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学 位 論 文 の 概 要 及 び 要 旨

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題　　目　SEISMIC DESIGN PROCEDURE FOR THE BOTTOM PLATE CORNER CONNECTION OF FLAT-BOTTOM CYLINDRICAL TANKS DUE TO UPLIFT RESPONSE OF THE BOTTOM PLATE DURING EARTHQUAKES
（平底円筒タンクの地震時の底板浮き上がり応答を考慮した底板コーナー接続部の耐震設計方法）

学位論文の概要及び要旨

In recent years, owners of above ground refrigerated liquefied flammable gas storage tanks, such as LNG storage tanks, have been requiring higher seismic design conditions for their tanks.

Under severe seismic design conditions, detailed verification of a soundness of structures including uplift behavior of a tank bottom plate has been required.

In most current seismic design procedures specified in standards, dynamic pressure for a design is typically calculated statically as if the maximum dynamic pressure represents an oscillation pressure during the earthquake. Besides, these do not consider effects of dynamic uplift behavior when calculating stress in a bottom plate. These procedures result in a more conservative design approach.

However, previous studies confirmed that static analysis fails to calculate dynamic response behavior including the uplift of bottom plates, correctly. This is because in most cases, effects of dynamic oscillation including the uplift of a tank bottom plate during earthquakes based on outcomes from actual dynamic experiments or theories are not taken into account. In this paper, to find a more accurate design procedure, the following steps are followed.

Firstly, a finite element (FE) analysis method, being a fluid-structure coupled 3-dimensional time-history FE analysis, hereinafter called ‘the FE analysis’, is used to specific tank for studying a tank response. It studies dynamic response behavior parameters such as response acceleration, base shear, dynamic pressure, uplift of a tank bottom plate, deformation of a sidewall, distribution of an axial force at a bottom of a sidewall and so on.

Secondly, two mathematical models are developed to approximate results achieved by a more complex and time-consuming finite element analysis. Besides, a seismic design procedure is developed. This consists of these two mathematical models which use as inputs, outputs of previous studies for deriving dynamic pressure.

Finally, the results obtained from the seismic design procedure are compared to the results obtained from the FE analysis.

The FE analysis revealed that the tank response such as the response acceleration, the dynamic pressure, the base shear and the uplift height of the tank bottom plate are significantly smaller than that due to static conditions. It implies reviewing dynamical behavior of tanks during earthquakes.

The FE analysis also shows that undulating deformation occurs at the top of a sidewall. This deformation has not been observed previously under static conditions typical of experimental laboratory studies. The magnitude of this deformation is affected by the stiffness of stiffener rings installed on the sidewall. By applying the FE analysis, it is discovered that this deformation has a relationship with the response acceleration, the dynamic pressure, the base shear and the uplift height.

Next, a new seismic design procedure referred to as 'Simplified Seismic Design Procedure' is developed to provide a more accurate evaluation for design of a connection between a bottom plate and a sidewall of inner tanks. This procedure takes into account the uplift behavior of a tank bottom plate by using the findings of the dynamic response of the tank including the uplift obtained from the FE analysis.

The proposed Simplified Seismic Design Procedure is established from a comprehensive application of;

- theories of bulging and rocking motion to calculate dynamic pressure,
- two proposed mathematical models to calculate displacement and stress of a connection between a bottom plate and a sidewall of inner tanks,
- parameters for the models obtained from the FE analysis.

The first mathematical model for design of a connection between a bottom plate and a sidewall of inner tanks is referred to as the 'Structural Mathematical Model'. This model takes into account the uplift of the outer edge of the tank bottom plate due to earthquake forces, subsidence of the bottom insulation and bulging deformation of the sidewall. The proposed model can be used instead of a more commonly used finite element analysis methods which are generally used for design of a connection between a bottom plate and a sidewall.

In finite element analysis methods, several properties are considered, including tank dimensions and plate thickness of each part, magnitude and distribution of dynamic liquid pressure that is affected by width and height of the uplift of a bottom plate, elasticity of a bottom insulation, and displacement of a tank sidewall due to a bulging mode during earthquakes.

This paper includes these important properties in the Structural Mathematical Model to estimate the uplift height and the stress distribution accurately. The bottom plate part of the model is developed based on a theory of elastic bearing beam. To increase accuracy but maintain practicality, a thin cylindrical theory is introduced in conjunction with the bottom plate part for considering influences of the bulging displacement of the tank sidewall on the bottom plate. From the case study by the proposed model, it is found that the bulging displacement of the sidewall has a significant effect on the uplift height of the bottom plate.

In establishing the procedure, secondary mathematical model is presented. This model is referred to as the 'Force Coupling Mathematical Model'. This additional mathematical model provides the axial force distribution at the bottom of the sidewall from the dynamic pressure induced by the bulging and rocking motion, which are an essential factor for the calculation process by the Structural Mathematical Model.

The proposed procedure is an alternative design method for a corner connection of tanks instead of current design standards or more complicated commonly used time-history finite element analysis. However, this procedure has been developed successfully only for the standardized specific tank. Therefore, further work is required to verify its suitability to tanks with alternative dimensions in detail. In addition there are several items, as specified in Chapter 7, to be solved to improve the procedure.