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Reducing The Risk From Non-Structural Building Components In Earthquakes

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ABSTRACT

The failure or movement of non-structural building components is often the main cause of personal injury and death, property damage and interruption to operations. The importance of addressing the non-structural building components continues to be demonstrated with every new earthquake that impacts an urban area. Many building structures have survived an earthquake with no structural damage but the facilities are rendered unusable due to extensive non-structural damage. The extent of non-structural damage to buildings in low seismic zones can be considerably greater than structural damage costs.

Non-structural components include all building components which are not part of the load resisting structure of the building. These include the building exterior, the building interior, and the building contents. The improper design and placement and inadequate restraint of non-structural building components pose a serious threat to the life safety of occupants of buildings in the event of an earthquake.

In recognition of the need for a comprehensive national standard for the identification and reduction of non-structural seismic hazards, Public Works and Government Services Canada (PWGSC) developed a guideline on the seismic evaluation and upgrading of non-structural components for office buildings. As part of an ongoing evaluation of the performance of mitigative measures for non-structural building components, PWGSC is conducting a series of shake table tests at the University of British Columbia. PWGSC is also working with the Canadian Standards Association (CSA) and the private sector to develop a national CSA guideline on the seismic risk reduction of non-structural building components. The CSA guideline, upon completion in the year 2000, will be applicable to normal office and residential buildings, as well as schools, health facilities and other occupancies.

This paper covers both PWGSC practice re office building fit-up and the recent development of the CSA guideline on the seismic evaluation and upgrading of non-structural building components. The results of the shake table tests will also be presented and discussed.

PROBLEM DEFINITION

Many buildings that survive an earthquake with little or no structural damage are rendered unusable due to extensive non-structural damage. The consequence of failure of non-structural building components impacts upon life safety, property damage and economic loss. These fiscal losses can comprise costs associated with death or injury to personnel (including the potential costs of litigation), loss of revenue due to business disruption, cost of repair and replacement of assets.

Non-Structural Building Components

Non-structural building components include all building components which are not part of the building structure. They include the building exterior, the building interior, and the building contents. The building structure is that part of the building which is designed to transfer all vertical and horizontal loads down through the building into the foundation. National building codes and guidelines are available for the structural design, evaluation and upgrading of new or existing buildings. However, similar national guidelines for non-structural building components are lacking. The following two sections briefly describe the Public Works & Government Services Canada (PWGSC) guideline for office buildings (PWGSC, 1995) and the Canadian Standards Association (CSA) guideline for office/commercial buildings, light industrial buildings, schools, hospitals etc.

PUBLIC WORKS AND GOVERNMENT SERVICES CANADA PRACTICE

PWGSC has adopted a seismic risk reduction programme to ensure that a level of basic life safety is provided. This programme includes;

a review of the seismic resistance of PWGSC facilities and upgrading as necessary,

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reduction of the non-structural hazards, and

employee preparedness

In 1995, PWGSC developed its own guideline for addressing the non-structural hazards in office buildings. This publication has since been made available to various governments and the private sector. Other than life safety considerations there is a related additional benefit in that restraining of building contents protects assets from damage. This provides for potentially earlier and easier resumption of business activities following a seismic event.

The primary objective of the guideline is to prevent life-threatening failure of non-structural building components during an earthquake. The guideline is intended to assist engineers and architects to:

help building owners identify non-structural building components which may be potentially hazardous;

evaluate non-structural building components for seismic hazards; and

recommend upgrading.

It applies to existing as well as new buildings but it should not be used to verify compliance of architectural building components in new buildings with the building code. It is restricted to normal office buildings and libraries and does not include sensitive equipment or critical operations.

It is now PWGSC practice to tie back the heating, ventilating and air conditioning systems, light fixtures and ceiling systems to the floor above. This has been done in new facilities (e.g. the office tower at Library Square, Vancouver) and as part of fit-up in existing facilities (e.g. the offices at 800 Burrard Street, Vancouver). Restraint devices have also been applied to computers, printers, fax machines, book cases, file cabinets, shelving units etc. in PWGSC offices in Vancouver and Victoria.

PWGSC Pacific Region is in the process of establishing a Regional Master Standing Agreement for application of restraint devices. This will allow federal departments in British Columbia to call up services against the agreement whenever a relocation of office furniture and equipment has occurred.

CANADIAN STANDARDS ASSOCIATION (CSA) GUIDELINE

A CSA technical committee, was established in September of 1997. It is responsible for the development, maintenance and approval of a guideline, developed through consensus, to provide engineers, architects, and building owners with consistent and effective means to reduce and control potential hazards due to non-structural building components during seismic events. The guideline will be in accordance with the National Building Code of Canada such that life safety is the paramount concern for seismic risk reduction. Economic loss due to property damage is to be minimized with a balance being established between incremental cost and protection.

The guideline will cover most general-use buildings such as office/commercial buildings, light industrial buildings, schools and hospitals. Lifelines within the building such as water and electricity distribution networks, will be included. The guideline will not address specific needs for nuclear plants and industrial plants which house high hazard materials. For laboratories, the guideline may be used for preliminary investigation purposes, but specialized advice from seismic experts will be recommended where hazardous materials and/or processes may be involved.

This new CSA guideline is being developed using PWGSC's document for office buildings as reference. The committee is in the second year of a three year programme to complete the guideline. A complete draft of the guideline is planned for spring of 1999 for peer review and public comment. By the year 2000, the new CSA national guideline will be available for wide distribution.

Functional and Operational Components

The technical committee has adopted the term "Functional and Operational Components" to replace the term "Non-Structural". Functional and Operational Components are those components required for the function and operation of buildings. In the proposed CSA guideline these are further subdivided into three sub-components i.e. Architectural (external and internal), Building Services (mechanical, plumbing, electrical, telecommunications) and Building Contents (common and specialized).

Mitigation Options

The mitigation options being considered to reduce the potential hazard are, to remove, relocate, replace or restrain components.

SHAKE TABLE TESTING OF FUNCTIONAL AND OPERATIONAL COMPONENTS OF BUILDINGS

PWGSC commissioned a second series of tests using the shake table at the Earthquake Engineering Research Laboratory of the Civil Engineering Department of the University of British Columbia (UBC) in Vancouver. The tests were conducted from 20 to 24 July 1998.

The components involved in the tests included bookshelves, file cabinets, a photocopier, library shelving units, a fully furnished office work station, a communication rack, a Local Area Network (LAN) rack, a motor control centre, various other seismic isolation and restraining systems and other office equipment.

Objectives of the Tests

The objective of the tests was to determine how commercially available office equipment and other components would perform during different simulated earthquakes. The tests were also used to investigate the effectiveness of various restraint and base isolating techniques for protecting equipment and personnel during earthquakes.

Set up

The components were either tested separately or mounted to a wall assembly, considered rigid for test purposes, all placed on concrete pad. Figure 1 shows the overall layout of the wall assembly on the shake table. Figure 2 shows the placement of equipment for testing on the afternoon of 21 July 98. Figure 3 shows the layout of the work station and components.

File cabinets were loaded with weights and bookcases were filled with books to simulate normal conditions.

Due to the physical constraints of the testing facility, the motion of the shake table was limited to two directions; east-west (horizontal) and vertical.

Components

The following is the list of components used for the tests;

file cabinet (83" H x 36" L x 18" W) (supplied by PWGSC)
file cabinet (62" H x 36" L x 18" W) (supplied by PWGSC)
book shelf (72" H x 33" L x 12" W) (supplied by PWGSC)
book shelf (47" H x 36" L x 12" W) (supplied by PWGSC)
office work station (supplied by PWGSC, manufactured by Teknion Furniture Systems)
office equipment (3 computer monitor, 2 keyboards, 2 desk CPUs, 2 monitor stands, one office desk chair)
LAN rack (90" H x 64" L x 33" W) (supplied by Sustema Inc.) (manufactured by LanRack)
Communications Rack (85" H x 31" L x 24" W) (supplied by Workers Compensation Board)
Motor Control Centre (91.5" H x 40" L x 20" W) (supplied by Square D Company)
Seismic Isolation Platform (47" L x 39" W) (supplied by Tekton Inc.)
Seismic Isolation Platform with caster base (supplied by Tekton Inc.)
76" library shelving (76" H x 36" L x 18" W) (supplied by Hi-Cube Storage Products)
66" library shelving (66" H x 36" L x 26" W) (supplied by Hi-Cube Storage Products)
photocopier (48" H x 48" L x 30" W) (supplied by Workers Compensation Board)
Light fixture (supplied by Canem West Services Inc.)
caster cups (supplied by M. Wang Engineering Ltd.)
fastening devices (supplied by WorkSafe Technologies)
fastening equipment (supplied by Terra Firm)

Input Motions

The driving signals were developed using accelerograms from past earthquakes and one artificially generated wave form as follows;

A1 - from 6th storey of Sylmar County Hospital from the 1994 magnitude 6.7 Northridge earthquake
A2 - from Kobe University record of the 1995 magnitude 7.2 Kobe earthquake

A3 - from the free field record at the Sylmar County Hospital from the 1994 magnitude 6.7 Northridge earthquake
A4 - from the 4th storey of a building in Watsonville from the 1989 magnitude 7.0 Loma Prieta earthquake
A5 - from the 7th storey of a hotel in Van Nuys from the 1994 magnitude 6.7 Northridge earthquake
A6 - from the 13th storey of a building in Sherman Oaks from the 1994 magnitude 6.7 Northridge earthquake
A7 - adapted from the artificially generated VERTEQ wave form developed by Bell Communications Research Inc. (horizontal component corresponded to the 50% record for the seismic zone 4 in the Uniform Building Code)
A8 - adapted from the artificially generated VERTEQ wave form developed by Bell Communications Research Inc. (horizontal component corresponded to the 100% record for the seismic zone 4 in the Uniform Building Code)
A9 - from the Joshua Tree Fire Station record from the 1992 magnitude 6.3 Landers earthquake

Test Summary

A total of 49 shake table tests were conducted over the four day period. The information obtained includes laboratory notes, photographs, two sets of video recordings and digital data measured by sensors mounted on the test equipment.

Figure 4 shows the results after a test with input motion A2. Figure 5 shows restraint devices for a CPU on the LAN rack. It should be noted that the bars holding the straps had not been designed specifically to fit the width of the LAN rack. Hence the result at figure 6 which shows the CPU being barely held from falling. The input motion for this test was A8 and the LAN rack was bolted to the concrete floor. Figure 7 shows the Seismic Isolation Platform from Tekton Inc. with the LAN rack mounted on top.

A comparison of the shake table input motion with the original accelerograms was conducted during the analysis of data from the testing. This showed that the shake table was able to reproduce the same demands as the original ground motions at frequencies above 1 Hz for the horizontal motions and at frequencies above 4 Hz for vertical motions. The horizontal motions with frequencies below 1 Hz and the vertical motions with frequencies below 4 Hz could not be realistically simulated by the shake table due to the physical limitation of the shake table setting.

Test Conclusions

It can be concluded from observations made during the tests and from the preliminary analysis of the data that most products and restraint devices, if appropriately sized and attached, protected the equipment sufficiently against the effects of simulated earthquakes. There was no damage to equipment when placed on the isolation platform. Conversely components and equipment that were not either restrained or placed on the isolation platform in many cases suffered damage.

CONCLUSION

The risk to life safety and damage to assets can be reduced considerably by use of mitigative measures for non-structural components. Until the CSA guideline is produced, the PWGSC guideline can be used to provide a systematic approach to reducing the potential hazards. Results of the shake table tests continue to demonstrate that adequate restraint of office equipment is capable of providing effective risk reduction during earthquakes.

REFERENCES

Public Works and Government Services Canada (PWGSC 1995). Guideline on Seismic Evaluation and Upgrading of Non-Structural Building Components. PWGSC Ottawa, Ontario. 59 pages

University of British Columbia (UBC). Shake Table Testing of Functional and Operational Components of Buildings. Department of Civil Engineering, Vancouver, British Columbia, 1998. 206 pages

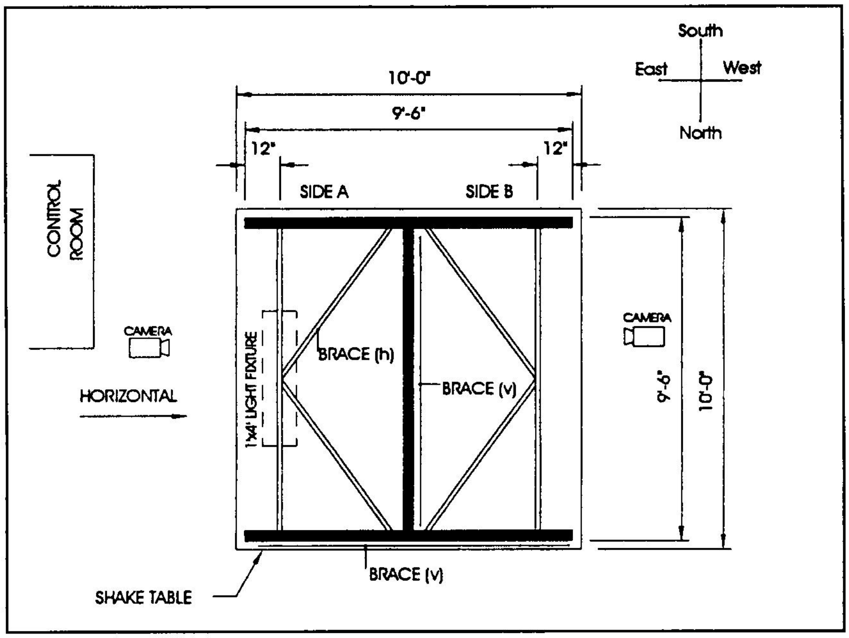

Figure 1 - General set up of wall assembly on shake table

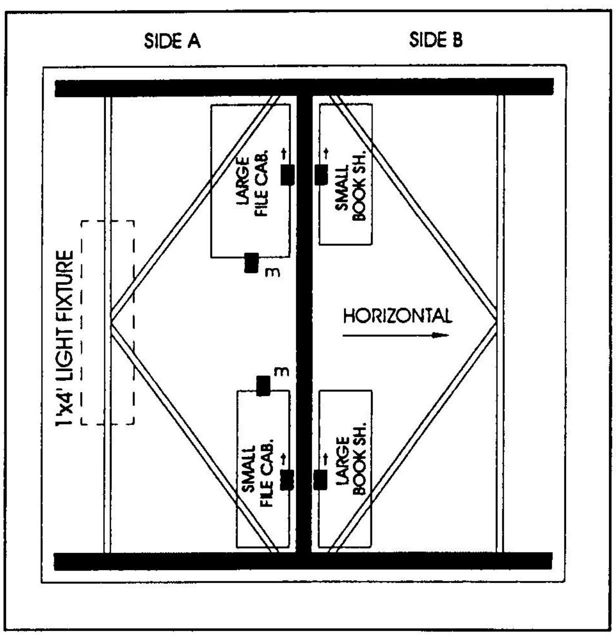

Figure 2 - typical equipment layout

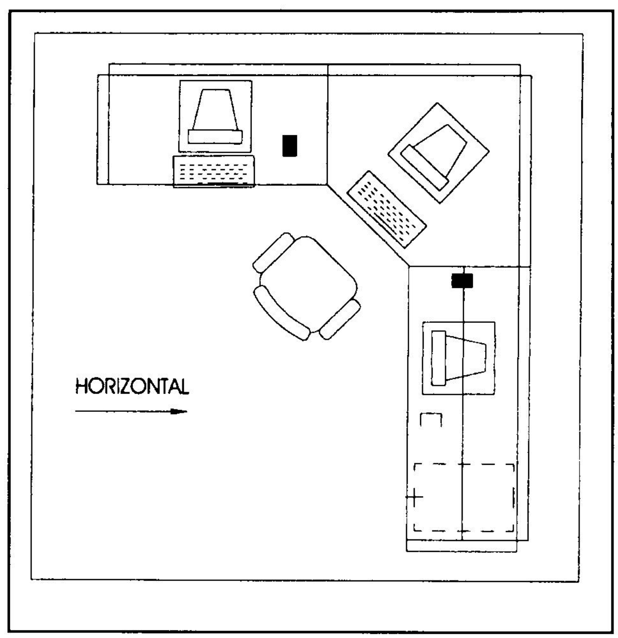

Figure 3 - work station layout

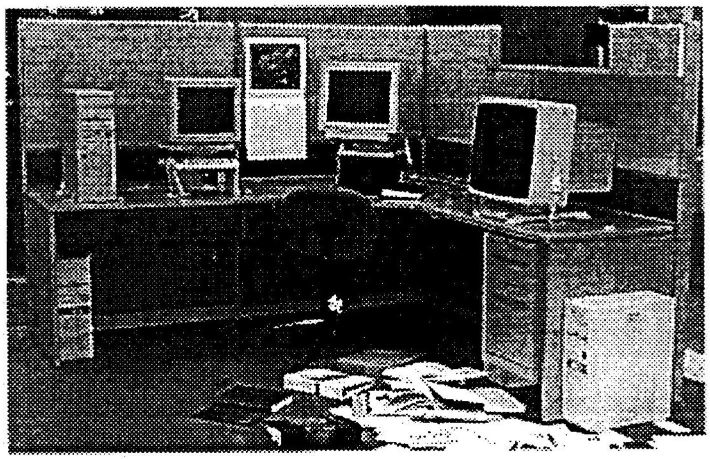

Figure 4 - workstation after test

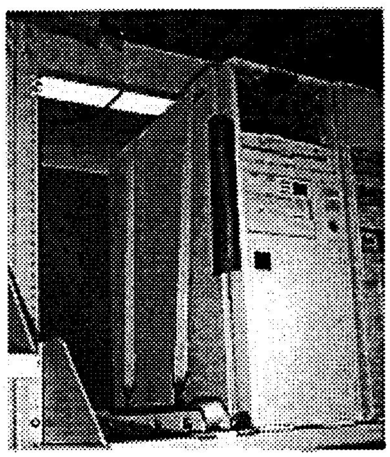

Figure 5 - attachments to CPU on LAN rack

Figure 6 - strap still holding the CPU

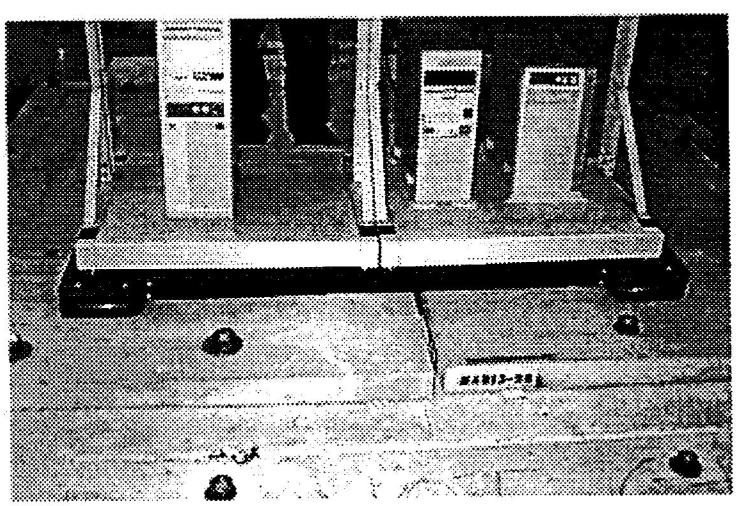

Figure 7 - LAN rack with base isolation