First Middle East Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures
8 – 10 February 2011, Dubai, UAE

SMAR 2011

Field Monitoring of an In-service Thrust Anchor Block and Pipeline

M. K. Rahman[1] , A. K. Abu Ghdaib[2], Aftab Ahmed[3], S.M. Shaahid[4], S. Rehman[1]

[1]Research Engr (Associate Professor), Center for Engineering Research (CER), King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia
[2]Engineering Specialist, Consulting Services Department, Saudi Aramco, Dhahran, Saudi Arabia
[3]Research Engr (Assistant Professor), CER, KFUPM, Dhahran, Saudi Arabia
[4]Engineer-I, CER, KFUPM, Dhahran, Saudi Arabia

ABSTRACT: A research program was conducted to investigate the notion that the size of concrete thrust anchor blocks for cross-country hydrocarbon pipelines, designed as per current industrial standards, can be reduced substantially. Field monitoring of an in-service large diameter hydrocarbon pipeline and an anchor block at a remote pig launching/receiving station was carried out to investigate this aspect. Crude oil temperature and pressure, stress, and strain in the pipeline and movement of the anchor block were monitored using about 30 sensors installed at the site for a period of three months under various operating conditions of the pipeline. Continuous crude oil flows through the pipeline interjected by two events involving shutdown and restarting the flow showing very small movements in the concrete thrust anchor block. The stress and strains in the pipelines gave an insight into the performance of the pipe anchor block system. Analysis of the data obtained from field monitoring of the pipe anchor block system indicated that size of the anchor blocks could be decreased.

1 INTRODUCTION

Large diameter buried pipelines are used extensively in Saudi Arabia for cross-country transportation of hydrocarbons in fluid and gaseous states. These pipelines carry hydrocarbons under pressure and at elevated temperatures. Passive earth resistance and frictional forces from soil pipeline interaction restrain the straight portions of the buried pipeline resulting in the generation of stresses due to pressure and thermal differential. These stresses are catered for in the design, and the thickness of the pipeline depends on limiting these stresses to below the allowable stresses (Abduljauwad et al., 2006 and ASME B31.4, 1998).

The buried cross-country pipelines emerges from the ground at intermediate locations along their routes, such as pumping stations, gas-oil separation facilities, pig launching and receiving stations and at the end near refineries. For the segment of pipeline in the transition zone, at the point of its egress from a buried state near above ground facilities, vertical bends are provided and the state of stress and the restraint condition changes and large harmful movements in the pipeline can take place in this zone. The movement in the pipelines at these locations is precluded by embedding them in concrete anchor blocks (Peng 1978 and ADP-L-044, 1986). These anchor blocks are designed to withstand the full thrust and pull forces due to thermal expansion and contraction and internal fluid pressure. The concrete anchor blocks are designed as per current industrial standards (SAES L-440, 2005 and SAES L-051, 1998). The design equations postulated in these standards for computing the load resisting capacity of these anchor blocks is based on conservative lateral earth resisting theories and several simplified approximations. The size of these concrete anchor blocks needed to preclude movement are enormous, and in some cases several hundred cubic meters of concrete is required in remote desert locations for construction of these anchor blocks, Figure 1. It is suggested by field engineers that the use of current design equations results in an uneconomical design and very large sized blocks. This opinion is enhanced by the fact that the anchor blocks designed in the early 1980s were smaller in size for the same diameter pipelines. This paper presents the results of field monitoring of an in-service anchor block and pipelines. The stresses and strains on the buried and exposed pipeline, and the movement of the anchor block under different operating conditions of the pipeline was investigated.

2 ANCHOR BLOCK PIPE INSTRUMENTATION AND MONITORING SCHEME

In a buried cross-country pipeline, longitudinal movements due to thermal gradient from hot crude oil and the Poisson's effect from internal pressure are restrained by soil friction. In the transition zone from buried to exposed state, the frictional force reduces from the point of virtual anchorage to zero at point of emergence from the ground. In this zone, the pipeline undergoes significant movements and has to be restrained by providing anchor blocks. The objective of the monitoring program was to measure these movements and stresses possible reduction of anchor block size. The sensors for monitoring of anchor block and pipeline were selected to measure movements in the block, strain in the buried and exposed portion of the pipeline, temperature in the pipeline and environment, and internal pressure in the pipeline.

The pipeline and the thrust anchor block is located in the Abqaiq desert at a pig launching station about 50 km from Dhahran. This site was selected because the pipeline could be opened and closed several times, as it is a bypass line which operates when other parallel lines are not in service due to maintenance. The 116.8 cm (46“) diameter pipeline, Figure 2, carries hot crude oil. The concrete thrust anchor block which was constructed in 1980 is 6 m long, 3 m wide and 3.6 m in height.

Figure 1. Concrete anchor block under construction.

Figure 2. Instrumented 46” dia oil pipeline.

Thirty sensors were installed on the pipeline and anchor block. The sensors installed and their purpose are as follows:

- Five linear motion transducers (LMTs) for measuring the horizontal movements in the thrust anchor block.
- Three LVDTs (Linear Voltage Displacement Transducer) for measuring any vertical motion or rotation in the thrust anchor block.
- Four strain gauges and two stress gauges in pit #1 (for buried pipeline at 20 m from the anchor block) in a longitudinal direction.

- Four strain gauges, two in a longitudinal direction and two in a transverse direction in pit #2 (for buried pipeline near the thrust block at 9 m from the block).
- Two stress gauges, one in a longitudinal and one in a transverse direction in pit #2.
- Three strain gauges and one stress gauge on the exposed pipeline.
- Two thermocouples for measuring temperature of the crude in the exposed pipeline.
- One thermocouple in the buried pipeline at pit #2.
- One temperature sensor for measuring environmental (ambient) temperature.
- One pressure sensor for measuring oil pressure in the pipeline.

For monitoring of buried pipelines, two pits located at 9 m and 20 m from the anchor block on the downstream side were excavated, and sensors were attached on the exposed surface of the pipeline, Figure 3. These pits were then backfilled with soil. For monitoring of anchor block, it was exposed partially by excavation of sand on one side and displacement transducers were fixed on it to record the horizontal and vertical movement of the block, Figure 4.

Figure 3. Buried pipeline exposed for fixing sensors.

Figure 4. Concrete anchor block with LMTs.

The pipeline was operational when the sensors were attached to it. Sensors in the exposed portion of the pipeline are shown in Figure 5. The sensors were connected to a data logger, Figure 6, and the data was continuously monitored and recorded at 10 minute intervals. The data logger was housed in a mobile lab at the site and the data was transmitted to a remote computer at 4-hour intervals through a mobile phone connected to the data logger.

Figure 5. Strain gauges and thermocouple on pipeline.

Figure 6. Data logger in the mobile laboratory.

The stresses and strains in the pipeline, movements in the anchor block and fluid and ambient temperature was monitored for a period of three months starting from July 2006 and ending in September 2006. The pipeline was operational during this period with the exception of two planned interruptions. The oil flow valve was closed two times, the first closure took place from July 17-22, 2006, and the second from August 10-15, 2006, during the monitoring period. The flow interruption was planned to evaluate its effect on stresses and strains in the pipeline and the movement of the thrust block due to thermal and pressure effects. The experimental data collected during the monitoring period and its analysis are presented.

3. MONITORING DATA AND ITS ANALYSIS

3.1 Ambient and Mobile Lab Temperatures

Figure 7 shows the ambient and mobile-lab air temperature variations during the measurement period. The ambient air temperature varied in the range of 22 ºC to 52 ºC, whereas the temperature variation in mobile lab was in the range of 29 ºC to 36 ºC, however, with a nonfunctional air-conditioning system the temperature in the mobile lab rose to 55 ºC.

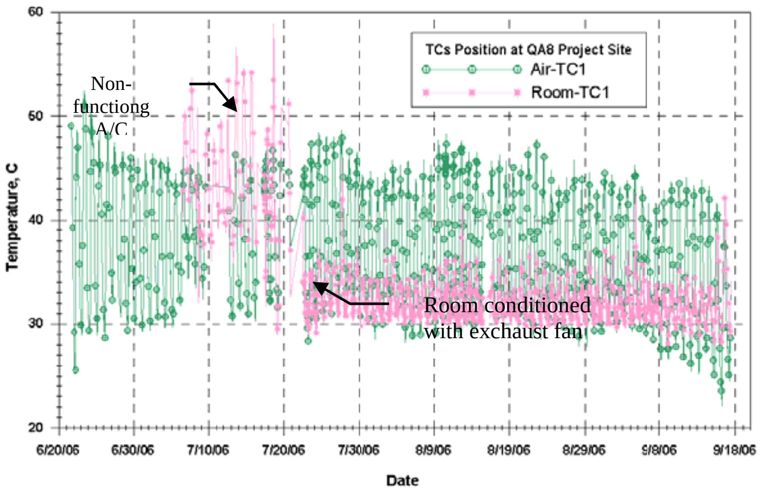

Figure 7. Ambient and mobile-lab temperatures at the Abqaiq site.

3.2 Thermal Response of Buried and Exposed Pipeline

Figure 8 shows the temperature variations on the exposed and buried pipe surface during the monitoring period. The temperature on the surface of the buried pipeline represents the temperature of the hot crude oil flowing through pipeline. During normal operation of the oil pipeline, the temperature variation on the exposed as well as buried pipe surface was found to be in the range of 63 °C to 70 ºC with the temperature in the buried pipeline being slightly higher. During the first closure of flow in the pipeline, the temperature of the buried pipeline dropped gradually over a period of five days from 66 ºC to 55 ºC, dropping by only 10 ºC. In the second shutdown period, the temperature drop was 14 ºC. The temperature in the buried pipeline did not reach the ambient soil temperature of 30 ºC. Topography at the site indicated that the anchor block is located in a saddle region and the buried pipeline remains filled with high temperature oil. In the exposed pipeline, the temperature dropped sharply to 48 ºC and then oscillated between 46 ºC and 52 ºC. The temperature rose to 68 ºC on resumption of oil flow.

3.3 Internal Pressure in the Crude Oil Pipeline

Figure 9 shows the internal pressure in the pipeline transporting the crude oil. The internal oil pressure shows cyclic behavior with pressure variation in the range of 1 MPa to 2 MPa. During the valve closure period the pressure in the oil pipeline dropped to zero from a pressure of 1.3 MPa. Prior to the second shutdown period, the pressure in the pipeline was about 2.0 MPa. The average pressure in the pipeline during operational period lies in the range from 0.5 MPa to 1.0 MPa with occasional peaks of 2.0 MPa.

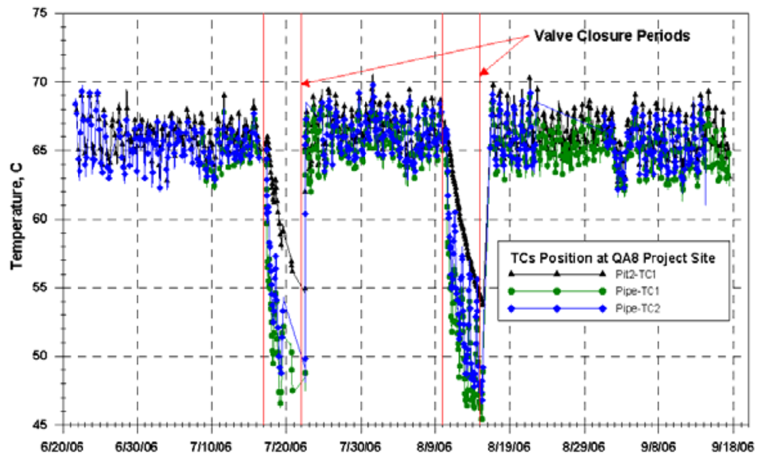

Figure 8. Surface temperatures on buried and exposed pipeline.

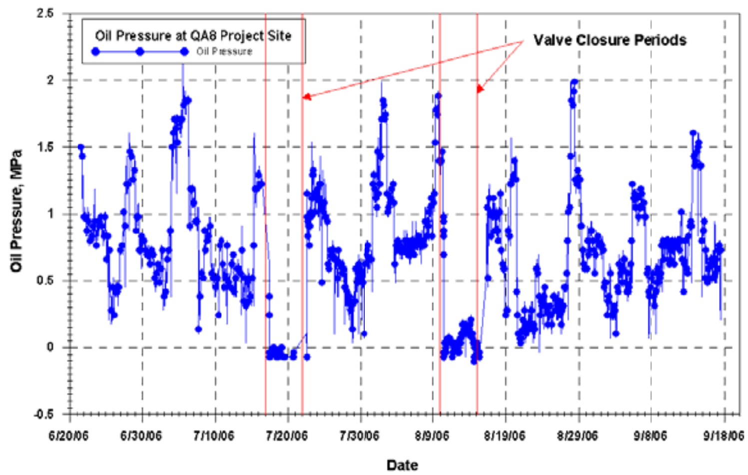

Figure 9. Oil pressure in the pipeline.

3.4 *Strain Response of the Pipeline in the Exposed Portion*

Figure 10 shows the strain measured on the exposed portion of the pipeline. The strains at two locations on the pipeline lie in the range of -2,900 με to +500 με with cyclic variation. The strain gauge SG1, located in the upper portion of the pipeline, has significantly higher compressive strain as compared to SG2, which is located at the bottom side of the pipeline. The tensile strain measured in the gauge SG2 was about +450 με to +500 με. The tensile strain in the exposed portion of the pipeline results from bending due to self-weight of pipe and its contents. During the valve closure period, the strains in the exposed pipe did not show any major changes.

3.5 *Strain Response of Buried Pipeline*

Strains measured in a buried pipeline include the compressive strain generated due to frictional soil restraint to thermal expansion, tensile strains due to Poisson's effect of hoop stresses from pressure, and compressive strains resulting from restraint to longitudinal movement due to pressure at the ends. Figure 11 shows longitudinal strain in a buried pipeline in pit #1. The strain in the pipe varies between -1,560 με and +600 με with a cyclic variation pattern. During the first valve closure period the cyclic variation continued with decreasing amplitude. The strain amplitude varied between +200 με and -1,100 με initially, which was reduced to +100 με and -

700 με after 3 or 4 days of valve closure. A sharp change with strain varying from +600 με to -1,500 με took place when the flow of oil resumed in the pipeline. Figure 11 shows that about 80% of the data points are in compressive zone, clustered in the range of -600 to -1,000 με. Consequently, a substantial number of data points also lie in the range of -1,000 to -1,400 με. The measured tensile strain is observed to be in the range of +200 με to 600 με.

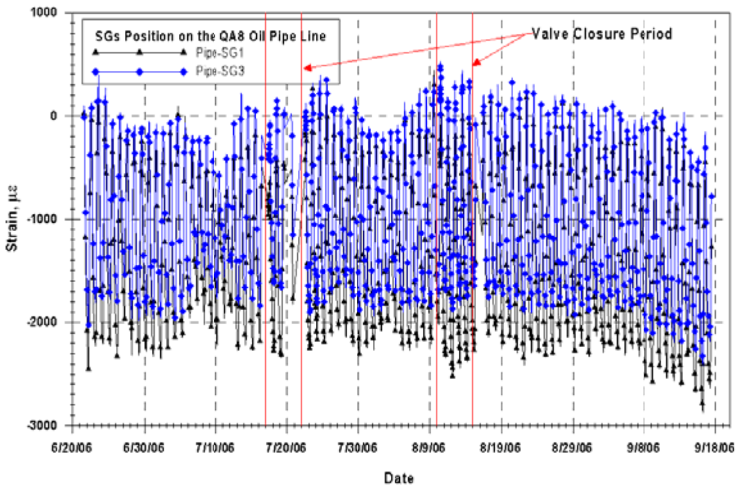

Figure 10. Strains on exposed oil pipeline.

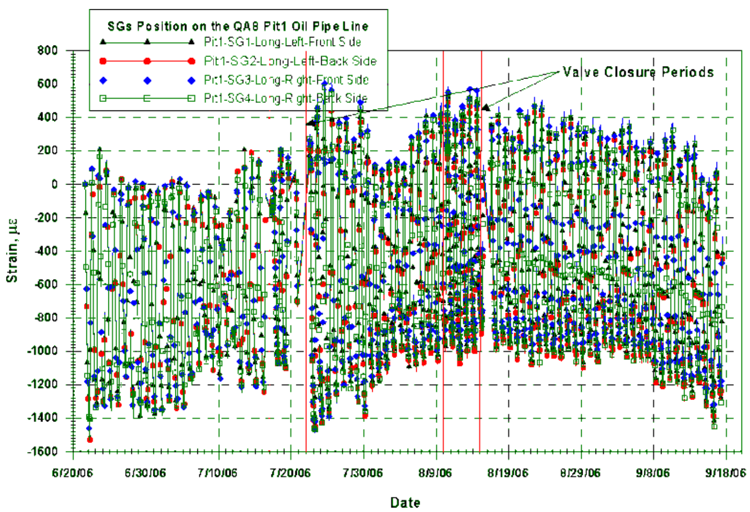

Figure 11. Strain in buried pipeline in pit #1.

Measurements on pipeline in pit #2, Figure 12, shows that the longitudinal strain is mostly compressive with occasional jumps in the tensile range. The maximum compressive strain is mostly of the order of -800 με. The maximum longitudinal tensile strain is observed to be about +150 με to +200 με. During the first valve closure event, the compressive strain slowly tapered off to -600 με, which increased again after the opening of the valve. During the second valve closure period however, the scenario is different with strain varying between +175 με and -750 με. The measured longitudinal strains clustered in the range of -600 με to -800 με is significantly lower than the strain measured on the pipeline at 20 m distance from the anchor block. This reduced value of compressive strain is an indication of the fact that the compressive strain near the block is released due to small movements observed in the anchor block. The transverse strain in the pipeline varies substantially with values between -1,200 με to 800 με.

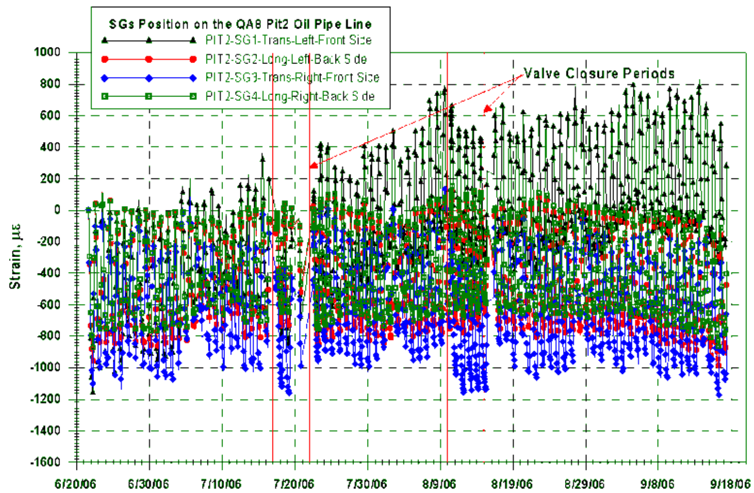

Figure 12. Time series plots for strain in buried pipeline in pit #2.

3.6 Stress Response in the Exposed Pipeline

Figure 13 shows the variation of pipe stresses measured in the exposed and buried oil pipeline. The stresses for the exposed pipe surface have been observed to lie in the range of -400 Mpa to +100 MPa. The maximum stress in exposed pipeline is 400 MPa, which is about 96% of SMYS (Specified Minimum Yield Strength). This is a high value as stresses in the pipe should not exceed 90% of SMYS. The high stresses measured in the exposed pipeline could be due to the restraint provided to the movement of the pipeline, which was visually observed at the site. This restraint probably results in high compressive stresses.

3.7 Stress Response in the Buried Pipeline

The longitudinal and transverse stress on the buried pipeline in pit #2 is shown in Figure 14. The longitudinal stresses on the pipeline reaches to a maximum value of 50 MPa (tensile) and a minimum value of -200 MPa. The transverse stress in the pipeline is compressive with values varying between 0 MPa and 200 MPa. There is no significant effect on the stress regime during the shutdown period. The maximum observed longitudinal and transverse stress is 0.54 SMYS, which is lower than the allowable stress of 0.72 SMYS. The longitudinal stresses measured at two locations in pit #1 (Figure not shown) vary between +75 MPa (tensile) to -350 MPa (compressive). The measured stress data points also show compressive stresses ranging from -375 MPa to -400 MPa. The maximum observed stresses in buried pipeline in pit #1 is about 0.85 SMYS, which is greater than the allowable stress of 0.72 SMYS, but less than 0.9 SMYS.

3.8 Movements in the Anchor Block

Figure 15 shows measured vertical displacement of the thrust anchor block. During the second week of July, there was a huge sand storm, which disturbed the position of the sensors resulting in high displacement, but later the sensors showed oscillations around the same value. The vertical displacement oscillated within 0.5 mm for most of the period with a maximum measured absolute value of 3 mm.

Figure 16 shows the horizontal movement of the anchor block. The closing and opening event of the flow valves did not have any effect on the horizontal displacement of the anchor block. The average horizontal displacement was found to lie in the range of 0.5 mm to 1.5 mm. It was observed that the horizontal or vertical movement in the anchor block due to pressure and temperature changes in the pipeline during operation and during the events when flow was closed and re-started is negligible. It is very important to note that the anchor block at this site was designed as a drag anchor block in 1980 and the size of this block is much smaller as compared to the other anchor blocks, which have been constructed in the recent years.

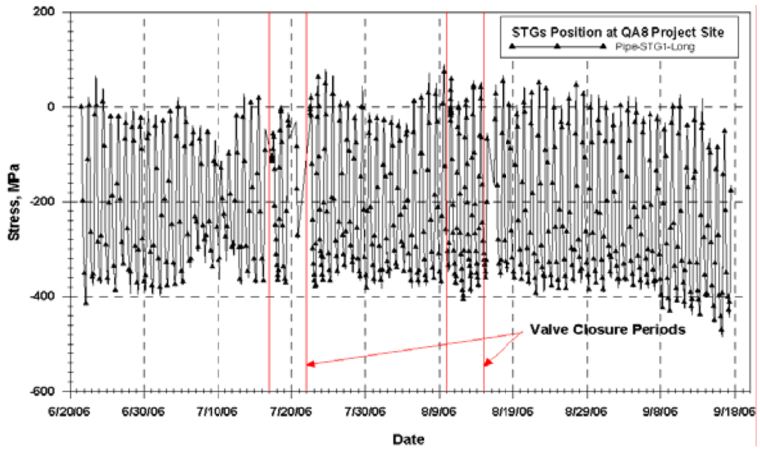

Figure 13. Stresses measured on exposed pipeline.

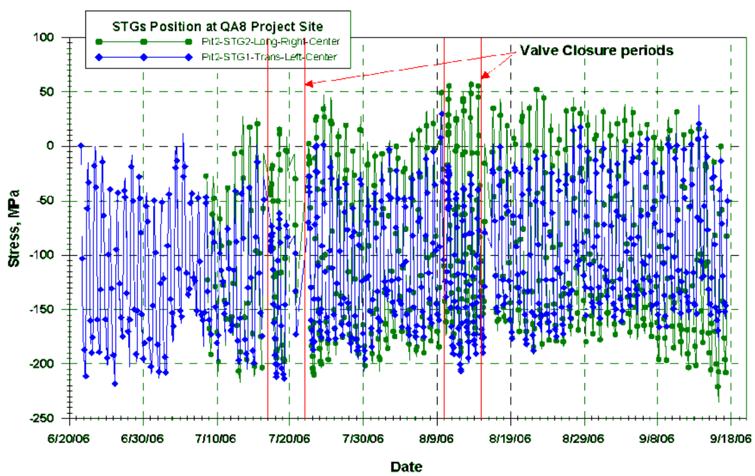

Figure 14. Stresses on buried pipeline in pit #2.

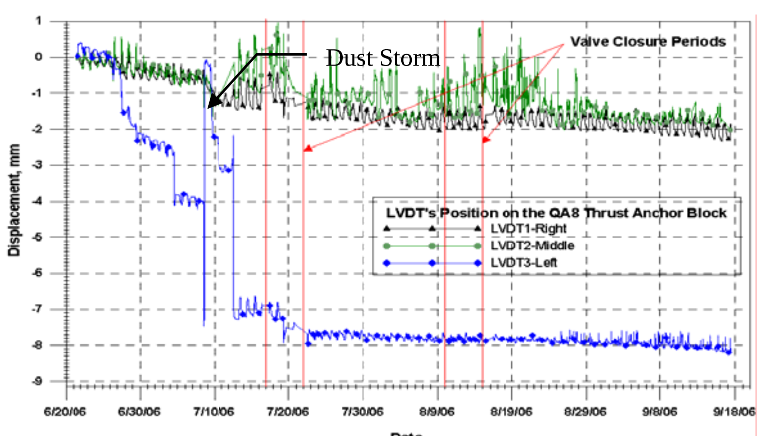

Figure 15. Vertical movement of anchor block.

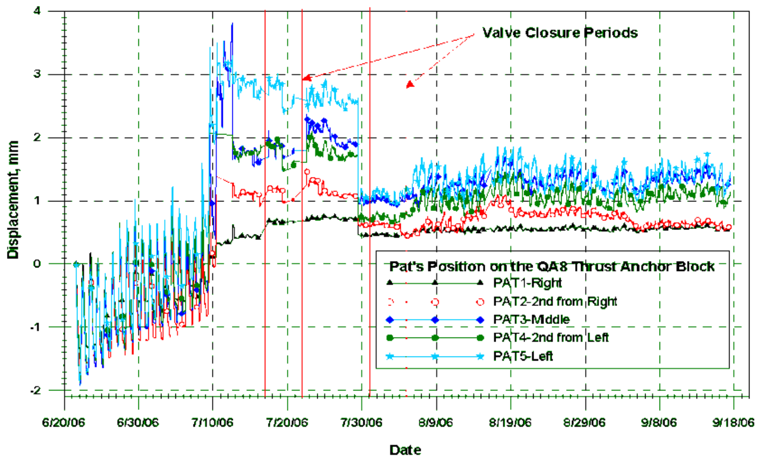

Figure 16. Horizontal displacement of thrust anchor block.

4 CONCLUDING REMARKS

The field monitoring carried out on an in-service anchor block demonstrated that the anchor block did not undergo any significant upward, downward or rotational movement due to temperature and pressure induced stresses during the events of crude oil flow stoppage and resumption in the pipeline. No significant movement in the anchor block took place when the pipeline was in service. The small movements observed, however, releases the stresses in the pipeline near the anchor block. High stresses were measured in the exposed pipeline, which can be attributed to observed restraint to free movement of the pipeline under thermal changes.

ACKNOWLEDGMENTS

The authors would like to thank the Research Institute at King Fahd University of Petroleum and Minerals (KFUPM) and Saudi Aramco for providing the support for conducting this research. This work was carried out under Saudi Aramco Contract No. 6600011900 and KFUPM Project No. CER 2275.

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