Features of LNG Tank Civil Engineering

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Abstract:

This report discusses our civil design capabilities for LNG tanks. Covering every civil engineering element of LNG full containment tanks, this technology will contribute to LNG terminal projects mainly in South-East and South Asia.

1. General

In response to increasing electricity demands, a number of projects are under planning to introduce LNG in South East Asia and South Asia. In order to provide the best technical solutions to satisfy the owners' needs, JGC has developed its civil design capabilities for LNG storage tanks. Covering the scope of seismic design, foundation design and structural design of outer concrete tanks, it enables the execution from the basic design to the detailed design.

While this report focuses on LNG full containment tanks (Fig.1), the contents can also be applied for the other types of LNG storage tanks. The civil structures of the full containment tanks consist of a base slab, outer concrete wall and outer concrete roof. The prestressing tendons are placed horizontally and vertically in the outer concrete wall to resist against the LNG liquid pressures and vapor pressures. The design is performed in accordance with the American codes of NFPA59A and ACI376, or European codes of BS EN14620.

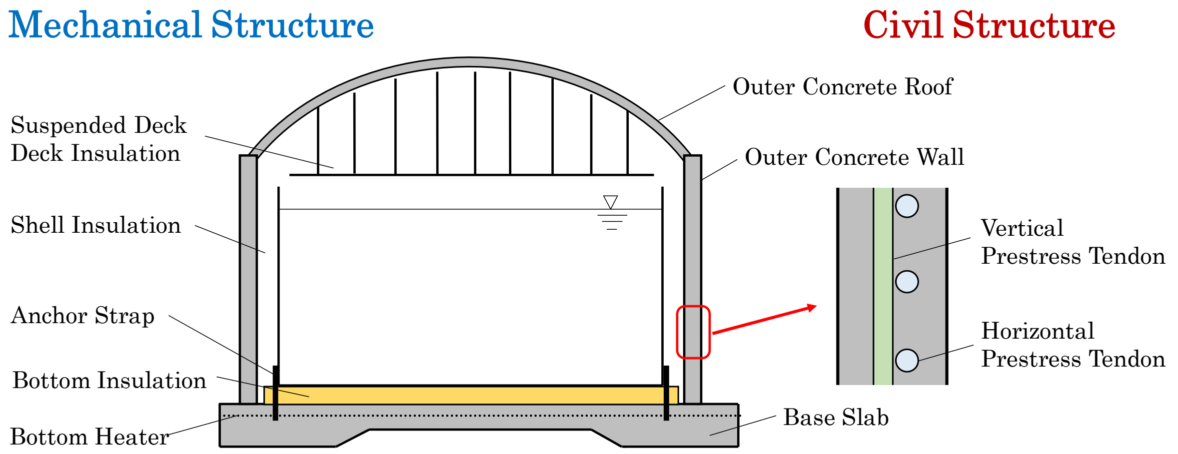


Fig. 1 LNG Full Containment Tank System

2. Design Flow

The design flow of LNG storage tanks is described in Fig.2. In the basic design phase, the foundation and seismic design will be performed in coordination with the mechanical design to determine the tank size and mass. Then, the civil design will move to the detailed design, in which the arrangements and quantities of steel reinforcement and prestressing tendons are studied.

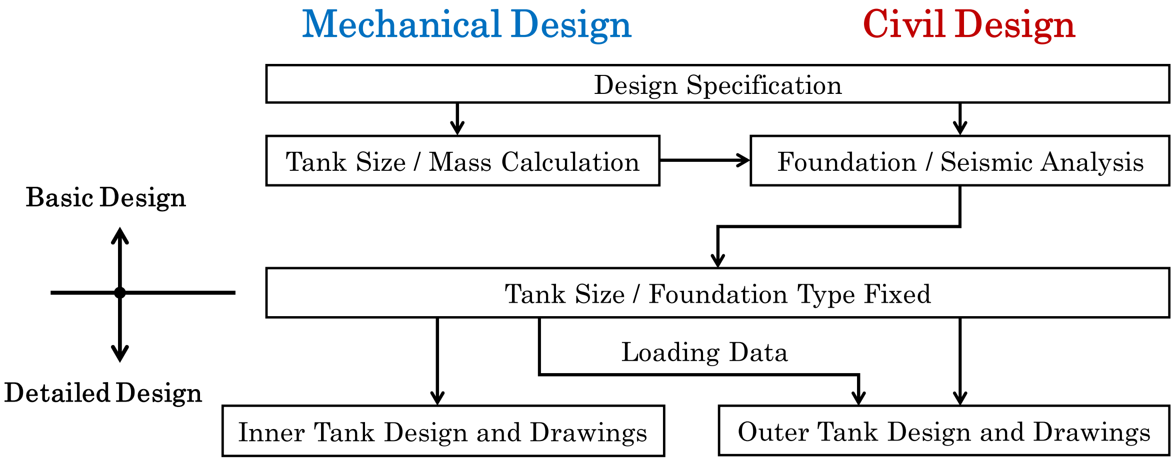


Fig. 2 LNG Tank Design Flow

3. Foundation Design

The foundation design is the process to study the applicability of piles or soil improvement methods according to the site soil condition and the availability of local resources and find the most cost-effective solution. JGC can offer a variety of foundation solutions based on its experience of executing plant EPC. For LNG storage tanks, it tends to be optimum from the aspects of cost and schedule to apply a raft foundation and use soil improvement options if necessary. In addition, the seismic behavior of raft foundations is less complicated than that of piled foundations as described in the later section.

The design requirement towards foundation settlements is to restrict it within the allowable values specified in ACI 376 and to avoid damage to piping connections caused by settlement relative to the adjacent pipe-rack foundation. In comparison with process units where numbers of equipment and piping are interconnected, the long-straight piping from an LNG storage tank to the interconnecting pipe-rack may allow for larger relative settlements.

Settlement analysis should be performed in detail to identify the behavior and therefore, should apply the nonlinear finite element analysis (FEA) to model the soil physical properties under the tanks appropriately.

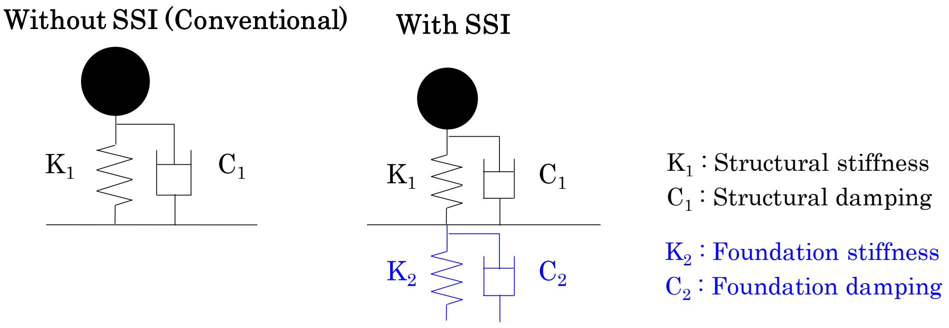
4. Seismic Design

The seismic behavior of heavy mass such as LNG storage tanks is influenced by the soil-structure interaction (SSI)NOTE1 effect. In the case of light weight structures with long fundamental periods, the foundation behaves rigidly when the structure vibrates. However, in the case of heavy structures with short fundamental periods, the deformation of the foundation becomes large and interacts with the structural vibration, showing the behavior of a flexible foundation. This is the SSI effect to cause the damping increase due to soil radiation and hysteresis and the period lengthening as the soil-structure system (Fig.3).

The analysis procedure to evaluate the SSI effect is not fully established yet and therefore, a designer has to select the most appropriate method in reference to the applicable codes and latest researches. There are several procedures to be applied from a simple hand-calculation, to a complex 3-dimentional dynamic SSI analysis (Fig.4), depending on the level of details required. With the dynamic SSI analysis, soil-structure FEA models are created and 3-directional (2-horizontal and vertical) earthquake time historiesNOTE2 are input at the bedrock layer. The response histories NOTE3 are outputted at each structural element and therefore, the detailed dynamic behavior can be observed.

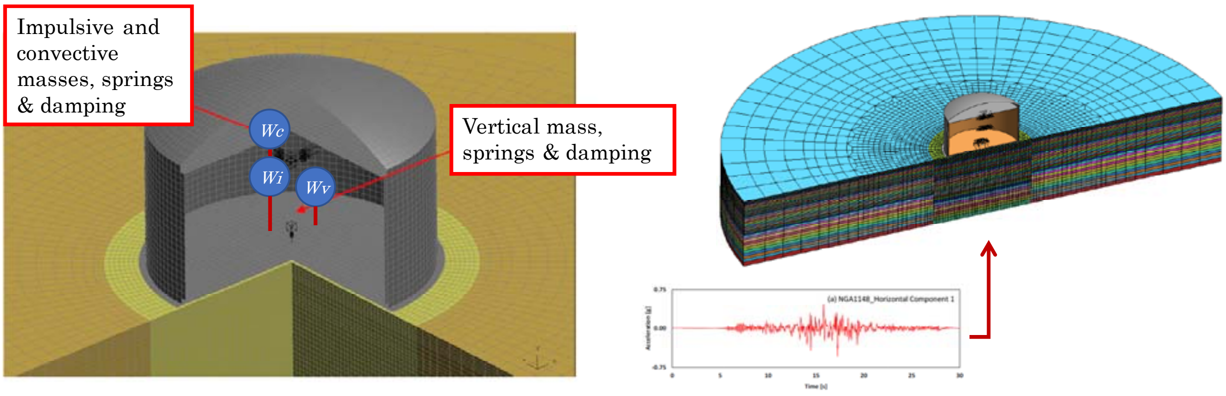
Further, in the case of pile foundations, the foundation stiffness and damping are influenced by complex dynamic group pile effects and thus may not be properly analyzed with the simple hand-calculation method, and require the evaluation of the dynamic SSI analysis. In this case, the design process becomes complicated, including the iteration to optimize the design layout.

There is a case to equip LNG storage tank foundations with seismic isolators in high seismic regions. Through the network with isolator suppliers, JGC can work for the isolated design.



SSI analysis model includes soil spring and damping.

Fig.3 SSI Effect



Input time-history motion at bedrock (X,Y,Z directions)

Fig.4 Dynamic SSI Analysis

5. Structural Design

In the structural design for outer concrete tanks, the arrangements and quantities of steel reinforcement and prestressing tendons are studied and then presented in the design drawings.

The structural design is performed with the FEA (Fig.5). With nonlinear concrete and steel reinforcement models, the tension strength of the concrete decreases at cracking and then the tension stress is transferred to the steel reinforcement.

Accordingly, the flexural stiffness of concrete members expresses nonlinearity in the FEA. In a conventional concrete structural design, while the deflection calculation is performed considering the stiffness reduction of concrete members, the strength calculation is made without the stiffness reduction as it is conservative to use the full stiffness. However, for the thermal stress at the outer wall in case of LNG spillage or the restrained stress at the wall bottom during horizontal prestressing, the conventional strength calculation using the full member stiffness may result in the excessive stress. The nonlinear concrete and steel reinforcement models achieve the reasonable design against these instances of thermal stress and restrained stress (Fig.6).

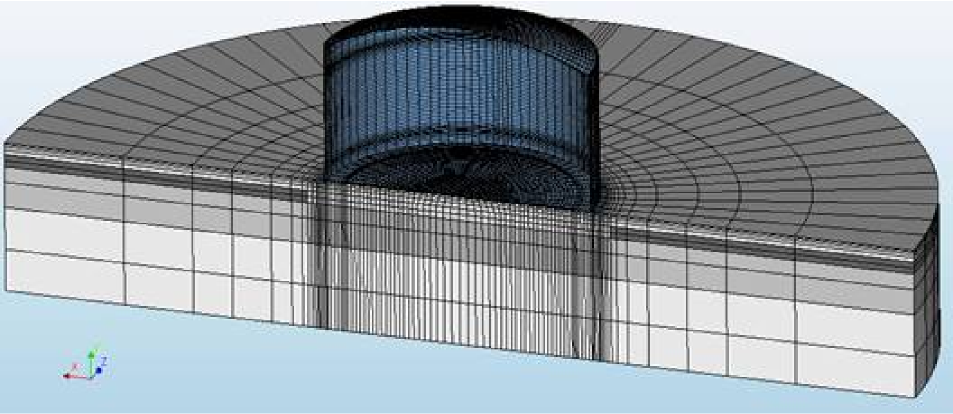
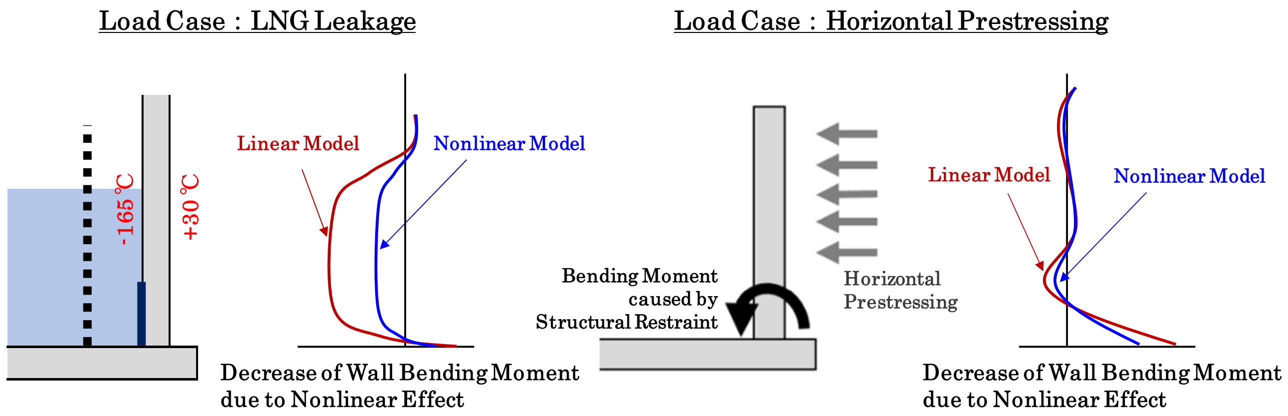


Fig.5 Structural Analysis Example (DIANA)

The load cases in accordance with ACI 376 are described in Tab.1. Nearly 100 load combinations are required in the detailed design. The structural analysis has to follow the construction steps. For example, when the prestressing is introduced at the outer wall, the stress distribution will be different depending on whether it is with or without a concrete roof or wall opening (Fig.7).

Several performance requirements are specified for each load combination. There are the serviceability requirements such as allowable crack widths, the strength requirements of structural members and the liquid tightness requirements of outer walls in the event of an LNG spillage.



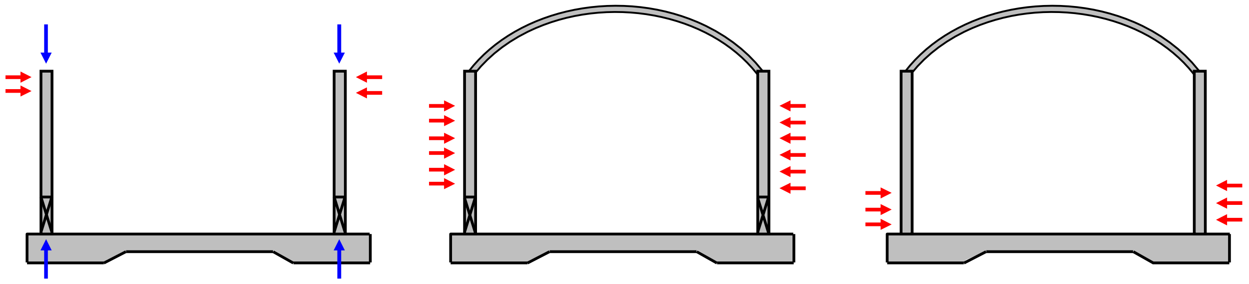
Load Case : LNG Leakage

Load Case : Horizontal Prestressing

Fig.6 Effect of Nonlinear Structural Analysis

Tab.1 Load Case

State	Load Case
Normal Load	Dead load, Live load, Prestressing (horizontal/vertical), Product pressure and weight, Wind load, Temperature load, Construction load (hydrotest/pneumatic test)
Abnormal Load	Earthquake load, LNG major leak, Aftershock earthquake in LNG leak, Fire, Blast, Impact load



1. Horizontal Prestressing without Concrete Roof

2. Horizontal Prestressing with Concrete Roof

3. Horizontal Prestressing after wall opening closure

Fig.7 Effect of Step Analysis

6． Closing

This report introduced the civil engineering features of LNG storage tanks, which have been applied for FEED projects and the accumulated expertise. It contributes to the optimization of the civil design of LNG storage tanks.

Further, some of these engineering features are also applicable to gravity base structures (GBS) or offshore wind turbine foundations. We will contribute to the design optimizations in these fields with due consideration given to the safety aspects through further developments of engineering levels.

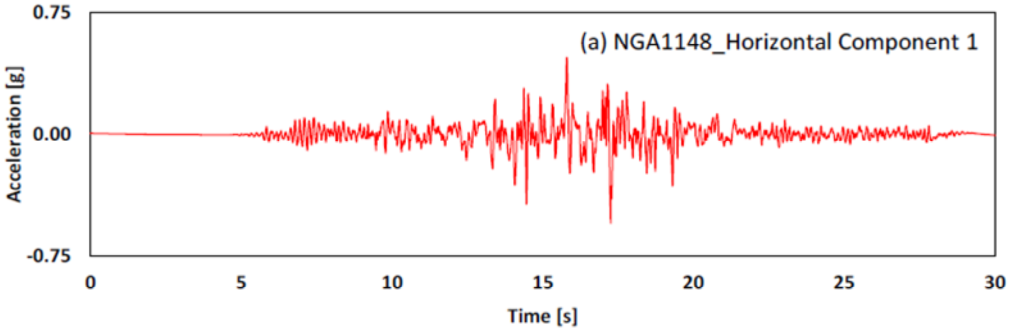
Terminology

NOTE1 Soil-Structure Interaction (SSI)

As a structure is placed on the ground, there is an interaction of forces and energies between the structure and ground when a structure vibrates during an earthquake. This is called soil-structure interaction (SSI). Except for special structures such as large tanks, the SSI effects are generally ignored and a simplified rigid-base design model is applied.

NOTE2 Earthquake Time Histories

Acceleration histories at ground, that change over time during an earthquake event as described in the figure below.



NOTE3 Response Histories

Acceleration histories at each structure in response to earthquake time histories.