An update on the seismic design of storage tanks

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ABSTRACT:

It is some time now since the Society published its updated "Seismic Design of Storage Tanks". Now that the Environmental Protection Authority has gazetted its intent to approve the document as a compliance standard for the HSNO Act 1996, it is timely to re-iterate the situations for which this manual is appropriate. It is also worth knowing its relationship with the commonly use standard API 650.

API 650 has also recently revised the Appendix E Seismic Design section amongst others. This now allows a more direct application of NZS1170.5 Seismic Hazard.

1 INTRODUCTION

Historically the New Zealand practice for seismic design of steel storage tanks was generally based on the following:

- US codes, mainly Appendix E of API 650.
- The 1980s modification of API 650 that was adapted for use in New Zealand (SDPP) for seismic design of petrochemical plants.
- The 1986 NZ Society for Earthquake Engineering (NZSEE) Recommendations for Seismic Design of Storage Tanks.

The 1986 NZSEE Recommendations for Seismic Design of Storage Tanks are a comprehensive document for Seismic Design of Storage Tanks. The document has been used extensively in New Zealand, and has been widely referenced internationally, including by Eurocode 8. A NZSEE study group completed a revision of the document and this was published by NZSEE in November 2009.

There have also been several updates to API 650 and API 620 with a significant change to API 650 Appendix E – Seismic Design of Storage Tanks in the 10th Edition Addendum 4 December 2005.

The Hazardous Substances and New Organisms Act 1996 (HSNO) and Hazardous Substances (Dangerous Goods and Scheduled Toxic Substances) Transfer Notice 2004 set out what standards may be used for the design and construction of above ground stationary tanks that store liquids that fall under the HSNO act. They did not include either the SDPP or 1986 NZSEE documents.

2 COMPLIANCE UNDER THE HSNO ACT

2.1 Issues to showing compliance to the HSNO Act

The design and construction standards listed in the Transfer Notice have created some issues in showing compliance for a number of tanks. Some of the issues identified are:

- Some of the standards do not contain a seismic design criteria and NZS 1170.5:2004 and its predecessor NZS 4203 state that tanks containing liquids are outside of their scope. This

leaves their use in New Zealand limited without the designer applying seismic design criteria from elsewhere and combining these into the other loading criteria from the standard.

- A number of the standards have minimum wall thicknesses that economically affect small to medium size tanks and complicate the ability to obtain continuing compliance for thin walled, typically stainless steel, storage tanks.
- AS 1692 provides minimum thicknesses for tanks under set categories based on a set of design input assumptions which make no reference to seismic loading. Further for design of tanks it only goes as far as stating the following for their design "Any storage tank shall be designed so that it is adequate for any load and pressure to which it might be subjected, and shall take into account any corrosive or abnormal conditions." It gives no equations or further guidance except to state category 6 tanks, tanks of a size that site erection is needed, "shall comply fully with BS EN 14105, API 620, API650, or other equivalent standard."
- AS1692 allows use of material thinner than the minimum wall thicknesses by stating "The possibility of using thinner materials … is recognized, especially for stainless steel. In such cases the design will need to demonstrate mechanical properties that are at least equivalent …to a tank built to this standard." But as per the above bullet point what design is there to show equivalence to?
- A number of tank configurations are not covered under the seismic loading standards available for use.

2.2 **Use of NZSEE Recommendations for Seismic Design of Storage Tanks 2009 under the HSNO Act**

Under section 79 of the HSNO Act the Environmental Risk Management Authority (ERMA), now the Environmental Protection Authority (EPA), can approve as a Code of Practice a document that specifies requirements equivalent to one of the listed standards. The revised NZSEE document has been intended to be recognised by EPA as an approved Code of Practice to enable its use for tank design that is covered by the HSNO Act.

In November 2012 EPA gazetted the intention of NZSEE to apply for approval of the recommendations as a Code of Practice, HSNOCOP 62 Seismic Design of Storage Tanks 2009. The basis of the application was "It provides for an alternative for the seismic design of stationary tanks designed to standards which do not have a seismic design methodology incorporated as part of the standard."

The approval of the NZSEE document as a Code of Practice will address a number of the existing issues by:

- Providing seismic design criteria with adjustments to enable the use of the NZS 1170.5 seismic hazard for standards that do not have a seismic design methodology.
- The application of the NZSEE document as the seismic design component of AS 1692 will firstly provide a means for designers to apply AS 1692 fully by including a seismic design methodology such that the tank is "designed so that it is adequate for any load and pressure to which it might be subjected." Secondly as an equivalent alternative it will enable wall thicknesses below the minimums of AS 1692 to be used, or checked for existing tanks, in compliance calculations.
- As the seismic design methodology in API 620 is based on that of API 650 and is only intended as applicable to flat bottom uniformly supported on the ground the NZSEE document provides an alternative that can be used for other tank configurations.

As part of the approval process EPA asked for submissions in relation to the approval. The submission period closed and EPA received 2 submissions and a later addition to 1 of those submissions.

2.3 **What further work needs to be done to get approval as a Code of Practice**

As part of the approval process EPA asked for submissions in relation to the approval. The submission period closed and EPA received 2 submissions and a later addition to 1 of those submissions.

In general the submissions noted:

- Support for the approval of the document as a Code of Practice.
- A request to allow substitution of seismic demands from API 650 by those from the NZSEE document for design of foundations on the basis that demands form API 650 are allowable stress design based.
- A request to allow substitution of seismic demands from API 650 by those from the NZSEE document in the design of the tank.
- The NZSEE document will provide a means to seismically assess irregular, elevated and horizontal tanks.
- A request to review the degree of designers interpretation that can be used in the risk matrices to determine the importance level of the tanks
- A request to include a note indicating that application of the Code of Practice should be by experienced storage tank design engineers due to the technical nature of the document and that other Codes of Practice are much more "cook book" style.
- A request to review the radial and circumferential stress limits of the wall base to floor joint, bottom knuckle.
- A request to amend the procedure of determining acceptable levels of flexural action/floor uplift for unanchored tanks.
- Confirm whether the NZSEE document can be used for design of tanks that would also be covered API 650, API 620, and BS EN 14015.

To address these NZSEE are in the process of reestablishing the Study Group to provide technical responses and advice to EPA on the NZSEE Study Group's opinion of cross standard requests.

3 **BASIS FOR SEISMIC DESIGN OF TANKS**

Procedures for the seismic analysis and design of storage tanks are generally based on the Housner multi-component spring/mass analogy. Both API 650 and the NZSEE document employ this approach. The analogy allows the complex dynamic behaviour of a tank and its contents to be considered as simple modes of response including a short period impulsive mode, with a period of around 0.5 seconds or less, and a longer period convective (sloshing) mode with periods up to several seconds. For most tanks the impulsive mode dominates the loading on the tank wall and the convective mode dominates the wave height and required freeboard. The mechanical spring/mass analogy for the assumed modes of vibration is shown in Figure 1.

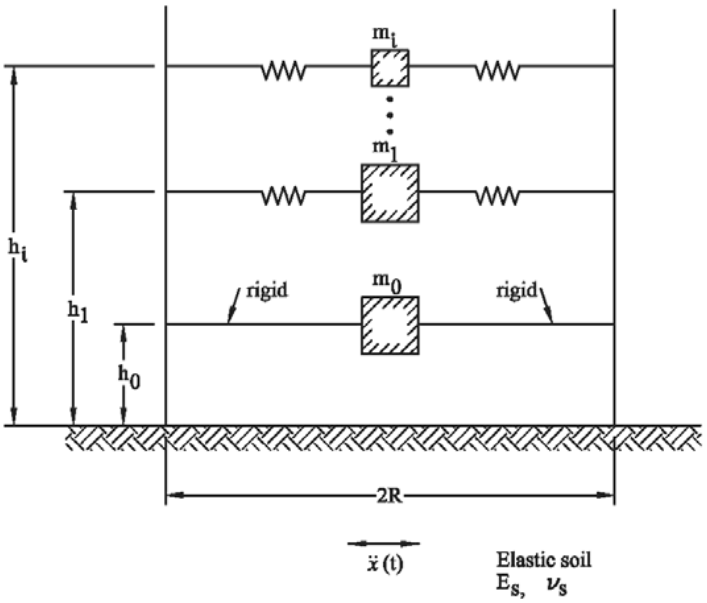

Figure 1. Mechanical spring/mass analogy for impulsive and convective modes of vibration

Damping levels for tanks have generally been assumed to be of the order of 2-5% for the impulsive modes and 0.5% for the convective modes. The additional effects of radiation damping (i.e. energy lost into the foundation) in reducing earthquake response can be considerable, providing equivalent viscous damping levels of as much as 20-30%.

4 API 650, APPENDIX E AND THE INCLUSION OF NZS1170.5 SEISMIC HAZARD

4.1 NZS/API 650

The current API 650 edition that is recognised as the NZS/API 650 standard is the 10th Edition dated 1998. It is suspected that wide use of later revisions of API 650 is being used as they reflect advancement in the knowledge of tank design and materials used. For example the 1998 version does not have a stainless steel section. It is the author's recommendation that an update by Standards New Zealand is required.

4.2 Appendix E and the inclusion of NZS1170.5 Seismic Hazard

In 2005, API 650 10th Edition Addendum 4 issued a significantly revised Appendix E for the seismic design of storage tanks. Prior to this date Appendix E contained figures for only US seismic zones and the means to apply this in a New Zealand context was to have equivalence of Wellington and the coast edge of California. From there the ratio of New Zealand locations to Wellington using Zone factors from NZS 4203 and then NZS 1170.5.

The 10th Edition Addendum 4 of API 650 changed the source of the seismic demand from within the code to from ASCE 7. It also included a method for regions not covered by ASCE 7. This was divided into two parts, one where a response spectrum complying with the local regulatory requirements was available and the other where only a peak ground acceleration is defined. This change enabled direct application of the NZS 1170.5 hazard spectrum into API 650. However care was required as the ASCE 7 seismic demand input into API 650 was based from a Maximum Credible Earthquake, MCE, 5% damped whereas NZS 1170.5 is a Design Basis Earthquake, DBE, 5% damped input. This difference can be accounted for by the MCE to DBE scaling factor, Q factor, in API 650 Appendix E. A value of Q equal to 1 is appropriate to apply when using the hazard spectrum from NZS 1170.5. This point is clarified in the commentary to Appendix E that was added in the 11th Edition Addendum 1 of API 650 in 2008. Also the T_s/T_c and T_sT_L/T_c^2 ratios used in calculating the convective spectral acceleration in API 650 are not required when applying NZS 1170.5 as this is included within the spectral shape factor of NZS 1170.5 beyond 3 seconds where a constant displacement is used.

Adjustments to both the impulsive and convective spectral accelerations are then made to account for damping, material over strength, ductility, and scaling to allowable stress design level. There is no variation in the reduction for damping and ductility as there is in the NZSEE document except for a differentiation between anchored and unanchored tanks.

5 NZSEE DOCUMENT VERSUS API 650 11TH EDITION

The two documents generally using the same design philosophy for vertical cylindrical tanks. Each has its advantages over the other and the extent to which these can be realised in the design is very dependent on the overall tank geometry, aspect ratio, and product design parameters. A designer may then need to consider both options available for design when optimising value of the design and construction costs. The following items are general comparisons that apply:

- For smaller tank sizes the NZSEE document will allow use of material thicknesses for the shell, roof and base below the minimum limits of API 650.
- Foundation loads from API 650 when converted from allowable stress design to DBE level will be lower than the NZSEE values for the same tank. This may enable economy in foundation design in some instances.
- Based on aspect ratios and geometrical dimensions there are tanks that require anchorage under API 650 that do not need to be anchored by the NZSEE document.
- API 650 requires a minimum anchor bolt diameter of 1 inch, 24mm, and a maximum spacing which may then require necking of bolts to avoid excessive design loads for tank attachment brackets and anchor embedment.
- API 650 does not specifically state the ability to reduce design loading for a reduced design life. This can be achieved using the NZSEE document however this should not be abused. To the NZSEE document, if a tank has been designed for a design life less than 50 years at the end of its design life period the tank should be decommissioned or additional protective measures installed, such as bunding, to extend the design life while maintaining the same or lesser probability of exceedance.

6 CONCLUSIONS

It will be to the benefit of the New Zealand industry to have the NZSEE "Seismic Design of Storage Tanks" approved as a Code of Practice for use under the HSNO Act 1996. The inclusion will resolve a number of design compliance issues that come about from the currently approved Codes of Practice.

Both API650 and the NZSEE document are valid design methods for vertical cylindrical tanks uniformly supported on the ground each with its advantages.

7 REFERENCES

American Petroleum Institute. *API 650 Welded Steel Tanks for Oil Storage*.

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