Monitoring Technology in Permafrost and Geotechnical Regions of MoHe-DaQing Pipeline

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ABSTRACT

MoDa pipeline is constructed from Mohe to Daqing since 2009，with 933 km length and 32 inch diameter. This Pipeline is operated by Petrochina Pipeline Company. It is the first completely buried oil pipeline constructed within the continuous and discontinuous permafrost zone of China where the average temperature in winter is about -30℃. This pipeline will transport roughly 300 thousands barrels of crude oil per day to northern markets of China from January 1st, 2011. It’s a significant cooperation for both Russia and China.

This paper will review the design, construction, and operational challenges of this pipeline. Analyses the happen possibility of frost heave/thaw settlement and slope instabilities in specific areas. Although traditional methods already were careful coincided, such as minimize thermal disturbance to the soil during construction, insulating permafrost slopes to minimize post-construction thaw, accommodating ground movement, and evaluating the effects of moving water bodies adjacent to the pipeline right-of-way，monitoring technology is still significant methods which include using thermostats sensors to monitor soil temperatures，using Brag fiber sensors to monitor material strain，using special displacement instrument to monitor frost heave and thaw settlement，Of course, the use of in-line inspection tools will be valuable as a supplement to conventional geotechnical monitoring.

According to these monitoring technical and data been selected，The relationship between pipe and soil have been made out for specific sites in order to assess the potential for frost heave thaw settlement and slope movement，and also include if this generated strains in the buried pipeline exceed the strain capacity. All these consequence will be significant for the integrity management of this pipeline. In the

end of this paper, several suggestions will be given to guidance next management work.

KEYWORDS

Monitoring Technology; Permafrost; Geotechnical; MoDa Pipeline; Frost Heave; Thaw Settlement; Slope Movement

INTRODUCTION

Mohe-Daqing pipeline is the first pipeline to be buried through away the permafrost regions of North China, with 926 km length and 32 inch diameter. The 441 kilometer pipeline was constructed over the 2009-2010 winter seasons, and has been in operation since January 2011. It is the first completely buried oil pipeline constructed within the continuous and discontinuous permafrost zone of China where the average temperature in winter is about -30℃. In the past several years，the extremely ambient temperature along this pipeline has arrived -52.3℃. From January 1st 2011, MoDa pipeline had begin to transport roughly 300 thousands barrels of crude oil per day to northern markets of China without any interruption. It's a significant cooperation for both Russia and China. According to the design figures，the input temperature of this pipeline is varied from -6.41℃ in winter time to 3.65℃ in summer which adjusted by the oil resources from Russian and also serious of tanks located in Mohe station. The oil temperature varying in a little step with natural variations in the surrounding ground temperature.

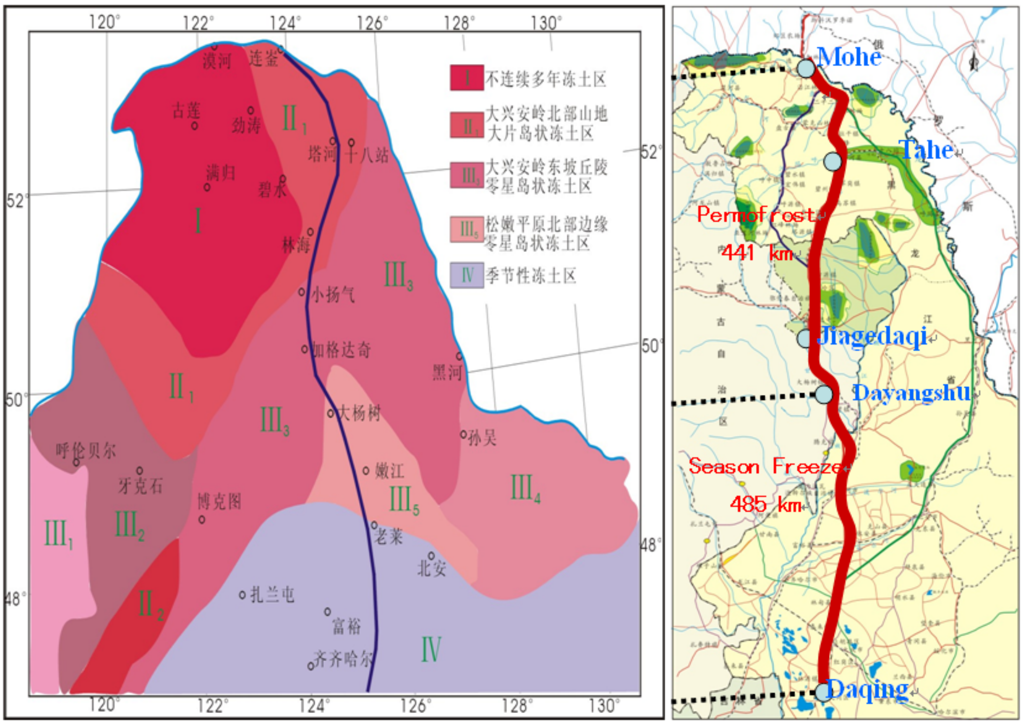

Figure 1. Permafrost Distribution of MoDa Pipeline

The effects of discontinuous permafrost on a pipeline are significant and different which include frost heave, thaw settlement, slope instability, ditch subsidence, and forest fires affecting the ground thermal conditions along the right-of-way. Coinciding with all these challenges, several traditional methods already were careful used. Such as using special layers outside the pipeline to prevent heat estrange between the soil and pipeline. Improve the thickness of the pipes which through away some special Permafrost region. These methods also include change soils which surround the pipes in specific areas. All these solutions are focused on minimize thermal disturbance to the soil during construction and operation time. Along the Moda pipeline right-of-way, a large number of slopes were initially considered subject to instability, in order to solve this problem, many slopes were designed with insulation in the form of wood chips to retard the post-construction thaw of ice rich permafrost soils, which would otherwise be expected due to the changes in ground cover and the loss of natural insulation from the organic layer and vegetation along the right-of-way that occurred during the pipeline construction.

Although so many methods already implicated in this pipeline, monitoring technology is still significant in permafrost and geotechnical regions which include using thermostats sensors to monitor soil temperatures, using Brag fiber sensors to monitor material strain, using special displacement instrument to monitor frost heave and thaw settlement, using slope indicator to monitor slope movement. This paper will focus on the principle and application of all these monitor system which already used in some specific regions as well as the result during the past several months. Of course, to ensure safety and integrity, several advice and suggestion will be given at the end of this paper to guides the next management works of this pipeline.

PRINCIPLE AND INSTALLNATION OF MONITORING SYSTEN

Soil Temperature Monitoring System. Except traditional safety risk, such as third party damage, cathodes protection and so on, the most significant challenge for MoDa Pipeline is frost heave, thaw settlement and slope stability. There are almost 441km pipelines through away permafrost region. In order to know weather the soil around the specific pipeline is freeze or not, temperature around the pipe is most important. By continue or discontinue monitor temperature circle of the soil, you can recognize the direction of the permafrost region. It also can help you to make a plan to deal with the potential risk. According to the pipeline right-of-way reconnaissance and survey in permafrost terrain, we select 20 typical monitoring site from MoHe station to JiaGeDaQi station which is the most potential geotechnical disaster happened area.

According the monitoring temperature statistics of the permafrost terrain along this MoDa pipeline right-of-way, the every year scope depth of temperature change in this area is about 12m. Considering the extremely weather, we monitoring 15m below the ground for original soil temperature which is about 20m far from the pipeline right-of-way. To monitoring pipeline temperature effect area, we choose 8m for each monitor unit. This figure come from the calculator with several input, such as operate temperature, specification of the soil, and also from some permafrost reference papers and experience. Each monitor unit composed with five PVC poles, one data storage system, a lot of thermometer sensors and some signal cable. Temperature sensors installed on the surface of the PVC poles. The distance of the sensors is 20cm for the first four meter and then 50cm for the last 4 meter. For original soil temperature monitoring unit, the distance of the sensors is 20cm for the first five meter and then 50cm for the next three meter and 1m for the last seven meter. The distance for each pole is mark as the figure 2.

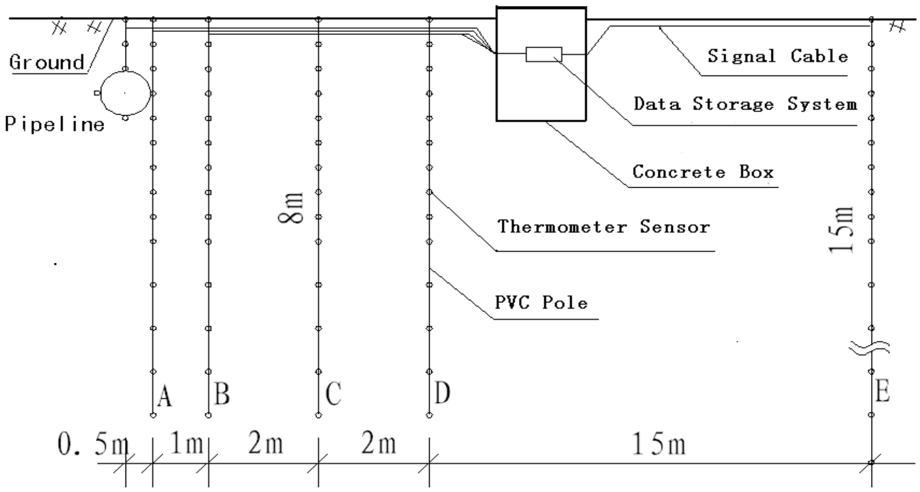

Figure 2. The sketch map of MoDa Pipeline Soil Temperature Monitor Unit

After this system finished construction, we can choose the frequency of all the data from each sensor. All this data will storage in the data control and select system which fixed in the concrete box. Because all this permafrost region construction is in winter season, to install the monitor system is also have to finish in winter, except face up the challenge of the weather, some necessary special instrument and equipment is most significant. Figure 3 shows the technical member worked on site.

Figure 3. Technical Worker Install Temperature Sensors on Site In Winter Time

Pipeline Material Strain Monitoring System. Due to the special permafrost ground conditions of the MoDa Pipeline route as described in Figure 1, the difference between the oil temperature and ground temperature can lead to the degradation of permafrost or alternatively ground freezing where the ambient temperature pipeline crosses a frozen/unfrozen boundary in ground conditions along the route. Such changes in the ground thermal conditions can result in ground movement and associated strains and deformations of the pipeline. In regions with fine grained frozen soils, when the volume of ice decreases during melting, it can cause thaw settlement. Correspondingly, freezing of saturated fine grained soils during the winter months, or pipeline downstream of a frozen to unfrozen ground transition along the pipeline, can cause ground uplift conditions. As this settlement and uplift is not uniform along the pipeline route, bending strains may be induced to the pipeline. Finally, in regions where the pipeline traverses a slope, seasonal ground thawing or thawing of permafrost can result in excess pore water pressures developing in the slope. These pore water pressures can lead to slope movement. This slope movement can generate significant axial and bending loads to the pipeline.

If the ground movement of the pipeline induces strains to the pipeline that are sufficiently large, this would cause wrinkling of the pipeline on the compression side of the pipe, or alternatively tensile fracture could occur on the tensile side of the pipe. So monitoring pipeline material strain in specific region is most important and significant. After pipeline right-of-way reconnaissance and survey in permafrost terrain, also considering investment and construction cost reason, we select 6 typical monitoring systems from MoHe station to JiaGeDaQi station. The monitoring length for each unit is 200m. Considering power and special environment on site, we choose FBG fiber sensors. Figure 4 shows the sketch map of each strain monitoring system in one specific place. Every system composed with 18 unit sensors which located on the surface of he pipes and composed with four FBG sensors. Three of these sensors is monitoring strain, and one for ambient temperature. The function of the temperature sensor is to compensate the affect of the strain change come from soil temperature. The distance for each monitoring unit is about 12 meter and all connected with fiber one by one.

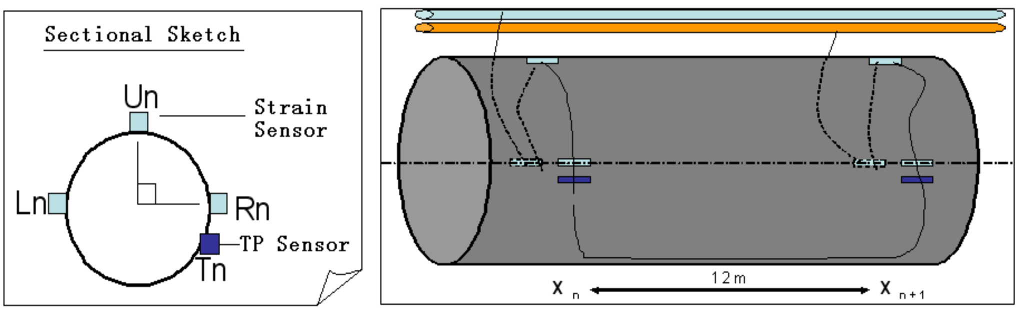

Figure 4. Sketch Map of Each Strain Monitoring System

The important things for strain monitoring system are how to choose the installation place and how to ensure the success ratio. Also this system is very expensive both for construction and data collection. The advantage of this monitoring system is we can get the real strain data at any time. From the monitoring data we can estimate if the pipeline strain is exceeded of not compared with the strain capacity of the pipeline. The compressive strain capacity and the tensile strain capacity of the MoDa Pipeline have been evaluated using a combination of full scale testing and analytical methods. Figure 5 shows the photo during construction time. All these works have to finish before the pipe through into pipeline ditch. Also special protection layers must be used to keep all the sensors lived.

Figure 5. Strain Monitoring Sensors Install on Site in Winter Time

Pipeline Displacement Monitoring System. Although Soil temperature monitoring system and Pipeline strain monitoring system can calculate indirectly about the pipeline states. In fact, pipeline management need more about displacement of the specific site. Figure 6 shows a simple method to monitoring pipeline uplift or settlement. This system composed with two parts, one is showed as Figure 6.

A special steel pipe weld in a round clip which fixed together outside the pipeline with bolt. When the pipeline moved, this steel pipe will also move up and down with the pipeline. Outside the steel pipe is a special sleeve which can protect the steel pipe separate with soil around it. Of course, the sleeve may freeze together with permafrost soil, but the steel pipe inside the sleeve is relative freely. In the end of the steel pipe we plaster a reflection clip to receive the laser light come from the distance measure instrument. This part installed in the pipeline which frost heave and thaw settlement were supposed to be easily happened. Considerable you can not monitoring so exactly, always in one unit we install five or six units which distance 100 meters from one to the other. In order to measure how many distance the pipeline moved, we also need another part which is fixed absolutely stable in the ground. The distance below the ground is depending on the deep of the freeze in that area. Always we choose 30m deep to ensure this part will never moved with froze soil.

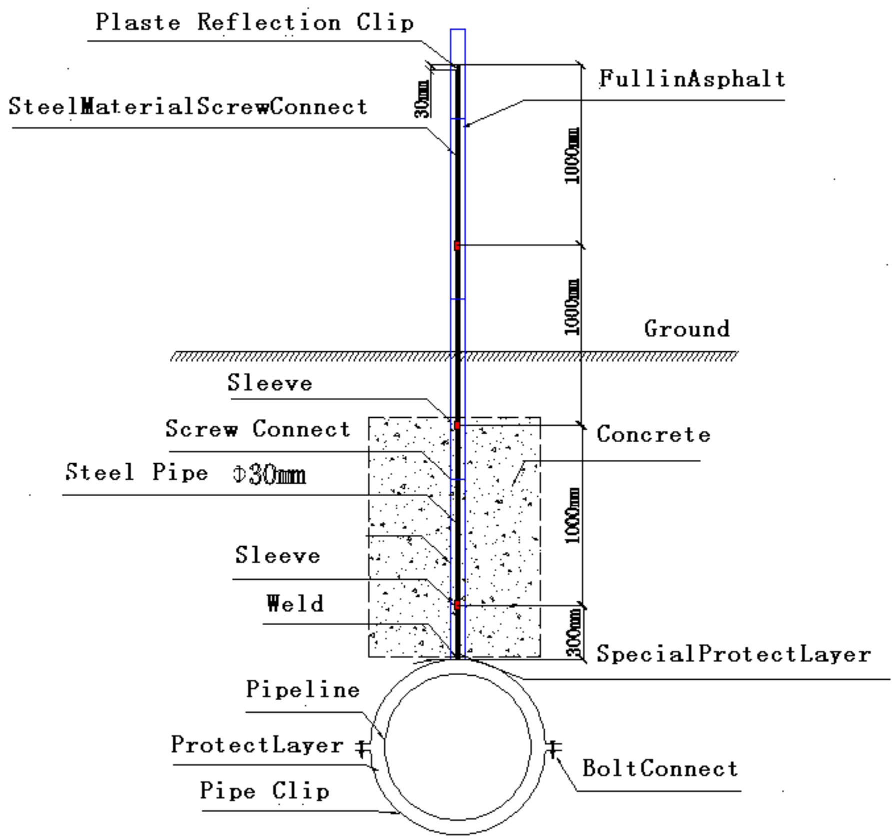

Figure 6. Sketch Map of Pipeline Displacement Monitoring Unit

In MoDa pipeline permafrost region, 68 monitoring units were chosen to install at 13 areas. Measurement data were collected once for each month as shows in Figure 7. From different data of each unit for each time, it is easily to calculate the displacement for this specific monitoring place which can help us to make a decision for pipeline safety management.

Figure 7. Technical Worker Use Theodolite to collect data on Site in Winter Time

DATA ANALYSE AND ASSESMENT FOR THE PAST TWO MONTH

Although all these monitoring system had finished installation before MoDa pipeline is business operated. Until now, some function of these monitor system is still not as successful as been designed before. Soil temperature monitoring system just finished test data selection. Stain monitoring system selected data two times. Fortunately displacement monitoring system which finished at October 2010 had already collected three times data. The first time is before oil entering pipeline, second is just after operating and third is operating one month later.

After analyzing all these data, the soil temperature around pipeline is from -2.89℃ to 1.68℃, this means some areas is already froze and some area is still unfreeze. Yet these data are still need to monitoring and validate later. The strain monitoring data shows when pipeline entering the oil, the pipeline strain all have some specific change, but all these data shows that generated strains in the buried pipeline were not exceed the strain capacity. Figure 8 show three times monitoring data for JM208 region which is typical sites with geotechnical issues. This region was composed with 9 monitor unit and entered oil during Dec1-Dec5. First data was collected before oil entered into pipeline and as zero. This figure proved that when the oil entered pipeline, a little displacement happened to balance the soil and then stable later.

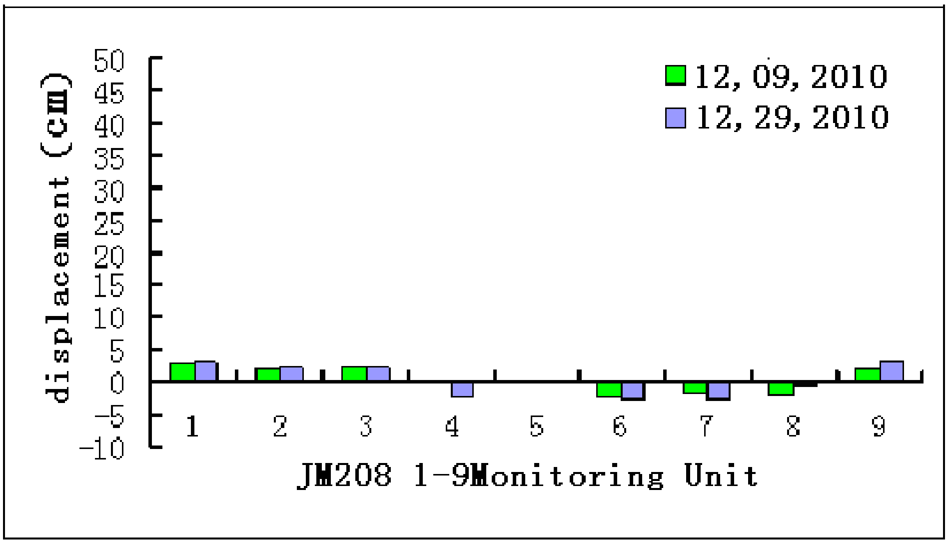

Figure 8 Three Times Monitoring Data for JM208 Region

CONCLUSION

MoDa pipeline is the first pipeline to be buried through away the permafrost regions of North China. It's a significant cooperation for both Russia and China. There are so many specific sites with geotechnical issues along pipeline Right-Of-Way. Although traditional methods already were careful coincided, monitoring system is still necessary to supervise and manage the permafrost region.

The soil temperature distribution around pipeline is one of the key parameters to reflect environment impact of the pipeline. According to soil temperature monitoring system, the change state area and extension of permafrost soil are estimated in real time. It is also significant to assessment potentially frost heave and thaw settlement in the permafrost region.

The pipeline strain conditions are significant in discontinuous permafrost for difference in oil and ground temperatures can degrade permafrost or cause ground freezing. This ground movement can strain and deform pipeline. To monitoring pipeline strain in specific area especially in end of slope is very important. Mathematics models have been developed to assess that if the potential generate strains in the buried pipeline exceeds the strain capacity.

Pipeline displacement monitoring system designed in this paper is very convenience mechanic system. By using theodolite the data is easy to collect. It is a direct method to monitoring frost heave and thaw settlement and being strongly suggested to application.

LOOKING FORWARD

Although several monitoring system are given in this paper, with the times passed by more and more useful data will be collected, still these system can not covered all permafrost region. The use of in-line inspection tools (GEOPIG) will be valuable as a supplement conventional geotechnical monitoring. Moda pipeline have plan to detect dents/ovalities/wrinkles also accurately measures pipe position and curvature through GEOPIG in-line inspection tools every year.

Except monitoring system and using GEOPIG, in order to management and maintenance this permafrost pipeline, routine activities, such as thaw depth investigations, visual patrols, sites reconnaissance annually are all more important, especially with the potential climate change impacts along the right-of-way. However, new measuring instruments and areas of interest should also be activated as they are required.

With the increase of pipeline construction in China, more and more pipelines will have to cross through permafrost terrain. This paper can provide useful reference for pipeline design, construction and management.

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