

State-of-the-Art Review on verification tests for seismic bracing products of non-structural components

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Abstract

The seismic performance of non-structural components (NSCs) represents a crucial aspect of the life safety and operational continuity of a building. A range of seismic bracing products is required to restrain NSCs, and in turn, minimise damage and injury in a seismic event. These bracing materials' characteristics play an important role in ensuring the performance of NSCs during and after an earthquake.

The behaviour of the bracing material in an earthquake can be anticipated using different testing methods. In this paper, a review of existing testing standards for determining the capacity of seismic bracing products both in Australia and internationally has been presented. A summary of each testing method will be mentioned, and finally, recommendations about the applicability of these standards to seismic bracing products in the Australian market will be made.

Keywords: Seismic Restraint Design, testing, Bracing Products, non-structural components

1 Introduction

The behaviour of non-structural components (NSCs) post-earthquake is one of the important objectives to maintain the quality operation of buildings. NSCs' performance under earthquake has 3 stages to deliver safe and reliable output post-event: Design, Manufacturing, and Installation.

For the design stage of seismic compliance for building services in Australia, we refer to AS 1170.4 to meet the earthquake requirements. While, in section 8 of this standard, non-structural components that are required to be designed against seismic loads have been identified; other vital subjects such as compliance requirements, specific design and criteria for seismic bracing products to be fit for purpose are wide open for designer interpretation. In this paper, we explore the testing for rating the capacity of seismic bracing products to ensure they can withstand the anticipated design loads.

Using a specific standard for testing seismic restraints, helps manufacturers to determine the capability of these items to withstand seismic loads based on best engineering practices and research. This will also provide more confidence for designers, ensuring that restraints are

performing as anticipated. The performance of bracings is usually vital in minimising the likelihood of injury to occupants by preventing the dislodgement of NSCs during seismic events. This is of greater importance, in post-disaster centre facilities, where continued operation of NSCs is required.

Currently, seismic designers in Australia may refer to international testing standards as an acceptance criterion for testing seismic bracing products and recognise products tested according to these standards to be fit for purpose until a related Australian standard gets published. This paper explores the common type of seismic bracing for MEP-F (Mechanical, Electrical, Plumbing and fire systems) components and their corresponding testing method based on current international testing standards.

2 Seismic standard test approach

In order to safely transfer the seismic loads imposed from NSCs, all the parts and components that are in the load path to the structure are required to have sufficient rating and work as anticipated in the design. This will include fasteners to structure, restraints assembly, the connection point between component and restraint, and non-structural components themselves.

Although the restraint testing standards are usually focusing on the rating for the restraint assembly alone, there are other verification methods for other components in the load path.

For instance, according to AS5216:2021 Design of post-installed and cast-in fastenings in concrete requires anchors that are transferring seismic load to have seismic anchor qualifications based on European ETA approvals. These approvals set out specific tests to ensure anchors are performing as expected during a seismic event.

If required within the scope of the project and standard, devices/equipment can be tested on a shaking table to ensure they will maintain their integrity and/or remain operational in an earthquake. Usually, this verification will be provided by the supplier of the unit or device.

For the purpose of testing seismic restraints, restraints are usually considered as an assembly of multiple parts which are working together to transfer the seismic loads imposed from NSCs to structure and in turn limit the motion of the non-structural components. The rating derived for restraints using the standard test is usually the rating for the entire assembly, not individual parts.

In the previous version of standards that are mostly superseded by a newer revision, a simple static push/pull test was allowed to achieve the rating for restraint; however, based on the recent research and common best practices in order to predict the behaviour of restraints as close to reality as possible, cyclic loading is required to test these elements.

For different types of seismic restraints, there are some different criteria for testing in the standards, which will be presented in the next section.

3 Typical seismic restraint

There are different types of seismic bracing systems for suspended components to withstand seismic loads. Finding the best solution for each project depends on different parameters such

as restraint's clash with the other disciplines, labour and material cost, type of supporting structure and NSCs' type. Seismic restraints for MEP-F supports can usually be found off the shelves, but there are many projects with more complexities that some degree of customisation in seismic restraints is required. In these conditions, new restraint needs to be designed or a combination of typical restraints and customised restraints to be used.

In this paper, only typical seismic restraints which are common in the Australian market have been mentioned.

3.1 Wire system

Wire bracing system is a regular solution for areas without clashes with other disciplines or usually when primary support is a steel roof. In this system, the wire only works in tension, so combination and arrangement of restraint wires should be in a way that provides restraint against the movement in the required direction.

Cable bracings are single-directional, single-axis and multi-angle restraints. Their test will include a single directional load (tension) applied along the restraint axis at different angles of 30,45 and 60 degrees measured to the horizontal plane. Based on the minimum required samples mentioned on the standard that is to be tested for each type and based on the resulting rating of a wire assembly can be determined (see Figure 1).

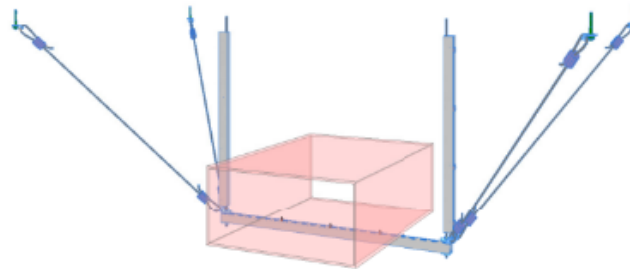


Figure 1. 4-way wire System (*SeismicPro* typical detail drawing, DWG. No. SP-DW1-D.1)

3.2 Rigid system

The rigid system name is coming from the solid bracing (strut) that transfers loads on the connection point of gravity support to the supporting structure. In this system, the bracing element can withstand tension and compression loads.

The strut system rated capacity can be determined similarly to with wire system, but the applied load needs to be bidirectional (both compression and tension) (see Figure 2).

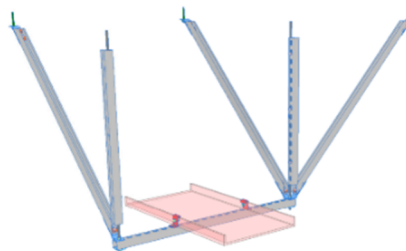


Figure 2. 3-way rigid System (*SeismicPro* typical detail drawing, DWG. No. SP-DH6-C.1)

3.3 Vertical post

This type of bracing is easy to install especially in a congested area, One or two vertical posts can be designed, so the load would be transferred to the structure from a moment-resistant vertical post. Restraint is to be tested with a bidirectional load on each orthogonal axis (X, Y, Z) as well as a combination of the horizontal and vertical direction in a plane that is the worst-case scenario (see Figure 3).

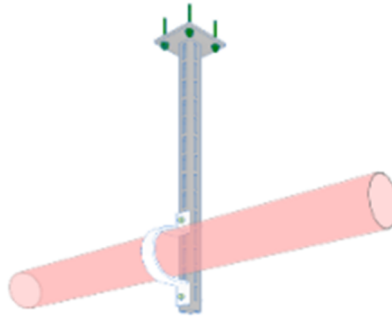


Figure 3. Vertical Post (**SeismicPro** typical detail drawing, DWG. No. SP-DH5-P)

3.4 Seismic restraints for Floor mounted

These components may be subject to a combination of shear force and overturning due to seismic excitation. Depending on whether the component tends to overturn, and if vibration isolation is required, seismic restraint for floor mounted can be bumpers, brackets, snubbers, and seismic isolators.

3.4.1 Seismic restraints with Vibration isolation

For floor-mounted components such as air handling units, cooling towers, generators, pumps, chillers and etc seismic restraint may need to be combined with vibration isolators. The seismic restraints restraint to be tested are subjected to multidirectional and multi-axis loads and are to be tested accordingly. Vibration requirement is also needed to be checked against device and project specifications (see Figure 4).

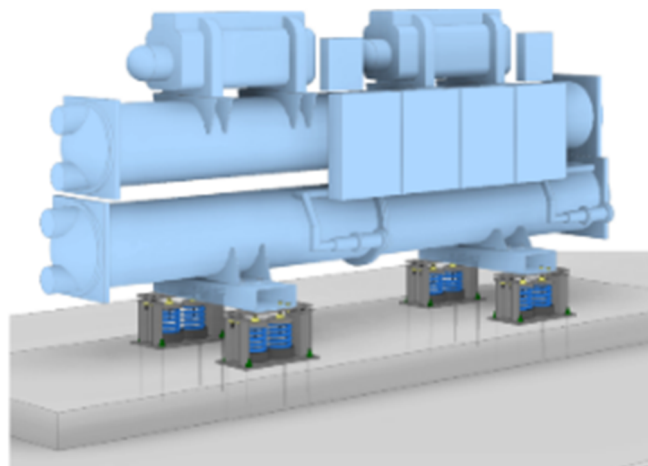


Figure 4. Seismic Spring restraint (**SeismicPro** typical detail drawing, DWG. No. SP-LBZ-1)

3.4.2 Snubbers/brackets/bumpers without a vibration isolator

Restraints for floor-mounted components that do not have integrated isolators can be bumpers (single directional, single axis), snubber (Multi-axis, Multidirectional with operating clearance) or brackets (Multi-axis, Multidirectional with operating clearance with no operating clearance). Depending on the direction of the load that they are designed to withstand appropriate testing is to be chosen from the standards (see Figure 5).

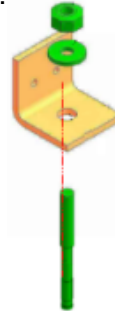


Figure 5. Bracket restraint (*SeismicPro* typical detail drawing, DWG. No. SP-SRD-9.4-P1)

4 Standards and Guidelines:

In this section, three guidelines and standards offering method of testing seismic restraints has been explored. These standards may be used to determine the rated capacity of restraints in clauses 3.1 to 3.4.

4.1 ANSI/ASHRAE Standard 171-2017:

The title of this standard is “Method of Testing for Rating Seismic and Wind Restraints” published by ASHRAE and approved by the *American National Standards Institute*. ASHRAE Standards and Guidelines are established to assist industry and the public by offering a uniform method of testing for rating purposes, suggesting safe practices in designing and installing equipment, by providing proper definitions of this equipment, and by providing other information that may serve to guide the industry. (ASHRAE 2017).

The current version of this standard was published in 2017, which replaced the 2008 version. In this revision, a cyclical, low-frequency test method was utilised instead of a static push/pull test method. It is also noted that the previous version is no longer considered valid. (ASHRAE 2017)

The test procedure for rating the capacity of restraints is based on the maximum loads a restraint can withstand without breakage or excessive deformation. Deformation limit, premature failure and determination of maximum capacity load are explained, so rating methodology with load and resistance factor design (LRFD) determined, although in annex C with allowable stress design (ASD) methods mentioned.

Further, the type of restraints that cover in this standard, terms, definitions, and units defined and a summary of the test and rating methods for each type of restraints and test lab setup and instrumentation especially Force/displacement test equipment, calibration, accuracy, fixtures, orientations and computer data acquisition and precision explained.

In the test procedure, loading cycles and frequency were identified. As an instance, the load-vs.-time plot illustrated in Figures 5 and 6 for Single and Bi-Directional load (see Figure 6).

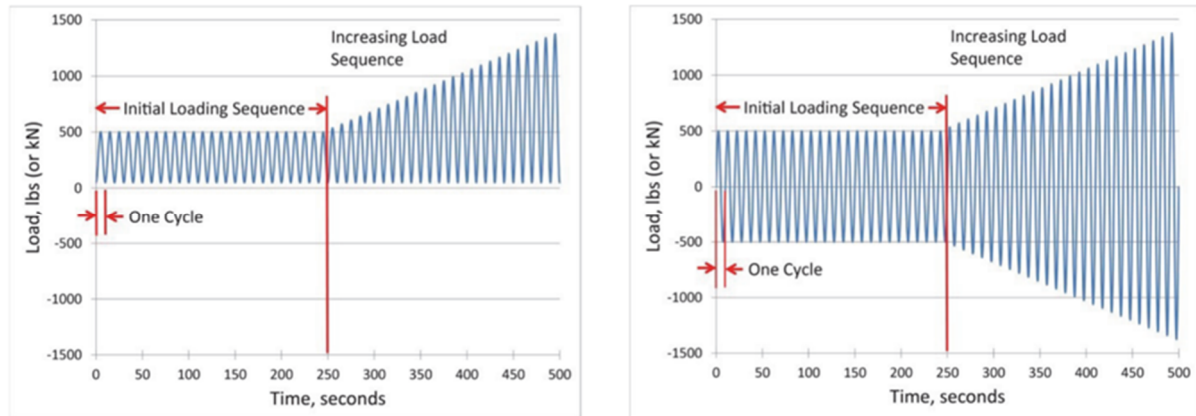


Figure 6. Single-Directional load-vs.-time plot (left) and Bi-directional Load-vs.-time plot (right). (ANSI/ASHRAE Standard 171-2017)

If a manufacturer desire to attain a certification or listing of tested restraints, some requirements are mentioned in annex D as conformance to the standard such as: (ASHRAE 2017).

- a- **Quality Assurance Program.** The manufacturer shall have an established and documented quality assurance (QA) program at each manufacturing, storage, or processing facility pertaining to the tested restraint. The QA documentation shall be available for review by an accreditation or inspection body as required.
- b- **Product Consistency and Sampling.** The manufacturer shall provide an affidavit for review by the certification or listing agency that the restraint samples tested are identical to standard production models in each facility where such restraints are manufactured. As a condition of certification or listing, the manufacturer may be required to allow the certification or listing agency to sample at random the restraints to be tested.

In an important section of the standard, test lab requirements are explained. Any of the following 3 situations are considered equally acceptable to attain certification or listing:

- c- **Accredited Test Lab,** the test labs that are accredited by ISO/IEC Standard 17025.
- d- **Non-accredited Nonmanufacturer Test Lab,** these test labs shall be inspected by a third-party inspection body accredited to ISO/IEC Standard 17020.
- e- **Non-accredited Manufacturer Test Lab,** in this condition testing conducted at a manufacturer's test lab that shall be supervised by a registered professional engineer and witnessed by personnel from either an accredited test lab or an accredited inspection body.

Readers may refer to ANSI/ASHRAE Standard 171-2017 standard for further information about test procedures and conditions.

4.2 ANSI/FM Approvals 1950-2016

The label of this standard is "American National Standard for Seismic Sway Braces for Pipe, Tubing and Conduit". This standard is intended to be used to evaluate the components and performance of seismic sway brace equipment. This American National Standard has been developed by the canvass method of standards development of the American National Standards Institute (ANSI/FM-1950)

These standard states the examination criteria for rigid seismic sway brace components for pipe, tubing and conduit.

The below subjects are included in the standard, readers may refer to ANSI/FM Approvals standard for further information about test procedures and conditions.

- Applicable documents
- Definitions
- Product information
- Application Requirements
- Requirements for Sample for Examination
- Materials, Marking
- Manufacturer's Installation instructions
- Calibration, test facilities and tolerances
- Requirements: The objective of these tests is to determine the maximum horizontal load a component can resist, at each orientation, for 15 equal amplitude cycles (see Figure 7).
- Initial Load, direction, and testing orientation: How the component is allowed to be installed, how to be loaded, the range of brace orientation, limiting deformation along the brace, allowable stress design (ASD) and brace orientation angle explained.
- Reporting requirements: At the conclusion of the test program, the collected data organized into a final report. Furthermore, sample properties and a description of the test method should be reported.

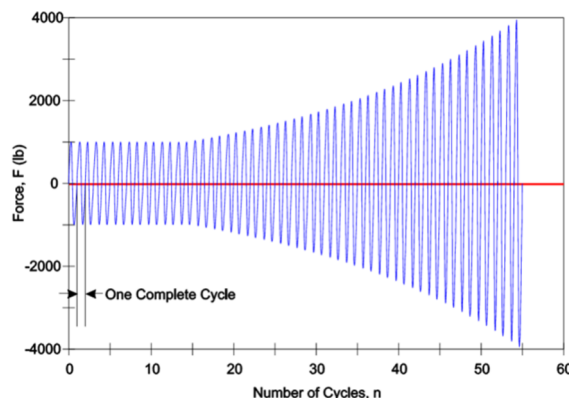


Figure 7. Force History Plot (Component testing) (ANSI/FM Approvals 1950-2016)

4.3 California OSHPD OSP:

The California “Office of State-wide Health Planning and Development” (OSHPD) has pioneered the enforcement of IBC requirements for special seismic certification. OSHPD’s involvement in special seismic certification began with the 2007 CBC when California adopted the IBC. Most recently, OSHPD made a voluntary pre-approval program for special seismic certification compliance on California healthcare projects.

This program began in 2008 and was named the OSHPD Special Seismic Certification Preapproval, or the OSHPD OSP. This program offers manufacturers a pathway for achieving compliance over an entire product line while also providing for expedited application on projects moving forward. To obtain an OSHPD OSP, a substantial amount of documentation must be prepared and submitted for review by OSHPD. In the standard, the test procedure has been categorised and explained, the figure is illustrating this procedure (see Figure 8).

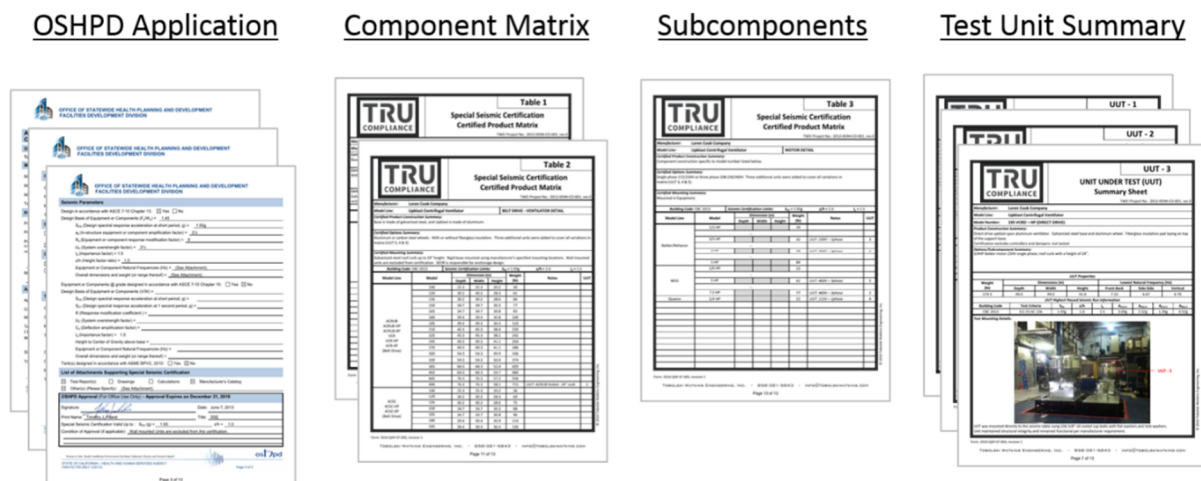


Figure 8. Published documentation from OSHPD for product reviews (California OSHPD)

5 Recommendation

Testing the products according to reliable and updated guidelines is a great investment that can give confidence to designers and contractors regarding the performance of seismic bracings during seismic events. Considering parameters such as comprehensiveness, and ease of test procedures use of ASHRAE-standard 171 - 2017 guideline is recommended by authors to be used for seismic bracing testing methods in Australia.

Below are some steps that manufacturers can take for testing and certifying seismic restraints products.

- Manufacturers need to assess the laboratories’ capability to conduct the test according to the seismic test guidelines’ loading requirement. For instance, if a lab can impose cyclic loads as required by guidelines. A simple static pull/push load might not be acceptable for seismic purposes.

- b. If production certification is required, lab accreditation is to be checked against standard requirements. If the lab is not accredited, they need to check if they can fulfill the alternative method for the certification when testing in non-accredited testing facilities.
- c. Different seismic bracing products require different testing set-ups. Manufacturers need to ensure that the test lab has adequate testing facilities to conduct the test according to each test setup.
- d. “Quality Assurance Program” in this standard is the core process of manufacturing procedure, and it is required for product testing and certification. The QA process and documentation are to be ready before initialising the testing process. Also, manufacturers are required to provide a statement that samples that are being tested have the same properties as products in the production line, which again can be achieved by the QA process in place.

6 Conclusion

The performance of seismic restraint products plays an important role in providing safety for occupants in buildings by limiting the movement of non-structural components within the building so that they do not break, flex, and get dislodged during an earthquake. They are also essential for the continuity of operation of important buildings after seismic events.

To ensure that they perform as expected, test set-ups need to be as close to reality as possible. There are several international testing standards specifically illustrating the requirement for testing seismic restraints. In lieu of such a guideline in Australia, manufacturers might utilise these standards to test and certify the bracing products for a rated capacity.

Providing comprehensive document submittal about test set-up, test results, QA processes and product rated-capacity certification; designers, contractors, certifiers, builders, and consumers can ensure that the building is a safer place as they have more confidence about products performing as they expected.

7 References

- AS 1170.4-2007, Standards Australia, Structural design actions Part 4: Earthquake actions in Australia.
- AS 5216-2021, Standard Australia, Design of post-installed and cast-in fastenings in concrete
- ANSI/ASHRAE Standard 171-2017: Method of Testing for Rating Seismic and Wind Restraints
- ANSI/FM Approvals 1950-2016: American National Standard for Seismic Sway Braces for Pipe, Tubing and Conduit.
- California OSHPD OSP CAN 2-1708A.5-2013: California Office of State-wide Health Planning and Development.
- Nazari Rad, A. et al (2019). Adequacy of Australian Standards for Non-Structural Component systems, Australian Earthquake Engineering Society 2019 Conference, Nov 29, Newcastle, NSW (Paper 52)