure a minimum 3 mm corrosion allowance.

In the station pipework, some of the items have 6 mm allowance for corrosion as well as erosion, for example, the Vortex separators.

#### CODES AND STANDARDS

The design and construction of the piping system has been in accordance with the ANSI/ASME Standard B31.1 "Power Piping". The manufacture of all pipe was to the API specifications permitted by B31.1 (Ref 5). The fittings were covered by selected ANSI, ASTM and API specifications permitted by B31.1.

The pressure vessels (eg vortex separators) in the station pipework system were designed to ASME VIII Div 1 "Boiler and Pressure Vessel Code".

The structural steelwork, concrete and foundation design and construction was in accordance with the appropriate NZ Standards.

In addition to above, statutory obligations requires the Maritime Transport Division (previously the Marine Division) of the Ministry of Transport (MOT) to approve the design and construction of all pressure pipework.

#### DESIGN PHILOSOPHY

With the physical arrangement of the power station and separation plants fixed, the interconnecting steam mains alignment was then determined by adopting the most direct practical route.

Stress analysis of the steamfield pipelines was carried out in selected segments, typically 350 m long between anchor points (Diagram 3). Thermal expansion displacements are absorbed in laterally supported vertical expansion loops equipped with angular expansion joints. Thermal expansion and in-line seismic loads are transferred to concrete anchor pads. Intermediate sliding supports resist transverse seismic and wind loads.

At the station, the lack of space and the large diameter (1600 mm NB) and relatively thin wall (9.5 mm) of the IP manifold required expansion joints to be used to absorb thermal displacement in place of expansion loops.

#### PIPE SIZES

The size, type and approximate quantity of pipe incorporated in the steam mains and branchlines is summarized in Table 3.

NPS mm	Pressure	Thickness mm	Type	Quantity m
Steamfield				
500	HP	7.9	SW	1110
500	HP	12.7	ERW	40
600	IP	7.9	SW	1690
600	IP	12.7	ERW	80
750	IP	7.9	SW	1970
750	HP	9.5	SW	3385
750	HP & IP	12.7	SAW	220
1000	IP	9.5	SAW	285
1000	IP	19.1	SAW	25
Static				
150	IP	7.1	SML	15
400	HP	9.5	SML	50
650	IP	9.5	SML	70
750	HP	12.7	SAW	330
750	IP	9.5	SAW	60
900	HP	12.7	SAW	55
900	IP	9.5	SAW	245
1100	IP	9.5	SAW	90
1600	IP	12.7	SAW	100

SML for seamless;  
SAW for submerged arc welded;  
ERW for electric resistance welded;  
SW for spiral welded.

Table 3: Pipe List

#### PIPE SUPPORTS

In the steamfield, the earthworks formations along the pipeline routes are constructed to National Roads Board (NRB) standards. On these the reinforced concrete foundations for the anchors, sliding supports and expansion loop support structures are constructed. Flat slabs are used in all cases except for the sliding supports where shallow bored concrete piles are utilized.

Penetrometer soundings were used to establish the soil strength parameters.

At the station, most of the pipework is supported by hangers (rigid, spring and constant load types) attached to steel structures. Where necessary, hydraulic dampers are used to restraint seismic loads. Earthworks for the reinforced concrete foundations are constructed to the same specification as that adopted for the power houses.

#### T H - EXPANSION

Vertical loops in the steamfield pipelines are fitted with angular expansion joints. These were installed with a 50% preset in order that the rotation specification of the expansion joints could be minimised. The geometry adopted for the expansion loops is largely influenced by their second function - to provide convenient vehicle crossings, eg for drilling rig access to production well heads.

The station pipework has been designed to make use of natural flexibility to absorb thermal expansion where practicable (Ref 6). Cold pulls are used to reduce thermal stress. Because of limited space and the possibility of out of phase relative movement, expansion joints in suitable configurations are used to ensure the integrity of the pipework during seismic conditions.

#### STEM CONDENSATE REMOVAL

The control of condensate accumulation in the steamfield pipelines is achieved by the provision of drain pots from which the condensate is removed

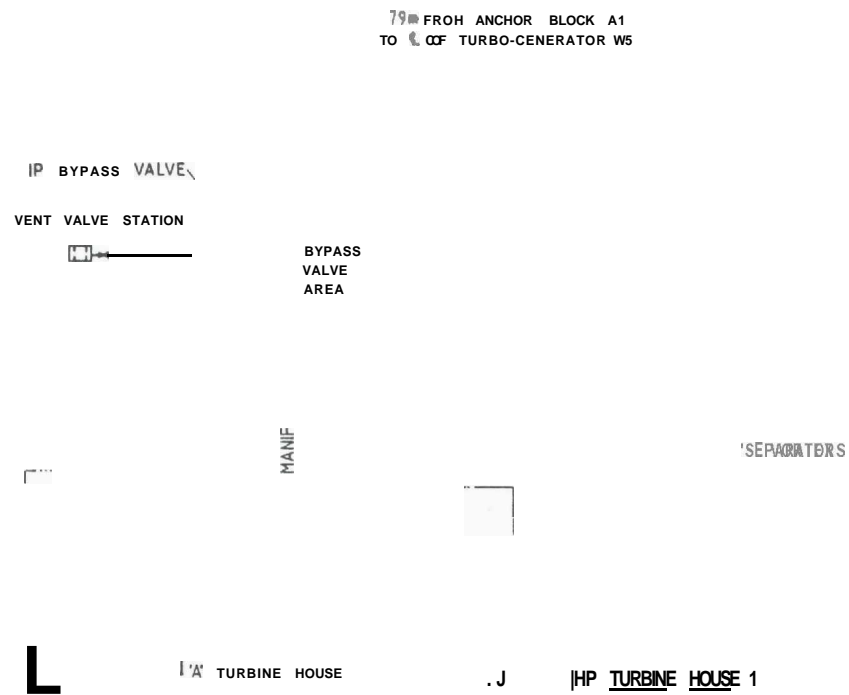
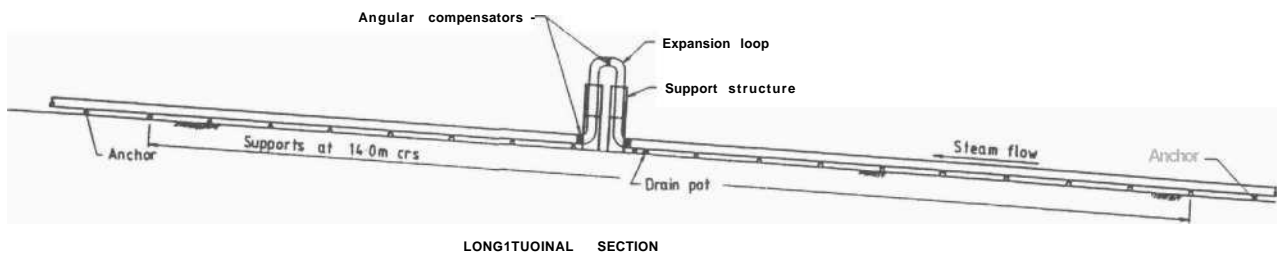
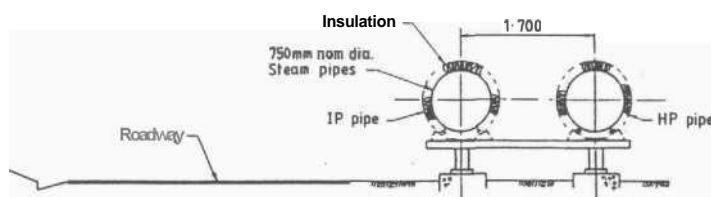


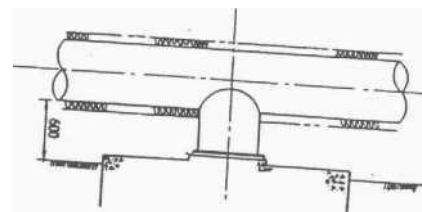
Diagram 2: Layout of Station Pipework.



## STEAMFIELD PIPEWORK



CROSS SECTION AT SUPPORT



ANCHOR

Diagram 3: Typical Segment of Steamfield Pipework.

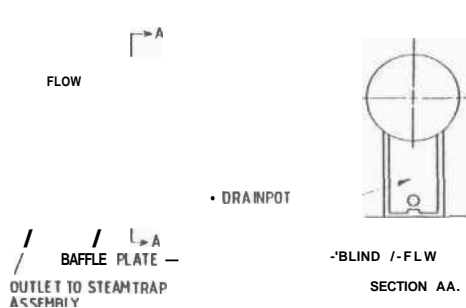


Diagram 4: Cross Sections of Typical Drain Pot

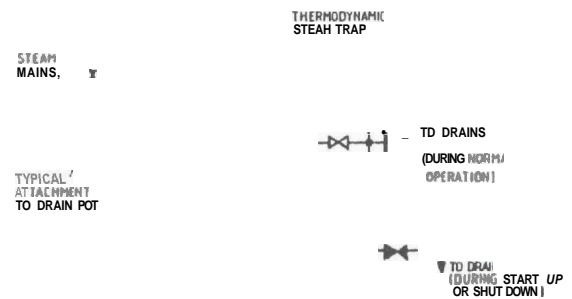


Diagram 5: Typical Thermodynamic Steam Trap Assembly.

K.C. Lee, D.G. Jenks

through steam trap assemblies. Hand valve drain points are also located at selected low points. These facilities in the pipeline are required in both conditions of thermal stability and when the pipeline is either heating up or cooling down,

A condensate drains system is provided to collect and remove condensate under all conditions from the station steam pipework.

The condensate formed during start-up will be at relatively low pressure and temperature and in large quantity within a short period. Condensate at pressure below 0.5 bar g during start-up will be discharged to open culverts draining to the Waikato River. Condensate over 0.5 bar g will be discharged to the atmospheric drains vessels that separate flashed steam before discharging water to the hotwell for reinjection.

During normal operation, condensate is collected in the drain pots which have steam trap assemblies for controlled discharge of condensate to the atmospheric drains vessels. Vortex separators collect condensate from the HP turbine exhaust pipes and interstage drains vessels collect condensate from the HP turbine casings.

The drain pots are a very efficient design which incorporates features as shown in Diagram 4. These features are the results of tests described in Refs 7 & 8. Each drain pot has a standardised steam trap assembly for controlled discharge of condensate. There are four types of steam trap assemblies depending on the pressure and quantity of condensate to be handled. Float traps are used for low pressure and high condensate flow; thermodynamic traps are used for high pressure and relatively lower condensate flow. The most commonly used steam trap assembly (T2 type) is shown in Diagram 5.

During shutdown most condensate will be evaporated by the hot pipes with air being admitted into the steam pipes to prevent vacuum conditions.

#### INSULATION

All steamfield pipework is fitted with a 65 mm thick layer of insulation material to restrict heat loss and provide personnel protection. The protective outer cladding is of aluminium or fibreglass (Ref 9).

Two insulation systems are installed on the station pipework; a thermal system, and an acoustic system.

The thermal system consists of one layer of insulating material and one layer of cladding. The thickness of the thermal insulating material varies with the size of the pipe and its duty, from 25 mm for 50 NB piping to 65 mm for 1600 NB piping.

All pipe fittings except pipe elbows are insulated with non-contact insulation boxes with 50 mm thick insulation. All cladding is 1.2 mm thick aluminium except pipe elbows which are clad with FRP cladding.

The station acoustic insulation system consists of two layers of 65 mm thick fibreglass insulating material with an intermediate cladding between them and an outer cladding. It reduces noise to an acceptable level when HP bypass valves and IP vent valves are in operation. The acoustic insulation is mainly installed on pipework in the Bypass Area.

#### CONSTRUCTION MANAGEMENT

The steamfield construction schedule spanned a period of approximately 5 years. The activities on the steamfield critical path programme for this

period were achieved by allocating work between "in-house" forces and "outside" contractors and were split up as follows: Earthworks, Concrete Foundations, Supply of Pipe, Supply of Fittings and Steelwork, Fabricate and Erect Pipework, Insulation and Cladding, Instrumentation, and Commissioning.

The construction of the station steam pipework was carried out under eight contracts: Pipework and supports, Control valves, Expansion joints, Isolating valves, Condensate drains pipework, Steam vent silencers, Miscellaneous items (eg small valves and pipe support elements), and Insulation and Cladding.

All site work including contract supervision was carried out under the direction of WORKS or PoverBuild NZ Ltd as applicable.

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