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Developing Standard Seismic Restraint Products for OFCs - A Case Study

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ABSTRACT: One of the impediments to a seismic risk mitigation program for operational and functional components (OFCs) in buildings is the cost of getting the work done. A large facility has thousands of small to large OFCs in it. Seismic mitigation procedure includes seismic risk assessment, seismic restraint design, restraint fabrication, restraint installation, project management, inspection, and issuance of Letters of Assurance. Seismic restraints are usually designed by structural engineers with a speciality in non-structural components. These components should be secured against seismic demand force and seismic demand displacement for buildings that are not base isolated.

The key element in this procedure is seismic restraint design, which leads to restraint drawings and later to cost estimation. Without engineered drawings it is almost impossible to come up with the cost estimation. Usually the building owners need the estimated cost at the risk assessment level, which is one step prior to engineering design. This can be a reason for delay in seismic mitigation programs, which may then result in unnecessary damage during ground shaking. One of the ways to solve this problem is to have the seismic restraint designed at an earlier stage in a mitigation project or to have pre-engineered products that can be used for a large and unique OFCs, which generally require custom design and fabrication.

Cost estimation at the earliest stage of seismic risk evaluation of OFCs can assist insurers as well as the facility owners. Insurers often calculate their earthquake coverage premium based on the general location of the facility. It the insurer is able to readily see the level of OFC risk following a CSA S832-14 assessment and the facility owner can accurately determine the cost of mitigation, a normal benefit/cost business decision can then be made.

This paper details, in case study format, the development of a generic seismic restraint system manufactured locally in British Columbia, Canada by EQ Restraint Technologies Inc. with installations in the Greater Vancouver region. The process of design calculation, drafting progression, prototyping, field testing and manufacturing will be detailed. The seismic restraint system is designed to fit many types of the free standing components such as lab equipment, shelving units, book cases, file cabinets, flammables cabinets, electrical components, servers, UPSs and fuel tanks. This analysis is designed to assist others in developing products that expedite the process of executing seismic risk mitigation of OFCs and a reasonable cost.

1. Introduction

During earthquake, damages to electrical and mechanical equipment and systems, inadequately restrained, could be very extensive, necessitate insignificant replacement or repair costs, as well as down-time costs. Furthermore, equipment or systems in uncontrolled free movement it could pose a threat to life and property.

Standard seismic restraints are custom designed elements (for a specific application, not general use) tasked with keeping non-structural components and/or equipment and systems from moving/overturning during earthquakes. Seismic restraint designs generally include 3 components: a fixed connection type between the restraint and the non-structural component; the main seismic restraining element; and the connection between restraint and structural element.

Paradigm Engineering Inc. (“Paradigm”) is a structural engineering company, specialized in the analysis of seismic restraining requirements for non-structural components. EQ Restraint Technologies Inc., an associated company, has tasked Paradigm with the technological objective of developing a generic seismic restraining technology suitable to secure sensitive equipment through a non-invasive installation method, thus protecting assets while providing flexibility in relocation options. The resulting restraint must support seismic demand associated with equipment/systems of up to 1,000lbf(5kN) in weight and H=2m x W=1m x L=1m in size, believed to cover a wide range of applications of free standing mechanical, electrical, and specialized laboratory equipment and shelving.

It is uncertain how the relationship between parameters like functionality and location of non-structural components, behaviour of specific restraint components at variable levels of acceleration and displacement during earthquakes, and the structural capacity of non-structural components and building structural elements, will affect the response of our technology(i.e. resisting to seismic demand forces and displacement) over the wide range of generic applications.

Our hypothesis is focusing on eliminating the connection through the body of the non-structural components and the challenges associated with a fixed, invasive connection to the equipment, by introducing a confinement method suitable to enable the restraint to remain permanently connected to the structural elements, while providing for ease of installation and relocation of equipment.

2. Methodology used to design a generic seismic restraint

2.1. Generic versus traditional restraint

Within the common practice of restraining the non-structural components in a traditional (invasive) and custom-made basis, the designer uses the component’s dimensions, weight and shape criteria to develop a seismic restraint. These components can be categorized based on their functionality, shape, position and connection to structural elements. The output is a specific seismic restraint system for each of these categories. The traditional method limits the ability to secure variable types of non-structural components, which could be acceleration dependent components, displacement dependent components and components that are both acceleration and displacement dependent.

Our technology is attempting to provide a generic seismic restraint system designed to respond adequately to these various seismic demand forces and displacements. During seismic activities, there are forces in horizontal and vertical direction that imposes to the centre of gravity of non-structural components. As a result, of these forces, the non-structural components tend to move in horizontal plane as well as vertical direction. Multiplying applied force by distance between centres of gravity and the base results in overturning moment in the vertical plane. At the same time, the product of applied force by distance between centres of gravity to centre of geometry yields to torsion in the horizontal plane. The EQRT 203 seismic restraint system secures the non-structural components against applied seismic forces, displacements, overturning and torsion as whole (which the general term for each one is seismic demand). Every element of EQRT 203 designed to play a role in securing the non-structural components against seismic demand and eventually preventing consequence hazard during seismic activities .EQRT elements are; (4) steel brackets, (4) confinement lips, (4) threaded rods, (16) wedge nuts, (8) screw anchors and two sets of tie down straps with J hooks. The tie down straps prevents the non-structural components from overturning. The steel brackets keep the non-structural component from horizontal displacement in one direction and confinement lips take care of the other horizontal direction. Since the seismic activity is cyclic therefore the non-structural components moves back, forth and side to side. Steel brackets and confinement lips are installed to the floor at four corners to resist against vibration modes in all direction. When the non-structural component is in overturning mode the tie down strap goes to tension these tension transfers to anchors through J hooks, threaded rod and gusset plates that connect the rod to the bracket. When horizontal force acts on confinement lip, it applies bending moment to the confinement lip. On the other hand, the confinement lip transfers this force to the threaded rod and tends to bend the rod. Therefore, the threaded rod should be designed in such a way that provides flexural, shear as well as tensile capacity. The anchors also resists applied shear due to imposed horizontal forces, applied shear because of torsion and applied tension yields because of tension in tie down strap.

In order to provide a sufficient statistical equipment sample we recorded weight and dimensions of over 70 different types of freestanding equipment and categorized it based on available data. The collected information was analysed through our in-house developed Mathcad algorithm for the worst-case seismic scenario. This worst-case scenario is defined by several variables. Some of them are related directly to the physical properties of the non-structural components such as equipment weight, aspect ratio (height to width ratio), location of centre of gravity, natural frequency of the non-structural components, base type (if the non-structural components is located on wheel/caster or leg or it is flat bottom) and structural capacity of non-structural components. The other variables are; location of non-structural components with respect to total height of the building (equipment located in higher stories are under the effect of higher seismic demand or A_x in part 4 of NBC), amplification due to soil type (ie softer soil versus harder soil F_a in part 4 of NBC), ground acceleration ($S_a(0.2)$ in part 4 of NBC), building structure type, natural frequency of the building, required performance level (eg post disaster facility like hospital vs normal building I_E in part 4 of NBC), and content of components (C_p in part 4 of NBC), flexibility of the nonstructural components (A_p in part 4 of NBC) and ductility of connection to structural (R_p in part 4 of NBC).

A proof-of concept design was produced to include a steel angle bracket, confinement lip, threaded steel rod, steel nuts and stainless steel washers, anchor bolts, and tie down straps. It was installed at several locations to determine installation requirements with regard to the connection to structural elements, and uncover any potential deficiencies related to the ease of relocation. Based on the observations drawn, as well as the Mathcad analysis results, the proof-of-concept design was modified as such: the bracket length was reduced from10 to 7 inches to reduce applied flexural stress on rod due to applied tension from tie down strap and the bracket height was increased from 3 to 4 inches to provide more confinement for equipment with higher base, longer legs or larger casters, the steel rod was originally ½” in diameter then it changed to 5/8”to provide more capacity against applied flexural, shear and tensile stress on rod specially when the confinement lips should be installed away from the bracket (Rod needs to be longer); the confinement lip was originally 2” wide, ¼” thick and 3” long then it changed to 1.5” wide, ¾” thick and 6” long. The longer length allow extension in the confinement at the front and back sides when the leg or wheel at the base are not flush with the corner of the equipment and they are offset from the edge. For the equipment the bottom of the door comes closer to floor the 1.5” width worked almost in all cases. Consequently, making the length longer and the width smaller caused in more flexural stress on the lip end (due to longer arm in the applied moment). Therefore the thickness is increased to ¾” from ¼” to provide more capacity against applied bending moment; a stainless steel sleeve was added for ease of tie down strap installation and to avoid potential contamination around the rod’s rough surface. The anchor bolts were originally “HILTI KWIK Bolt”style, which have been changed to screw type anchors due to less embedment required for applications where the floor is post tension slab, as well as being easily removable and reusable.

Fig. 1 - Components of EQRT 203 Seismic Restraint.

2.2. Monitoring EQRT 203 seismic restraint behaviour on Shake Table.

Our modeling analysis has indicated that the re designed restraint (named EQRT 203) is suitable to restrain equipment of up to 1,000 lbf (5KN) in weight and 2mx1mx1m (height, width and length) in size. This result is theoretical, and will be tested soon at University of British Columbia, shake table facility. This will provide us with the opportunity to witness the actual behaviour of the equipment during past earthquake scenarios, and thus validating the restraining technology and confirming the designed capacity of the developed seismic restraint under real earthquake conditions. We expect that the shake table testing results will also allow us to further improve the efficiency of the technology and capacity of the restraint system.

3. Conclusions

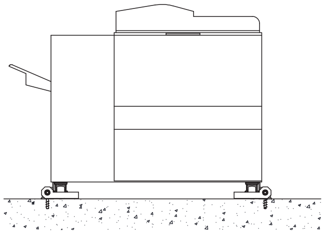
Off-the-shelf seismic restraining products in the market either don't have the generic functionality, and/or are limited to specific type of non-structural components. Ideally for each category of non-structural components, either based on their functionality and shape or nature of their behavior during earthquakes, there should be one type of restraint system that fits a wide range of components, within reasonable limits of weight and dimensions.

We learned that the behaviour of generic restraints could be severely influenced by specific building code requirements, and the multitude of seismic demand forces and displacements specific to the shape, weight and dimensions of each equipment and location. While the modeling of the non-structural components and their standard dynamic analysis could provide good indicators of how the restraint may perform under real earthquake conditions, full validation can only be obtained upon the completion of the shake table test scheduled at UBC in the next fiscal year.

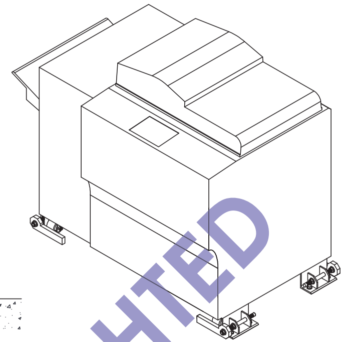
4. References

CANADIAN STANDARDS ASSOCIATION, "CSA - S832-14 - Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings," 2014.

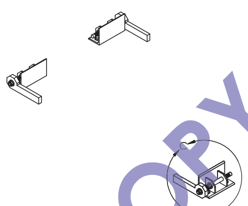
Below includes 16 drawings which shows typical application EQRT 203 Seismic restraint.



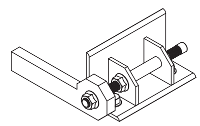
FRONT VIEW
SCALE 1: 22



COPY MACHINE W/ SEISMIC RESTRAINT



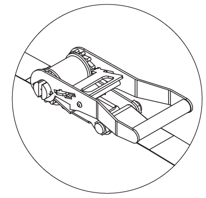
SEISMIC RESTRAINT AT BASE



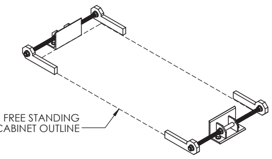
EQ RESTRAINT 203-7-9
DETAIL C
SCALE 1 : 6

USE:
(2) HILTI KWIK HUS-EZ Ø = 1/2"
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]

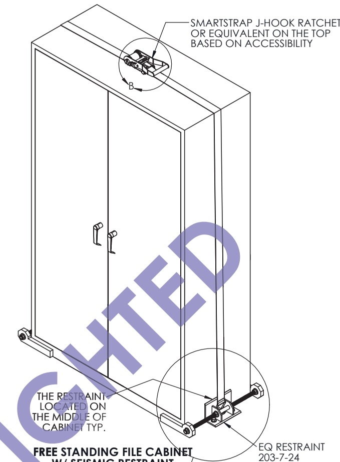
ASSUMES: (BY OTHERS)
- ALL EQUIPMENT COMPONENTS ARE CAPABLE OF WITHSTANDING THE SEISMIC FORCES.
- MIN. CONCRETE STRENGTH f_c = 20.7 MPa [3000 psi.]
- SLAB IS CAPABLE OF WITHSTANDING THE SEISMIC FORCES
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]



RATCHET
TIE DOWN STRAP AND RATCHET RATING: 10kips
DETAIL B
SCALE 1 : 5

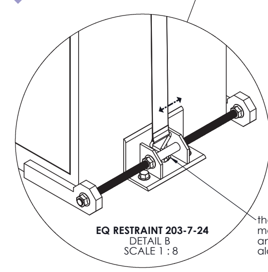


SEISMIC RESTRAINT AT BASE



FREE STANDING FILE CABINET W/ SEISMIC RESTRAINT

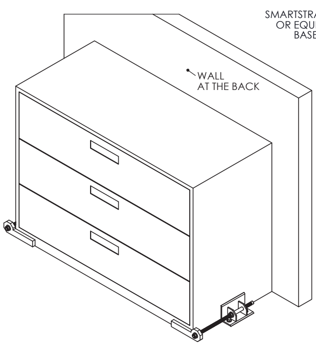
USE:
(2) HILTI KWIK HUS-EZ Ø = 1/2"
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]



EQ RESTRAINT 203-7-24
DETAIL B
SCALE 1 : 8

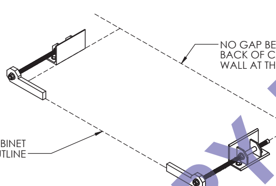
GENERAL NOTES:

ASSUMES: (BY OTHERS)
- ALL EQUIPMENT COMPONENTS ARE CAPABLE OF WITHSTANDING THE SEISMIC FORCES.
- MIN. CONCRETE STRENGTH f_c = 20.7 MPa [3000 psi.]
- SLAB IS CAPABLE OF WITHSTANDING THE SEISMIC FORCES
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]
- TIE DOWN STRAP AND RATCHET RATING

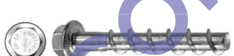


SHORT FILE CABINET W/ SEISMIC RESTRAINT
NO J-HOOK RATCHET OR EQUIVALENT REQUIRED

TALL FILE CABINET W/ SEISMIC RESTRAINT



SEISMIC RESTRAINT AT BASE
SCALE 1: 16



USE:
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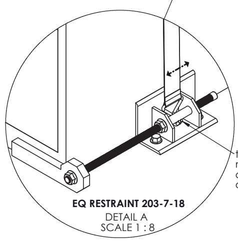
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]



EQ RESTRAINT 203-7-18
DETAIL A
SCALE 1 : 8

ASSUMES: (BY OTHERS)
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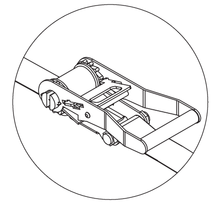
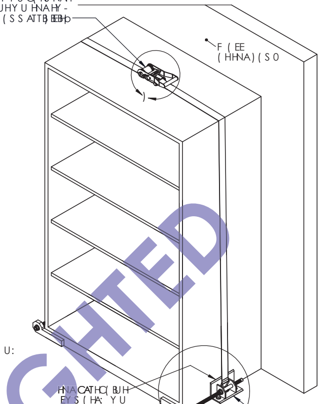
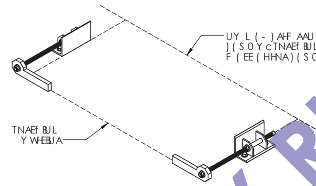
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]



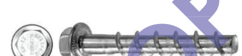
RATCHET

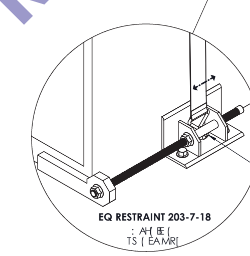


TALL SHELVING W/ SEISMIC RESTRAINT

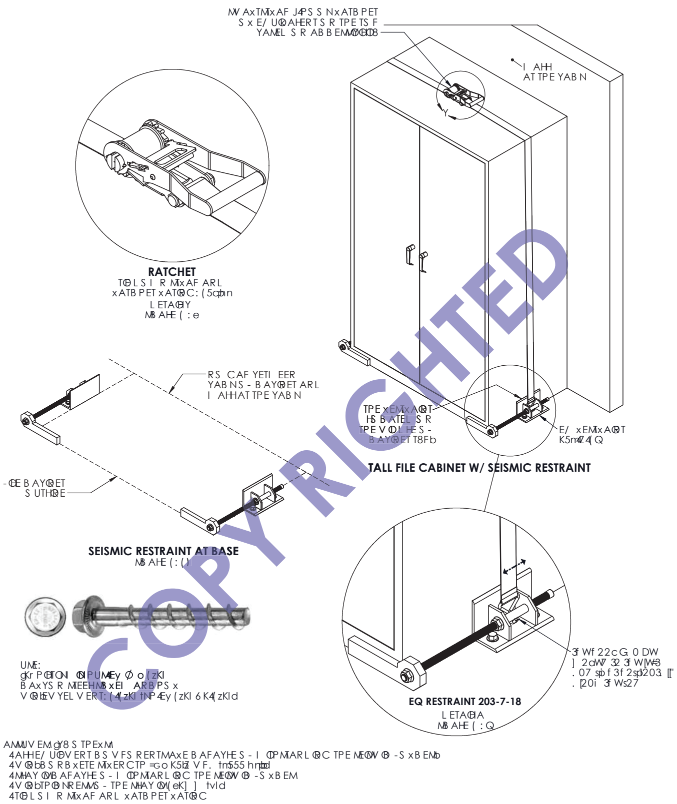


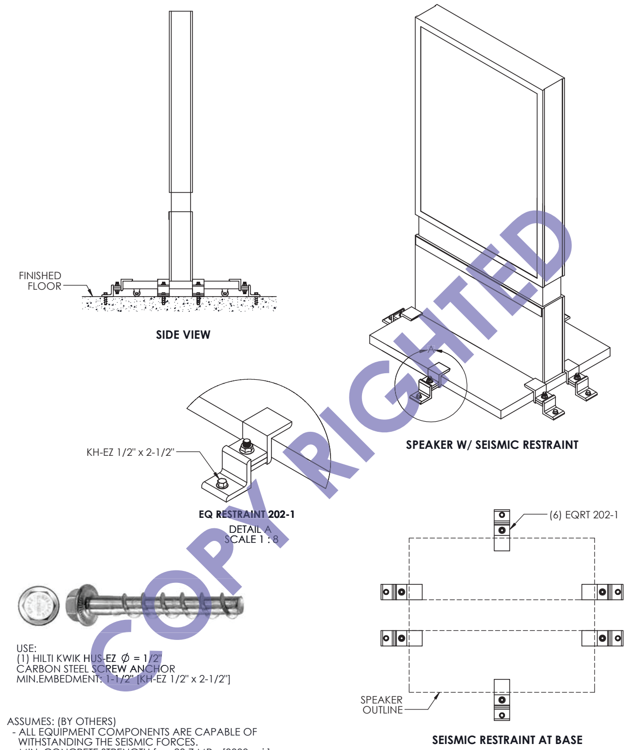
SEISMIC RESTRAINT AT BASE





EQ RESTRAINT 203-7-18





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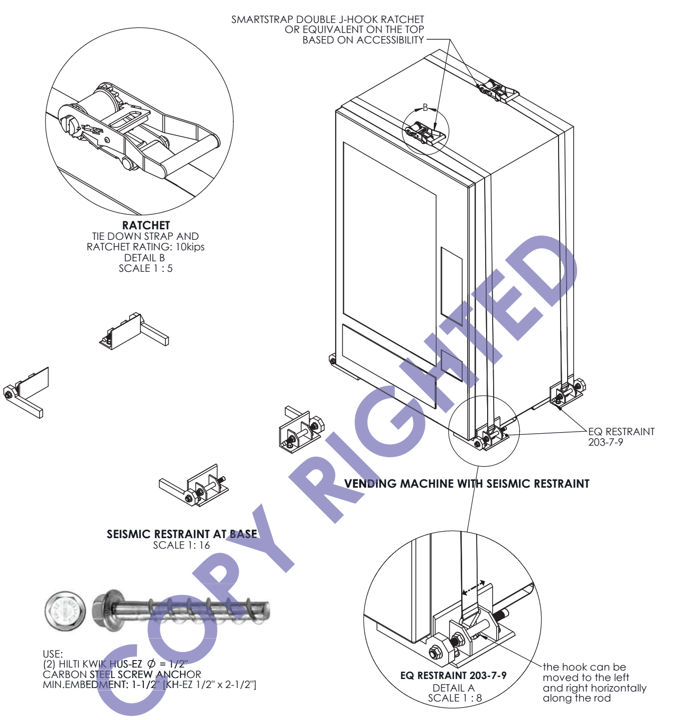

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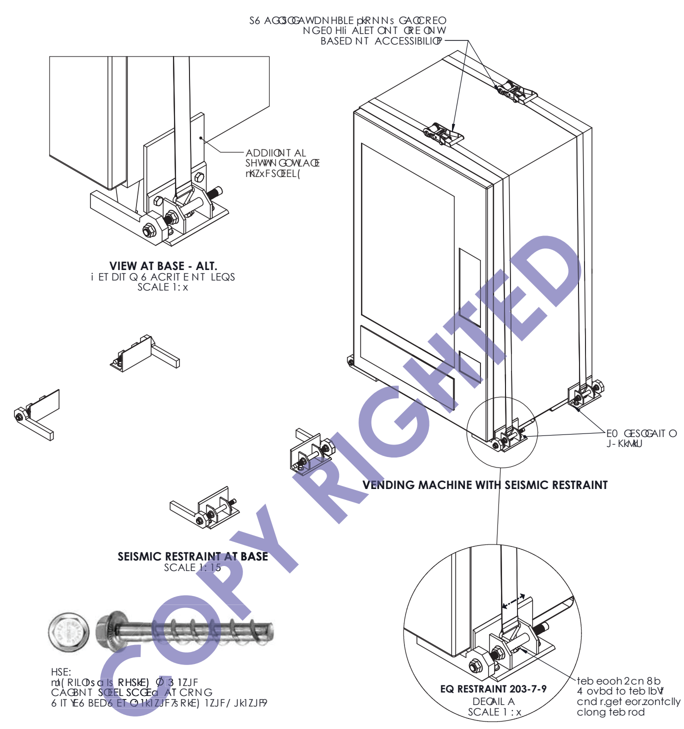
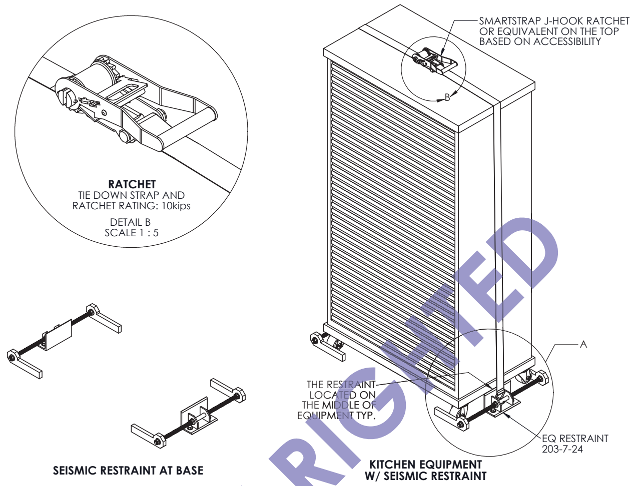
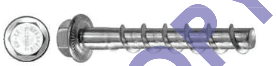
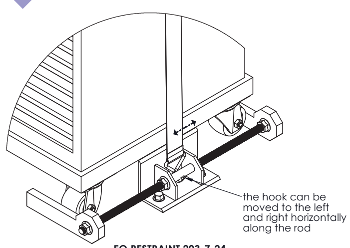
- TIE DOWN STRAP AND RATCHET RATING







USE:
(2) HILTI KWIK HUS-EZ Ø = 1/2"
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]



EQ RESTRAINT 203-7-24
DETAIL A
SCALE 1 : 8

GENERAL NOTES:

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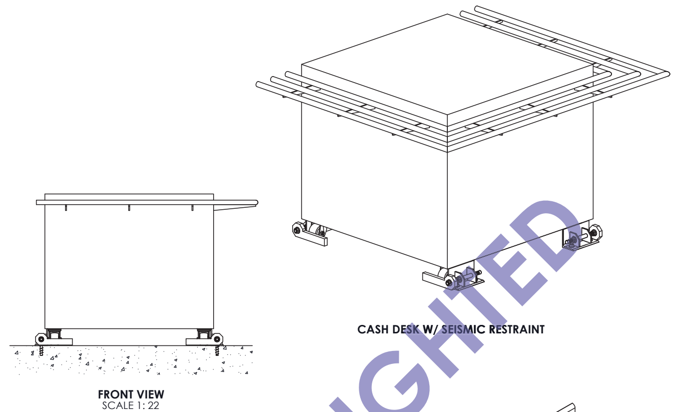

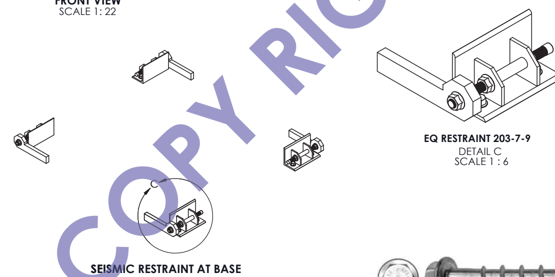

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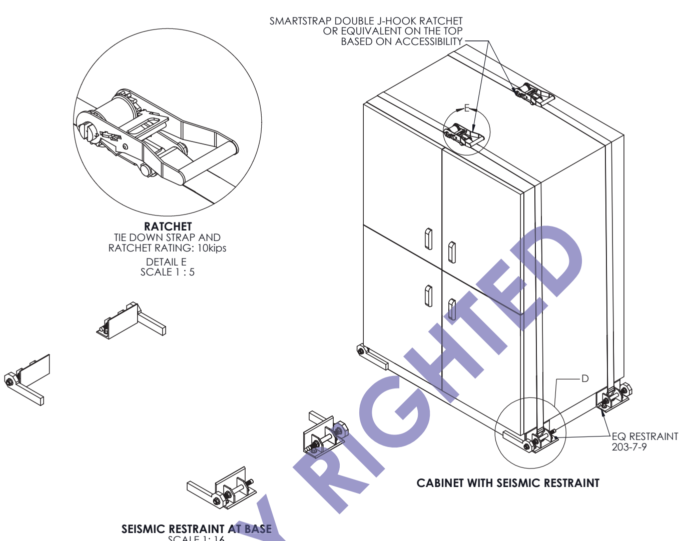

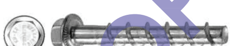

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CARBON STEEL SCREW ANCHOR
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EQ RESTRAINT 203-7-9
DETAIL D
SCALE 1 : 8

ASSUMES: (BY OTHERS)
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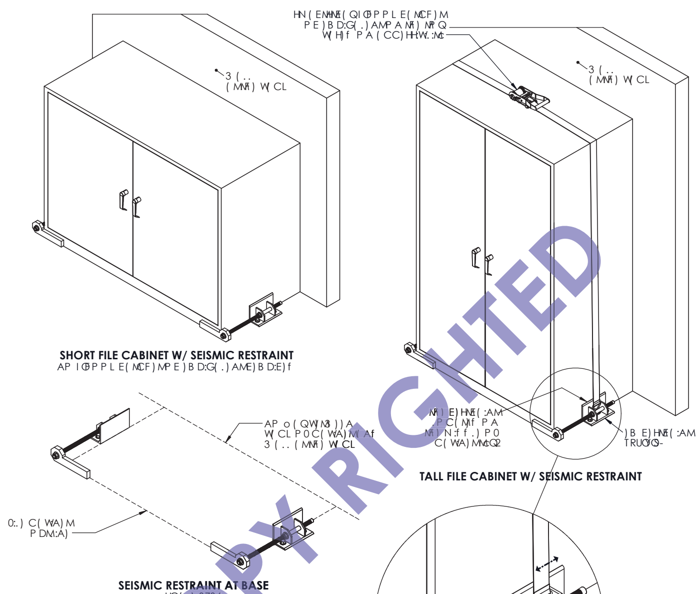

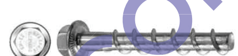

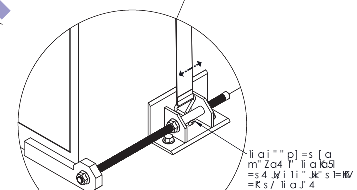

EQ RESTRAINT 203-7-18

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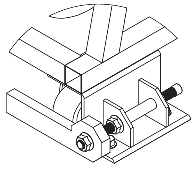
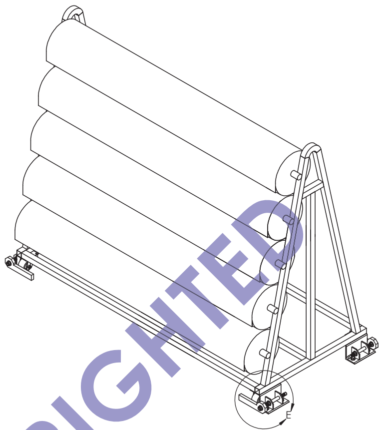
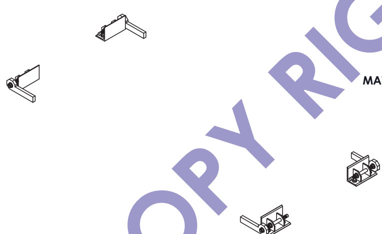


EQ RESTRAINT 203-7-9

DETAIL E
SCALE 1 : 6



MAT ROLLER W/ SEISMIC RESTRAINT



SEISMIC RESTRAINT AT BASE

ASSUMES: (BY OTHERS)
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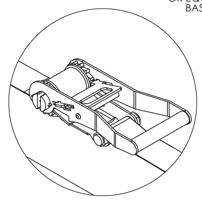
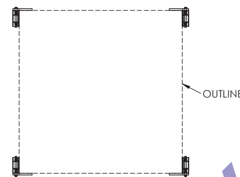
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]

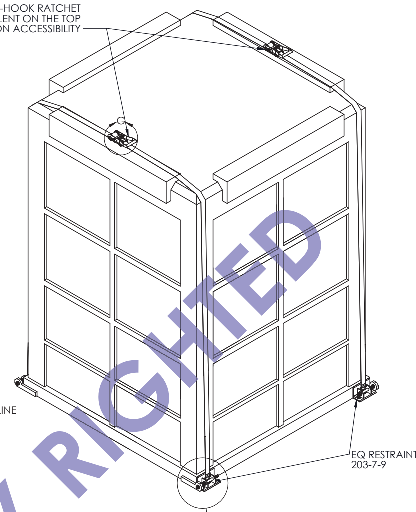


RATCHET
TIE DOWN STRAP AND
RATCHET RATING: 10kips

DETAIL G
SCALE 1 : 5

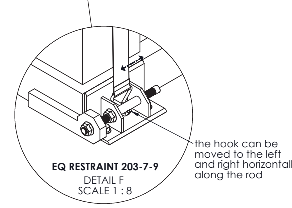


SEISMIC RESTRAINT AT BASE
SCALE 1: 42



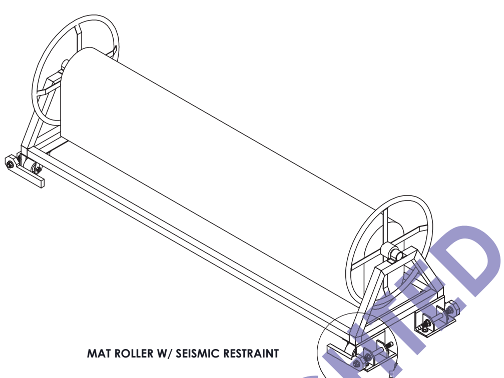
POLICE BOOTH W/ SEISMIC RESTRAINT

USE:
(2) HILTI KWIK HUS-EZ Ø = 1/2"
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]

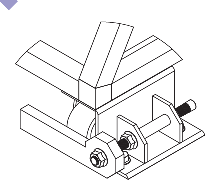


EQ RESTRAINT 203-7-9
DETAIL F
SCALE 1 : 8

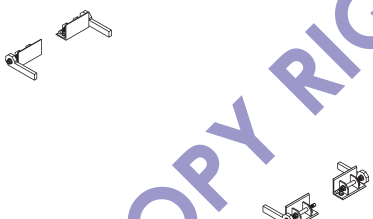
ASSUMES: (BY OTHERS)
- ALL EQUIPMENT COMPONENTS ARE CAPABLE OF WITHSTANDING THE SEISMIC FORCES.
- MIN. CONCRETE STRENGTH fc = 20.7 MPa [3000 psi.]
- SLAB IS CAPABLE OF WITHSTANDING THE SEISMIC FORCES
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]
- TIE DOWN STRAP AND RATCHET RATING



MAT ROLLER W/ SEISMIC RESTRAINT



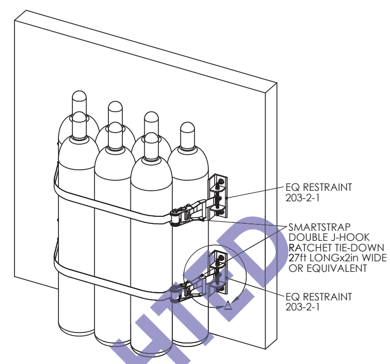
EQ RESTRAINT 203-7-9
DETAIL E
SCALE 1 : 6



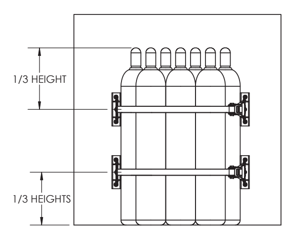
SEISMIC RESTRAINT AT BASE
SCALE 1 : 20

ASSUMES: (BY OTHERS)
- ALL EQUIPMENT COMPONENTS ARE CAPABLE OF WITHSTANDING THE SEISMIC FORCES.
- MIN. CONCRETE STRENGTH fc = 20.7 MPa [3000 psi.]
- SLAB IS CAPABLE OF WITHSTANDING THE SEISMIC FORCES
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]

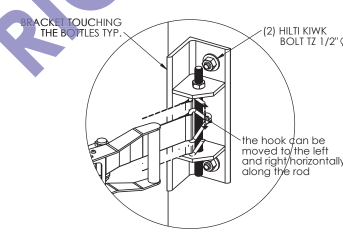
USE:
(2) HILTI KWIK HUS-EZ Ø = 1/2"
CARBON STEEL SCREW ANCHOR
MIN.EMBEDMENT: 1-1/2" [KH-EZ 1/2" x 2-1/2"]



ISOMETRIC VIEW
MEDICAL GAS BOTTLES WITH SEISMIC RESTRAINT



FRONT VIEW
MEDICAL GAS BOTTLES WITH SEISMIC RESTRAINT
SCALE 1 : 28



EQ RESTRAINT 203-2-1
DETAIL A
SCALE 1 : 6

USE:
(2) HILTI KIWK BOLT TZ Ø = 1/2"
EXPANSION ANCHORS / BRACKET
MIN.EMBEDMENT: 2" [KB-TZ 1/2" x 3-1/4"]

GENERAL NOTES:

ASSUMES: (BY OTHERS)
- ALL EQUIPMENT COMPONENTS ARE CAPABLE OF WITHSTANDING THE SEISMIC FORCES.
- MIN. CONCRETE STRENGTH fc = 20.7 MPa [3000 psi.]
- SLAB IS CAPABLE OF WITHSTANDING THE SEISMIC FORCES
- MIN. THICKNESS OF THE SLAB IS 152mm [4"]

APPLICATIONS:

- MEDICAL GAS BOTTLES

SUBJECT:	SEISMIC RESTRAINT OF NONSTRUCTURAL COMPONENTS				
DWG NO.:	103-1	**DATE:** 2014-01-21	**DWG ISSUED:**	FOR FABRICATION	
			REVISION: 00	**SCALE:**	1:20
			DRAWN BY: EY	**SHT NO:**	1 / 2
			DESIGN BY: AM	**CHK BY:**	MD

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