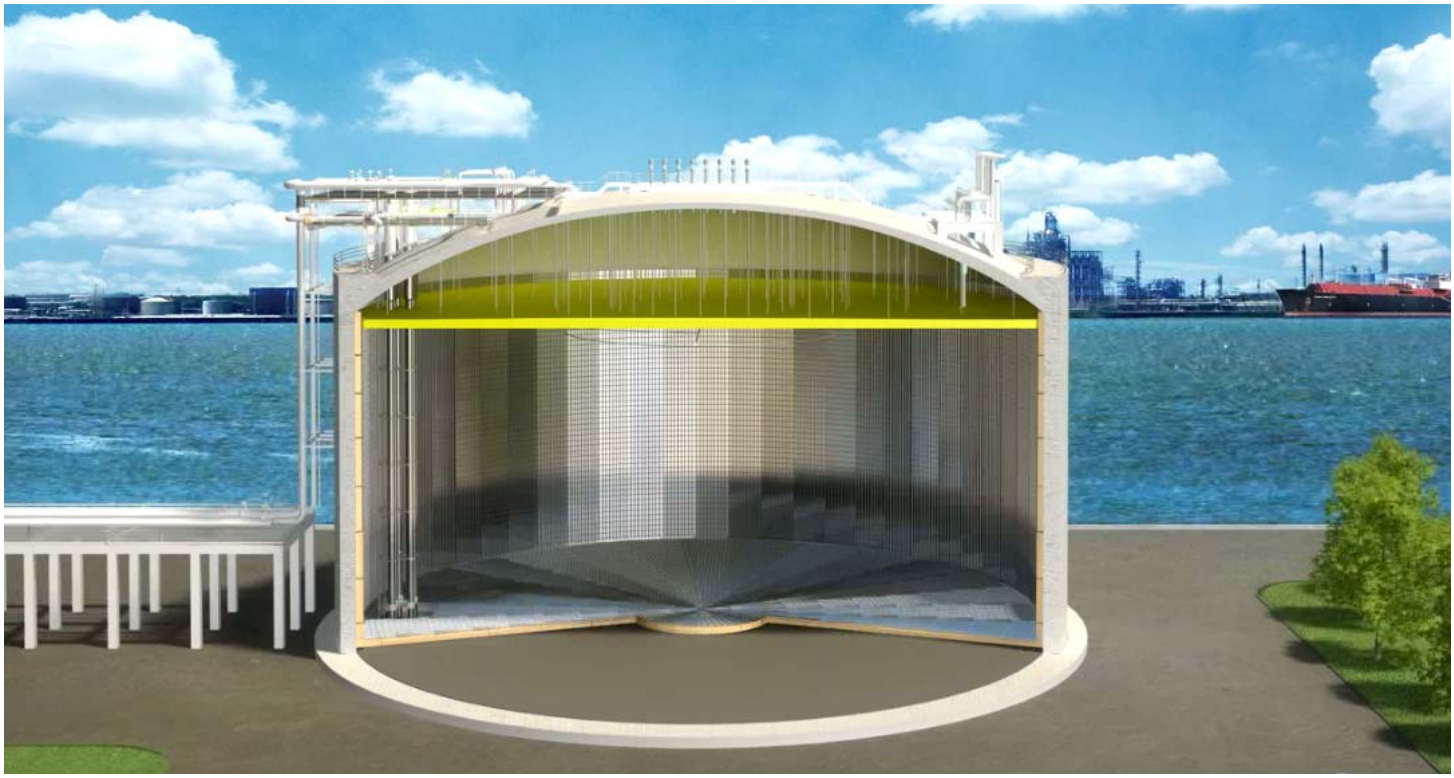

NFPA59A TASK FORCE

To recommend requirements for Membrane tank systems

Task Force Members:

- Denise Beach, Daniel Gorham, and Janna Shapiro (Moderator), NFPA
- Adnan Ezzarhouni (Chair), GTT
- Alex Cooperman, CB&I
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- John Blanchard, CB&I
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I. INTRODUCTION

In the March 11th/12th 2014 NFPA59A meeting, a task group was created to recommend requirements for membrane tank systems. The purpose of this paper is to record the work of the task group in development of the Membrane tank requirements for inclusion in NFPA59A.

II. TIA PROCESS TO INCLUDE MEMBRANE CONTAINMENT TANK SYSTEM

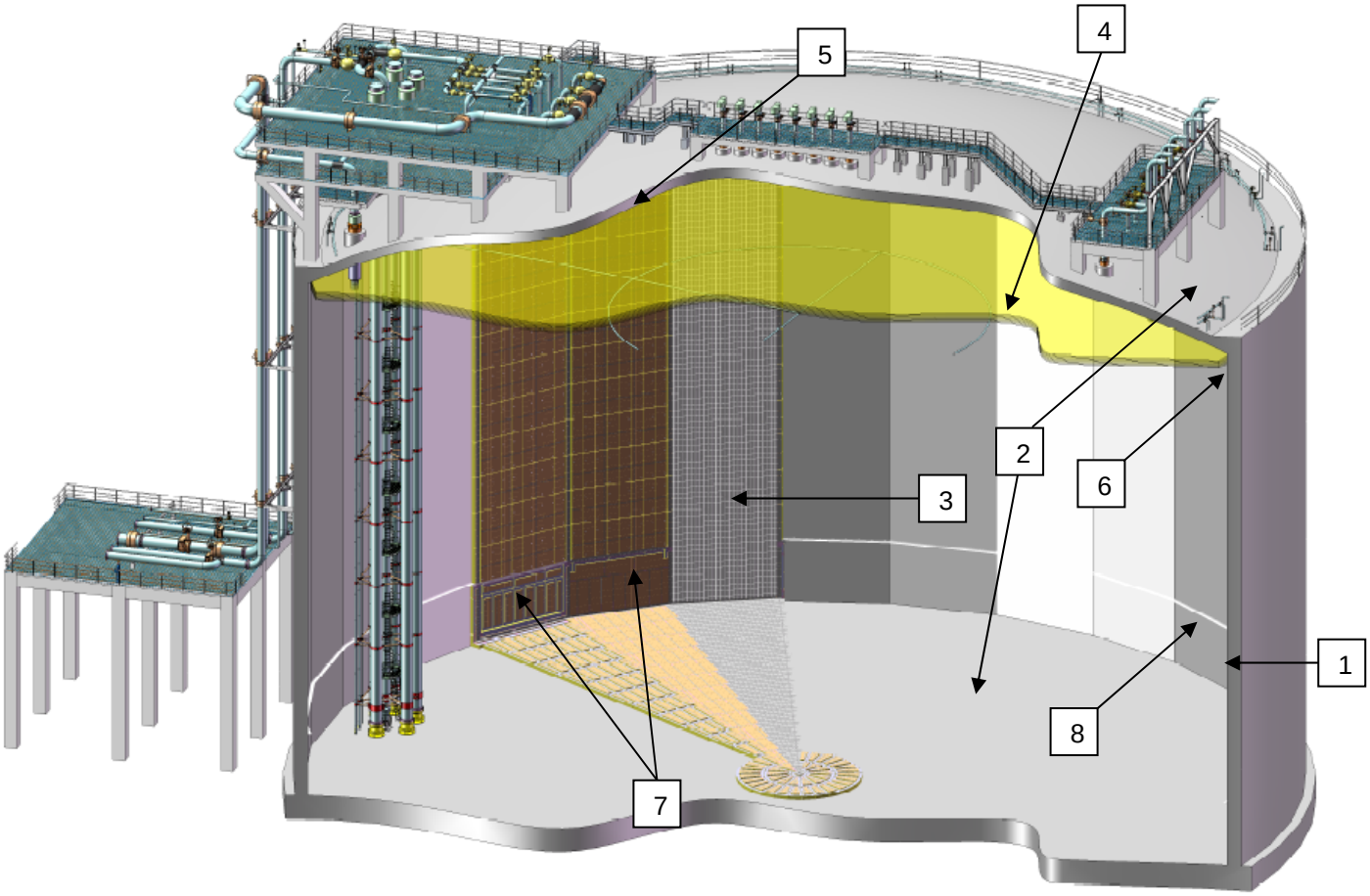
During March 2014 NFPA59A meeting, public inputs were reviewed. The Public Input No. 50-NFPA 59A-2013 put alert on Membrane containment tank system, which was addressed on the Definition clause only. During the meeting, TC agreed to remove the Membrane definition. However, in order not to send the wrong signal to the LNG industry (such as the technology is not allowed), the technical committee decided to create, on an urgent basis, a subcommittee to prepare wording for inclusion of a full treatment of membrane containment tank for issuance as a TIA coincidentally with the 2016 version. This subcommittee has now completed its work and agreed wording is proposed as a TIA. Acceptance of this TIA on an emergency basis is consistent with the following bases as prescribed in the standard:

(f) *The proposed TIA intends to correct a circumstance in which the revised NFPA Standard has resulted in an adverse impact on a product or method that was inadvertently overlooked in the total revision process or was without adequate technical (safety) justification for the action. In the absence of a TIA (expected to be released concurrently with 2016 edition), membrane containment systems will not be in NFPA59A 2016 edition and will be deferred until the next revision in 2018 (or 2019). From a practical standpoint, the absence of a TIA will restrict competition in an important timeframe when LNG as fuel, particularly in marine applications, is driving the development of LNG distribution and delivery systems. Proponents who are seeking options are facing a significant barrier in terms of regulatory uncertain without specific treatment of membrane tanks in NFPA 59A.*

Moreover, the timeframe for project development is such that developers cannot practically consider membrane alternatives without using European Norms, Canadian or other standards for references to membrane tanks

III. MEMBRANE TANK DESCRIPTION

The following sketch illustrates the main elements which of a Membrane containment Tank system.



The membrane tank system design philosophy is based on the separation of each function. Each element from the concrete outer tank to the primary container is designed to ensure one function as described below:

- In normal operation:

- An outer concrete tank (1) ensures structural resistance to contain the LNG and gas pressure loads and to withstand external hazards. It works at ambient temperature and is therefore not subjected to large thermal stresses. It consists of a cylindrical wall made of post-tensioned concrete bounded by a reinforced concrete slab and a reinforced concrete dome roof (2).
- A primary corrugated membrane (3) is both liquid and gas tight. The primary membrane is not a structural component of the system (it has only a tightness function). It incorporates a double network of orthogonal corrugations, which behave like bellows, allowing for free contraction and expansion, in two directions, under thermal variations. It is made up of membrane sheets welded onto inserts in the insulating panels and lap welded to each other. The membrane is anchored on the top of the wall through a peripheral insert (6).
- The carbon steel liner (5) inside the dome roof, the compression ring on the top of the walls and the primary membrane are all tightly welded to ensure the global gas tightness of the containment system.

- A continuous moisture barrier is applied behind the insulating elements to the inner face of the concrete base slab and sidewall tank to prevent any water, liquid or vapor migration from the concrete to the insulation space during the life span of the structure.
- Between the membrane and the concrete wall, an insulating structure (7) maintains the concrete tank structure at ambient temperature. The insulation is "load bearing" in that it transmits the LNG loads from the membrane inner tank to the concrete outer tank. Its thickness is determined according to the daily boil-off rate requirement. This insulation space is tight from the inside (primary membrane) and the outside (moisture barrier), and permanently maintained under a nitrogen atmosphere, which enables it to be monitored. It is considered as an independent space (insulation space). Nitrogen monitoring (breathing) allows for the continuous control of the integrity of the inner containment tightness.
- An insulated suspended deck (4) keeps the roof at an acceptable temperature with adequate insulation. The suspended deck, which consists of aluminum plates covered with layers of glass wool or fiberglass blankets, is installed at the upper part of the primary barrier container. The insulation thickness is determined according to the daily boil-off rate requirement. The deck is provided with vent holes ensuring the passage of product vapor across the suspended deck.
- All piping and instrumentation connections to the tank (tubular structure and the insulation space monitoring system) are provided through the tank roof. There is no penetration through the membrane. The tubular structure is anchored to the tank roof and only guided at the bottom part of the tank.

- In abnormal condition:

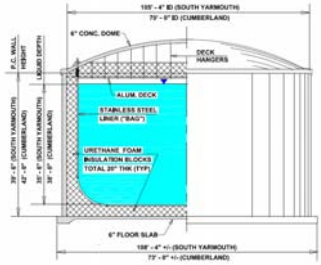
- In the insulating space, a sampling nitrogen system allows for the detection of any product vapor ingress (gas samples are taken continuously and automatically analyzed to make sure that there is no gas vapor behind the membrane). In the case of a methane leak, the nitrogen sweeping mode is activated to maintain the resulting gas concentration in the insulation space below 30% of the lower flammable limit.
- A secondary membrane, anchored at 5 meter height on the wall through a peripheral insert (8) ensures liquid tightness in order to protect the tank's bottom corner, between the vertical walls and the base slab, against sudden thermal cooling induced by cryogenic temperatures for a time duration such that the system can be shut down safely (and decommissioned if necessary). This system is called the Thermal Protection System (TPS). In this respect, the membrane tanks ensure the same functional requirement of that of 9% Ni Full Containment technology.

IV. REFERENCES

The first membrane above ground tanks were commissioned in 1972 and are still in service. Today, there are just over 100 Membrane tanks in service worldwide.

8,000m3 above ground Ethylene tank at a petrochemical plant in Lavera, France

Owner: Naphtachimie (Total/INEOS).
Commissioned in 1972 (still in Service in 2015)



Two Prestresse concrete Membrane type LNG storage, USA
8,200m³ (South Yarmouth, MA) & 4,000m³ (Cumberland, RI)
Commissioned in 1974

Dozens of Inground Membrane LNG tanks in Japan, from 30,000m3 to 250,000m3 capacity

Owner: Japanese utilities (Tokyo Gas, TEPCO, etc)

10 x 100,000m3 above ground Membrane LNG tanks in Korea

Owner: Kogas

Membrane above ground tanks under construction in South East Asia

Owner: EWC

V. SAFETY PROFILE OF MEMBRANE TANK

The membrane technology as an extensive track record and operational history, via experience obtained on LNG tanks and tankers, but also on LPG and ethylene tanks. Moreover, many Quantitative Risk Assessments have been performed by Korean, British, French and US entities, for comparison of the Membrane and 9%Ni Full Containment systems. Each of them came to the same overall conclusion: both technologies provide the same risk profile and same level of safety:

- *N.Ketchell & P. Genoud, LNG 12 – Perth. - 1996* : Quantification and Comparison of the Risks of LNG storage concepts – Membrane and full containment.
- *Korean Journal of Chemical Engineering, Vol.22, No.1, 1-8, 2005* :Risk Assessment of Membrane Type LNG Storage Tanks in Korea-based on Fault Tree Analysis, by Hyo Kim, Jae-Sun Koh and Youngsoo Kim from Department of Chemical Engineering, University of Seoul Korea, and Theofanius G. Theofanous from Center for Risk Studies and Safety, University of California, Santa Barbara, CA, USA.
- *S. R. Lee, 23rd World Gas Conference, Amsterdam 2006*: Safety Comparison of LNG tank designs with fault tree analysis.
- *ESR Technology, UK, 2011:* Comparative QRA of the GST® Membrane and Full Containment LNG storage tanks, by ESR technology UK.

VI. EXISTING CODES AND STANDARDS

As of January 2015, the following existing Codes and Standards refer to Membrane tanks::

Country	standard	Edition	title	Comments
Europe	EN1473	2007	Installation and equipment for liquefied natural gas - Design of onshore installations	*Addresses definition and equipment relative to membrane tanks.*
USA	NFPA 59A	2013	Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG)	*Definition of a membrane tank only.*
Europe	EN14620 parts 1 to 5	2006	Design and manufacture of site built, vertical, cylindrical, flat bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C	*Addresses the full design of membrane tanks.*
Canada	CSA Z-276	2015	Liquefied Natural Gas (LNG) Production, Storage and Handling	*Full inclusion of requirements for Membrane containment tanks in line with other tank technology requirements.*
Japan	JGA RP 107-2		Recommended practice for LNG in-ground storage	*Deals only with in-ground storage tanks; No English version exists for this Japanese standard.*
Korea	KS B 6943	2007	Standard for Membrane type inner tank	*Design of membrane type inner tank.*
USA	ACI376	2011	Code Requirements for Design and Construction of Concrete Structures for the Containment of Refrigerated Liquefied Gases	*This Code is not applicable to membrane tanks. However, it says that with appropriate additional engineering analysis and justification, portions of this Code may be applied.*
Canada	BCOGC	2014	Oil & Gas Activity act; LNG Regulation	*This regulation integrates Membrane tanks with reference to EN14620 for parts exclusive to membrane, ACI376 for concrete outer tank, and API625 as general codes.*

The design requirements for an above ground Membrane tank system are available since 2006 through the EN-14620 standard parts 1 to 5. The equivalent American standard is the recent API 625

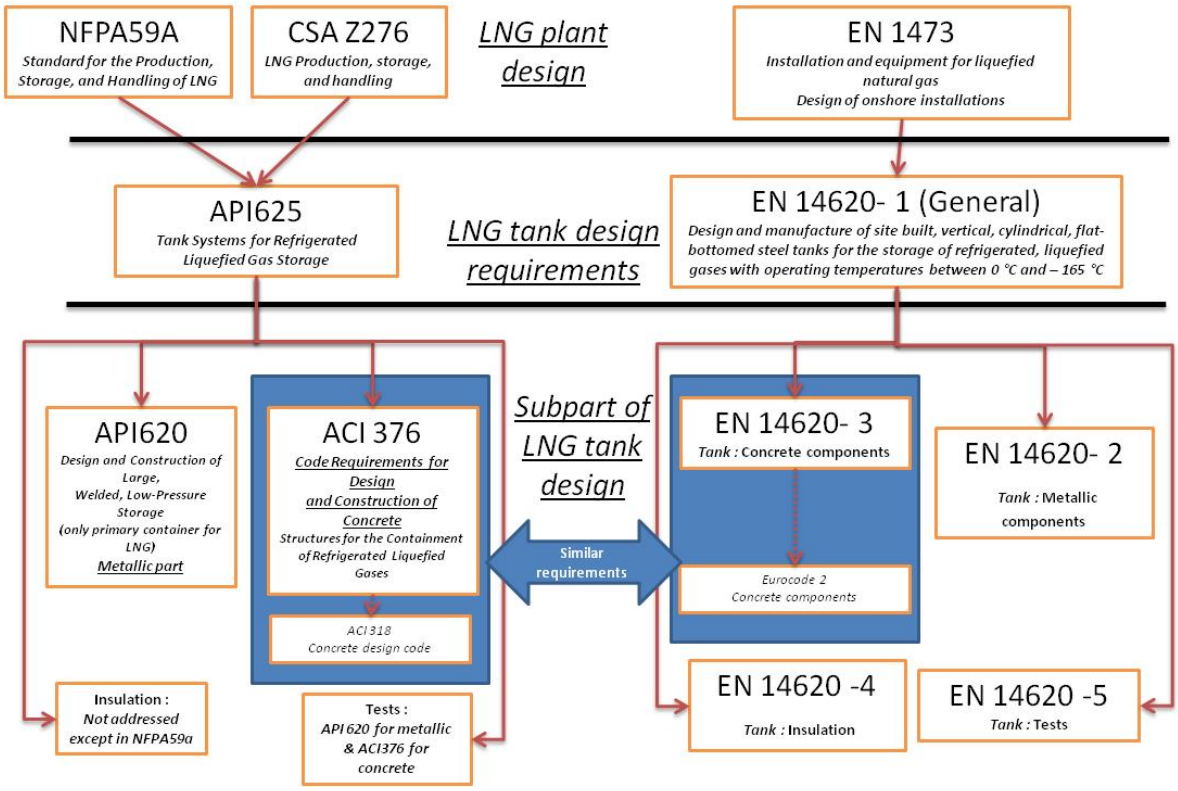
(1st edition in 2010) but it does not address Membrane tank systems. Also, the very recent ACI 376 Standard addresses requirements for Concrete parts of LNG tanks. As noted above this code also states that while Membrane is not addressed, portions of this Code may be applied to the structural design of a concrete outer tank of a membrane tank using both primary and secondary tank criteria.
In February 2015, Canadian Standard Association (CSA) published the 2015 version of Z276 standard (equivalent scope of the NFPA59a) with full inclusion of membrane storage technology. Members in this task group who were also involved in this membrane inclusion in Canada are : Alex Cooperman (CBI), Keith Mash (Shell), Brian Eisentrout (CBI) and Adnan Ezzarhouni (GTT)

VII. SUGGESTED WAY TO INCORPORATE MEMBRANE REQUIREMENTS WITH THE TECHNICAL SUBSTIANTATION

As of 2014, the requirements of a tank system are addressed though two main international Standards: EN 14620 since 2006, and API 625 since 2010.

NFPA59A is not a tank design standard, but an LNG Facility standard similar to EN 1473 or CSA Z276 which simply refers to relevant design standards for the tank itself and addresses safety requirements for plant siting, such as fire scenarios, earthquake, etc..

Here below is a global representation of how the codes fit together:



The suggested way to incorporate the Membrane tank system into NFPA59A, which was also the CSA 276 committee adopted, is to consider the same Sub-standard for Membrane tank systems (NFPA59A→API625→ACI376+API620) for all common components, and to refer to European Std for parts which are exclusive to the Membrane system (NFPA59A→API625→EN14620).

In terms of technical substantiation, Membrane containment system tank is a full integrity system. This means the performance of the tank system shall be similar to what is required of a full containment system:

- Able to store LNG and natural gas inside the tank in all normal operating conditions.

- Able to retain LNG and natural gas inside the tank, in all abnormal design conditions (seismic, release of the LNG to the secondary container, external & internal hazards, etc…)

In order to do so, all the requirements for a full containment shall be also applicable to membrane containment system.

LNG tank storage has to comply with other tank design codes. Currently, NFPA59a refers to API625 for LNG tank overall design, ACI376 for civil tank design and API620 for mechanical design. Membrane containment tank systems are fully addressed in EN14520 and partially in ACI376. Relevant references to these standards have to be made in the proposed standards. Currently, ACI376 does not fully include the membrane containment system, so additional requirements have been added to close the gap. For membrane components exclusive to the technology, the language refers to EN14620, but additional prescriptive requirements are added as agreed within the task group, in order to be more conservative for membrane tanks in a first release.

Finally, all components in membrane containment tank systems which are similar to other systems (roof, suspended deck, etc.) will be referred to the same American standard.

VIII. EXISTING DEFINITIONS OF MEMBRANE TANKS

Standard	Definition of a Membrane LNG tank	Comments
NFPA59A (2013 edition)	**Membrane Tank System:** A tank system consisting of a thin metal primary container together with thermal insulation and a concrete container jointly forming an integrated, composite structure that provides liquid containment, where hydrostatic loads and other loadings on the membrane are transferred via the load-bearing insulation onto the concrete container such that the vapors are contained by the tank roof.	
CSA Z-276 (new 2015 edition)	**Membrane containment tank system** — a tank system consisting of a thin metal liquid barrier integrated with load bearing thermal insulation supported by a self standing outer container jointly forming an integrated, composite tank structure designed to contain LNG in the event of leakage from the liquid barrier, and where the roof of the outer container is either steel or concrete designed such that the excess vapor caused by a spill of LNG from the liquid barrier will discharge through the relief valves.	This definition is the most updated available in the industry, and quite complete.
EN 14620	**Membrane containment :** A membrane tank shall consist of a thin steel primary container (membrane) together with thermal insulation and a concrete tank jointly forming an integrated, composite structure. This composite structure shall provide the liquid containment. All hydrostatic loads and other loadings on the membrane shall be transferred via the load-bearing insulation onto the concrete tank. The vapours shall be contained by the tank roof, which can be either a similar composite structure or with a gas-tight dome roof and insulation on a suspended roof. In case of leakage of the membrane, the concrete tank, in combination with the insulation system, shall be designed such that it can contain the liquid.	

IX. LIST OF PROPOSED CHANGES TO NFPA59A 2013 EDITION

Proposed changes are divided in three topics:

- **General:** The proposed changes covers all inclusions of general tank performance requirements from the code, not specifically related to mechanical or civil design but rather the tank hazards.

- **Mechanical :**The proposed changes includes references to EN14620 standard and additional requirements that the task force decided in order to be comfortable with the technology (These changes are somewhat more prescriptive that the EN standards in some cases).

- **Civil:** The proposed changes includes references to ACI376 and additional requirements for membrane tank since ACI 376 does not specifically include membrane (even though it can be used a strong basis).

Exhaustive proposed changes are listed on the TIA.