A New Design Method for Anchor Blocks of Gas Transmission Pipelines

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ABSTRACT

Natural gas transmission pipelines transport the natural gas at elevated temperatures and high internal pressures. The pipelines will expand when they are put into operation under the influence of increased internal pressure and temperature. The movement due to such expansion is significant for large diameter pipelines which operate at a high pressure and elevated temperature. The pipeline needs to be restrained near compressor stations in order to prevent the transmission of such movement to equipment and facilities within the station. Concrete anchor blocks are commonly used to restrain the movement of buried pipelines on both sides of compressor stations. Anchor blocks for transmission pipelines are usually massive because of the high axial stress in the pipe which results in large thrust force. Current design procedures are usually based on providing an adequate margin of safety against block sliding, block overturning and soil bearing pressure. This paper presents the results of an analytical study on the response of soil, pipeline and anchor block at different operating pressure and temperatures. Nonlinear finite element analyses which include modeling of soil-pipe and soil-block interactions are carried out to evaluate the design procedures. The results indicate that the concept used in the current design procedures is fundamentally flawed because it is based on controlling forces rather than displacements. Based on the results of these analyses, a more rational design procedure which is based on controlling the displacements is introduced. The proposed design procedure results in a substantial reduction of the size of anchor blocks.

KEYWORDS

Anchor Block, Pipeline, Design Method, Finite Element Analysis, Soil-Structure Interaction

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1. **Introduction**

Natural gas transmission pipelines transport the natural gas at elevated temperatures and high internal pressures. When the pipeline is put into operation, it tends to expand along its length due to internal pressure and temperature. In buried pipelines, the pipe movement due to such expansion is fully restrained by the surrounding soil except for a relatively small length near the ends where the axial displacements are significant for large gas transmission pipelines. The large axial displacement may cause serious damage to equipment and structures attached to the pipeline. In order to reduce the axial displacement, the pipeline is usually restrained near compressor stations by anchor blocks. Massive concrete anchor blocks are commonly used in gas transmission pipelines to resist the high thrust force resulting from the internal pressure and temperature (Figure 1).

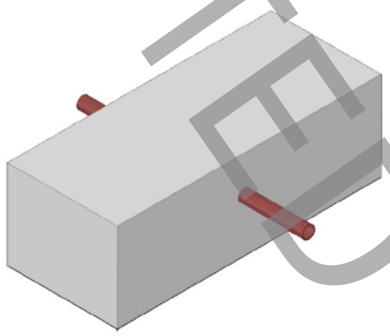

Figure 1. A typical anchor block

The previous studies on performance and design of anchor blocks include research by Al-Gahtani [1] who developed a simple procedure for the optimum design of anchor blocks. He used the Rankine's theory [2] to compute the active and passive earth pressures on the anchor block. Friction forces on sides, bottom, and top of the anchor block were taken into account by using a specific coefficient of friction between concrete and soil. Block sliding, block overturning, and soil bearing capacity were the main design parameters. Duncan and Mokwa [3] conducted two series of field experiments on a 900 mm x 1900 mm x 1100 mm anchor block. In this study, the calculated passive earth pressures from different theories were compared to the test results. The logarithmic spiral method with 3D correction gave the best estimate of the measured maximum passive force, and the Rankine method gave a reasonable estimate of the force. The performance of buried steel pipelines subjected to relative soil movements in the axial direction was investigated using full-scale pullout testing in a soil chamber by Wijewickreme et al. [4]. Test results were compared to the requirements of the design guidelines [5]. The results showed that the guidelines gave a very conservative estimate of friction force between dense sand and pipeline. For loose sand, the measured and the calculated friction forces were in a very good agreement.

The objective of this paper is to evaluate the response of the anchor block when the pipeline is operated under high internal pressure and temperature. The current design requirements for the anchor block are evaluated and a more rational design procedure is proposed.

2. **Current Design Procedure**

The current design procedure is based on the assumption that the anchor block fully restrains the pipeline and the pipeline thrust force resisted by the anchor block is calculated using the following equation [6].

$$Q_o = A[(0.5 - v)S_h + E\alpha(T_2 - T_1)] \qquad (1)$$

Where Q_o = the thrust force, v = the Poisson's ratio, E = modulus of elasticity, A = cross-sectional area of pipe, T_2 = the maximum operating temperature, T_1 = temperature at the time of installation and S_h = hoop stress due to fluid pressure. The forces acting on the anchor block are shown in Figure 2. The driving forces are the thrust force (Q) and the force resulted from the active soil pressure (F_a). Resisting forces are the force resulted from the soil passive pressure (F_p); and soil friction at the bottom, top, and sides of the anchor block (FR_b, FR_t, FR_s). The dimensions of the anchor block are calculated to provide adequate margins of safety against sliding and overturning of anchor block as well as soil bearing failure.

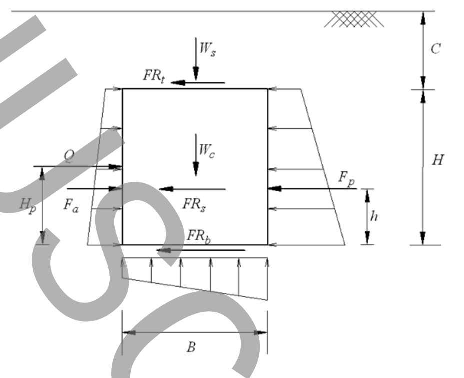

Figure 2. Forces acting on an anchor block

3. **Analytical Study**

Nonlinear finite element analyses were carried out on 16", 30", 42", and 56" gas transmission pipelines in four types of soils i.e.: dense sand, loose sand, hard clay and soft clay. The anchor blocks were designed in accordance with the current design procedures. Analyses included modeling of soil-pipe and soil-block interactions. The operating pressure was 1050 psi and the differential temperature varied between 0ºC to 65ºC. The force and displacement responses of the anchor blocks were evaluated at various operating conditions. Figure 3 shows a typical force response of the anchor block. As shown in this figure, the friction force reaches its maximum value at 45ºC temperature. Sliding of the anchor block beyond this temperature increases the rate of the passive soil resistance. However, the sum of the passive and friction forces (indicated as TOTAL in the figure) is less than the thrust force calculated in the current design procedure, i.e., Eq. (1). The reduction of the thrust force is attributed to movement of the block anchor.

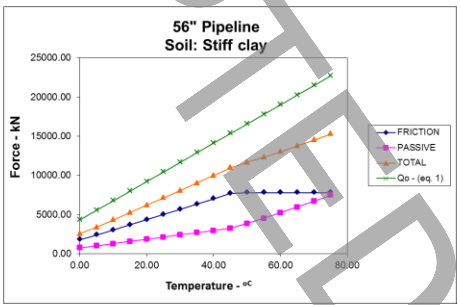

Figure 3. Anchor block forces vs. temperature

Figure 4 shows the displacement response of the anchor blocks. It indicates that the total force resisted by the anchor block (i.e., the thrust force) decreases with increasing anchor block displacement. These results indicate that the concept used in the current design procedures is fundamentally flawed because it is based on controlling forces rather than displacements. Furthermore, the thrust force is significantly overestimated because it is based on a fully restrained anchor.

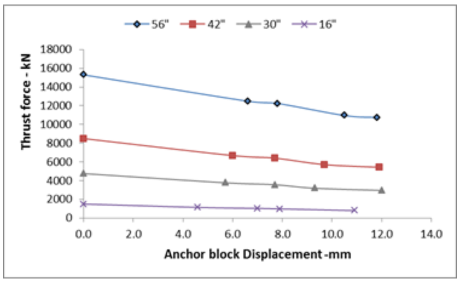

Figure 4. Thrust force vs. anchor block displacement

4. New Design Method

A new procedure for design of anchor blocks which is based on controlling the displacements is proposed. The maximum allowable anchor block displacement for typical pipeline configurations within compressor stations in Iran had been found to be 20 mm [7]. In the proposed design procedure, it is assumed that the anchor block would be displaced 20 mm and the thrust force acting on the anchor block (Q) is evaluated based on this displacement (Figure 5). Empirical formulas are developed to calculate the actual thrust force on the anchor block. This force is considerably less than the thrust force evaluated in the current design procedure (Q_o) and thus, The proposed procedure results in a substantial reduction of the size of anchor blocks.

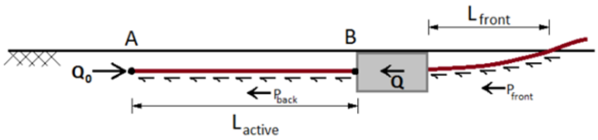

Figure 5. Distribution of forces near the anchor block

5. Conclusions

A new procedure for design of anchor blocks is proposed. The proposed design procedure results in a substantial reduction of the size of anchor blocks.

6. References

[1] Al-Gahtani, H. J. "Optimum design of buried pipeline block anchors", *Practice Periodical on Structural Design and Construction*, 14(4), pp.190-193, (2009).

[2] Rankine, W. "On the stability of loose earth", *Philosophical Transactions of the Royal Society of London*, Vol. 147, (1857).

[3] Duncan, J. M., & Mokwa, R. L. "Passive earth pressures: theories and tests", *Journal of Geotechnical and Geoenvironmental Engineering*, 127(3), pp.248-257, (2001).

[4] Wijewickreme, D., Karimian, H., & Honegger, D. "Response of buried steel pipelines subjected to relative axial soil movement", *Canadian Geotechnical Journal*, 46(7), pp.735-752, (2009).

[5] ALA (American Lifelines Alliance). "Guidelines for the design of buried steel pipe", Reston, VA. (2001).

[6] Peng, L. C. "Stress analysis methods for underground pipelines", *Pipe Line Industry*, 47(5), pp.65-74, (1978).

[7] Vasseghi A. "Final research report on optimum design of anchor blocks", Iranian Gas Engineering and Development Company, (2013), (in Persian)

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