The Seismic Design of Pressure Equipment and its Supports – IPENZ Practice Note 19

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ABSTRACT: IPENZ Practice Note 19's (IPENZ 2013) purpose is to give guidance to engineers and design verifiers in the area of seismic design of industrial plant including pressure equipment. The Practice Note updates the 2007 paper (Lindup 2007) that discussed using the AS/NZS 1170 (Standards New Zealand 2002) set of standards for the design of industrial plant. The Practice Note uses relevant legislative requirements and updates from members of the IPENZ Practice Note Working Party to develop design methods for the typical components of an industrial plant including pressure equipment and their supports to assist the design engineer in this process.

This paper updates members on the content of the IPENZ Practice Note issued January 2013. The Practice Note had the intention of covering both the design of new plant and modifications to existing plant. The modification aspect proved to be difficult to achieve consensus and the initial issue of the Practice Note has a placeholder appendix (Appendix D) that will be updated when industry consensus has been achieved.

Two other appendices have yet to be issued, Appendix F "Use of Producer Statements for Support Structures" and Appendix H "Seismic Coefficients for the Design of Pressure Equipment". One example calculation has yet to be issued, Example E7 "Low Temperature Piping".

1 INTRODUCTION

The IPENZ Practice Note (IPENZ 2013) is based on a paper presented to the New Zealand Society for Earthquake Engineering Technical Conference in 2006 and published in the Society's Bulletin in September 2007, (Lindup 2007). That paper modified a guideline published by the American Society of Civil Engineers Task Committee on Seismic Evaluation and Design of Petrochemical Facilities (ASCE 1997) for use with the NZS 1170 set of standards (Standards New Zealand 2002). Although aimed at petrochemical plants, the ASCE guidelines are able to be used for other industrial plants that have nonbuilding structures not similar to buildings.

In 2007 a project to write a New Zealand standard on pressure equipment suitable for international standardisation purposes came to the attention of IPENZ. The need to include seismic provisions in this coincided with similar issues with AS/NZS 1170 arising in the geothermal industry.

Attention focused on the seismic design provisions of the Approved Code of Practice for Pressure Equipment (Excluding Boilers) (Department of Labour 2001), commonly referred to as "ACPPE". This document mixes limit state and working stress seismic concepts in a way that could be interpreted to give designs that would underperform in a dangerous manner. The Engineering Practice Board of IPENZ drew this problem to the attention of the former Department of Labour (DoL), now part of Ministry of Business, Innovation and Employment (MBIE), who agreed to consider seismic resistance in a revision of their ACPPE (Department of Labour 2001). IPENZ took the view that the Lindup paper (Lindup 2007) was the best available guidance on the problem and promoted its use within the pressure equipment industries.

As the work on the Practice Note gathered support within the profession and manufacturing industry, the former DoL agreed that when it was completed to their satisfaction, it would be referenced as a

means of compliance in the revision of the ACPPE (Department of Labour 2001). The Practice Note has been jointly written by a Working Party of engineers who are working in the field of industrial plant design. It was peer reviewed by a group of interested persons and then was released for comment to the IPENZ membership in March 2012. There has been subsequent modifications based on the feedback from IPENZ members and the industry and these have been outlined below. The contributors to the Practice Note and the Peer Reviewers have been listed in Section 6.

2 STRUCTURE OF THE PRACTICE NOTE AND ITS CONTENTS

2.1 Title of the Practice Note

One of the significant changes to the Practice Note since its release for IPENZ membership review has been in the title. To clarify the intent of the Practice Note and more fully describe the contents, the title has been changed to: "Seismic Resistance of Pressure Equipment **and its Supports**". The addition to the title has been shown in bold. Much of the content of the Practice Note relates to pressure equipment's supporting structure and/or foundations, items that are covered by both the Building Act and the Pressure Equipment Regulations and it was felt that the title change clarified what the Practice Note covered.

2.2 Structure of the Practice Note

The main body of the Practice Note contains an Introduction plus updated versions of Sections 1 to 13 of the Lindup paper (Lindup 2007). The major changes that occurred in developing the IPENZ Membership Review version have been outlined in Section 2.3.

The two appendices in the original paper (Lindup 2007) have been increased to nine overall with input into these from various members of the IPENZ Working Party. The extra appendices address additional issues arising from the design of pressure equipment and the feedback received during the IPENZ membership review.

2.3 Practice Note Development Prior to the IPENZ Membership Review

The major changes to the Lindup paper (Lindup 2007) to arrive at the IPENZ Membership Review version of the Practice Note were:

- Section 1 "Why the Need to Adapt the Structural Design Actions Standard" was deleted and a "Preface" was added to clarify the scope of the practice note and explain its purpose.
- Section 2 "Background" and Section 3 "Relevant Legislation" was incorporated into a new Section 2 "Regulatory Environment".
- "Terminology and Abbreviations" became Section 3; this was a new section which was felt to be necessary to clarify the terms within the Practice Note.
- Section 4 "Structural Systems" the nomenclature for the two sub-categories of nonbuilding structures was updated to align with the 2010 edition of the ASCE Guidelines (American Society of Civil Engineers 2010); building-like structures now becomes a "Nonbuilding structure similar to buildings" and a nonbuilding-like structure now is called a "Nonbuilding structure not similar to buildings".
- Section 4 "Structural Systems" a flow chart has been added to aid the structural type selection process.
- Section 5 "Applicable Design Standards" the list of standards has been updated and added to. Table 1 "Standards used in the design of industrial structures" was not incorporated.
- Section 6 "Seismic Design Philosophy" Section 6.2.3 *HSE Act Requirements – Pressure Equipment* has been rewritten and now includes reference to AS 1210 (Standards Australia 2010) and its recommendation for the Design Working Life for pressure vessels. AS 1210

(Standards Australia 2010) sets the Design Working Life for pressure vessels to 25 years and this has an effect on the earthquake annual probability of exceedance, hence the level of earthquake shaking pressure equipment needs to be designed for. Table 2 of the Lindup paper (Lindup 2007) was updated to align with AS 1210 (Standards Australia 2010).

- Section 6 "Seismic Design Philosophy" Section 6.4 *Importance Levels* has been altered to incorporate the AS 1210 Appendix J (Standards Australia 2010) relationship between the AS 4343 Hazard Level (Standards Australia 2005) and the AS/NZS 1170.0 (Standards Australia and Standards New Zealand 2002) Importance Level. Table 3 from the Lindup paper (Lindup 2007) was updated to reflect AS 1210 Appendix J (Standards Australia 2010). An additional column has been added to the table to show the relationship between the Part Classification from NZS 1170.5 (Standards New Zealand 2004) Section 8 and Importance Levels.
- Section 6 "Seismic Design Philosophy" Section 6.6 *Limit State Objectives* has been expanded to discuss the difference between serviceability limit state checks for a structure and that for parts and components.
- Section 6 "Seismic Design Philosophy" Section 6.10 *Acceptance Criteria* has had a new table added "Suggested Drift Ratio Limits for the two Serviceability States, SLS1 and SLS2".
- Section 6 "Seismic Design Philosophy" a new section has been added, 6.22 *Buckling.* This section briefly outlines the types of pressure equipment that may have components prone to buckling failure.
- Section 7 "Earthquake Analysis" Section 7.2.3 *Hazard Factor Z* has been updated to mention the increased Z values for the Christchurch area.
- Section 8 "Guidelines for Earthquake Analysis of Combination Structures" Section 8.3 *Example 3 Discussion* has been updated in line with the changes made to the Example 3 in the Lindup paper (Lindup 2007); this is now Example E3. The discussion includes both references to the existing Pressure Equipment, Cranes and Passenger Ropeways Regulations 1999 (PECPR) requirements and the Practice Note's requirements for the supporting concrete structure and the pressure vessels.
- Section 9 "Guidelines for Earthquake Analysis of Parts and Components" Section 9.5 *Examples 2 and 5 Discussion* have been updated throughout to align with the values calculated in Examples E2, E5 and E6. The discussion includes both references to the existing PECPR seismic requirements and the Practice Note's recommendations for the piping, the pipe supports and their foundations.
- Section 9 "Guidelines for Earthquake Analysis of Parts and Components" a new section has been added, Section 9.6 *Retrofitting or modifying existing plant.* This refers the user of the Practice Note to Appendix D, which is discussed below and in Section 2.4.
- Section 12 "Conclusions and Recommendations" was deleted.
- Appendix B " Equivalent Static Analysis Method (ground floor) NZS 1170.5" was added. This appendix was written by the Working Party to give a step by step method to determine both $C_d(T_1)$ and $C_{vd}(T_v)$ for the design of structures supported at grade.
- Appendix C "Equivalent Static Analysis Method (above ground floor) NZS 1170.5" was added. This appendix was written by the Working Party to give a step by step method to determine both F_{ph} and F_{pv} for the design of parts and components supported at a height above grade by a structure. This replaces Table 12 in the Lindup paper (Lindup 2007).
- Appendix D "Guidelines for Retrofitting or Modifying Existing Plant" was added. The IPENZ working party noted that existing plant will at best have been designed to comply with an earlier set of seismic codes and standards and possibly with no recognition of seismic actions. A risk based approach to this problem was developed by the Working Party and outlined in the Appendix D of the version released for IPENZ membership review. The intent

of this version was to provide a defined risk-based methodology to engineers and owners to use when analysing the seismic effect of alterations to existing pressure equipment. It was not intended to require the retrospective re-design of existing equipment, unless triggered by some significant change.

- Appendix E "Example Calculations" was modified. The examples in Appendix B from the Lindup paper (Lindup 2007) have been taken and updated to comply with the recommendations of the Practice Note that include the changes outlined above. Example 5 from the 2007 paper has been split into two examples, E5 and E6. Example E5 designs the structural support whereas Example E6 examines the pressure piping on the support. In addition, a new example E7 was provided for the seismic design of ammonia suction piping located in a cold store in Napier. All the examples referenced the recommended minimum seismic coefficients that were proposed in Appendix H as well as those that arise from using the current ACPPE (Department of Labour 2001) for pressure equipment.

- Appendix F "Use of Producer Statements for Support Structures" was added. PECPR Regulations require pressure equipment and their foundations to be designed and constructed in accordance with recognised standards. Appendix F included sample certifying forms that would be completed and issued to the appropriate inspection body stating that. In addition for the Design and Construction Review statements, a Design Features Report template was included to illustrate the main parameters used to derive the seismic coefficient, wind speed and the snow loading.

- Appendix G "Rotating Equipment Seismic Issues" was added. The ACCPE (Department of Labour 2001) Parts 7 and 8 refer to various types of rotating equipment that are subject to the PECPR Regulations. Some of the types included are: compressors, pumps, gas turbines, steam engines and steam turbines. In order to ensure that the equipment is safe to operate, Equipment Controllers are required to ensure that the equipment is designed, inspected, operated and maintained in accordance with the PECPR Regulations. The seismic design of the rotating equipment is an essential element of the design. The methodology described in Appendix G draws significantly on the guideline "Guide for Seismic Evaluation of Active Mechanical Equipment", (American Lifelines Alliance 2004).

- Appendix H "Recommended Minimum Seismic Coefficients for the Design of Pressure Equipment" was added. A table of minimum seismic coefficients for the design of pressure equipment was proposed to replace the table currently referenced by the ACPPE (Department of Labour 2001) that is in AS/NZS 1200 Appendix I (Standards Australia 2000). The Appendix H table, Table H1, has minimum seismic coefficients that vary according to the Hazard Factor Z for the site and the design earthquake's return period.

  Currently for pressure vessels and pressure piping the minimum values from AS/NZS 1200 Appendix I (Standards Australia and Standards New Zealand 2000) can be disregarded if a site specific seismic hazard study has been undertaken as per ACPPE (Department of Labour 2001) Clauses 5.4.4 (10) or 6.4.3 (2) and is then used in the determination of the seismic coefficients.

  It was the Practice Note's recommendation that this continues to be the case and is extended to all pressure equipment. Thus if the site specific seismic hazard study is used to determine either $0.8*C_d(T_1)$ or $0.8*F_{ph}/W_p$, the working stress design seismic coefficient may be lower than the minimum coefficient set out in Table H1.

  The site specific seismic hazard study should include appropriate geological and geotechnical investigations as per accepted guidelines such as the "Guidelines for Geotechnical Earthquake Engineering Practice in New Zealand", (New Zealand Geotechnical Society 2010).

  An additional table, Table H2 was included to show the effect of locating pressure equipment at height above grade.

  The notes to both tables detailed how the values were derived from NZS 1170.5.

- Appendix I "References" was Section 13 from the Lindup paper (Lindup 2007) updated with the additional references used within the Practice Note.

2.4 **Modifications to the Practice Note subsequent to IPENZ Membership Review**

In addition to that outlined in Section 2.1 above, the major changes to the IPENZ Membership review version of the Practice Note that have been introduced to the published Version 1 of the Practice Note were:

- The Terminology and Abbreviations section has been taken out of the section numbering system, brought to the front of the document and subsequent sections have a lower number.
- "Structural Systems" now Section 3; additional text has been added throughout to clarify the difference between pressure equipment and pressure equipment supports. Additionally guidance is given on which are the guiding Acts and Regulations for the typical structures listed.
- "Seismic Design Philosophy"; Section 5.18 "*Working Stress Methods"*, the text has been updated to refer to ASCE7-10. In addition, the section was expanded to reference the philosophy included in overseas standards for allowing non-structural working stress designed components to absorb earthquake energy through yielding.
- "Seismic Design Philosophy"; Section 5.20 "*Seismic Anchor Motion for Distributive Systems",* the piping seismic effects equation has been modified from using the American Lifelines Alliance (American Lifelines Alliance 2002) proposed standard Equation S304-1 to that used in the ASME standard B31Ea (American Society of Mechanical Engineers 2010).
- "Guidelines for Earthquake Analysis of Combination Structures" Section 7.2.1; the section "*Rigid Nonbuilding Items – Case 1"* has been updated in line with the changes made to the section on Working Stress Methods and some text has been moved to Section 8 *"Guidelines for Earthquake Analysis of Parts and Components"*.
- "Guidelines for Earthquake Analysis of Parts and Components" Section 8.4.1; the section "*When Supporting Structure is Analysed using ESA"* has been updated throughout to align with the sections on Working Stress Methods and Guidelines for Earthquake Analysis of Combination Structures, Sections 5 and 7 respectively.
- Appendix D "Guidelines for Retrofitting or Modifying Existing Plant" Some owners of major industrial plant did not agree with the approach outlined in the membership review version and felt that if adopted by the MBIE, it would make their plants uneconomic to modify.

  A workshop held to review all the feedback received, resolved to remove this version of Appendix D and insert a placeholder appendix to allow the publishing of the Practice Note. The meeting also agreed to set up a sub-group to arrive at an approach that was acceptable to plant owners, design verifiers and practising engineers.

  Subsequent work has highlighted issues with the processes to be followed when extending the life of a time-expired plant. There are apparent conflicting legal requirements between the Building Act and the HSE Act. Discussions are continuing with MBIE, the Ministry with regulatory responsibility for both Acts to arrive at an agreed approach.

  This approach is to be incorporated into an update of Appendix D in a subsequent version of the Practice Note.
- Appendix E "Example Calculations"; the Example E7 "Low Temperature Piping" was not included in the first issue of the Practice Note because there was not consensus on the approach used in determining an appropriate value for the ductility factor for the low temperature piping. A separate Practice Note is planned for refrigeration piping and issues addressed in that Practice Note along with allowable ductility factors will affect the worked example. Hence it may be some time before Example E7 is issued.

- Appendix F "Use of Producer Statements for Support Structures" was not included in the first issue of the Practice Note because the working group had not completed their discussions on the content of the appendix. However, CPEng structural engineers have started to use versions of the Support Structure Producer Statements that were included in the IPENZ Membership Review issue.
- Appendix H "Recommended Minimum Seismic Coefficients for the Design of Pressure Equipment" was not included because there was more discussion required within the Working Group on the recommended minimum values.

3 LEGISLATIVE REQUIREMENTS FOR INDUSTRIAL PLANT

The legislation governing pressure equipment is administered by the Ministry of Business, Innovation and Employment (MBIE) through the Health and Safety in Employment Act 1992 (HSE Act), the Health and Safety in Employment (Pressure Equipment, Cranes and Passenger Ropeways) Regulations 1999 (PECPR Regulations) and the Approved Code of Practice for Pressure Equipment (Excluding Boilers) (Department of Labour 2001).

The design of structures that support pressure equipment within their framing or on their foundations, is covered by both the Building Act and the PECPR Regulations. Whereas vertical or horizontal pressure vessels, compressors and pumps etc. at grade is covered by the PECPR Regulations but the design of their foundations is covered by both the Building Act and the PECPR Regulations. Access up and around such structures e.g. walkways and ladders, must be in accordance with the Building Act unless those items support pressure equipment such as pressure piping. They then would be covered by both the Building Act and the PECPR Regulations.

Local authorities often will exempt new or modifications to industrial plant structures from the necessity to obtain building consents under Schedule 1 of the Building Act. Discussions with the local authority early in the design phase will often result in just the need to apply for a Schecule 1(i) or 1(k) exemption.

When the pressure vessel inspectors come to inspect new work on behalf of MBIE, they will obtain the Design Verification certificates for the pressure equipment involved and will look for statements from a CPEng engineer certifying that the supporting structures comply with the PECPR Regulations. These certificates are discussed in the following section.

4 PRODUCER STATEMENTS FOR INDUSTRIAL PLANT

4.1 Background

The PECPR Regulations require equipment, which includes the foundations, to be designed and constructed in accordance with generally accepted design practice and manufactured according to the verified design. Inspection Bodies require a statement from a suitably qualified CPEng that the supports and foundations have been designed to an appropriate level. In the past standard IPENZ/NZIA/ACENZ Producer Statements or modified versions of these have been used for that purpose, even though they were intended for use for buildings under the Building Act. The Inspection Bodies require different information on the statement and now tend to reject the use of standard IPENZ/NZIA/ACENZ Producer Statements. The standard Producer Statements can still be used for certifying structures that are not supporting pressure equipment.

4.2 Pressure Equipment Support Structures and Producer Statements

A modified form of the standard Producer Statements for design and design review was included in Appendix F in the IPENZ Membership Review issue. These along with a Design Features report provided the data used by the civil or structural CPEng engineer to design or design check the support structures for pressure equipment. This may be structural supports for pressure piping or foundations for pressure vessels or their attachment details to the floor or walls of an existing building.

The Design Verification (DV) certificates issued by the approved Design Verifiers (that the pressure equipment is PECPR compliant) state what seismic coefficient was used in the verification process. These are reviewed by the Inspection Body during the construction phase of the project. It was hoped by the pressure vessel inspectors that there would be an audit trail between the seismic data on the DV certificate and that on the Support Producer Statement.

However, in cases where the pressure equipment is supported above grade, the seismic coefficient used to design the pressure equipment will normally not match that used for the support. This is illustrated in Examples E5 and E6 in the Practice Note. These two examples determine seismic coefficients for a pipe support (Example E5) and for the piping located on the pipe support (Example E6):

For example:

Pipe support design unscaled coefficients: $C_d(T_1) = 0.71$ for $\mu = 1.25$ or $C_d(T_1) = 0.29$ for $\mu = 3.0$

Pressure piping design unscaled coefficients: $0.8F_{ph} = 0.87$ for $\mu_p = 1.25$ or $0.8F_{ph} = 0.41$ for $\mu_p = 2.0$

It is hoped that a subsequent version of the Practice Note will be issued with an agreed form of the support structural certification for use by engineers and these will be accepted by the Inspection Bodies.

5 CONCLUSION

The requirements for the designers of pressure equipment and their supports located within New Zealand to comply with both the Building Act and the Pressure Equipment, Cranes and Passenger Ropeways Regulations leads to an interface between the mechanical and structural design disciplines. The IPENZ Practice Note "Seismic Resistance of Pressure Equipment and Their Supports" aims to provide guidance for both these disciplines. There is guidance within the proposed Practice Note for:

- The derivation of seismic coefficients for the items that make up industrial plant including worked examples.
- Rotating equipment seismic issues.

Further work is required to complete Appendices D, E, F and H. Pressure equipment support structures will commonly be designed using a different seismic coefficient to the pressure equipment they support and the design certification needs to clearly show how the value used in the design of the support has been calculated.

6 THE WORKING PARTY

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Figure 1. Typical industrial plant items

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