CASE STUDY: GROUND SOURCE THERMAL PILES

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ABSTRACT

The new Administration Offices building for Hutt City Council is heated and cooled by a ground source heat pump, and for the first time in New Zealand, the use of ground source pipework located within the structural piles of the building, known as thermal piles.

The original 1950's building has been refurbished, including comprehensive seismic strengthening which required around 70 new structural piles. Each pile extends up to 20 metres below the surface of the ground, where the temperature remains constant throughout the year. The piles also pass through a sub-aquifer, above the locally well-known aquifer in this area.

The stability of the ground temperature is the key to the use of a ground source heat pump, with a resultant high efficiency. The use of pipework which is lowered into the hollow steel structural piles, provides a good ground loop arrangement, as well as allowing a dual function for the piles. This presentation talks about the initial feasibility analysis and modelling work carried out, the ground properties testing, and the actual installation of the ground loop pipework and equipment. The building was occupied in April 2016, and the installation has been in successful operation since then.

The building has won awards for its Architectural significance, and as a heritage building a lack of chimneys or external chiller plant has been of significant importance. An in-use energy rating certification process for the building is also currently under way.

1. INTRODUCTION

1.1 Building Configuration

In 2012, the Hutt City Council occupied a three-storey 1950's building of masonry construction. The building was found to have very poor seismic performance, but had a high heritage value. The decision was made to refurbish the existing building, with an extension, but to retain as much as possible of the existing structure, in particular the front façade. This required some detailed structural design, including the use of a significant quantity of new screwed hollow steel piles.

Given the ground properties, the number and depth of piles and the arrangement and use of the building, it emerged that the use of a ground source heat pump, using the proposed new structural piles, might be an appropriate option. On this basis, a detailed feasibility report was undertaken, to examine the benefits and cost.

As part of this report the graphic shown in Figure 1 was developed to clearly demonstrate the configuration of the pipework relative to the new building.

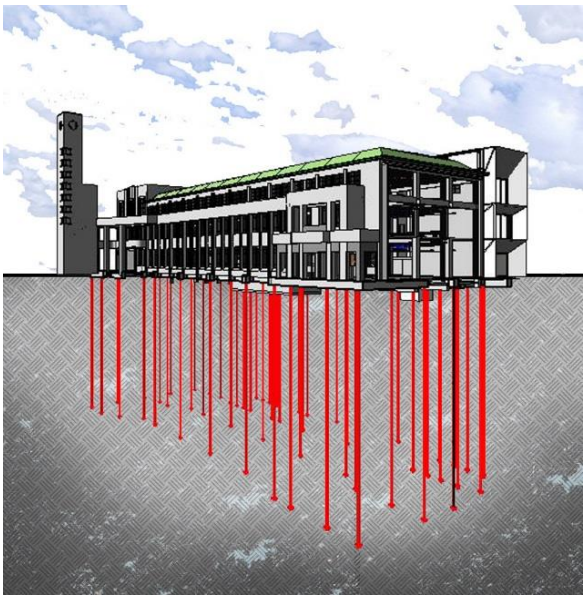


Figure 1: Building Configuration

1.2 Ground Source Heat Pumps

In simple terms, a heat pump is an item of equipment which transfers heat from a low grade source to a high grade output, using a refrigeration cycle. In building services these commonly use the ambient air as a source, by passing the air through a heat exchange coil. Ground source heat pumps use the ground as a source, by running water through pipework embedded in the ground.

In heating mode, a ground source heat pump takes heat from the ground, and raises it to a higher temperature to provide heating to the building. The advantage in doing so is that the ground temperature, particularly at greater depths, is very consistent, and during cold weather (when more heating is required) is closer to the temperatures required by the heating system. This has a significant effect upon the efficiency of the heat pump.

Conversely, during hot weather the heat pump is reversed, rejecting heat to the ground, and again the consistent ground temperature is significantly closer to the temperatures required for cooling. This again leads to a higher efficiency in operation of the heat pump.

1.3 Ground Properties

The ground properties at the Administration building site are very favourable for ground source heat pump use. As part of the structural design of the building a geotechnical report was prepared by Tonkin and Taylor Ltd in July 2012. This report identified the ground materials to sand, gravel and silt, with a water table of around 2-3 metres.

1.4 Ground Temperatures

Below a relatively shallow zone (3-5m depth) of seasonal temperature fluctuation, the soil, stone and groundwater beneath the ground form a large relatively stable mass. Typically, temperatures at a depth of 5-10 metres or more remain stable year-round, varying less than a degree from 10ºC. This is as described in the CIBSE Technical memorandum TM51 publication.

This stability of ground temperature contrasts with the typically cyclical ambient air temperature. This means that ground source heat pumps are thermodynamically more efficient than air source heat pumps.

The ground properties, with a high water table, also means that heat rejected or absorbed by the ground loop is able to dispelled more effectively. The containment of the ground loop pipework within the hollow steel building piles also means that there is no material effect upon the local groundwater or need for water rights required.

2. ANALYSIS

2.1 Building Thermal Modeling

As part of the design of the building the design team as a whole create and use a three-dimensional model of the building. The model is used for the design of all elements of the building, including structure, means of construction and building services such as heating, cooling and ventilation.

The model also enables a number of means of preparing graphic representations of the building, such as the view shown in Figure 2, or other features such as 'walk-through' videos. At a technical level the three-dimensional model enables the transfer of information about the building to other computer analysis programmes, including thermal modelling. In this manner the building shape, the area of glazing, the thermal properties of different parts of the building envelope and other information is then provided to the thermal modelling software.

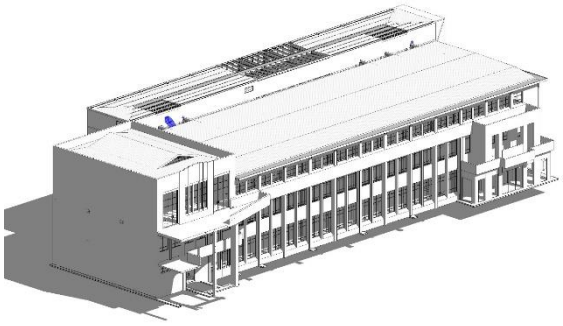


Figure 2: Building 3D Model

The thermal analysis software allocates zones to each part of the building to calculate the thermal loads and the energy use of the building, based upon predicted occupancy patterns and the specific means of providing heating and cooling. The graphical representation of these zones is shown in Figure 3.

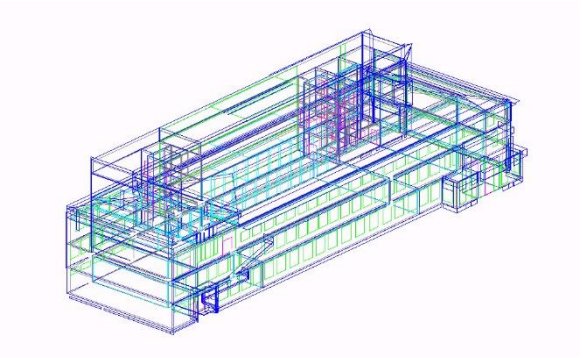


Figure 3: Thermal analysis 3D Model

A full evaluation report was provided for the Administration building. This used the thermal analysis to estimate the annual energy use of the building for both a conventional system and the proposed ground source heat pump system. The estimated capital costs of these two options was then used to provide a net present value payback prediction for the Council, based upon their own evaluation criteria. Alongside this, the carbon dioxide emissions were also calculated and are represented by Figure 4 below, which demonstrates a reduction of around 70% in CO_2 emissions for the GSHP compared to a conventional solution.

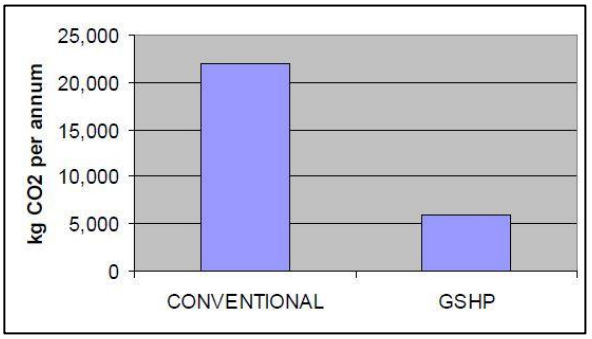


Figure 4: Predicted CO_2 emissions

3. GROUND TESTING

3.1 Testing

To confirm some of the assumptions included in the report, it was necessary to carry out thermal testing of the local ground conditions. Testing of the ground formation thermal conductivity and emissivity at the site was carried out by specialist company Central Heating (NZ) Ltd. The actual measured thermal characteristics were then fed to simulation software to analyse the number and depth of the piles, the number of loops in each pile and the flow rates through each pile.

3.2 Test Rig

In July 2014, two test bores of 18m depth were drilled, in different parts of the construction site and U-tubes inserted and grouted. A test rig was then established and a number of 48-hour test carried out to determine the thermal properties of the ground at the depth of the pile. The test rig was as shown in Figure 5 below.



Figure 5: Ground Testing Rig

3.2 Test Results

The test results showed that the proposed design, with some minor adjustments, could achieve the required thermal exchange in both heating and cooling mode. The purging required was achievable and the number of piles and loops within each pile were appropriate.

4. INSTALLATION

4.1 Preparation

The pipework loops were attached to the steel reinforcement cage which is contained within each structural pile. Pipework was medium density polyethylene, of a diameter suitable for the water flows required. No joints in the pipework were permitted other than the connection points at each end.

A typical configuration is shown in Figure 6 below.



Figure 6: Typical Thermal Pile Steelwork

Once the pipework was located within the cage, the entire cage was lowered into the pile installed in the ground. This required additonal cranage as whilst the piles were sectional, the cages had to be lowered as a single item.



Figure 7: Installation of steel reinforcing cage

Figure 7 above shows a cage being lowered into a pile. It can be seen from this photograph that the pile is a significant distance away from the exterior wall of the building – this demonstrates the extent of the new structure required.

The use of high density polyethylene pipework throughout allows some flexibility in the event of loclaised earth movement, due to settlement or low strength earthquake.

4.2 Pile Cap Detail

The most critical part of the design of the pipework within the piles is the point at which the structural pile joins the ground beams and other structure of the building. Obviously structural loads are highest at this point, whilst the pipework rising up the pile needs to leave the pile to connect to the reticulation pipework.

The willingness and co-operation of the project Structural Engineers, Dunning Thornton, to amend their design to accommodate the pipework was key to the success of this aspect of the design. The photograph in Figure 8 below demonstrates the complexity of the arrangement in this location.



Figure 8: Pile Caps

4.3 Manifolds

The flow and return pipework connecting to each of the piles was extended to a centralised manifold assembly located within a basement space below the building. From the manifolds the common main flow and return pipe runs up the building to the chiller plant located in a rooftop plantroom.

With around 64 piles and flow and return pipework connecting to each one, the running of this pipework, including allowance for its bending radius, was of significant importance and complexity. The co-operation and attention to detail of Naylor Love Ltd, as main contractor for the project, was key to the success of this aspect of the installation.



Figure 9: Centralised Manifolds

A critical part of the flow and return pipework and manifold arrangement was the flushing of possible debris and venting of air from all the pipework. A thorough process was followed to ensure this was achieved.

5. OUTCOMES

5.3 Soft Landings

There is a relatively new stage of involvement for building designers known in the industry as 'soft landings'. Soft landings works on the principle that the building services designers have a prolonged involvement in the building process, beyond the conventional termination of this once construction is completed. In this manner the understanding and knowledge of the fundamental principles developed during the early stages of the building process are not lost, but continue to be around to support the building owner and occupiers as they grow to understand how to use the building.

Stephenson and Turner have been employed to provide soft landings for the Administration building, working closely with EECA and the Hutt City Council facilities management staff.

5.1 Building Monitoring

As part of our soft landings role we have monitored the operation of the building services using a web-access building management system (BMS). This provides a graphic representation of the installation and provides real time information and data logging of all measurements recorded by the BMS. These include items such as internal temperatures, fans speeds and air volumes.

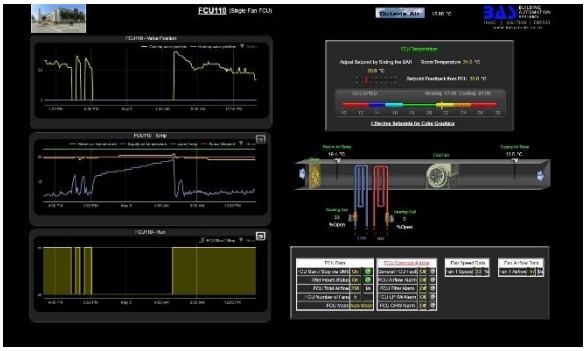


Figure 10: Building Management System

During the first year of the building occupation we have worked with EECA to identify and implement possible energy use reduction measures. Adjustments have been made to operating times, setpoint temperatures and other variables to reduce the energy required by the building. In this way, guideline targets for these reductions, provided by EECA, have been met and exceeded.

5.2 NABERSNZ Energy Rating

NABERSNZ is an energy rating scheme, administrated by EECA, which provides an independently certified star rating which clearly shows the building's energy performance compared to others. The rating is adjusted for the local climate, the size of the building, the number of occupants and the hours of use of the building. It is based upon historical information gathered over a period of one year.

With the building in continuous occupation for a period of just over a year at the time of this paper, information is currently being gathered in order that a NABERSNZ rating for the Administration building is achieved.

6. CONCLUSION

The administration building has been demonstrated as an ideal application for a ground source heat pump using the structural piles of the building.

The installation has allowed plant and equipment which has an extended life expectancy as well as being hidden from

view. It also allowed a dual function use of the structural piles, avoiding the cost of drilling separate boreholes for the ground source heat pump. The building performance has been carefully optimised, and is currently under review, with the intention that it be demonstrated as of high performance.

Many lessons were learnt during the various stages of the installation work completed. These will improve the efficiencies in installing a similar system in another project, but will also enable a more informed evaluation of the suitability of this system for any subsequent project.

ACKNOWLEDGEMENTS

Building Architectural design: Architecture+, Wellington

Structural design: Dunning Thornton, Wellington

Geotechnical report: Tonkin & Taylor: Wellington

Building Services design: Stephenson & Turner, Wellington

Ground thermal testing: Central Heating NZ, Christchurch

Main Contractor: Naylor Love, Wellington

Optimisation: The Energy Efficiency & Conservation Authority (EECA)

REFERENCES

The Chartered Institution of Building Services Engineers London: *Technical Memorandum 51: Ground source heat pumps*. (2013).

The Building Services Research and Information Association London: *Building Guide 4 – The soft landings framework (2009)*.

The New Zealand Green Building Council website - About NABERSNZ: http://www.nabers.govt.nz