Engineering Standard

SAES-L-440 27 September 2009

Anchors for Buried Pipelines

Saudi Aramco DeskTop Standards

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1 Scope

This Standard covers the design requirements for reinforced concrete or structural steel anchors used on buried pipelines. The design of reinforced concrete anchor blocks shall also comply with the applicable sections of SAES-Q-005 and SAES-Q-001.

2 Conflicts and Deviations

2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department (CSD) of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

The selection of material and equipment, and the design, construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition of the references listed below, unless otherwise noted.

- Saudi Aramco References

Saudi Aramco Engineering Procedure

SAEP-302 — *Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*

Saudi Aramco Engineering Standards

SAES-A-114 — *Excavation and Backfill*

SAES-H-002 — *Internal and External Coatings for Steel Pipelines and Piping*

SAES-Q-001 — *Criteria for Design and Construction of Concrete Structures*

SAES-Q-005 — *Concrete Foundations*

Saudi Aramco Engineering Report

SAER-6172 — *Size Optimization of Concrete Thrust Anchor Blocks for Pipelines*

4 Definitions

Full Thrust Anchor Blocks*:* The full thrust anchor blocks are designed conservatively so that they will resist the full thrust force with deflections in the range of several millimeters or less. The possible reduction in the anchor force due to friction between pipe and soil is not considered.

Drag Anchor Blocks*:* Drag anchor blocks are used at the ends of the buried pipelines just before they come above the ground. They are designed to reduce the end movement to less than 25 mm. The reduction in the anchor force due to friction between pipe and soil is considered in the sizing of the drag anchor blocks.

Design Conditions*:* All conditions (such as pressure, temperature, ambient conditions, service, etc.) that govern all or part of the design and the selection of piping components.

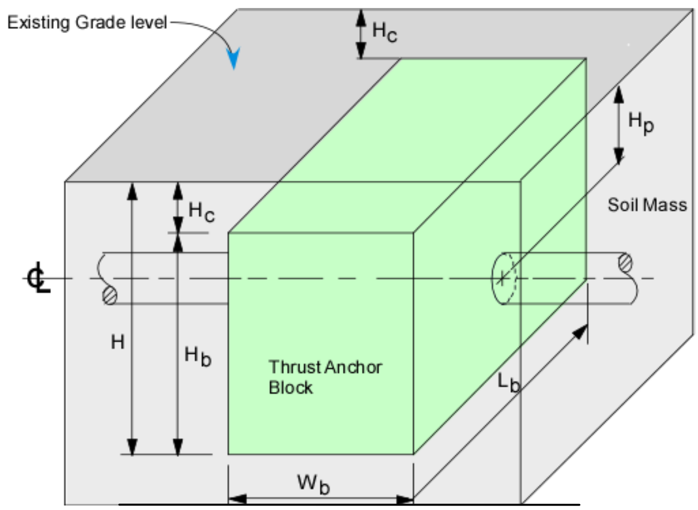
Maximum Allowable Operating Pressure (MAOP)*:* The maximum allowable fluid pressure in hydrocarbon pipelines for continued operation at the most severe condition of coincident internal or external pressure and temperature (Maximum or Minimum) expected during service life.

Pipe Friction*:* It is the frictional resistance on the pipe/soil interface due to axial pipe movement. Friction at the pipe soil interface is a function of the confining pressure and the coefficient of friction between the pipe and the backfill material.

Virtual Anchor*:* A point or a region along the axis of a buried pipe where there is no relative motion at the pipe/soil interface.

Transition Length*:* The length of pipeline between the free end and the point of virtual anchor over which the frictional restraint is assumed to vary linearly from full restraint to zero restraint over a distance called the active length.

5 Standard Nomenclature for Anchor Block



H_p = Height from Existing Grade Level to the center line of the pipe

H_c = Height of soil cover from Existing Grade Level to the top of the anchor block

H_b = Height of the Concrete Anchor Block

W_b = Width of the Concrete Anchor Block

L_b = Length of the Concrete Anchor Block

H = Total height from the Existing Grade Level to the bottom of the block

6 Thrust Force on Anchor Blocks

6.1 The full thrust force (F_a) on anchor blocks for pipelines shall be determined in accordance with the formula below (using consistent units):

$$F_a = A_p [E * \alpha * (T_2 - T_1) + (0.5 - \nu_{ps}) * S_h] \quad (1)$$

6.2 The Hoop stress in Equation (1) shall be computed as:

$$S_h = PD_o / 2t_p \quad (2)$$

Where:

F_a = Thrust force on the anchor block

A_p = Cross sectional area of the pipe wall

E = Modulus of elasticity of pipe steel

α = Coefficient of linear thermal expansion of steel

T_2 = Design operating temperature

T_1 = Installation or Tie-in temperature

ν_{ps} = Poisson's ratio of pipe steel

P = MAOP = Maximum Allowable Operating Pressure

S_h = Hoop stress at MAOP = $P*D_o/(2*t_p)$

t_p = Wall thickness of pipe

D_o = Pipe outside diameter

7 Sizing of Anchor Blocks

7.1 The anchor blocks in sandy soil and soil with friction and cohesion shall be designed using the company-owned program SOPTAB for "Size Optimization of Thrust Anchor Blocks" or equally qualified programs/analyses which take into account for the following aspects.

7.1.1 The Log-Spiral theory (Terzaghi, 1943, Caquot and Kressel, 1948) shall be used for the computation of passive earth force of the backfill soil mass.

7.1.2 The preliminary dimension of the anchor block can be established based on bearing pressure exerted by anchor flange on concrete mass and the punching shear of the anchor flange through the concrete block. The minimum width, height and length of the thrust anchor block are thus established.

7.1.3 The 3-D effects in the failure zone of the backfill soil mass due to finite size of anchor block, resisting the movement of the block, can be optionally used for enhancing the passive earth force by multiplying the computed 2-D passive earth resistance by a factor F_{3D}, which can be computed using Brinch Hansen theory (Brinch Hansen, 1966). The maximum value of F_{3D} should not exceed 1.3.

7.1.4 Friction on the bottom and sides of the anchor block is accounted for using appropriate soil models and soil parameters.

7.1.5 The hyperbolic load-deformation model (Duncan and Mokawa, 2001) can be used to compute passive resistance based on the deformation of the backfill soil under the applied service thrust force, which acts on the anchor block.

7.1.6 The "transition length" or the "active length" or the "length to point of virtual anchor" of the pipeline is computed from the pipe friction on the pipeline. The length of the pipeline up to the point of virtual fixity is computed for incorporating the effect of pipe-soil interaction in the sizing of the thrust anchor block if desired by the design engineer.

7.1.7 The design engineer can opt to take advantage of the inevitable predicted movement in the full thrust anchor block in computing the pipe-soil friction for reducing the thrust anchor force and thereby reducing the size of the anchor block.

7.1.8 An iterative approach can be adopted in which the length, width and height of the concrete anchor block is changed until all conditions for safety and stability of the thrust anchor block are satisfied. This includes the following checks:

7.1.8.1 Check for ultimate load carrying capacity of the anchor block

7.1.8.2 Check for factor of safety against overturning of the anchor block

7.1.8.3 Check for factor of safety against sliding of the anchor block

7.1.8.4 Check for bearing pressure at the base of the anchor block due to vertical and lateral loads.

7.1.9 A typical example for designing full thrust anchor block using SOPTAB is provided in the Appendix A.

7.1.10 The design of the load transfer system for the transfer of load from the pipeline to the anchor block including the thickness of anchor flange, number and thickness of stiffeners, end plates and other components, the welded connection between various steel members of the load transfer system should be designed based on full thrust force F_a.

7.1.11 The reinforcing steel for the anchor block, one-way and two-way shear capacity of the anchor block, flexural reinforcement requirements, shrinkage and temperature reinforcement, development length and anchorage requirements and the design of steel for column action around the flange plate should also be based on full thrust force using standard applicable codes and standards.

**Commentary Notes:*

- *The company-owned computer software SOPTAB will be available upon request from the Civil Engineering Unit of CSD.*

- *The software ADTAB (Analysis and Design of Thrust Anchor Blocks) is available for use by CSD engineers only.*
- *The Civil Engineering Unit of CSD may be contacted for details.*
- *The allowable bearing pressures should be obtained from the geotechnical report and this should be calculated to limit settlement to 25 mm or less.*
- *Specific details are provided in Appendix-B*

7.2 Unless reliable data is available for the specific site, the following basis shall be used for sizing concrete anchors:

a) In rock areas:

I. If the block is embedded in a very hard cemented soil (highly weathered rock), then the designer shall use SOPTAB to size the anchor block.

II. If the block is totally above ground, then SOPTAB program is not applicable in this case; the designer shall use standard engineering procedures to design the anchor block.

b) In well compacted or very dense natural soil:

I. If the anchor block is above the water table, then the designer shall use the computer program SOPTAB or equivalent.

II. If the anchor block is totally or partially below the water table, then the designer shall use the computer program SOPTAB or equivalent except that he needs to:

i. Reduce friction by 30%

ii. Account for uplift pressure

c) In sabkha soil:

I. The designer may strengthen the soil and reduce settlement by use of a soil pad, geogrid/geotextiles or other ground improvement technique. If the anchor block is above ground then SOPTAB program is not applicable in this case and the designer shall use standard engineering procedures in design with the approval of CSD.

II. The designer may use a piled anchor. The anchor block will be above ground and the designer shall use standard engineering procedures in design with the approval of CSD.

Commentary Notes:

- *When dewatering is required to facilitate anchor block construction, the effect or dewatering on nearby structures, pipelines, facilities, shall be considered.*
- *Excavation, backfilling, and compaction should be as per SAES-A-114.*

8 Stability of Anchors

The resultant of all anchor forces shall have a line of action parallel and close to the centerline of the pipeline.

Commentary Note:

The approach in checking stability of concrete thrust anchor blocks, is totally different from that in checking the stability of foundations which is covered in SAES-Q-005. Factors of safety which are used in SAES-Q-005 are not applicable for buried pipeline anchor blocks. Stability of an anchor block against overturning is assured by alignment of the pipe thrust force and the resisting forces. A sliding stability check per SAES-Q-005 is not required because pipeline anchor blocks are sized based on allowable movement criteria.

9 Anchor Attachments

7.1 For fabricated anchors, the attachment of the anchors to the pipeline shall be with a full encirclement sleeve welded at each end with continuous full size fillet welds not exceeding 1.4 times the pipe wall thickness. The sleeve shall have strength at least equivalent to the pipe.

7.2 Welded anchor flanges embedded in concrete shall have adequate stiffness to ensure proper distribution of the load within the allowable concrete bearing stress.

7.3 The finished steel fabrication including the pipe, sleeve, and anchor flange or anchor plate inside the anchor block shall be coated per SAES-H-002.

7.4 A minimum distance of no less than 10 cm shall be provided between rebar and the sleeve or anchor flange to ensure adequate cathodic protection of the pipeline. In addition, four 60 pounds magnesium anodes shall be installed for the pipeline one at each quadrant of the anchor.

Revision Summary

27 September 2009	Major revision to incorporate recommendations in Saudi Aramco Engineering Report SAER-6172.

Appendix-A – A Typical Example For Designing Full Thrust Anchor Block Using SOPTAB

King Fahd University of Petroleum and Minerals

Size Optimization of Thrust Anchor Blocks

ارامكو السعودية Saudi Aramco

Project : Anchor Block at Abqaiq GOSP-2 **Project Location :** Abqaiq

Block type : Thrust

Input Data :

Pipeline Data

Pipeline specification :	API-5L	
Nominal outside diameter :	10.75	in
Nominal wall thickness :	0.25	in
Depth G/L to top of pipeline :	4	ft
Minimum soil cover over pipe :	3	ft
Specific gravity of pipe fluid :	0.85	
Allowed corrosion in thickness :	0.15	%

Pressure / Temperature Loads in Pipeline

Operating pressure :	500	psi
Operating temperature :	180	°F
Tie-in (Installation) temperature :	70	°F

Pipeline Material Properties

Pipeline grade :	X-60	
Specified minimum yield strength :	60000	ksi
Poisson's ratio of pipe steel :	0.3	
Coeff. thermal expansion steel :	6.5E-06	°F
Young's modulus of elasticity :	30000000	ksi
Design factor allowed hoop stress :	0.72	
Design factor for combined stress :	0.9	
Density of pipe material :	490	pcf

Backfill Soil Properties

Unit weight of dry/moist soil :	100	pcf
Coeff. of friction pipe/soil :	0.4	
Coeff. of friction concrete/soil :	0.4	
Angle of internal friction of soil :	30	deg
Cohesive strength of soil :	0	psf
Allowed bearing pressure soil :	3	ksf
Modulus of elasticity of soil :	900	ksf
Poisson's ratio of soil :	0.33	
Wall friction angle :	21	deg

Concrete Properties

Unit weight of concrete :	150	pcf
Concrete strength :	3000	psi

Miscellaneous

Maximum allowed movement :	0	in
Wall thickness of sleeve :	0.25	in
Flange Diameter :	4	in
Block width :	4	ft
Edge distance block Height :	1	in
Edge distance block width :	1	in

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King Fahd University of Petroleum and Minerals

Size Optimization of Thrust Anchor Blocks

Saudi Aramco

Project : Anchor Block at Abqaiq GOSP-2 **Project Location :** Abqaiq

Block type : Thrust

Analysis & Optimization Results :

Forces on Anchor Block

Thrust anchor force on the block:	197.75	kip
Hoop stress at MAOP :	12647.06	psi
Thermal stresses - Temperature gradient :	21450	psi
Friction force b/w pipe and soil :	1.43	kip/ft
Movement in pipeline - No anchor block :	11.6	in
Axial force due to thermal stress :	176.89	kip
Axial force due to Poisson's effect :	-31.29	kip
Axial force due to end pressure :	52.15	kip
Thrust anchor force on block :	197.75	kip
Reduction in thrust force from pipe/soil friction :	0	kip
Thrust anchor force with pipe/soil friction :	197.75	kip
Ultimate anchor force for block sizing :	336.18	kip
Coeff. earth pressure Log-Spiral :		
Kpφ :	5.45	
Kpc :	0	
Kpq :	4.05	
3-D effect factor :	1.73	kip
Ultimate passive earth force :	325.61	kip
Total frictional force on the block:	56.28	kip
Passive earth force at service loads :	190.06	kip
Resisting force at service loads :	246.34	kip
Active earth force at service loads :	210.95	kip

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King Fahd University of Petroleum and Minerals

Size Optimization of Thrust Anchor Blocks

Saudi Aramco ارامكو السعودية

Project : Anchor Block at Abqaiq GOSP-2 **Project Location :** Abqaiq

Block type : Thrust

Stability Checks

Ultimate active force on block :	349.38	kip
Ultimate resisting force on block :	381.89	kip
Factor of safety against overturning :	1.39	
Factor of safety against sliding :	1.17	
Allowable soil pressure :	3	
Maximum soil pressure :	0.32	
Minimum soil pressure :	2.08	

Final Block Dimensions

Height of block :	6	ft
Width of block :	7	ft
Length of block :	11	ft
Volume :	462	ft^3

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Appendix-B – Equations for Computations

Hyperbolic Model (Cole 2003)

The equation is given as follows:

$$P = \frac{\Delta}{\frac{1}{K_{\max}} + \left(1 - \frac{P_{ult}}{K_{\max}\Delta_{\max}}\right)\frac{\Delta}{P_{ult}}}$$

Where P is the passive earth force mobilized depending upon the deflection Δ.

P_{ult} is the maximum passive earth force

K_{max} is the initial stiffness of the load-deflection curve

Δ is the displacement of the structure.

Computation of F_{3D}

The Brinch Hansen correction factor F_{3D} applied to the passive earth resistance computed using 2-D plane strain theory is given by the following equation:

$$F_{3D} = 1 + (K_p - K_a)^{\frac{2}{3}}\left(1.1E^4 + \frac{1.6}{1 + 5(b/h)} + \frac{0.4(K_p - K_a)E^3}{1 + 0.05(b/h)}\right)$$

$$E = 1 - \frac{h}{z + h}$$

The 3-D passive earth force P_{3D} is given as:

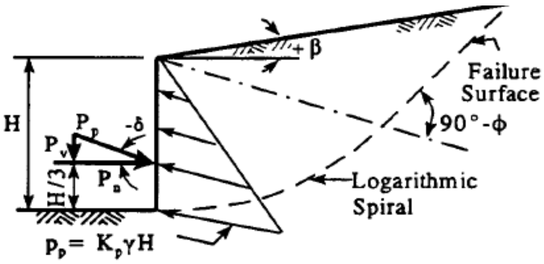
$$P_{3D} = P_{2D} \times F_{3D}$$

Log-spiral Theory

REDUCTION FACTOR (R) OF K_p FOR VARIOUS RATIOS OF - δ/φ

φ \ δ/φ	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	0.0
10	.978	.962	.946	.929	.912	.898	.881	.864
15	.961	.934	.907	.881	.854	.830	.803	.775
20	.939	.901	.862	.824	.787	.752	.716	.678
25	.912	.860	.808	.759	.711	.666	.620	.574
30	.878	.811	.746	.686	.627	.574	.520	.467
35	.836	.752	.674	.603	.536	.475	.417	.362
40	.783	.682	.592	.512	.439	.375	.316	.262
45	.718	.600	.500	.414	.339	.276	.221	.174

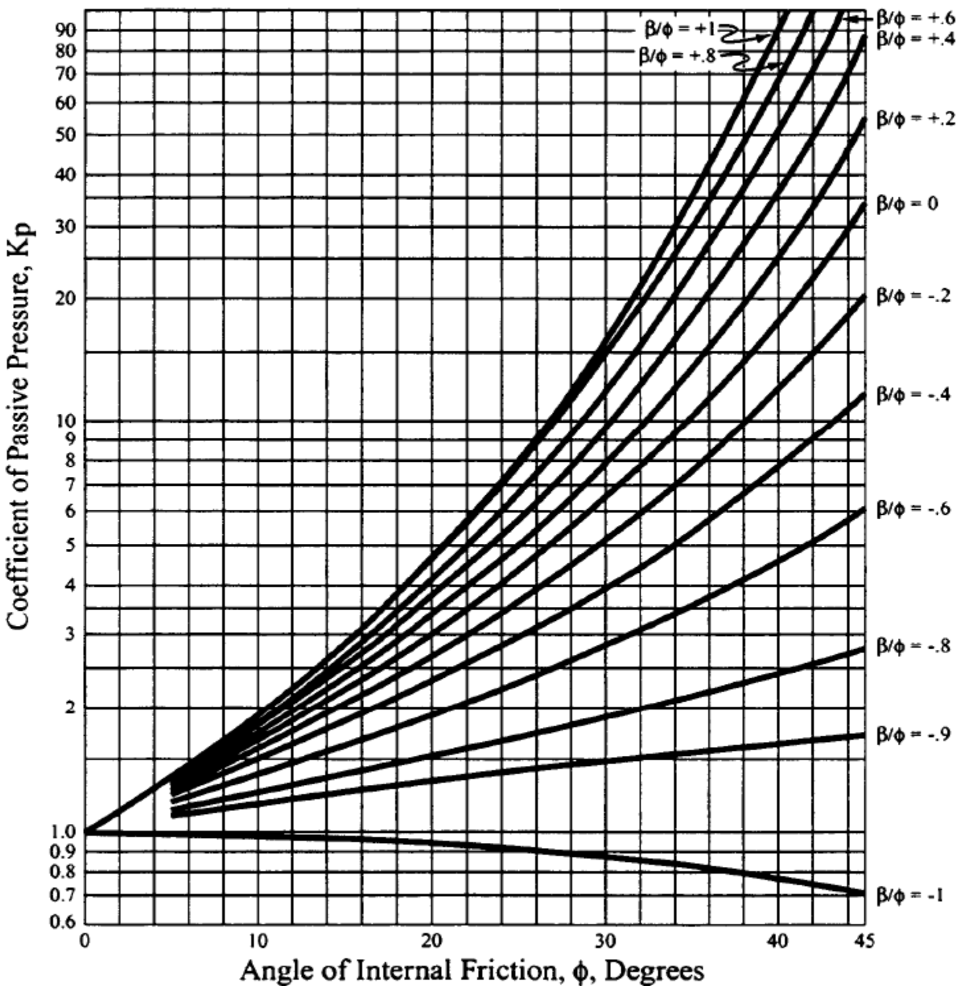
Note: Curves shown are for δ/φ = -1



$P_p = K_p \gamma H^2/2$; $P_n = P_p \cos\delta$; $P_v = P_p \sin\delta$

Example: $\phi = 25°$; $\beta/\phi = -0.2$; $\delta/\phi = -0.3$

$K_p = R(K_p \text{ for } \delta/\phi = -1) = (0.711)(3.62) = 2.58$



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