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Geotechnical Aspects of the Maui B/A Pipeline

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ABSTRACT: The Maui B/A pipeline is a 15.3 km Pipeline connecting the Maui A and Maui B Platforms off the Taranaki coast of New Zealand. It is buried at least 1 m below the seabed in water depths exceeding 100 m. The pipeline conducts the product at elevated temperatures, inducing thermal instability related problems in the pipe. A number of issues needed to be examined during the design and construction of the pipeline including trench stability, backfill selection and design, thermal properties of soils, and uplift resistance of the backfill materials. The predictions made during design are compared to the observed performance of the pipeline.

1.0 INTRODUCTION

Shell Todd Oil Services Ltd (STOS) are further developing the Maui Gas Field by installing a second platform (Maui B) to service a lobe of the field. For economic reasons it was decided to install this second platform as an unmanned satellite platform controlled from the existing Maui A platform. The Maui B platform will have only sufficient facilities to manifold the wells together and enable maintenance of the facility.

The raw wellstream fluid, comprising a mixture of liquid and gaseous hydrocarbons, carbon dioxide and water, is produced at temperatures above ambient. Of concern was that ice-like gas hydrates formed from methane and water at high pressures and at ambient temperatures, could accumulate and block the pipeline as the fluids cooled due to the lower sea temperature.

2.0 GEOLOGIC SETTING

The site is located some 35 kilometres off the South Taranaki coast (Figure 1). The site is contained within the so-called Taranaki Basin, and is situated within an area of deposition described as the "central mud belt". Silts have been accumulating in this area for the last 6000 years and the average rate of deposition has been on the order of 1 mm/year.

The muds on site vary in thickness between the Maui A and Maui B platforms, but are always over 6 m thick. A layer of sand lies under the muds.

While on the surface, the sea can get very rough, the on-bottom conditions are mild. The currents are less than 1 m/s even under nominal 100 year conditions, and the oscillatory motions due to wave action are similarly slow.

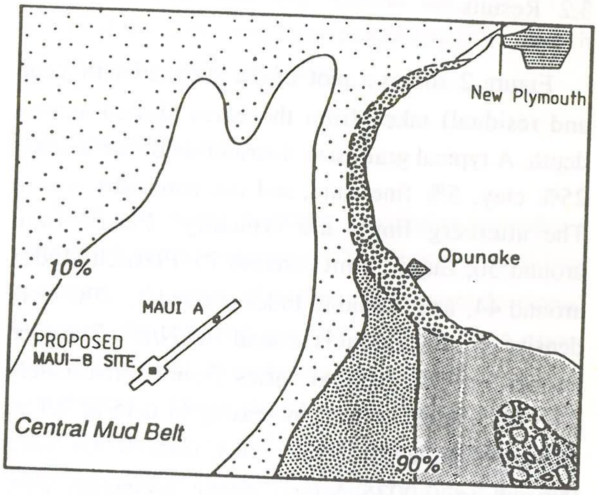

Figure 1 - Site Location

3.0 INVESTIGATION

3.1 Investigation

The general area is well known, as it has been extensively drilled for exploration wells. In addition there was the body of experience developed during the installation of the original A platform and its subsequent operation.

A site specific survey was performed which took four samples around the Maui B site, and four samples along the route (NZOI,1989). CPT's were taken at each location, and thermal conductivity was measured. The survey also included a seismic survey to determine the thickness of mud, seabed topography, and to determine whether there were any major obstacles that would impede the pipe installation process.

The samples were taken by a gravity piston coring device which obtained a sample 60 mm in diameter to a minimum depth of three metres .

Laboratory testing was performed on these samples in order to determine undrained shear strength (via shear vane), atterberg limits, natural moisture content, particle size distribution, and effective stress parameters through consolidated undrained tri-axial testing, and also shear box testing.

A second phase of testing was performed after the installation of the backfill to determine the particle size distribution of the backfill and the width of the dumping profile.

3.2 Results

Figure 2 shows a plot of the vane strength (peak and residual) taken from the cores plotted against depth. A typical grain size distribution of the muds is 25% clay, 5% fine sand, and the remainder is silt. The atterberg limits are typically Plastic limit around 30, Liquid limit around 75, Plasticity Index around 44, and Liquidity Index around 1. The bulk density of the material is around 16 kN/m^3 The cone strength of the material varies from approximately 0.05 MPa at the surface increasing to 0.15 at 2.7 m depth. Sleeve friction varies from 0.005 MPa through to 0.0075 MPa. Some anomalies were noticed in the cone plots where there were areas of no strength recorded. Thermal conductivity was measured to be around 1.2 w/m/°K. The tri-axial data was inconclusive in terms of reliable effective stress data. These results show that material is a very soft to soft sensitive clayey SILT.

The seabed surveys showed that the seabed is essentially flat, with no obstacles along the proposed route. The survey picked up some old anchor drag marks from exploration work done in the 1970's.

4.0 DESIGN REQUIREMENTS

A number of severe geotechnical constraints were imposed on the project. These constraints were briefly examined during the design phase, and were examined in greater detail during the post-design/pre-construction phase.

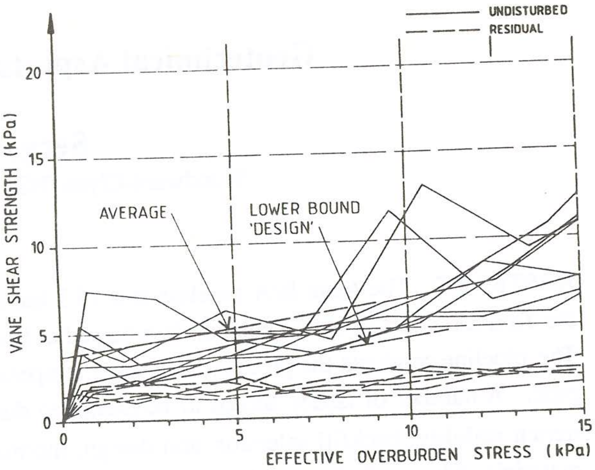

Figure 2 - Vane Shear Strengths vs Overburden Stress

4.1 Trench Behaviour

Initial concerns about the trench behaviour were expressed by the contractor. The plough was designed to provide a trench with 30° side slopes and a depth of 2 m, and the soils needed to be stable under these conditions for up to 3 months. No previous trenching had been performed in the area, and the behaviour was unknown. Precedents from other parts of the world were mixed. Stand-up time, percentage of failure, and deformation characteristics were required to be predicted both under the open state, and also in the long term backfilled state. Also the ploughability, pipe sinkage and other construction considerations were frequently discussed.

4.2 Pipeline Behaviour

The pipeline has a design operating temperature of 78°C, and the average seawater temperature is 12.3°C (RJ Brown -Murray North, 1990). The pipe diameter is 0.508 m, with a wall thickness of 22 mm. Figure 3 shows a typical design section. Because the pipeline will be laid at the ambient temperature, and the trench backfilled before the pipe is heated, an axial compressive force will be developed that is proportional to the amount of restraint, and the operational temperature difference.

The pipe line becomes prone to buckling depending upon such factors as backfill uplift resistance, and the deviation of the pipeline from the straight. Construction tolerances required that deviations from the straight in the order of 0.5 m be designed for.

4.3 Backfill Behaviour

A number of backfill issues needed to be considered. The primary issues were those of uplift resistance, and of thermal conductivity. There was also a requirement that the material remained stable under storm conditions.

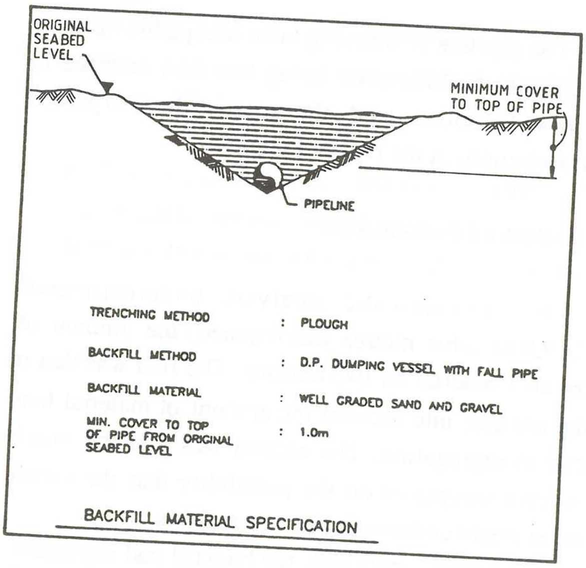

Figure 3 - Typical Design Section

5.0 INTERPRETATION AND ANALYSIS

The available information was required to be evaluated to provide information for the factors discussed above. The evaluated soil strength is shown by the dotted line. This line, while conservative, was chosen because it took into account concerns regarding the reliability of the soils information. These may be compared to the predictions made from the cone plots, and other information such as the anchor drag marks.

Soils modulii were calculated in a number of fashions, including the cone strength data, tri-axial data, as well as multipliers on the shear strength. These all indicated that the appropriate Youngs Modulus for the soil was around 1-2 MPa.

5.1 Trench Behaviour

Calculations based on the Taylor charts showed that the trench had marginal factors of safety of around 1.1-1.2, depending upon the assumed height of the spoil heaps. Given the paucity of the information and the variability, only a rough assessment could be made of the likelihood of failure along the trench length. The Vanmarke (1979) methodology was employed. This predicted that there would be approximately 1 failure per kilometre which would involve approximately 9 cubic metres each. An 'average' shear strength was employed for this analysis.

Some computer modelling was also employed in order to assess the likely deformation behaviour of the trench, both with and without the pipe. This indicated that there was some possibility of the trench sides flowing to the pipe level.

5.2 Pipe Behaviour

Shell's in-house buckling calculation procedures were employed to examine the likelihood of buckling occurring. A series of design charts were developed to assess the required amount of cover for a given degree of out of straightness, and length of out of straightness. These charts were developed initially for a 0.3 m, 0.5 m and 0.7 m out of straightness. The cover depths examined included 0.8 m, 1.0 m and 1.2 m for a gravel backfill cover. The uplift force for a critical 0.5 m imperfection is around 13 kPa.

5.3 Backfill Behaviour

Use of basic upheaval buckling formulae showed that the indigenous material did not have enough uplift resistance to prevent buckling. There were technical concerns about installing the indigenous material as a backfill material, because backplough technology was in its infancy. Hence a gravel backfill was preferred. A well graded material was needed to ensure the stability of the material under storm conditions, and to ensure that the material had a thermal conductivity of less than 2.5 W/m/°K. The contractor chose a material with D_{100} of 75mm, with a D_{50} of around 15mm, and D_{10} of 0.2mm.

The minimum required D_{50} was 3mm. Tests in the quarry showed that the material had a conductivity of around 2 W/m/°K

Theory was developed for use in the event of trench collapse (eg due to an in-filled anchor hole) utilizing a two layer backfill system. The bottom layer consisted of the flowed mud, with a gravel overlay.

Further probabilistic analysis was performed in order to determine the likely quantity of backfill that would be required. This showed that the likely quantity would be of the order of 75,000 cubic metres.

It was found that during the backfill operation that loss of material was occurring, raising the possibility that, if the fine material was being lost, then there was the possibility that thermal heat loss would occur due to convection within the fill as well as conduction. This involved the extension of existing theory (van Traa et al,1989) in order to determine the permeability at which convection would start becoming significant. It was predicted that the convection starts becoming dominant at a permeability of around 10^{-2} m/s for the situation at Maui, and that thermal heat loss increases rapidly once convection gets under way.

Various remedial options were developed in the event that those predictions were verified in the field. The one selected involved placing a remedial blanket over the existing backfill using a low-permeability material. The material finally selected was the indigenous sea bed material.

6.0 PERFORMANCE

6.1 Trench Stability

The trench remained stable after ploughing. There were some extremely minor failures only, which may in fact have been due to spoil material spilling back into the trench. Some spoil material that had clearly fallen was angular and had broken in a brittle fashion. In one area, the pipe had been pushed more than 1.5 m into the sea-bed during laying, leaving near vertical sides in excess of 1 metre high. Trench side deformation was minimal.

The fact that the material stood better than the analysis predicted suggests that sample disturbance weakened the samples considerably. Subsequent samples using a 100 mm tube showed that the real near surface shear strength was more in the order of 5 kPa. The degree of disturbance is assessed to be due to the diameter of the cores, and the transport used between time of sampling and time of testing. The sensitivity is clearly high, and this is well demonstrated in cores taken in the spoil heap, where the inter-clod strengths were very low.

The plough left a very straight and smooth trench, except for areas near each end, where there was some additional imperfections due to starting and finishing the plough and also the pipe push in.

6.2 Pipeline Buckling

The pipeline is behaving in an acceptable fashion, despite the backfill cover being less than designed in a few locations, and the greater than expected imperfections at the two end points.

6.3 Backfill Performance

The probabilistic analysis underestimated (119,000 cubic metres was required) the amount of backfill material for two reasons. The first was that it did not take into account the amount of material lost due to segregation. The second was that too much concern was placed on the possibility that the trench sides would collapse during the analysis.

As already mentioned, the backfill had segregated during the placement operation (through a fall pipe). This meant that the majority of the material left in the trench appeared to be quite coarse. This was confirmed by implication during the initial commissioning of the pipe, when the heat loss was very high, leading to unsatisfactory performance of the pipe. Model tests of the remedial blanket have since been carried out. It is likely that it will be installed to ensure satisfactory thermal performance of the pipeline

7.0 ACKNOWLEDGEMENTS

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