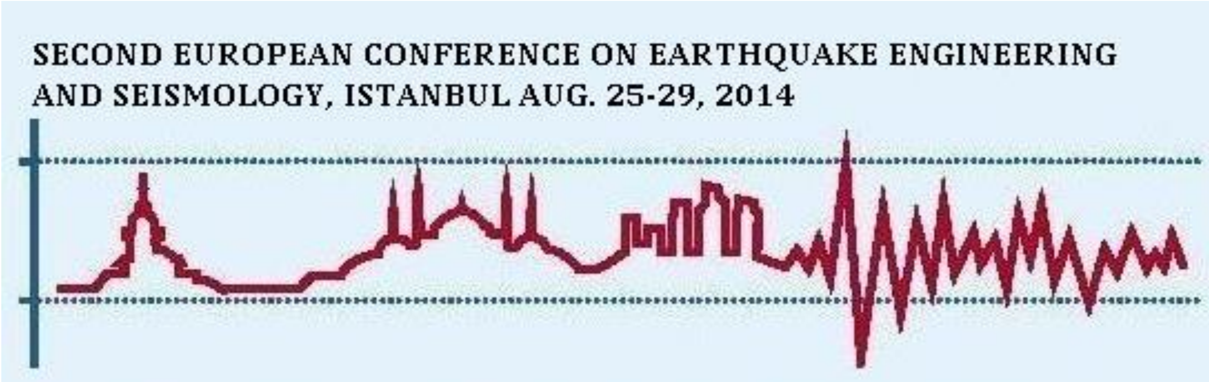

RECENT DEVELOPMENTS IN NON-STRUCTURAL ASPECTS OF PERFORMANCE BASED DESIGN

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ABSTRACT

Earthquakes are non-predictable natural disasters. For now nobody can foresee a coming earthquake and escape from its consequences. What can be done is to observe earthquakes, collect empirical data and analyze these data for estimating effects of future earthquakes. This is the basis for seismic protection in these days.

In today's world, professional earthquake engineers are able to design buildings depending on the expected seismic forces. But an unacceptable mistake done by decision makers of major projects is to neglect the importance of seismic restraint of non-structural systems (especially installations). In fact, seismic restraint of non-structural systems is crucial particularly for fire sprinkler pipes, fuel lines, emergency and energy systems etc. Without having a functioning mechanical and electrical system there will be no fire protection, no energy supply, no communication and no health services which will cause fatal results for human life and public safety.

INTRODUCTION

During an earthquake, a building can stand still if it has been constructed properly. But can we use that building after the earthquake? The answer of this question can only be "yes", unless the building is still functional. This means, a building is useless without electricity, heating/air conditioning, water supply, etc.

There is a more important question: How can we save lives during and right after an earthquake? Is it enough to make a building stand still after the seismic activity? What if a small fire has started? Will there be people to stop that fire? Or will we depend on our automatic fire sprinkler system to stop this little fire? What if our sprinkler piping has been damaged by the earthquake? A bunch of people will be trying to escape from the building and that small fire and/or smoke can easily cause deaths.

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1.1. RECENT CODE DEVELOPMENTS

Just like the weather forecasts, seismic forces can not be known exactly. Instead, these can be calculated with empirical formulas. Seismic forces can be calculated through globally accepted building codes. The most widely used building code in year 2000 was IBC (International Building Code) which have had joined the previous ones (UBC, BOCA, SBCCI etc). IBC is being updated every three years and in each update there have been some minor differences for non-structural seismic requirements from the previous ones. But in year 2006, some major topics for instance functional & structural integrity has been added.

In year 2003 IBC started to refer ASCE 7 (American Society of Civil Engineer's) for seismic requirements of non-structural components. Recently the most up to date code for seismic requirements of non-structural components is ASCE 7-10 (is being refered by IBC 2012). Except Japan, almost the rest of the world is using ASCE 7 for non-structural seismic design.

Since many local codes (including Turkish Code) are technically inadequate in terms of seismic protection for non-structural systems, ASCE 7 is being used world wide.

$$F_p = \frac{0.4\,x\,a_P\,x\,S_{DS}\,x\,W_P\,x\,I_P}{R_P}\,\text{x}\left(1 + 2\,x\,\frac{z}{h}\right) \tag{1}$$

$$F_{PV} = \pm 0.2\,x\,S_{DS}\,x\,W_P \tag{2}$$

Formula (1) Horizontal Seismic Force.
Formula (2) Vertical Seismic Force.

The horizontal seismic design force (F_P) and vertical seismic design force (F_{PV}) can be calculated with empirical formulas, as per ASCE 7-10 (13.3-1) based on observations on past earthquakes.

1.2. WHEN AND WHERE SEISMIC RESTRAINT IS REQUIRED

The purpose of seismic restraint for Non-Structural components is to assure that facilities will function after an earthquake without requiring any repair and/or replacement of neither equipments nor utilities. For life supporting systems the main goal is damage prevention to keep the systems functioning right after an earthquake. For all other systems seismic mitigation is still an important objective first for human safety and second for damage minimization.

To achieve the above explained life safety and damage prevention level all facilities and fixtures shall be seismically restrained per standards and codes requirements.

Once the seismic force assumed to act on a non-structural component (piping, equipments etc) is calculated, the next step is to make the necessary protection. This can be done either by fixing it to the structure as descibed by the codes or by restraining it with specifically designed and manufactured seismic restraint assemblies (snubber, isolator, seismic steel cable, bracket etc). In both cases, it is a must to calculate the design forces and detailing the protection system.

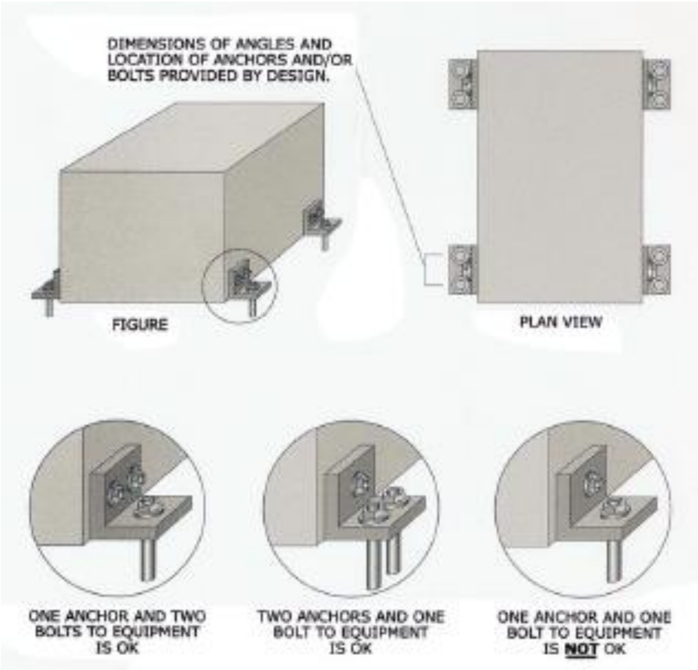

Figure 1. Rigidly floor mounted equipment.

Rigid mounted equipments, if having any moving parts when functioning, may cause disturbing vibration and noise in buildings. Therefore vibration isolation may be a need for these types of equipments. When equipments are vibration isolated, the seismic forces acting on these equipments will be amplified. This should be taken into consideration during performing the seismic calculations.

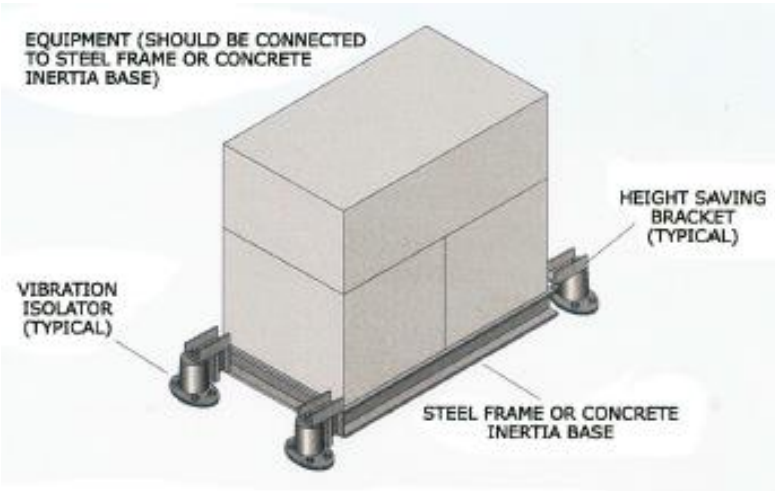

Figure 2. Vibration isolated floor mounted equipment.

Unless otherwise specified, all mechanical, electrical distribution installations shall be restrained to resist seismic forces ocured both on horizontal (lateral and longitudinal) and vertical directions.

Ralated code requirements, such as NFPA 13 (National Fire Protection Association) “Chapter 9 Hanging, Bracing and Restraint of System Piping”, SMACNA (Sheet Metal and Air Conditioning Contractors National Association) “Seismic Restraint Manual 3rd Edition”, ASCE 7-10 (American

Sociaty of Ciliv Engineering) “Chapter 13 Seismic Design Requirements for Non-Structural Components” etc.. should be taken as referance to detail the design where seismic restraint is needed.

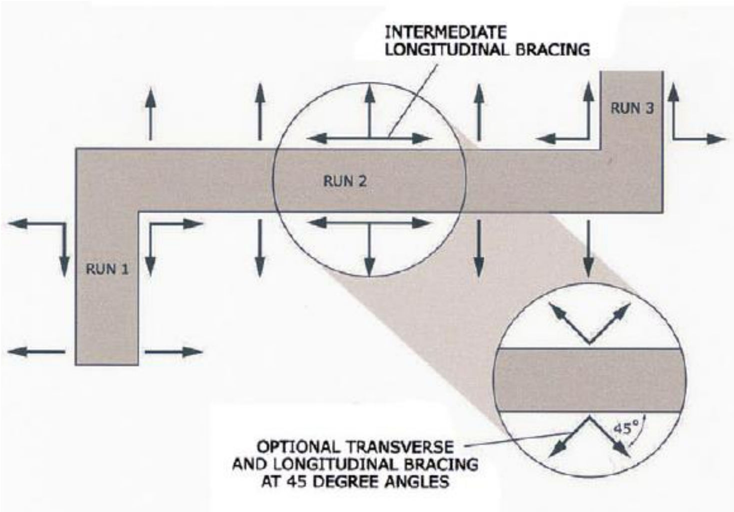

Figure 3. Schematic figure of distribution installation restrained lateral and longitudinal directions.

Below table can give an aspect of “G” accelerations for different type of non-structural components. The code also provides exempt conditions for the non-structural components, but for the ones that are not exempt from seismic restraint, these forces should be considered.

Table 1. "G" Accelerations for Non-Structural Components

	FIRE PIPE	PIPE	DUCT	NEOPRENE ISOLATED	SPRING ISOLATED	AIR SIDE	WET SIDE
a_P:	2,5	2,5	2,5	2,5	2,5	2,5	1
R_P:	4,5	4,5	6	2,5	2	6	2,5
z:	1	1	1	1	1	1	1
h:	1	1	1	1	1	1	1
I_P:	1,5	1	1	1	1	1	1
$*S_{DS}$:	1,10	1,10	1,10	1,10	1,10	1,10	1,10

$*S_{DS}$ (design earthquake spectral response acceleration) value is calculated from US Army CORPS tables and site parameters (Istanbul site parameters).

F_P:	1,10 Wp	0,73 Wp	0,55 Wp	1,32 Wp	1,65 Wp	0,55 Wp	0,53 Wp
F_{PV}:	0,22 Wp	0,22 Wp	0,22 Wp	0,22 Wp	0,22 Wp	0,22 Wp	0,22 Wp

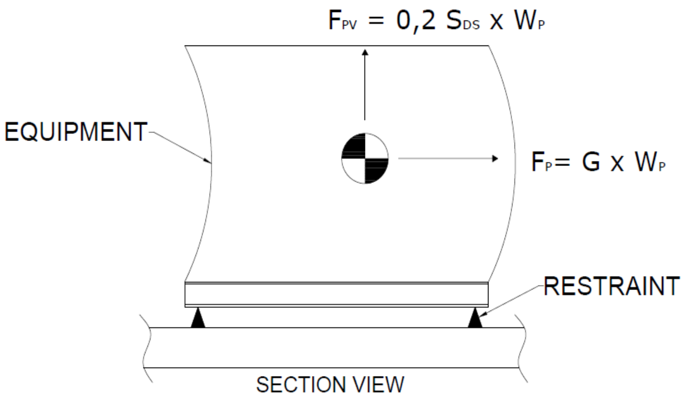

Figure 4. Free body diagram for floor mounted equipment.

1.3. PERFORMANCE BASED DESIGN

Projects of different kinds require different attention and design considerations. This is also determined in many codes and standards under a topic called “performance levels” meaning the expected strength of a building against earthquake forces. For example, a hospital must have the highest performance since it would be the first place for people to go right after an earthquake, where a warehouse of simple materials would be the last place to worry about.

Building performance is a combination of the performance of both structural and non-structural components. FEMA (Federal Emergency Management Agency) has described four non-structural performance levels. Performance based seismic design clearly describes how a building is likely to perform in potential hazard. It permits design of new buildings or upgrade of existing buildings with a realistic understanding of the risk, occupancy interruption, and financial loss that may occur as a result of future earthquakes.

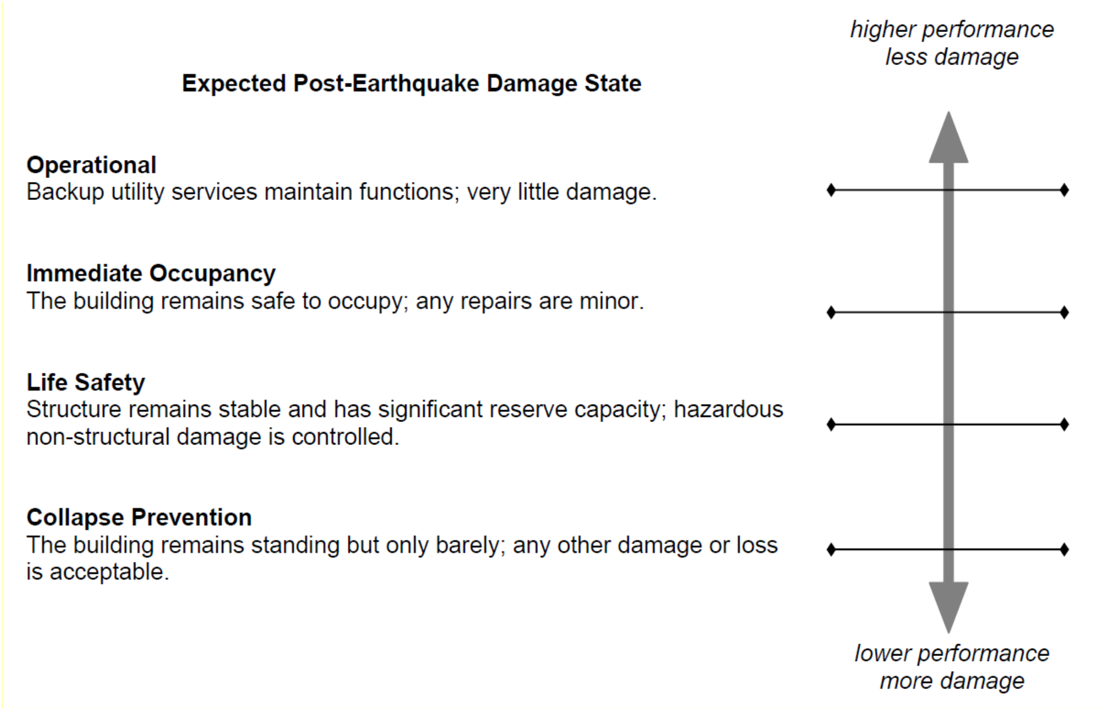

Figure 5. Building Performance Levels and Ranges (FEMA 356)

1.3.1. Operational Non-Structural Performance Level

At this level, most nonstructural systems required for normal use of the building including lighting, plumbing, HVAC, and computer systems are functional, although minor cleanup and repair of some items may be required.

1.3.2. Immediate Occupancy Non-Structural Performance Level

Minor window breakage and slight damage could occur to some components. Presuming that the building is structurally safe, occupants could safely remain in the building, although normal use may be impaired and some cleanup and inspection may be required. In general, components of mechanical and electrical systems in the building are structurally secured and should be able to function if necessary utility service is available. However, some components may experience misalignments or internal damage and be nonoperable. Power, water, natural gas, communications lines, and other utilities required for normal building use may not be available. The risk of life-threatening injury due to nonstructural damage is very low.

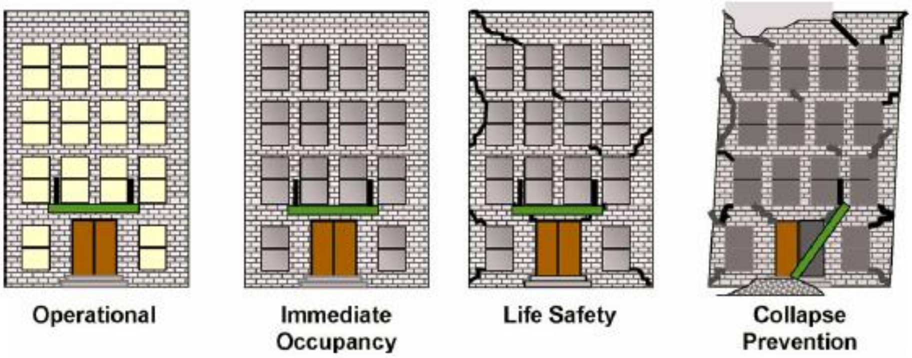

Figure 6. Graphic illustration of Performance Levels (FEMA 389)

1.3.3. Life Safety Non-Structural Performance Level

Nonstructural Performance, Life Safety, is the post-earthquake damage state in which otentially significant and costly damage has occurred to nonstructural components but they have not become dislodged and fallen, threatening life safety either inside or outside the building. Egress routes within the building are not extensively blocked, but may be impaired by lightweight debris. HVAC, plumbing, and fire suppression systems may have been damaged, resulting in local flooding as well as loss of function. While injuries may occur during the earthquake from the failure of nonstructural components, overall, the risk of life-threatening injury is very low. Restoration of the nonstructural components may take extensive effort.

1.3.4. Hazards Reduced Non-Structural Performance Level

Nonstructural Performance, Hazards Reduced, represents a post-earthquake damage state in which extensive damage has occurred to nonstructural components, but large or heavy items that pose a high risk of falling hazard to a large number of people such as parapets, cladding panels, heavy plaster ceilings, or storage racks are prevented from falling. The hazards associated with exterior elements along portions of the exterior of the building that are available for public occupancy have been reduced. While isolated serious injury could occur from falling debris, failures that could injure large numbers of persons either inside or outside the structure should be avoided.

Nonstructural components that are small, lightweight, or close to the ground may fall, but should not cause serious injury. Larger nonstructural components in areas that are less likely to be populated may also fall.

The intent of the Hazards Reduced Performance Level is to address significant nonstructural hazards without needing to rehabilitate all of the nonstructural components in a building. When using this performance level, it will generally be appropriate to consider Hazards Reduced Performance as equivalent to Life Safety Performance for the most hazardous, highest risk subset of the nonstructural components in the building.

Table 2. Non-Structural Performance Levels and Damage

Nonstructural Performance Levels and Damage Mechanical, Electrical and Plumbing Systems				
System/Component	Nonstuctural Performance Levels			
	Hazards Reduced	Life Safety	Immediate Occupancy	Operational
Piping	Some lines rapture. Some supports fail. Some piping falls.	Minor damage at joints, with some leakage. Some supports damaged, but system remain suspended.	Minor leakage at a few heads or pipe joints. System remains operable.	Negligible damage.
Ducts	Duct break loose of equipment and louvers; some supports fail; some ducts fall.	Duct break loose of equipment and louvers; some supports fail; some ducts fall.	Minor damage at joints, but ducts remain serviceable.	Negligible damage.
Fire Sprinkler Systems	Some sprinkler heads damaged by collapsing ceilings. Leaks develop at couplings. Some branch lines fail.	Some sprinkler heads damaged by swaying ceilings. Leak develop at some couplings.	Minor leakage at a few heads or pipe joints. System remains operable.	Negligible damage.
Plumbing	Some fixtures broken; lines broken; mains disrupted at source.	Some fixtures broken; lines broken; mains disrupted at source.	Fixtrues and lines serviceable; however, utility service may not be available.	System is functional. On-site water supply provided, if required.
HVAC Equipment	Most units, do not operate; many slide or overturn; some suspended units fall.	Units shift on supports, rapturing attached ducting, piping and conduit, but do not fall.	Units are secure and most operate if power and other rquired utilities are available.	Units are secure and operate. Emergency Power and other utilities provided, if required.
Electrical Distribution Equipment	Units slide and/or overturn, rapturing attached conduit. Uninterruptable Power Source systems fail. Diesel generators do not start.	Units shift on supports and may not operate.Generators provided for emergency power start; utility service lost.	Units are secure and generally operable. Emergency generators starst, but may not be adequate to service all power requirements.	Units are functional. Emergency power is provided, as needed.

Current seismic design provisions typically require that non-structural components be secured so as to not present a falling hazard; however, these components can still be severely damaged such that they cannot function. Loss of electric power, breaks in water supply and sewer out-flow lines, or non-functioning heating or air conditioning will render a building unusable by tenants. Breaks in fire sprinklers will cause flooding within all or part of a building, soaked carpets and walls, inundated files and records, and electrical shorts or failures in electrical equipment and computers. Other examples of non-structural damage that can be expected in a code-compliant building subjected to strong ground shaking include extensive cracking in cladding, glazing, partitions, and chimneys; broken light fixtures; racked doors; and dropped ceiling tiles.

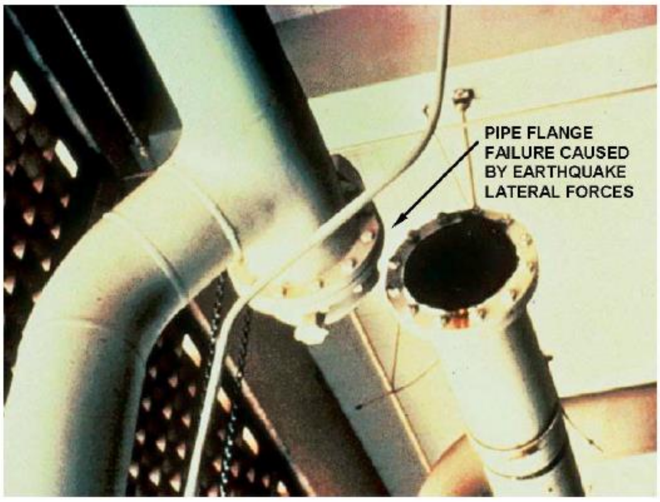

Figure 7. Photo of pipe flange failure caused by earthquake lateral forces.

Figure 8. Photo of electrical panel failure caused by earthquake lateral forces.

CONCLUSIONS

This paper is prepared to give the general overview of non-structural seismic restraint systems, to give information about recent code developments, to give information of performance based design and to determine when and where seismic restraint is required for non-structural components.

Seismic protection of mechanical and electrical systems in our buildings and facilities is crucial in terms of human life safety in the first place and also minimizing the costly damages. It is a matter of non-structural seismic engineering, which must be done by following the local and international building codes. It should also be done by professional non-structural seismic engineers. Finally, a necessity is to use certified seismic products only. These are the guidelines for the construction industry including the project owners, designers and consultants, contractors, control engineers and all other decision makers.

This issue is also very important for the code writers including government officials, university professors and managers of non-profit organizations. The weaknesses in local codes in terms of non-structural seismic protection must be taken into consideration carefully. Necessary precautions should be determined in the local codes and standards.

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