LIFE CYCLE OF THE LAST LNG STORAGE TANK IN FROZEN GROUND

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ABSTRACT

The LNG underground storage tank of the SONATRACH - GL4/Z LNG complex (Arzew – ALGERIA), was the last underground storage tank in frozen ground in the world still in service until July 2004, date at which the decision was taken by SONATRACH to put it under conservation preceding its decommissioning.

Since its first operation in 1965, this storage tank in frozen ground, although it has successfully undergone good service conditions, has developed some natural problems (distortion, cracks and inflation of the surrounding ground), working conditions problems (LNG leaks) and structural problems (disorders of the roof structure).

Different methods and check means have been used on the environment of the tank (GPS for position checks and frost front temperature monitoring), on the storage tank itself (internal wall endoscopy), and on the structure of the tank (structural expertises). A valuable set of information was thus provided to SONATRACH which helped for decision making in the field of safety and industrial risk prevention for this exceptional construction.

These actions, analysis and inspections conducted on this construction have allowed its operation in good working conditions for over 40 years.

This storage tank is now at the end of its operating life and an important project is now commencing in order to end definitively its life. This project involves special arrangements and techniques.

PURPOSE OF THE PRESENTATION

The Poster deals with the following topics:

(i) Operation history of the underground tank,

(ii) Conditions for its operation (generated boil-off gas, malfunctions),

(iii) Major problems encountered during its operation including those leading to the decision of stopping its operation and putting it into conservation (LNG leaks, disorders of the structure and the geotechnical deformation of the environment),

(iv) Monitoring and the measurements methods (endoscopies, expertises and GPS auscultations), with presentation of the different results and evolutions (life cycle period up to February 2006),

(v) Motivations for the decommissioning decision,

(vi) Procedures for its taking out of operation

PRESENTATION OF THE UNDERGOUND STORAGE TANK

The liquefied natural gas tank in excavation of the GL4/Z complex at Arzew is composed of:

"The reservoir itself, without shell, built in one excavation achieved in the soil.

"A superstructure forming the roof of the reservoir supported by a ring of buried concrete.

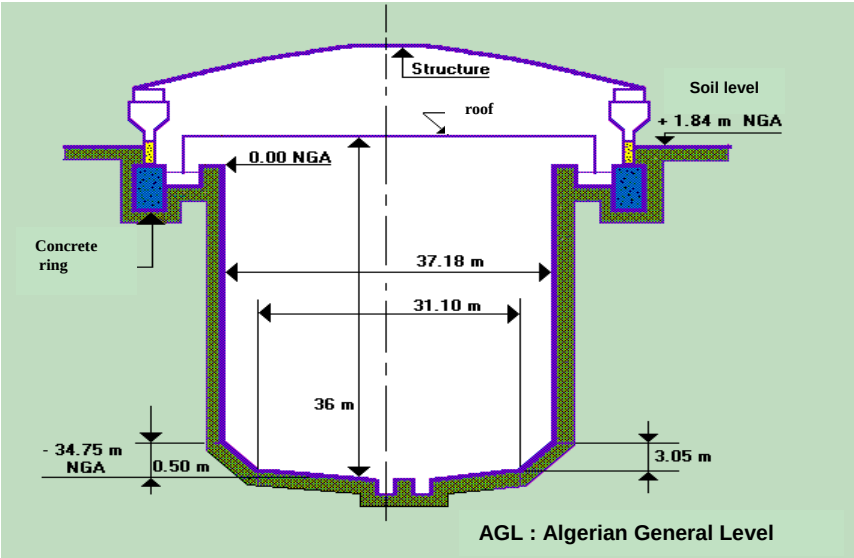

Figure 1: LNG INGROUND STORAGE TANK T5101

RECALL OF THE CONDITIONS OF THE EXCAVATION REALIZATION

- Until 2004, GL4/Z's tank T5101 was the last inground storage tank remaining in operation in the world.
- The CONCH Company has constructed the tank during the years 1964-1965.
- The excavation has been executed in accordance with the geological conditions of the site, by freezing the earth segment while digging inside the erased segment that acts as support during the phase of excavation and then constitute the limits of the storage.
- The mechanical strength and the tightness of the tank are achieved by the progressive frost of the soil in contact with the LNG whose temperature is -161 C°.
- The excavation has been executed mainly on the layers of sandstone and marl soils.
- Technical data:
- The tank has a diameter of 37,20 m and a depth of 36m. It is located at 100 m from the seaside.
- Storage environment :
- The environment of the tank is equipped with 48 thermocouples installed at different depths and distances (16 thermocouples at angles of 120 degrees) to allow control of the ice wall growth by following the isotherms propagation: -100C°, -50C°, and 0 C°.

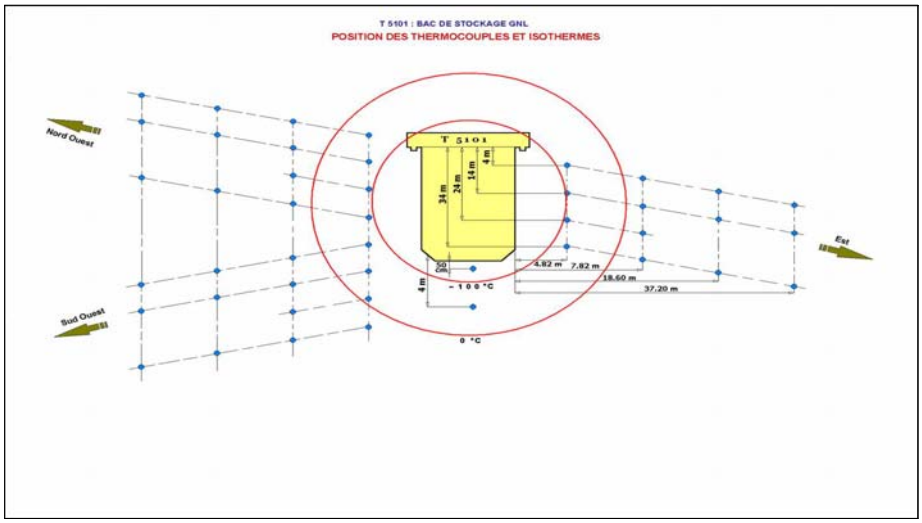

Figure 2: thermocouples arrangement

FEATURES OF THE STORAGE TANK

- The main characteristic of this storage type is the absence of insulation and barrier of leak tightness on the vertical wall. Only the frost of water contained in soil ensures its impermeability.
- This type of storage cannot be heated.

STRUCTURE OF THE TANK ROOF SUPPORT

- The reservoir is covered by a roof in aluminium alloy suspended to the profile in the metallic framework that is shape crossed as meridians and parallels laying on a ring made of carbon steel mounted on 60 pillars made of steel concrete, recessed in a ring of steel concrete.

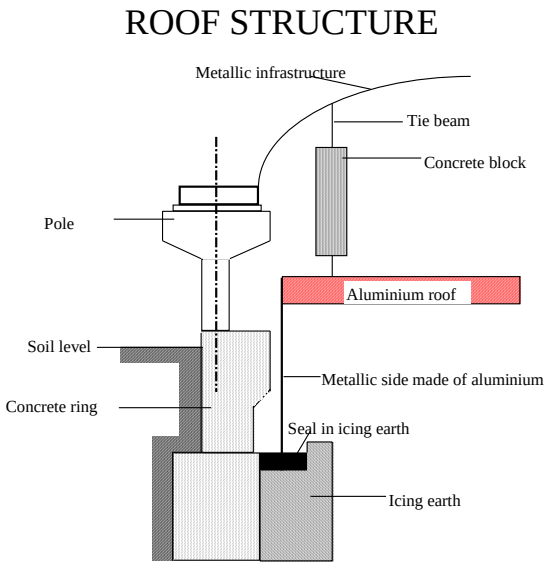

Figure 3: Roof Structure

PROBLEMS OF SIMILAR INGROUND STORAGE TANKS

a) **Transcontinental Gas Pipes Line Corporation**

A LNG tank in excavation installed close to New Jersey (Hackensak) underwent problems of exploitation following an increase of the boil off pressure. These problems were significant enough to require its decommissioning.

b) **British Gas (Canvey Island, England)**

Cracks at approximately 60 ft (18 m) depth between the four tanks created leaks between them.

The boil off from the four tanks greatly exceeded the anticipated 0.12 % of the tank content per day. This boil off stabilised at approximately 0.5% to 1 % per day of tank contents.

c) **Tennessee Gas Pipeline Company (Hopkington, Massachusetts)**

At Hopkington two tanks had been constructed.
The major problem was cracks in the rock and communication at 100 foot of depth between the two tanks.

As they were constructed entirely in rock, they have been left empty for their decommissioning after purging with cold nitrogen.

PROBLEMS ENCOUNTERED DURING THE GL4Z TANK OPERATION

After the tank completion some basic problems appeared:

Natural problems

- Lift up of the tank: During the course of its life span the tank developed some disproportionate ascents (heaving more important earth side than sea side).
- Distortions, inflation and fissuring of the environment soil: The soil at the surrounding of the tank showed evolutionary inflations in variable directions and distances; series of cracks and pads with cavities were observed on the ground level. These distortions evolve in accordance with the progression of the frost front.
- Ground heave and displacements of pipe work trestles to a much greater extent than expected. This remains a problem which requires continual adjustment of trestles, pipe supports and the pylon of the cold flare in the affected area.

Exploitation problems

- A leak of LNG occurred at the level of a thermometric well located 4 meters west south. The explanations on the origin of this leak rely on two (02) assumptions:
    1. one of them is bounded to a crack with vertical progress taking birth on the West North generator of the tank wall.
    2. and the second one, it is due to a likely slip of the soil during the heave of the tank that would have generated cavities leading to a constant leak of the cold gas.
- The sealing of this leak has been achieved by injection of gasoline that formed a plug of ice which freezing point is -110 C°.
- The tracing of the isotherms -100 C°, -50 C° and 0 C° re-established demonstrated that the operation was conclusive.
  Important boil off (0.3 % to 0.5%)
  Roll over phenomena

Structural problems

The damage on the structure of the roof support appears on the following elements:

- *Lining of the pillars:*
  - detachment of the lining leaving the pillars armatures uncovered
  - Vertical cracks and scaling of the lining
  - crumbling of the concrete at its base
- *Pillars:*
  - fissures and bursting on the upper lateral parts at the level of contact with the concrete ring,
  - fissures and detachment of the concrete on the overhead face of the pillars.
- *Slipping plate:*
  - blockage at the level of the contact points of the concrete ring.
- *Metallic slings:*
  - Distortions by buckling

ORIGIN OF THE PROBLEMS

Nature of the soil

The significant earth movement allows assuming the presence of a rocky zone that opposes to the displacement of ice, introducing an increase of the volumes and creating zones of internal stresses that are at the origin of the distortions and foreseeable cracking at the top.

Sea proximity

- The sea plays the role of a heating device with a limitation of the freezing in its direction.
- The disproportionate tensions on the sea side and the earth side sea are the origin of the major part of these distortions.

Seismic movements

The nature of the deteriorations seems to separate this hypothesis.

Ice wall growth

- The position of the frost front (isotherm 0°C) has evolved until 30 m.
- The front of frost also evolves downwards; the progression is sensibly in the same order of magnitude that the one of the horizontal progression.
- The simulation of the water movements shows that the flux of water toward the ice front in the area of non-frost represents the main reason of inflation.
- The movements of water in the less important frozen area can lead in the long run an inflation of the frozen soil.

METHODS AND MEANS OF CONTROLS OF THE TANK ENVIRONMENT

- Ice wall growth: the front of frost is monitored monthly measuring the temperatures for the follow-up of the progression of the cold front (isotherm 0 C°).

- The thermocouples are located according to 03 directions: east, Northwest, and Southwest at the depths of: -4 m,-14 m, -24m and -34 m and from the corresponding distances of 4.82 m, 7.8 m, 16.8 m and 37.20 m.

DATES AND PROMINENT FACTS OF THE OPERATING CYCLE

- The tank has been constructed in **1964-65** and has been put in service in August 1965.
- **In 1967**, the first problems appeared in the month November by obvious distortions of soil around the storage tank and by the deterioration of 27 pillars of roof support. A simple repair of the pillars has been done in 1968. It consisted of fretting all pillars in dice of concrete.
- **From 1970 to 1989**, measurements of levelling have been achieved by an expert geometer.
- **In 1977**, a serious accident occurred on the 18 " extraction pipeline. A valve made of aluminium exploded at the discharge of the immersed pumps. An operator was killed. The LNG spill, that had not been detected and stopped immediately, reached the sea and caused fast phase transitions and a huge vaporisation.
- **November 27th 1979**, a crack in soil lead to an LNG leak that appeared by an exit of cold gas at a thermocouple well. This leak has been plugged by the introduction of gasoline in the crack.
- **In July 1984**, an endoscopy of the storage has been achieved by the Direction of Studies and New Techniques of the GAZ DE FRANCE. It showed the presence of cracks in the low part of the excavation. The photograph examination of the inside of the tank puts in evidence and permits to specify the results of three types of anomalies:
  - ✓ A peripheral horizontal crack,
  - ✓ Two vertical marks (one of them associated to a crack),
  - ✓ Distortions of the double sided roof.

  The observation did not reveal distortion of big amplitude capable to generate a crumbling. However the inspection of the wall surface doesn't allow to evaluate the extension of the cracks in the ground.
- **From 25 to 28th of October 1987**, a general inspection led by the Technical Direction of the SONATRACH Liquefaction division was made on the civil works and it focused notably on the very preoccupying state of the storage and its cold flare.
- **In 1988**: a progression modelling of the frost front has been achieved by the Central Laboratory of the Ponts et Chaussées de Paris, under the supervision of GAZ DE FRANCE,
- **From 1990 to 1991**: the geodesic sessions undertaken during the audit by SOFREGAZ showed crack, and cavities generated by a “cryosuccion” phenomena.
- SOFREGAZ recommended the shut down of the storage tank, as soon as possible.
- **From 1990 to 1991**, the Algerian National Center of the Spatial Techniques (survey office) took the relay to do a campaign of more precise geometric auscultation.

- **In September 1998** SAFIR during the renovation program of the plant proposed to separate the problems (leaks of the roof and repair of the roof tank) that are different in type and are not linked together.
- **From 2000 to 2006:** This tank in frozen ground has been a subject of research from the Algerian National Center of the Spatial Techniques. The research consisted of diagnoses which were carried by using the Global Positioning System (GPS).

  These techniques have allowed SONATRACH to monitor step by step the evolution of the tank and its environment over sessions covered in: February 2000, July 2002, June 2004 and February 2006.
  The results of this period are illustrated by graphs below:

The comparison of the results of the three GPS campaigns permitted to put in evidence displacements about 129mm in planimetry and 252 mm in altimetry.

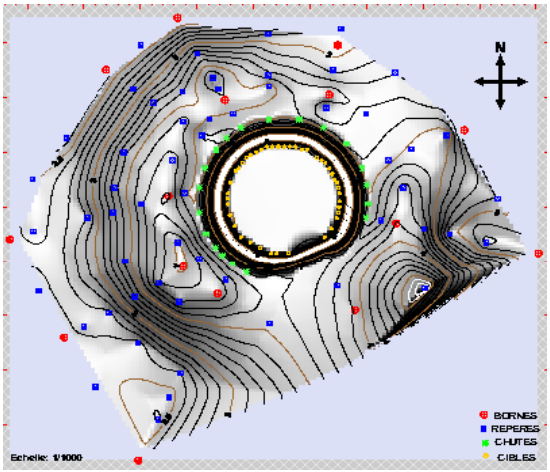

Figure 4 : Reference configuration (feb. 2000)

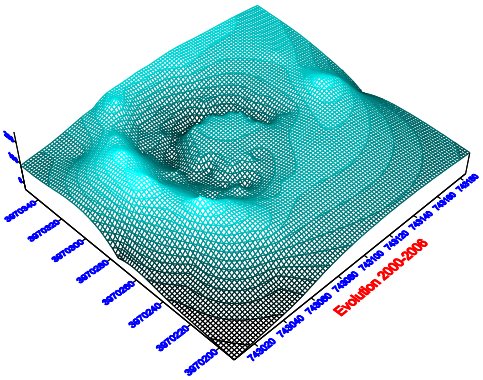

Figure 5 : Altimétric displacements : 2000-2006

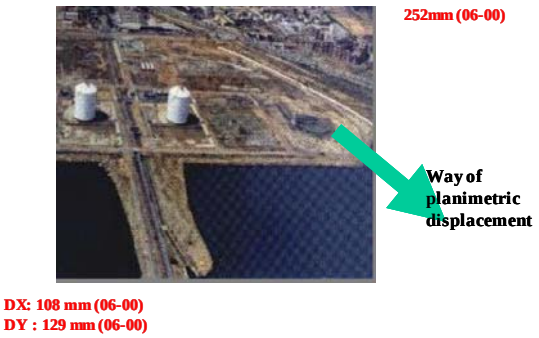

Figure 6 : Maximal displacement : 2000-2006

Figure 7 : Planimetric displacements 2000-2006

- **In May 2002** Freyssinet conducted an expertise on the support pillars of the metallic ring, the wall of the circular concrete foundation, the slipping plates and the roof supports with their connections.

- **August 2004: Matrix Report recommendations**

  ''Of greatest concern is the underground LNG storage tank. This vessel has past its useful life; it was due for retirement in 1990. The support structure is already failing and collapse of this structure is imminent. An engineering study completed 21 months ago concluded that supports are deteriorating, the storage tank has tipped towards the sea and that repair is necessary. Nothing has been done and the damage to the concrete support pillars is now extensive, to the point that the reinforcing steel is exposed and corroding. The road around the tank has collapsed on the seaward side. We believe this tank is beyond economic repair and should be shutdown*.*

  Failure of ground LNG storage tank is a serious possibility; the vessel should be taken out of service immediately"

  Extract from Process Safety Management GL4-Z Assessment Report (30august 2004) by Matrix Solution Inc

- **27 September 2004 :** Sonatrach decision to decommission the in ground tank

- **13 February 2006:** decommissioning contract signature.

TANK DECOMMISSIONNING

Safety criteria:
Important general safety criteria to be satisfied:(i)there had to be no possibility of inflammable gas mixture accumulating within the tank, (ii) until the tank was completely filled, the wall of the tank had to retain their integrity,(iii) after infilling, the in filled tank and surrounding soil had to be in a safe and stable condition.

Safety risks and environmental concerns
The major safety concerns : (i) Oxygen Deficient Atmosphere (ii) Cryogenic Temperatures (iii) Fire or Explosion (iv) Environmental Concerns,(v) Thawing of Tank Walls and Prevention of Tank Walls Collapsing,(vi) Valve 39 (vii) Static Electricity Build up During Filling,(viii) fully check P & IDs as-built, (ix) Working at night,(x) Close proximity of nearby town,(xi) Unknown composition and volume in tank,(xi) Special safety precautions.

Tank decommissioning procedure

Step 1 – Empty Tank to the Low Level
The intent: Transfer LNG product from the underground tank, T-5101 to the above ground LNG storage Tanks

Step 2 – Circulation of Light Ends
Intent: To remove heavy LNG, the tank will be flushed with light LNG. The intent is to remove as much of the heavy ends as possible so that the weathering time period is reduced.

Step 3 – Tank Weathering and Monitoring
The tank weathering procedure contains two parts. The first will purge the cool down line. This will allow liquid Nitrogen to be introduced to the spray bars to cool down the tank shoulders. The second part will weather the tank of the remaining LNG.
Intent: (i) The intent of this part is to purge with Nitrogen vapour

(ii)The intent of this second part is to allow the residual LNG to boil off using the heat stored in the earth surrounding the tank.

Step 4 - Purging of Tank and Associated Pipe work**:** The purge of the tank and associated pipe work has been broken down into smaller and more manageable steps

Intent: The intent of this step is to purge with Nitrogen vapour after the tank weathering phase

Step 5 – Disconnection of Piping Connections
Intent: This step will disconnect the piping connections from the tank.

Step 6- Remove In-Tank Pumps

Intent: The intent of this section is to describe the steps involved in removing the in-tank pumps.

Step 7- Cut in holes and Fill the Tank
Intent: The intent of this step is to cut nine holes in the tank roof and use them to fill the tank with sand**.**

Step 8, 9&10 - Opening of Tank Roof and Dismantling of Roof Structure
Intent: After the tank is filled with sand as specified above, the roof structure can be dismantled and removed. The intent of this step is to open the tank roof and dismantle the roof structure in a safe and efficient manner.

Step 11 - Excavation of Concrete walls at the top section of the tank

Intent: The intent of this section is to break the concrete retaining walls and the roof pillar structures

Steps 12 and 13 - Final Fill
Intent: To bring the surface of the tank to the same level as the surrounding ground.

Step 14 – Long Term Precautions and Checks
After dismantling of the tank roof structure and the filling the underground cavity, the area needs to be monitored on a regular basis for at least a year to measure the temperature changes of the soil around the cavity using the temperature probes currently installed.

Gradual warming of the ground is anticipated which will gradually thaw the underground block of ice. It is anticipated that water will gradually seep into the water table. It is recommended the soil temperature be monitored for at least a year to measure changes in soil condition. This data should be reviewed on a regular basis and the decision to monitor the area revised accordingly.

In addition to the above, monitor the filled area for any settlement and add additional fill materials (top soil) as required.

CONCLUSION

The scale of all techniques deployed during its life cycle until the end illustrates the permanent objective of SONATRACH to keep a maximum level of safety for its installations and for the environment. The huge work of decommissioning operation should be considered as factors to be taken into account at design stage in similar fields.

The experience of GL4Z in this case has proven that LNG could be stored in ground and that the nature of soil is an important parameter and a primary condition. Although there is no evidence that this was ever built, it proves that at the time the CONCH concept was technically feasible.

If a little care and maintenance are given during the life of the tank, although it seems hazardous to operate this kind of tank, the experience of GL4/Z has shown that it has been a safe mean of LNG storage.

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