# Testing Nonstructural Components for Earthquake Resistance

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September 2, 2010

**Abstract**

This paper develops the experimental procedures needed to test the earthquake resistance of a nonstructural component. The design procedures and seismic performance of an Anglorack computer rack is examined to determine if they comply with the *New Zealand Standard's Seismic Performance of Engineering Systems In Buildings (NZS 4219:2009)(*P4219 Committee, 2009). The design and performance of the computer rack will also be assessed for compliance under the standards used in the United States and by generic requirements set forth by telecommunication industry, Telcordia Technologies (Network Infrastructure and Operations, 2006). The restraint system design for the computer rack and the shake table, as well as the steps needed to conduct a shake table experiment will be described to determine if the nonstructural component functions adequately in event of seismic activity.

**Introduction**

The University of Auckland was given the task of determining if an Anglorack computer rack complies with the seismic design standards set forth by New Zealand. This enclosure system is referred to as a nonstructural component; it is a 591mm x1533mm x 591mm freestanding electrical cabinet that houses computer servers. It is crucial that the seismic performance of the enclosure system meets building specifications to safeguard the electrical contents inside during earthquakes.

The failure modes of nonstructural components during a seismic event can cause severe damage and human injuries. Structures that are not restrained properly can overturn, slide, rock, and uplift when subjected to earthquake motion. The seismic response of the computer rack depends on the enclosures structural stiffness, which is affected by its designed restraints. The combined effects of the ground's acceleration and the structure's heavy weight can result in large seismic forces developing in the structure. The computer rack is prone to overturning due to its large mass and its high center of gravity relative to its base. To prevent the computer rack from overturning an anchorage method was chosen to restrain the structure and transfer the seismic force to the building floor it is positioned on.

The anchors or fasteners must be designed for adequate seismic loads and must account for usage of any bracing systems; in this experiment a bracing system is not used. Placement of the anchors must have enough clearance in respect to the dimensions of the structure's base and the shake table's restraint holes. The anchor connections consist of ductile steel bolts that fix the base of the computer rack to the concrete ground or the shake table. The spacing of the anchors, the distance between the edge of the concrete and the anchors, embedded depth of the anchor bolts, and pull-out tension and shear forces on the anchors are crucial aspects of the restraint design. The shake table restraints must be designed to prevent the enclosure from overturning completely during testing.

**The New Zealand Standard**

The computer rack will be tested to verify if it complies with the *New Zealand Standard's Seismic Performance of Engineering Systems In Buildings (NZS 4219:2009)* (P 4219 Committee, 2009). The first design procedure is to determine the earthquake load demand, $F$, on the computer rack. According to equation 3.1 in the *NZS 4219:2009;*

$$F = CW$$

in which the earthquake load demand depends on the lateral coefficient, $C$, and the weight of the component, $W$. The lateral coefficient is calculated using equation 3.2 in the NZS 4219:2009;

$$C = 2.7C_H Z C_P R_C$$

where $C_H$ is the floor height coefficient, $Z$ is the zone factor for the New Zealand location, $C_p$ is performance factor, and $R_c$ is the component risk factor. Assuming the component's operating weight is 16.01 kN, the floor height coefficient is 3.0 for components above ground floor, the zone factor for Auckland is 0.13, the performance factor is 0.85, and the component risk factor is 0.9, the lateral coefficient and the earthquake load demand are calculated to be 0.806 and 12.90 kN, respectively. The relative displacement of the nonstructural component is determined from the building's calculated design displacement. For this experiment the building's design displacement is unknown and therefore the relative displacement of the enclosure reflects the structure's risk factor and its height. The relative displacement of the computer rack is computed to be 45mm according to the *NZS 4219:2009* equation 3.3;

$$D = 0.025R_cH_z$$

where $H_z$ is the height between fixing points.

The forces on the anchors need to be determined to design secure restraints for the computer rack. According to equation 3.5 and 3.6 in *NZS 4219:2009* the horizontal and the vertical force on each support for a rigidly mounted, unbraced component is calculated to be 3.22 kN and 14.92 kN, respectively. The horizontal force, $R_h$, on each support is computed from equation 3.5;

$$R_h = (CW)/ N$$

where $N$ is the total number of supports which is assumed to be four. The vertical force, $R_{vc}$, on each support is computed from equation 3.6;

$$R_{vc} = \pm (CW)/ (nB) + (W/N)$$

where $n$ is the number of supports acting in tension, which is two, and $B$ is the spacing of the supports, taken to be the width of the structure . The designed restraint system must have sufficient capacity to resist these forces. A bolts size of M12 with a minimum end distance of 24mm is adequate to endure the calculated restraint forces. If the anchors are cast into concrete masonry the minimum edge-distance, measured from the center of the bolt to the outer face of the concrete, must be greater than the embedment length of 100 mm; whereas the spacing between the bolts must be greater than twice the embedment length.

To test the design earthquake standards, the computer rack is restraint onto a shake table. Under the New Zealand standards, the nonstructural component will be tested for five minutes. The accepted criteria is met if the computer rack can sustain the earthquake load demand for the duration of the test without collapsing, opening, or becoming detached from its fixings, while the electrical equipment inside operates continuously (P 4219 Committee, 2009).

**Network Equipment-Building System (NEBS) Requirements**

In high seismic zones like California, it is required by law that computer rack enclosures have earthquake restraints. The telecommunications industries in United States have computer rack enclosures comply with Telcordia Technologies Network Equipment-Building System (NEBS) Requirements: Physical Protection GR-63-CORE specification (Network Infrastructure and Operations). The specification are also regulated by the American Society of Civil Engineers (ASCE) *Standard Minimum Design Loads for Buildings and Other Structures* (ASCE 7-02), which is also a provision of the Uniform Building Code (Leet, 2005).

According to the ASCE Standards there are two different methods to determine the seismic design loads; a dynamic method for irregular shaped structures and a simplified equivalent static force method for symmetric structures. Due to the simplicity of the computer rack, the earthquake design loads are computed by the equivalent static force method (Leet, 2005). Assuming the computer rack is a steel moment-resisting frame, a very ductile structure, with a total dead load of 16.01 kN and an extreme occupancy factor, the magnitude of the base shear for a steel frame with rigid anchors is calculated to be 11.04 kN, which is comparable to the earthquake load calculated from the New Zealand Standard. Static computation of the internal forces on a fixed-end frame is done to determine the loads on the anchors. The horizontal force and the vertical force on each support is 5.58 kN and 15.23 kN, respectively, which are also within close approximation to the forces calculated for the New Zealand Standard.

According to the ASTM specifications described in the *Civil Engineering Handbook*, the restraints will fail when the tensile capacity of the anchor bolts are reached, causing a cone pullout type of failure (Chen, 2003). The design of anchor bolts is crucial for designing adequate restraint systems. The design capacity of the anchor bolts reflects the limit state of the tensile fracture of the anchor and the cone pullout. By computing the limit state of the tensile fracture and the cone pullout, it is determined that the minimum required gross area and embedded length of the anchor is 2.06 $mm^2$ and 227.33 mm, respectively. The embedded length of the anchor exceeds the New Zealand requirement of 100 mm. By examining the tension and shear stress, as well as the given dimensions to the anchor above, a bolt size with a diameter of 15.87 mm (or bolt size of M16, grade 8.8) is adequate to fix the structure into the concrete or shake table.

In United States the seismic design and performance of nonstructural components in buildings must be in compliance with the NEBS requirements. To evaluate the seismic design and response of the component a static and waveform (shake table) test are conducted. The computer rack can be tested at any earthquake severity level; Earthquake Risk Zone 4 is the highest ground acceleration of 0.4 - 0.8 g's, representing an earthquake magnitude of 7.0 – 8.3 on the Richter scale. A chosen acceleration-time-history waveform will generate an earthquake motion on the shake table to test the seismic performance of the computer rack. According to the Telcordia Technologies requirements, the Test Response Spectrum (TRS), which is the shake table's analyzed acceleration, must meet or exceed the Required Response Spectrum for 1.0 to 50 Hz range for the specific earthquake risk zone chosen. The deflection at the top to the computer rack relative to its base must be measured using a Liner Variable Displacement Transducer (LVDT). The acceleration of the computer rack as well as the shake table must be measured; accelerometers should be placed at the top and at mid-height of the enclosure and on the shake table. The computer rack is mounted to a concrete slab using anchors which is then fastened to the shake table. The design of the computer rack restraints are shown in Figure 3 of the Appendix. A static test procedure is conducted by applying a horizontal load at the top of the computer rack to measure its strength and stiffness. During the static test the top of the enclosure should not deflect more than 75mm and the structure should not acquire permanent damage. Upon removal of the load, the top of the structure should revert within 6mm of its original position.

The physical performance during and after the shake table (waveform) test will determine if the computer rack is earthquake resistant. The computer rack, including the connections, cannot permanently deform during the test; the structure cannot bend, buckle, crack, or have a deformed base or failed anchor. The doors, shelves, and the electrical equipment inside cannot disconnect, separate, or be mechanically damaged. The electrical equipment inside the computer rack must be operating during and immediately after each seismic test without having to be repositioned or rebooted. During the shake table test the top of the computer rack cannot deflect more than 75mm relative to its base and must have a natural mechanical frequency greater than 2.0 Hz (P4219 Committee, 2009). The relative displacement according to the New Zealand standard is within the guidelines of Telcordia Technologies's requirements.

**Experiment Setup and Procedure**

Since the restraint holes on the bottom of the computer rack do not coincide with the holes on the shake table, a steel base plate must be fabricated for the placement and the restraint of the enclosure onto the shake table. The steel base plate is 591mm x 743.3mm x 16mm with four 14mm diameter holes to restrain the computer rack and twelve 10mm diameter holes that allow for the plate to be bolted to the shake table as shown in Figure 3 in the Appendix. The shake table restraints are designed to prevent the computer rack from overturning completely, therefore it must account for the structure's height and the deflection distance allowed. T-shape steel columns are designed for the shake table restraint that stand at a height of 1333mm, higher than center of mass of the enclosure, and will be welded onto a steel plate that will be placed on the shake table. The dimensions and design of the shake table restraints are shown in Figure 4 in the Appendix. The restraints are located more than 75mm away from the computer, equal to the maximum deflection the top of the computer rack can undergo before failing Telcordia's performance criteria.

The instrumentation configuration for the experiment will consist of LVDT at the top of the enclosure to measure the deflection relative to its base and accelerometers on the shake table and at the top and at mid-height of the enclosure. The accelerometer must have a minimum dynamic range of 0.5 to 100 Hz. The shake table acceleration data will allow the configuration of the Test Response Spectrum by using a Response Spectrum Analyzer with 2% damping.

To comply with the New Zealand Standard, the computer rack will be tested for five minutes during which the seismic design loads must be resisted and without the enclosure collapsing, opening, or becoming detached from its fixings, and the electrical equipment inside operating continuously. To comply with Telcordia Technologie's NEBS requirements the computer rack must sustain the seismic design loads computed according to the ASCE *Standard Minimum Design Loads for Buildings and Other Structures.* The top of the structure cannot deflect more than 75mm and the TRS must meet or exceed the Required Response Spectrum for 1.0 to 50 Hz range for the specific earthquake risk zone chosen. The computer rack, its connections, and its anchors cannot permanently deform or detach during the test and the electrical equipment inside cannot be mechanically damaged (P4219 Committee, 2009).

**Conclusion**

Unfortunately, the duration of this internship did not allow time for the restraints for the computer rack testing to be fabricated and therefore the computer rack was not tested for its seismic response. Upon fabrication of the restraints, the computer rack and the restraints can be setup on the shake table and the seismic test can be performed to determine if the nonstructural component is earthquake resistant. By analyzing the seismic response of the computer rack, its acceleration and deflections at various points, it can be concluded if the nonstructural component complies with the New Zealand Standard and the Telcordia Technologies Network Equipment-Building System (NEBS) Requirements.

**Acknowledgements**

If it was not for Dr. Lelli Van Den Einde, my UCSD mentor, informing me about the PRIME opportunity I would not have known about this internship. Thank you to Dr. Lelli Van Den Einde, Dr. Jason Ingham, and Dr. Liam Wotherspoon, my University of Auckland mentor, for guiding me through this internship and providing a great learning and cultural experience. I appreciate the time and effort Dr. Quincy Ma spent explaining the different projects and concepts to me. Thanks to Sujith Padiyara for allowing me to work in the computer lab, helping me with AutoCad, and showing me around Auckland. I appreciate having friendly and helpful lab technicians and workers in the structural laboratories of University of Auckland and the Powell Laboratory at UCSD. I am honored to be selected and involved in PRIME and thank you to everyone working with PRIME and AIP program. A special thanks to Dr. Gabriele Wienhausen and Dr. Peter Arzberger for organizing and providing undergraduates at University of California, San Diego with this incredible experience to study, work, and travel abroad.

## Appendix

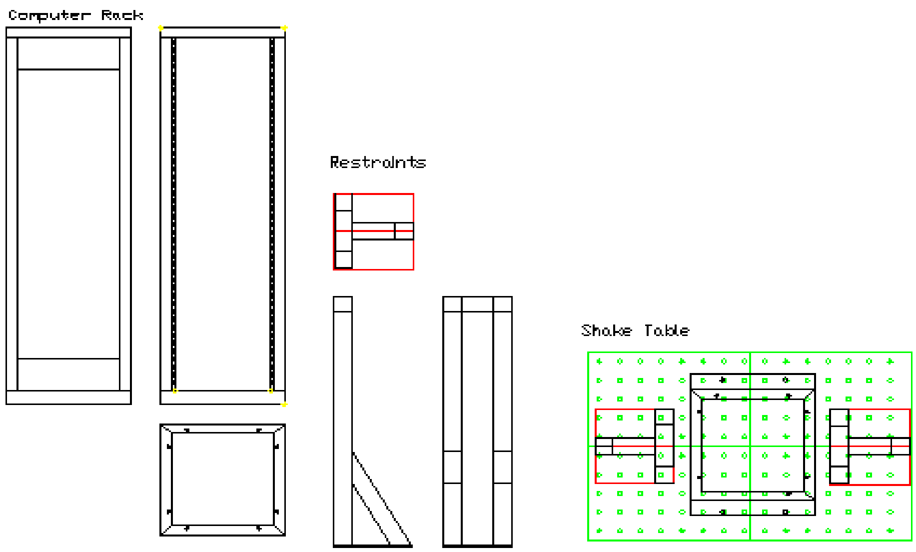


**Figure 1. Drawing of the computer rack and the design of the restraint systems.**

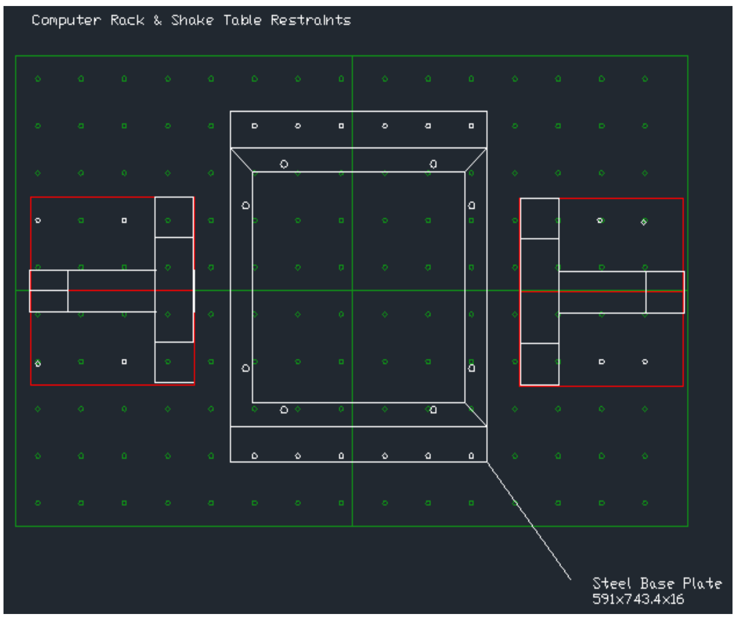
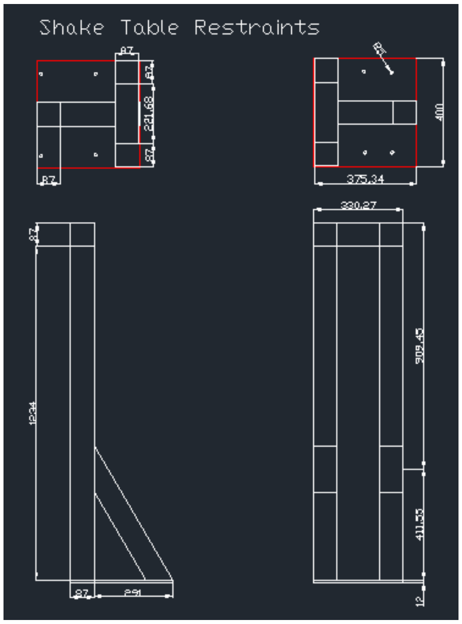
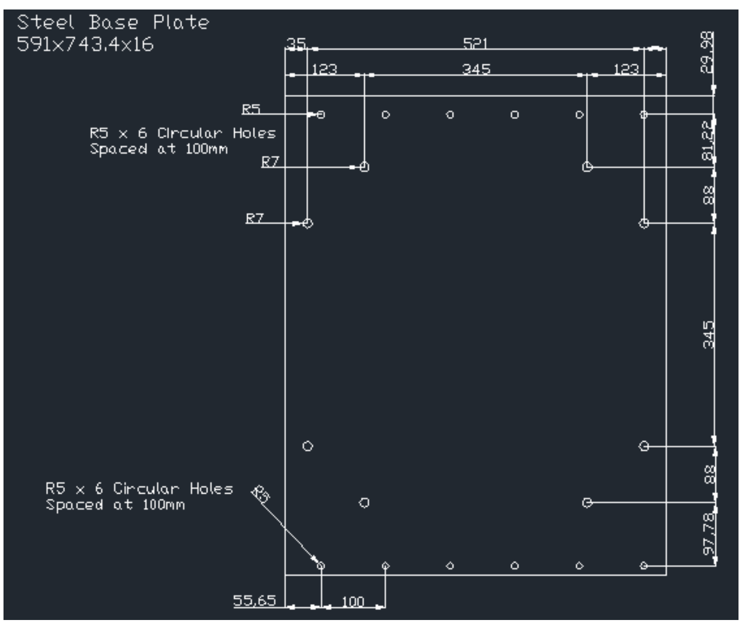



**Figure 2. AutoCad drawing of the placement of the computer rack and shake table restraints on the shake table.**


Shake Table Restraints
87
87
221.68
87
87
R5
400
375.34
330.27
87
909.45
1234
411.55
12
87
291


Steel Base Plate
591x743.4x16
35
521
123
345
123
29.98
R5
R5 x 6 Circular Holes
Spaced at 100mm
R7
81.22
88
R7
345
88
R5 x 6 Circular Holes
Spaced at 100mm
R5
97.78
55.65
100

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