



Engineering Standard

SAES-Q-005

28 June 2009

Concrete Foundations

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1 Scope

This standard covers mandatory requirements governing the design and construction of all concrete foundations, except for retaining walls, which are covered by SAES-Q-009. Additional design and construction requirements for heavy machinery foundations are covered by SAES-Q-007. Additional design and construction requirements for pipeline anchor blocks are covered by SAES-L-440.

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 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.

3.1 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-113

Geotechnical Engineering Requirements

SAES-A-114

Excavation and Backfill

SAES-L-440

Anchors for Buried Pipelines

SAES-M-001

*Structural Design Criteria for Non-Building
Structures*

<u>SAES-M-009</u>	<i>Design Criteria for Blast Resistant Buildings</i>
<u>SAES-M-100</u>	<i>Saudi Aramco Building Code</i>
<u>SAES-Q-001</u>	<i>Criteria for Design and Construction of Concrete Structures</i>
<u>SAES-Q-007</u>	<i>Foundations and Supporting Structures for Heavy Machinery</i>
<u>SAES-Q-010</u>	<i>Cement Based, Non-Shrink Grout for Struct. & Equip. Grouting</i>
<u>SAES-Q-012</u>	<i>Criteria for Design and Construction of Precast and Prestressed Concrete Structures</i>

Saudi Aramco Materials System Specification

<u>12-SAMSS-007</u>	<i>Fabrication of Structural and Miscellaneous Steel</i>
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Saudi Aramco Standard Drawing

<u>AA-036322-001</u>	<i>Anchor Bolt Details – Inch and Metric Sizes (Rev. 08 or later)</i>
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Saudi Aramco Best Practice

<u>SABP-Q-002</u>	<i>Spread Footings Design</i>
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3.2 Industry Codes and Standards

American Concrete Institute

<i>ACI 318</i>	<i>Building Code Requirements for Structural Concrete</i>
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American Institute of Steel Construction

<i>AISC 303-05</i>	<i>Code of Standard Practice for Steel Buildings and Bridges, March 18, 2005 Edition</i>
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American Petroleum Institute

<i>API STD 650</i>	<i>Welded Steel Tanks for Oil Storage</i>
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American Society of Civil Engineers

<i>ASCE/SEI 7 - 05</i>	<i>Minimum Design Loads for Buildings and Other Structures</i>
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<i>SEI/ASCE 37 - 02</i>	<i>Design Loads on Structures during Construction</i>
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4 Design

The design and specifications for construction of concrete foundations shall be adequate for the structures' intended use, in accordance with commonly accepted engineering practice and the requirements described in this section.

4.1 Soils Analysis

4.1.1 A geotechnical investigation is required for all new structures and foundations as described in SAES-A-113.

4.1.2 The allowable soil bearing pressures shall be based on the results of the geotechnical investigation, and a consideration of permissible total and differential settlements. Soil pressures shall be calculated under the action of vertical and lateral loads using load combinations that result in the maximum soil pressures. The maximum soil pressure shall not exceed the applicable allowable value. The conventional method shall be used for calculating maximum and minimum soil bearing pressure for foundation design (the Meyerhof method is not acceptable). If specifically allowed in the geotechnical report, the maximum allowable soil pressure may be increased for transient loads, including wind, seismic and hydrotest loads.

Commentary Notes:

- 1. The foundation design engineer should be cautioned that allowable soil bearing pressures taken from older geotechnical reports may not have considered eccentrically loaded foundation when establishing the limiting values. These values must be verified by the Civil Engineering Unit of the Consulting Services Department prior to use.*
- 2. For guidelines on the conventional methods (e.g., $P/A \pm M/S$) of calculating maximum and minimum soil bearing pressures for foundations, refer to Saudi Aramco Best Practice SABP-Q-002 "Spread Footings Design."*

4.1.3 Foundations shall be founded on either undisturbed soil or compacted fill and at least 600 mm below the existing or finished grade surface, unless a detailed soils investigation indicates otherwise. In the case of foundations supported on compacted fill, the geotechnical investigation and/or SAES-A-114 shall govern the type of fill material and degree of compaction required.

Commentary Note:

Because shoring or the equivalent for may be required for excavations 4 ft (1.2 m) deep or greater and because it is costly to shore excavations, minimizing the depth of spread footings shall be considered in the design.

4.2 Foundation Stability

Foundation stability shall be checked using service load combinations from SAES-M-001, SAES-M-100, ASCE/SEI 7 and/or SEI/ASCE 37 for any other probable and realistic combination of loads. Foundation stability factors for blast resistant buildings shall be in accordance with SAES-M-009.

- 4.2.1 The minimum overturning "stability ratio" for service load combinations including wind loads shall be 1.5. For foundation design of buildings and open frame structures, where the dead load factor is 0.6 from ASCE/SEI 7 Section 2, the minimum overturning "stability ratio" shall be 1.0.

Commentary Note:

This requirement is consistent with ASCE/SEI 7 provisions, in which the "factor of safety" is built into the 0.6 "dead load factor" in the load combinations.

- 4.2.2 Overturning and sliding caused by earthquake loads shall be checked in accordance with ASCE/SEI 7, Chapters 12 and 15.
- 4.2.3 For earthquake loads calculated by the "Equivalent Lateral Force Procedure" in ASCE/SEI 7, additional stability checks shall be done in accordance with ASCE/SEI 7, Section 12.8.5, "Overturning." For foundations designed using seismic load combination from SAES-M-001 Tables 3, 5 and 7, the reduction in the foundation overturning moment permitted in ASCE/SEI 7, Section 12.13.4, "Reduction of Foundation Overturning" shall not be used.
- 4.2.4 Long-term and differential settlement shall be considered if designing foundations supporting interconnected, settlement-sensitive equipment or piping systems.
- 4.2.5 Except for foundations supporting ground supported storage tanks, uplift load combinations containing earthquake loads need not include vertical earthquake forces when used to size foundations.
- 4.2.6 The minimum factor of safety against sliding for service loads other than earthquake shall be 1.5. For foundation design of buildings and open frame structures, where the dead load factor is 0.6, the minimum factor of safety against sliding shall be 1.0. The coefficient of friction used in computing the safety factor against sliding for cast-in-place foundations shall be 0.40, unless specified otherwise in a detailed soil investigation. Passive earth pressure from backfill shall not be considered in computing these safety factors.
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- 4.2.7 The minimum factor of safety against buoyancy shall be 1.2 if using actual un-factored service loads.

4.3 Other Requirements

- 4.3.1 The design and construction of concrete foundations shall comply with the requirements of SAES-Q-001. Concrete foundations manufactured by a precast vendor under factory conditions shall comply with SAES-Q-012.

- 4.3.2 Foundations supporting steel bases, including structural columns, pipe supports, process equipment, vessels and towers shall conform to the following:

- a) The top of concrete shall be a minimum of 150 mm above finished grade.

Exception:

This requirement is not applicable to instrument stand pipes or pedestals inside of buildings that are not subjected to wash down water.

- b) The design concrete compressive strength of concrete shall be 27.6 MPa (4000 psi) at 28 days for foundations constructed on the project site.
- c) The selection and specification of non-shrink cement based grout for foundations shall comply with SAES-Q-010. The minimum thickness of grout shall be 25 mm measured from top of concrete foundation to bottom of steel base plate.
- d) Foundations shall not be placed above other foundations, underground piping, telecommunication or electrical items in such a manner as to exert pressure on these items without prior written approval by the Supervisor, Civil Engineering Unit, Rotating Equipment & Civil Engineering Division, Consulting Services Department. The zone of foundation pressure is defined as a plane extending outward and down from the bottom edges of the foundation at a 45-degree angle.
- e) Foundations (including pipeline anchor blocks) constructed near slopes should ensure that a 45-degree plane extending downward from the bottom edge of the foundation does not intersect the slope face. A slope stability analysis should also be performed to demonstrate that the slope is stable with the addition of the foundation/structure loads.
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- f) The identification of potential underground interferences such as; buried pipe, electrical or telecommunication items shall be done during detailed design by using existing drawings, probing, exploratory trenches, ground penetrating radar, etc. Foundations shall be located in such a manner to avoid existing underground items or those items shall be relocated. In the event that it is impossible to avoid interferences, prior written approval by the Supervisor, Civil Engineering Unit, Rotating Equipment & Civil Engineering Division, Consulting Services Department shall be obtained to allow piping, electrical or telecommunication cable to penetrate foundations.

Exception:

This requirement is not applicable to new electrical or telecommunication cable or new piping entering a building below grade that has been designed to penetrate gradebeams. In this case the cable or piping shall be clearly shown on the drawings and the penetrations sleeved if necessary.

4.3.3 Slab Mounted Pedestals

Slab-mounted pedestals may only be used when all of the following conditions are met:

- a) The pedestals, reinforcing steel, anchor bolts and supporting slab are proven to have sufficient strength by calculation.
 - b) Pedestals are supported on concrete paving at least 150 mm thick (see also item e below).
 - c) The top of the pedestal is at least 150 mm above the finished paving elevation.
 - d) Pedestals have a vertical compressive load less than 2000 kg and supporting items that are not settlement sensitive nor subject to vibration.
 - e) The applied loads do not create tension in the pedestal dowels, or the pedestals are supported on a thickened concrete slab and the calculations show that the reinforcing steel is sufficiently developed in both the pedestal and slab to resist the applied loads.
 - f) Pedestals are not located within 150 mm of a paving joint.
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4.4 Precast Concrete Foundations

- 4.4.1 Precast concrete foundations may only be used when the foundation alignment in plan and elevation are not critical or minor variations in the precise location/elevation can be accommodated. Precast concrete shall not be used for foundation supporting heavy machinery as defined in SAES-Q-007.
- 4.4.2 Concrete foundations manufactured by the Contractor on or near the project site shall comply with SAES-Q-001. Concrete foundations manufactured by a precast vendor under factory conditions shall comply with SAES-Q-012.
- 4.4.3 Installation of precast foundations shall comply with one of the following methods:
- a) A 50 mm lean concrete seal slab shall be placed in the bottom of the excavation immediately before placing the precast concrete foundation. The precast concrete foundation shall then be set in place prior to hardening of the lean concrete.
 - b) A layer of clean sand not more than 50 mm thick shall be placed in the bottom of the excavation. If clean sand is used, it must be carefully leveled prior to placing the precast concrete foundation and a 0.15 mm (6 mils) plasticized sheet vapor barrier shall be placed beneath the foundation.

4.5 Concrete Ring Wall Foundations

Concrete ring walls for tanks shall conform to the following:

- a) The design of concrete ring walls for tanks shall comply with SAES-M-001 and Appendix B of API STD 650.
 - b) Foundations for ground supported storage tanks where the internal pressure is sufficient to lift the shell shall be designed for the requirements of API STD 650 Appendix F.7.5.
 - c) Ring wall foundations shall be proportioned so that the average unit soil loading under the wall or wall footing equals the soil pressure under the confined earth at the same depth, in order to minimize differential settlements. The minimum ring wall width shall be 300 mm.
 - d) Ring wall foundations shall be designed to resist horizontal active earth pressure in hoop tension with horizontal reinforcing sized to take all of the tension. Passive earth pressure shall not be used to reduce the horizontal design loads.
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- e) The design concrete compressive strength for ring wall foundations shall be 27.6 MPa (4000 psi) at 28 days.

4.6 Pile Foundations

The minimum safety factor against the ultimate pile capacity under long-term operating loads shall be 2.0 for compression piles and 3.0 for tension piles, unless otherwise established in the soils analysis or actual pile load tests.

4.7 Anchors for Cross Country Pipelines

4.7.1 Anchor blocks for pipelines shall be designed per SAES-L-440.

4.7.2 The foundation stability safety factors and other requirements defined in section 4.2 of this Standard are not used for the design of pipeline anchor blocks.

4.8 Anchor Bolts and Embedded Items

4.8.1 Anchor bolts shall be in compliance with Standard Drawing AA-036322 Sht. 001 (Rev. 08 or later). Material selection and galvanizing of anchor bolt assemblies shall be per the requirements in 12-SAMSS-007.

4.8.2 Anchor bolts and embedded items shall be set accurately, using templates within the tolerances specified in the AISC Code of Standard Practice Section 7.5, unless more precise placement is specified on the drawings. The bottom of anchor bolts shall be secured to prevent movement or tilting of the anchor bolts during concrete placement.

4.8.3 Anchor bolts set in a foundation pedestal should never extend below the bottom of the pedestal into the footing.

Commentary Note:

Extending the anchor bolts into the footing would require the anchor bolts to be partially embedded in the footing prior to forming the pier, which makes it almost impossible to maintain proper alignment.

4.8.4 The design of anchor bolts shall be in accordance with the requirements of Appendix D of ACI 318.

4.8.5 The minimum anchor bolt diameter shall be 20 mm ($\frac{3}{4}$ "), except when specified otherwise by the vendor for small equipment or for the anchorage of small miscellaneous steel items such as; ladder supports, small piping supports, handrail anchorage, stair stringers, small platforms, etc.

- 4.8.6 Anchor bolts that are exposed to the weather in coastal areas, subjected to frequent wash downs, or subjected to firewater deluge testing shall have their diameters increased by 3 mm as a corrosion allowance in addition to the coating required by 12-SAMSS-007. For the purpose of this standard, coastal areas are defined as all locations within one kilometer of the shoreline of the Arabian Gulf; all of the Ras Tanura Refinery and Terminal; and all locations within three kilometers from the shoreline of the Red Sea.

Commentary Note:

When required, the additional 3 mm corrosion allowance should be applied to the calculated anchor bolt diameter (i.e., if the required anchor bolt diameter is calculated to be 17 mm in a coastal area - the diameter is then increased 3 mm and a 20 mm diameter bolt should be installed. It is not required to increase the minimum anchor bolt size of 20 mm by a further 3 mm).

- 4.8.7 Anchor bolts subject to uplift or vibration shall be equipped with an additional nut to serve as a lock nut to ensure against loosening.
- 4.8.8 Minimum clear distance from anchor bolts or anchor bolt sleeves to edge of concrete shall be 100 mm. Additionally, the minimum edge distance for design purposes measured from the centerline of the anchor bolt to the edge of the concrete shall be as specified on Mandatory Standard Drawing AA-036322-001. Metallic anchor bolt sleeves are not permitted.
- 4.8.9 Post-installed anchor bolts shall not be used for new construction without prior written approval from the Supervisor, Civil Engineering Unit, Rotating Equipment & Civil Engineering Division, Consulting Services Department. When approved for use, the post-installed bolts shall be designed per ACI 318, Appendix D and in strict compliance with the manufacturer's recommendations.

Commentary Note:

Post-installed anchor bolts are any type of anchor bolt that is installed after the foundation concrete has hardened. This includes expansion anchors, undercut anchors, adhesive anchors, etc. Bolts set in pockets may be used without prior approval as long as it is recommended by the equipment manufacturer and installed/tested per the grout manufacturer's guidelines.

5 Installation

All concrete foundations shall be fabricated and constructed to SAES-Q-001 and this standard. Foundations furnished by precast vendors shall comply with SAES-Q-012.

Special requirements for construction that are not covered in the standards shall be shown on the drawings or in the project specifications.

Revision Summary

22 April 2009

Reaffirmed the contents of the document and reissued with minor revisions.

28 June 2009

Editorial revision to update reference to Standard Drawing AA-036322-001.