RISKS FROM THE RESPONSE OF NON-STRUCTURAL COMPONENTS TO SEISMIC LOADS IN BUILDINGS

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ABSTRACT:

See over

Risks from the response of non-structural components to seismic loads in buildings

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Abstract

This paper addresses the risks of failure of non-structural components (NSC) in buildings in future earthquakes. Non-structural components are classified into (I) mechanical components (e.g. boilers, tanks, pumps, and HVAC equipment), (II) Electrical and electronic components (e.g. transformers, generators, switchboards, computer networks, telecommunication systems and other electronic components) and (III) Architectural components (e.g. exterior curtain walls and cladding, non-loading bearing partitions, ceiling systems and ornaments such as marquees and signs). Failures of NSC could have severe life-safety and economic consequences which include damage caused by the overturning and falling of objects, and the loss of continuous functioning of key facilities. Floor-mounted or freestanding components with behaviour sensitive to the floor motions are of particular interest in this paper. Thus, damage to components resulted from inter-story drifts are outside the scope of the discussions.

This paper presents results of a recent field survey conducted by the authors on a range of building facilities in the Melbourne Metropolitan area. The survey highlights the fact that many critical NSC are potentially vulnerable to seismically induced damage due to the general lack of restraints. Simple analytical tools have been developed for the vulnerability assessment of the NSC, which are at risk. The assessment involves modelling the floor motions in terms of its peak response acceleration, velocity and displacements for any given earthquake motion affecting the building. This broadband approach to modelling is an innovative departure from the conventional approach of merely addressing accelerations. This paper also provides a brief description of a planned shaker-table testing program for studying the fragility of some floor-mounted components.

Introduction

Non-structural components (NSC) represent a high percentage of the total capital investment in the majority of buildings. Failure or damage to these components in an earthquake could disrupt the continuous functioning of a building and subject its occupants to significant risks. In buildings, NSC could generally be divided into (I) mechanical components, (II) electrical and electronic components, and (III) architectural components. Mechanical components include boilers, tanks, pumps and

HVAC equipments. Electrical and electronic components include transformers, generators, switchboards and telecommunication systems. Architectural components include items such as exterior curtain walls and cladding, non-load bearing partitions, ceiling systems, and ornaments such as marquees and signs. With a growing trend to "paperless offices" or "e-offices", the seismic protection of computer hardware deserves priority attention.

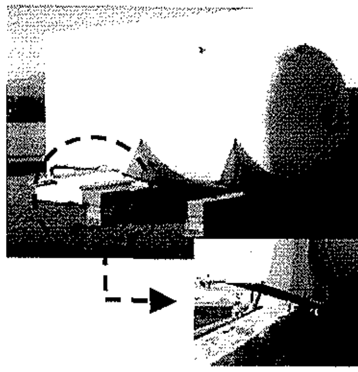


Figure 1. Rooftop tank failure, 1994 Northridge earthquake

This research is mainly concerned with roof/floor-mounted equipment, which are typically mechanical, electrical or electronic components. The motion sensitive behaviour of these components is central to the interests in this investigation. Components that are sensitive to inter-story drifts such as full-height partitions and vertical piping are outside the scope of discussions in view of the length limitations of the paper.

The vulnerability of non-structural components is well illustrated in recent experience from major earthquakes worldwide (Hall 1995, Phan and Tylor, 1996, and Naeim, 1999). An example of the failure of a typical roof-mounted component is shown in Fig.1 (Naeim 2001). Cost statistics on seismically induced non-structural damage are scarce. However, reports from reliable sources indicate that the economic costs of nonstructural damage generally well exceed those of structural damage in recent earthquake events (e.g. Brunsdon, 2001). The survey of 355 high-rise buildings by Arnold (1987) following the 1971 San Fernando earthquakes shows that 79% of the damage bill was associated with the failures of non-structural components. It has also been found that serviceability failures of building components could create havoc in terms of deaths and injuries. Lifeline facilities such as hospitals are generally exposed to higher consequence failures (Monto et al, 1996). Non-structural components in low and moderate seismic regions are particularly vulnerable due to the lack of restraints and suitable detailing.

To mitigate the potential risks to high consequence damage, it is important to envisage possible damage scenarios and accurately identify the types of existing components that require retrofitting in averting the damage. To fulfil this research objective, the investigation is divided in to following phases:

- Phase 1: Field surveys of a range of NSC commonly found in buildings and hospital facilities in the Melbourne Metropolitan Area.
- Phase 2: Broadband modelling of the seismically induced motions on the building floor at different levels in the building.
- Phase 3: Studies into the dynamic behaviour of representative NSC models based on both analytical modelling and shaker-table testings. The behaviour of components in sliding, rocking and overturning in partially restrained and unrestrained conditions will be examined in detail.
- Phase 4: Development of a practical and reliable scanning process which could accurately identify components which require retrofitting.

Field Survey of NSC in Melbourne

Field surveys of existing NSC had been conducted on a range of facilities including hospitals, office blocks and buildings for educational purposes. The survey reveals a general lack of restraints in roof/floor-mounted components, which include critical equipment. Some equipment are merely freestanding and hence could be subject to sliding, rocking, overturning or pounding when the building floor is in motion. Photos taken from field surveys (see the left hand half of Fig. 2) reveal the absence or lack of restraints of the components. Shown alongside the surveyed photos are recommendations by a Canadian organization for suitable retrofitting measures (*www.terrafirm.ca/sitemap.htm*). The comparison reveals a major vulnerability problem that has resulted from current local practices.

Retrofitting every NSC in all building facilities is clearly prohibitively costly and hence not feasible to implement. Thus, the research is targeted at modelling vulnerability accurately in order that limited resources could be directed effectively to avert potential high-consequence failures. Analytical and experimental investigations for accomplishing this key objective are outlined in the rest of the paper.

Proposed Analytical Method

The seismic evaluation of a component should be based on pre-defined objectives. Basic safety objectives would often be satisfied if the component does not slide or overturn in an earthquake. However, the component (e.g. computer/telecommunication equipment, transformers and generators), or a system, would need to function continuously in order to satisfy the "Immediate Occupancy Objectives". Thorough analysis or shaker-table testing could be required to ensure that certain high performance objectives are satisfied with the prescribed level of ground shaking. The analytical procedure for the vulnerability modelling of NSC is presented schematically in Figure 3.

The motions of the building floor would need to be modelled accurately in order that seismic actions on the components could be ascertained. Similar seismic performance levels apply to both the building structure and the non-structural components that are housed in the building. In the investigation, a range of building structures has been subject to time-history analyses.

Non-structural components would respond differently to the floor motion depending on a number of factors including the component dimensions (see Figure 4), weight and flexibility of the supports.

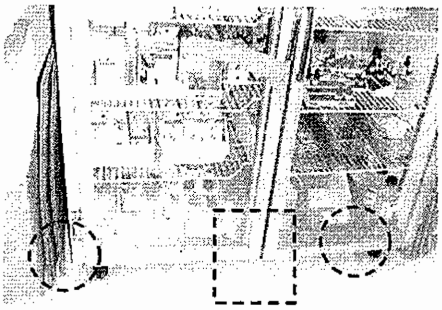
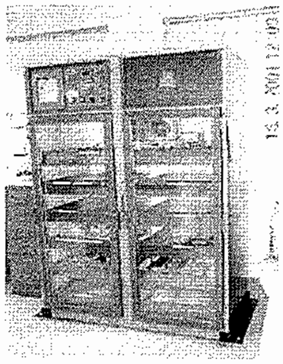
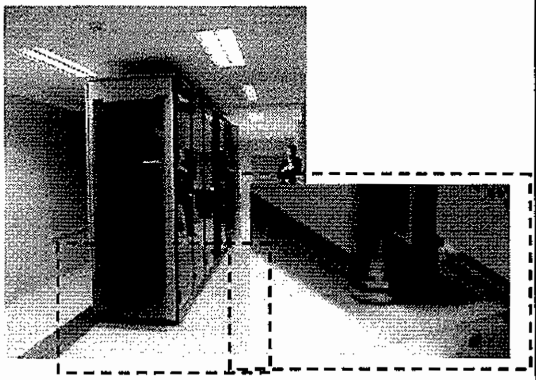
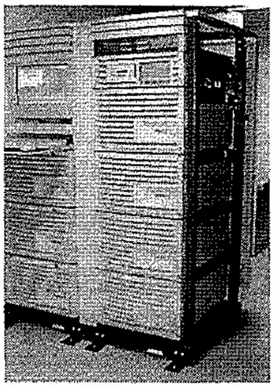
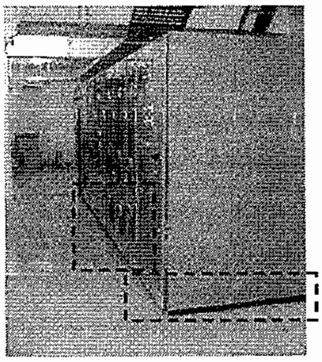
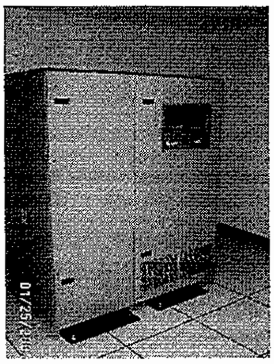
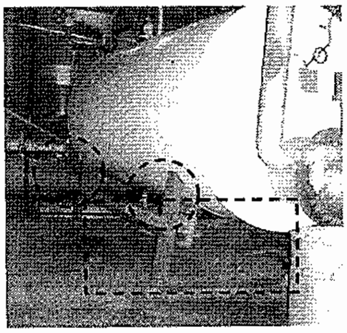
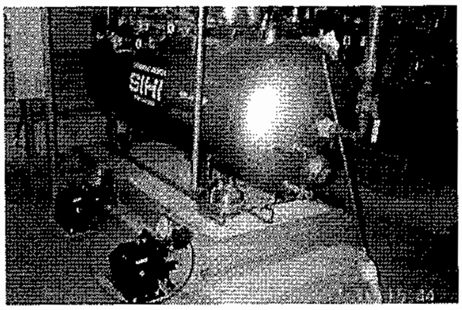
Photos taken from Melbourne **(No straps found)**	Retrofitted equipment **(Straps installed)**
	
	
	
	

Figure 2 Photos of equipment from local surveys (left) and of equipment with supplementary restraints (right). (Photos of equipment with supplementary restraints have been reproduced with permission from Terra Firm Earthquake Preparedness Inc.)

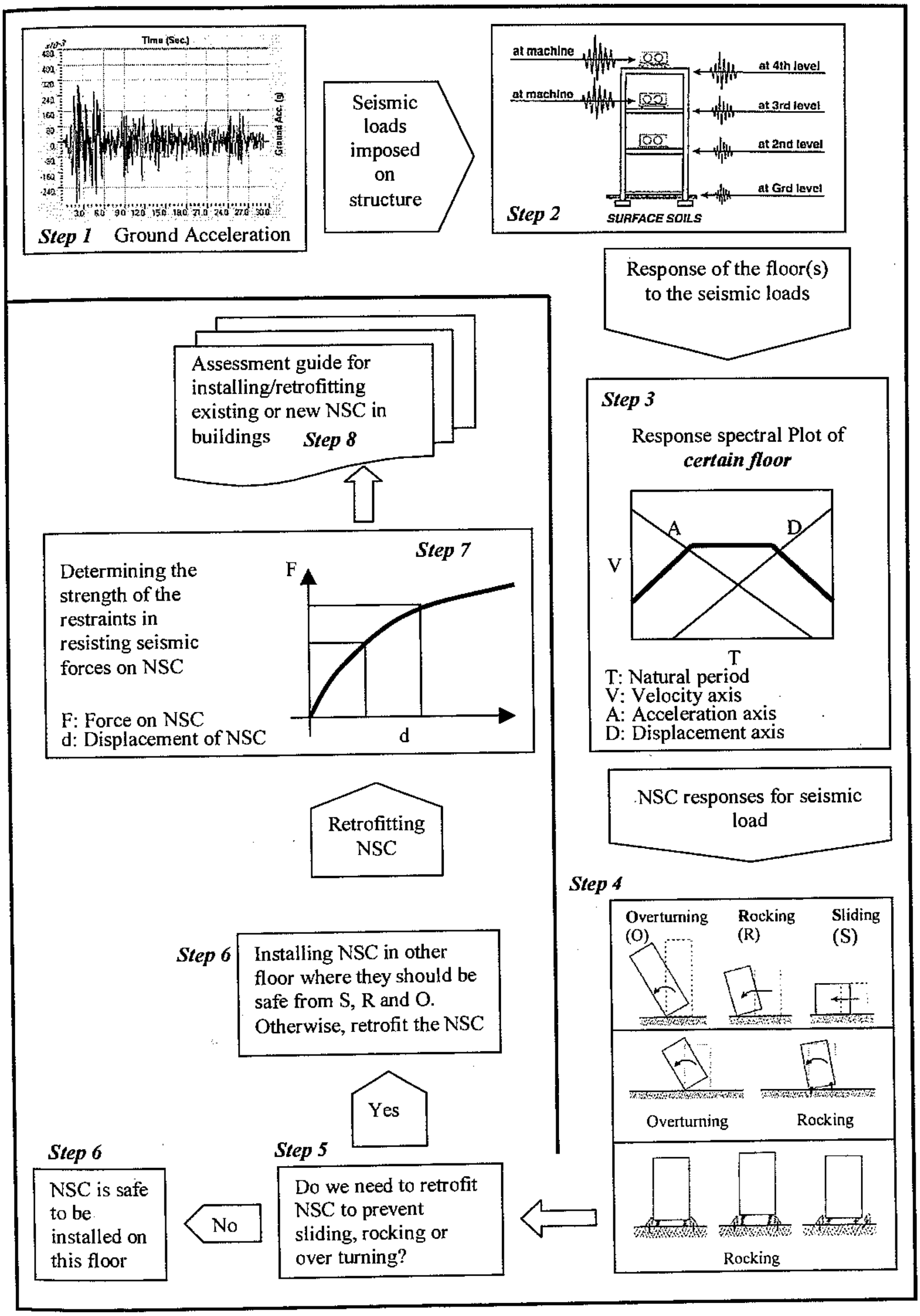


Figure 3. Schematic representation of the NSC assessment procedure

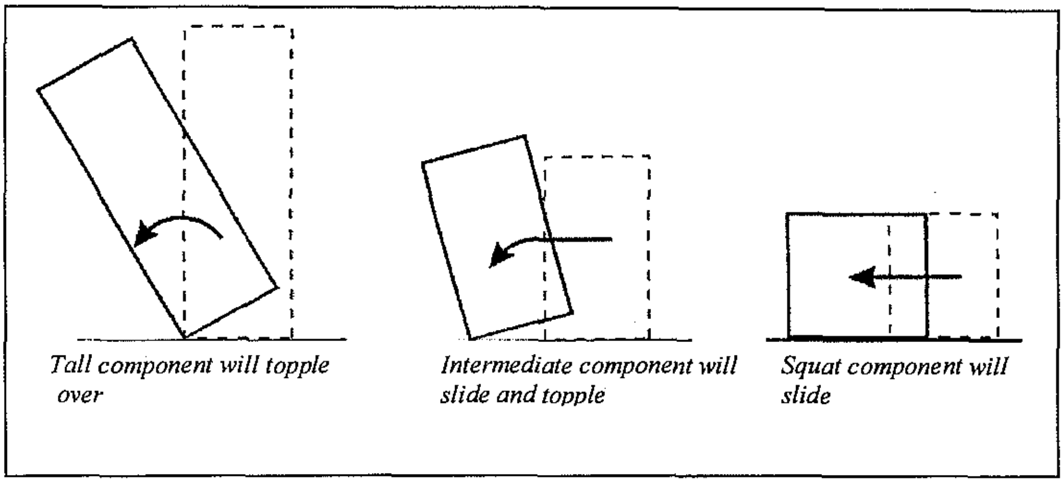


Figure 4. Effect of component height on the components response to seismic loads

The damage mechanisms of floor mounted and freestanding components could be linked to the Ao-Vo-Do (object peak acceleration – object peak velocity – object peak displacement) parameters (see Figure 5a) for determining the component vulnerability. The component is deemed safe from overturning if either Do is insufficient to move its centre of gravity (c.g.) far enough to its edge or if Ao is insufficient to result in static instability (see Figure 5b). Vo represents the strain energy stored in the NSC when responding to seismic actions. Rocking of the component might cause damage to the restraints or the attached accessories (such as pipes). The Ao-Vo-Do parameters can also be combined to obtain refined estimates in situations where initial assessment shows non-compliance.

Should the initial DB (Displacement Base) assessment based on Do shows non-compliance, drift may be re-calculated based on Vo using energy principles. Should the first two assessments show non-compliance, drift may be re-calculated again based on Ao using conventional principles of force and stiffness. Interestingly, the component is deemed satisfactory should any one of the three assessments show compliance.

This is justified by the fact that each of the Ao-Vo-Do lines making up the tri-linear envelope represents an upper bound estimate of the seismic demand as shown in Figure 5a. This new modelling framework is in significant contrast with the contemporary acceleration based approach, which often requires the natural period of both the component and the building to be determined, or else the "Ao envelope" would be overly conservative. Flexibility and versatility is clearly lacking in the traditional force-based approach. Refer Lam and Gad (2002) for further details.

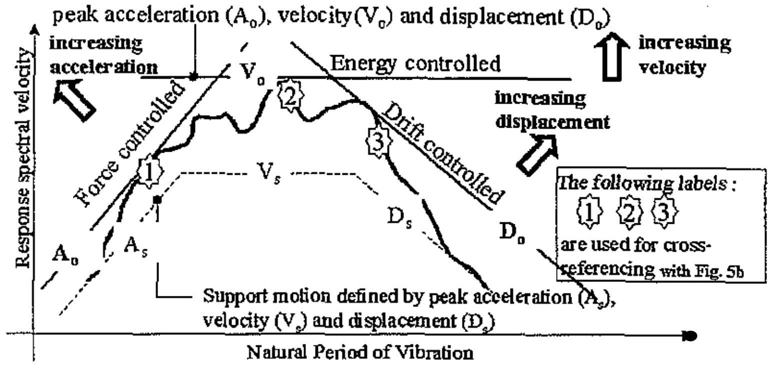


Fig. 5a Proposed generalized floor spectrum mode

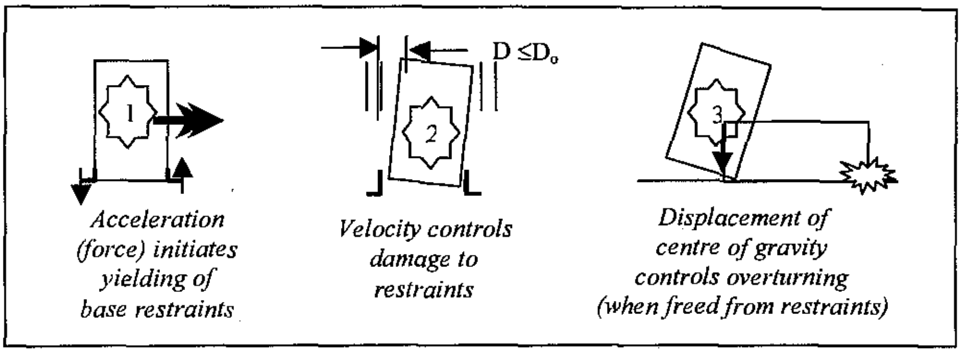


Fig. 5b Floor mounted component response

Proposed Experimental Program

An experimental program using the shaker table has been planned for the research. A physical model will be built with adjustable weights and drawers in order that NSC of varying dimensions and centre of gravity properties could be tested repetitively on the shaker table without requiring a large number of specimens to be made. The testings will cover both restrained and unrestrained components with different motion sensitivity behaviour. Real components will also be tested for comparison with testing of the model specimen. Different floor surface finishes will be used in the testing to simulate a whole range of conditions that are likely to be encountered in practice. Importantly, equipment will be tested in accordance with different performance objectives.

Conclusions

Field surveys conducted in Melbourne show a general lack of restraints on components compared with overseas recommendations. Retrofitting every NSC in all building facilities is clearly prohibitively costly and hence not feasible to implement. The research is targeted at modelling vulnerability accurately in order that limited resources could be directed effectively to avert potential high-consequence failures. The structuring of the research into four distinct phases in developing a practical and reliable assessment procedure has been outlined. An innovative feature in this development includes the broadband modelling of the floor motion and the associated scanning procedure which models the likelihood of overturning.

Acknowledgments

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