Explaining the State of Seismic Consideration of Architectural Non-structural Components in Design Process Case Study: Bam Earthquake

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Abstract: Effects of architectural nonstructural components on the building system behavior are considered as secondary effects, although interaction between these components and structure cause economical losses or human injuries over the years. This article reviews the damages of architectural nonstructural components in Bam earthquake in 5 Dey 1382's/26 December 2003 to offer some strategies for reducing the risk of earthquake impact on them. Qualitative qualitative research methods with inductive approach is used.

Key words: Non structural components, Damages, Strategies

INTRODUCTION

Nonstructural components are those elements in a building which are supposed not to participate in carrying the applied loads to the structural system, including the seismic forces. Past earthquakes have shown that the damage to non-structural components of buildings usually cause more injuries, fatalities, and property and financial loss than those inflicted by structural damage. These elements can be divided into four main categories (IBC, 2000)

1. Architectural elements (which are referred to as A-NS components in the future text)
2. Mechanical facilities
3. Electrical and communicational facilities
4. Building contents

The characteristics of elements in each of the above mentioned categories are not only different from those of other categories, but also are quite numerous and distinct within each category, particularly in the case of A-NS elements. This great variety of characteristics has made the study of A-NS components' seismic behavior, much more difficult than the building's structural elements. Past earthquakes has diverted the attention of building engineers to the vulnerability of the A-NS elements. These elements have shown their high vulnerability, even in recent earthquakes, in which the level of structural damages have been comparatively low. Past earthquakes have proven that the A-NS elements are highly vulnerable, if not designed for earthquake excitations. There have been many incidents when a building which sustained only minor structural damage was deemed unsafe and unusable as a result of extensive damage to its A-NS components. The consequences of the A-NS components vulnerability can be summarized as follows:

1. Direct and Indirect Hazard to Life:
   Failure of A-NS components and the debris caused by falling objects could be a direct hazard to life safety; furthermore it could critically affect the performance of vital facilities such as emergency command centers, fire and police stations, hospitals and pose an indirect hazard to life.

2. Economic Losses:
   Since the costs of construction and/or installation of the A-NS elements versus their relative volume of the whole construction work are usually much more than those of building's structures, the financial loss due to the direct damage to A-NS elements can be relatively high, even when there is no structural damage. This

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is particularly true in the case of industrial buildings in which the building cost itself is very little in comparison with the costs of A-NS components and interior equipment.

3. Premature Collapse:
   The premature collapse of a building by the nonstructural elements may be accelerated by the uncounted for contribution of these elements to carrying of the lateral seismic load.

4. Interrupting the Rescue Activities:
   Interrupting the rescue activities because of damage to the nonstructural elements is a case which has occurred in some hospitals in past earthquakes. A similar case occurred in Bam airport, in which damage to the nonstructural elements interrupted the operation of the Control Tower.

2. Architectural Non-structural Risk Mitigation Efforts:
   A great deal of research efforts have been devoted over the past 40 years to the development of methods for the seismic analysis and design of architectural non-structural elements.
   New Zealand was an early leader in the development of code provisions and innovations in design practice to contend with drift-induced non-structural damage. Increasing success with controlling structural damage also led the Japanese to focus on non-structural damage. In United State the San Francisco (1906), Santa Barbara (1925) and Long Beach (1933) earthquakes exposed the vulnerability of brick parapets and exterior walls. In 1927, provisions for nonstructural components were included for the first time in an appendix of the Uniform Building Code (Historical UBC, 2005). They were mainly confined to architectural elements, towers, tanks, contents, chimneys, penthouses, etc. But these provisions were not mandatory at that time because they were given in an appendix and remained there until the 1961 edition of the UBC when the seismic provisions for non-structural element were recommended in the main body of the code for the first time. This code also addressed the requirement of designing the anchorage of non-structural elements. The 1964 Alaska earthquake first pointed out the vulnerability of modern exterior precast wall panels, elevators and suspended ceilings; Consequently, in the 1967 edition of the UBC connection for exterior panels were incorporated (Historical UBC, 2005).
   The 1971 San Fernando earthquake caused collapses of metal library shelving, debris falling on exit stairways and failures of suspended ceilings, light fixtures, and HVAC (Heating, Ventilation and Air Conditioning) ducts; as a result, the subsequent edition of UBC (UBC 1973) included "storage racks", and "suspended ceiling framing systems" in the design provisions of non-structural elements.
   While improving codes was expected to be effective to decline the earthquake damages, continued poor performance of these components in 1980's and 1990's earthquakes has been illustrated the inefficiency of them. Since then, proposing guidelines has been started as an parallel approach toward reducing A-NS component damages. Nowaday, improving codes and proposing guidelines are two major approaches toward reducing A-NS components' damages.

4.1. Upgrading Code Provisions:
   Lessons learned from past earthquakes led to the incorporation and continual modification of several international building codes. The provisions has been grown to include a wide variety of A-NS components, since the mid-1970.
   In the U.S.A., the UBC included access floor systems (UBC 1976) and signs and billboards (UBC 1997) as architectural components; Importance factor (UBC 1976) and amplification factor (UBC 1997) were also added for analyzing seismic performance of non-structural components.
   These additions resulted in new and extensive code provisions for seismic design of building's structure and non-structural (A-NS) components in the US., called: "International Building Code "(IBC 2000). The seismic provisions in the 1994 and earlier editions of the UBC were based on allowable stress design. In 1997, the UBC seismic provisions were revised from an allowable stress design basis to a strength design basis. This made the seismic design force for non-structural elements in UBC 1997 and IBC 2000, 1.4 times greater than those found in the UBC-94. (Bachman, R.E. and Drake, R.M., 1998). Estimating the efficiency of code provisions is still a comprehensive effort by proficient to reduce the risk of non-structural damages in future earthquake. They try to analyze existing codes with practical laboratory experiments, or theoretical calculation. The result is either proposing new codes, or suggesting some modifications to existing ones.
4.2. Proposing Guidelines:
Proposing practical guidelines as designing techniques or retrofitting existing A-NS components, has been another approach in this regard. Despite the presence of seismic requirements for nonstructural components in seismic codes since 1937, the practice of designing for the seismic restraint of nonstructural components has evolved slowly over time.

It was because, there has been a lag between the creation of a code provisions and their adoption by local region seismic hazards in different regions and countries; furthermore, after adoption by a local jurisdiction, implementation of nonstructural code provisions has taken many years to become common practice as a result of lack of practical guides and techniques.

Since 1985, in the US, a comprehensive project related to non-structural components has been undertaken as part of the National Earthquake Hazards Reduction Program (NEHRP), and sponsored by the Federal Emergency Management Agency (FEMA). Results from this project are presented in a number of reports. The reports address the following major issues related to non-structural components:

i. Seismic evaluation and Design requirements for non-structural components of new buildings
ii. Techniques for Seismic Rehabilitation of existing non-structural components

The first studies on seismic vulnerability evaluation of the nonstructural elements started just a few years after the first works on improving seismic design code provisions. Reitherman (Reitherman, R., 2009) did a study on reducing the risks of nonstructural earthquake damage, and presented a practical guide which was published as FEMA 74. Since then, FEMA 74, has been revised many times and been referenced in almost all other guidelines. (Wiss, J., Elstner A., 1994, Fierro, E.A. and Perry, C.L., 1998).

FEMA has also published other booklet series which provides practical information to owners, operators, occupants, designers and engineers of office and commercial buildings on the vulnerabilities posed by earthquake damage to nonstructural items and the means for mitigating these problems. these booklets have two specific objectives: 1) to aid the user in determining which nonstructural items are most vulnerable to earthquakes and are of most concern, and 2) to propose ways and practical techniques toward implementing cost-effective countermeasures.

Seismic retrofitting of existing nonstructural components, especially for essential buildings, was an issue which was brought under limelight after the 1994 Northridge earthquake. As an example, Eidinger and Goettel (Eidinger, J. and Goettel, K. 1998) performed a study on the benefits and costs of seismic retrofits of nonstructural components for hospitals, essential facilities and schools. They provide examples for bracing of fire sprinkler pipes, upgrades of suspended ceilings, installation of flexible utility and contents connections between buildings, anchoring of equipment and window retrofits. Other research centers, such as Applied Technology Council (ATC, 2008) and National Center for Earthquake Engineering Research (Soong, T.T, 1994), have been also proposed guidelines and practical techniques for these kinds of components.

In addition to institute's Guidelines and proficient's researches, industrial guidelines were also developed for specific equipment or systems and often offer details on the seismic restraint system of non-structural components; such as American Society of Heating, Refrigerating and Air-Conditioning Engineers guidelines (ASHRAE, 1999) or "Seismic Restraint Manual, Guidelines for Mechanical Systems," which published by the Sheet Metal and Air Conditioning Contractors' National Association, Inc., (SMACNA, 1998). With much regret, in the case of architectural non-structural components, there are not such extensive industrial guidelines.

Despite these efforts, the earthquake of 17 August 1999 in Turkey resulted in over 20,000 deaths, 50,000 injured, and over $30 billion in damage. A significant portion of the damage and the casualties were attributed to the failure of non-structural elements (Saatcioglu, Gardner and Ghobarah, 2001). In the recent earthquake in L'Aquila, Italy on the 6th of April 2009, most of the buildings with non-structural damages were also considered non-livable (A.palermo et al., 2010). It has shown that problems with inadequate performance of nonstructural components are going to occur. In spite of past efforts to improve designing and bracing A-NS components and contents, costly failures are still possible.

3. Architectural Nonstructural Components in Iranian Buildings:
In the case of Iranian buildings there are some particular features which make the non-structural elements of these buildings different from those of other countries, especially US and Japan as the two developed seismic countries. Some of these differences are due to the different building construction styles in Iran and the US, and some others relate to the lifestyles in the two countries, which is basically a cultural problem.

Regardless of their roots, these differences are of great importance as the Iranian codes have been developed and are still being developed mostly based on the US corresponding documents. These features are different depending on the category of the nonstructural elements.(hosseini, 2004)
A-NS components have the most different features from the corresponding group in developed seismic countries, and are the most problematic group among the nonstructural elements in Iran. The particular features of this group are:

1. **Heavy Weight:**
2. **Low Inherent Integrity:**
3. **Weak Connection to Supporting Structure:**

The external walls and internal separating walls and partitions, made of massive brick masonry, as well as the stone façade or cladding, particularly the 3cm brick finishing of the external walls, Internal veneer, such as ceramic tiles, and internal walls and ceiling finishing are samples of components having the second and the third characteristics. The top wall and the parapet cornices are the sample components having the first and the third characteristics. Finally, window frames are the sample components which have the third characteristics in Iranian buildings. (Hosseini, 2004)

**4. Behavior of the Nonstructural Elements in the Bam Earthquake:**

The December 26, 2003 earthquake of Bam with magnitude of 6.5, which hit the city of Bam, town of Baravat, and several surrounding villages in Kerman province, destroyed more than 70% of the buildings in the stricken area, and also caused extensive nonstructural damages to the buildings which remained structurally intact. The observed cases of nonstructural damages are mainly architectural.

The major damage to the A-NS components was observed in masonry walls and partitions, internal and external façade and veneers, and particularly access floor systems. Lots of damages to ceilings, glass finishing and windows and doors glasses, parapets and other attachments were also observed. The cause of most of the damages can be categorized as follow:

1. **Lack of Proper Connection Between A-NS Components Itself or Between Them and Supported Structure:**
   (figure1&2) lack of connection between many masonry walls(either exterior or interior) to its corresponding structure were quite evident. In addition, many exterior walls, such as yard walls, which supposed to carry just their own weight were collapsed, as a result of having no lateral resistance system such as buttresses. The popping out of many windows and doors' frames was due to the lack of proper connection between them and their surrounding wall.

2. **Choosing Inappropriate Material:**
   In regions with high seismic hazard like Iran, materials should be choosing, considering their seismic behavior. In Bam, broken glasses were the damage of almost all of the buildings. Even thick glasses of doors such as banks or the City Hospital were broken to pieces and outspread every were.

   The most usual façade in Bam and many other cities in Iran is brick façades (generally called 3cm brick façade). While it have the most accordance to the Bam's native climate and seismic feature, choosing other material such as ceramics for façades, in all most all buildings, led to failure.

3. **Weak Connection or Incorrect Implementation of Them Between A-NS Components Itself or Between Them and Supported Structure:**

   In many cases where there were connections, failures were observed because of incorrect implementation of executed details which led to weak connections. Lack of withstanding the out of plane loads by many non-load bearing walls, was observed even in cases which had connections but, the connections were either weak or incorrect.

   While no specific pattern can be found for damages to veneers in Bam, scattered location of damages to façade in building elevation represent, either lack of integrity of the material or construction process.

4. **Lack of Interval Maintenance:**
   Rotten joints, especially in windows and door frames, were another reason of their failure. Loosed screws of stone façade were also led to many veneer debris.

**Discussion:**

In recent earthquakes, in which the level of structural damages has been comparatively low, A-NS components have shown their high vulnerability. Codes have become more and more sophisticated and proposing guidelines and retrofitting techniques have been continued, with respect to lessons learned from past earthquakes or state-of-art experiments, in order to reduce the damages to and from them. While they are two
comprehensive efforts which are still continued but, especially for A-NS components, are not as effective as they expect to be, regard to the result of recent earthquakes.

Bam earthquake, is a recent one in which, seismic damages of A-NS components can be observed in buildings which were constructed with mostly new provision, even in very recent earthquake in Italy namely, L’Aquila, on the 6th of April 2009 (A. palermo et al. 2010, Grimaz, 2010), we have seen damages which are very similar to ones, we have seen in Bam earthquake.

Categorizing A-NS components' damages in Bam earthquake, the state of their seismic consideration in design and built process can be defined. An ideal system design and built in building industry can be as it shows in figure 6, it is started from architectural schemas up to building construction (Cherry, 1999).

- The most extensive damages to A-NS components in Bam earthquake was the result of lack of proper connection between A-NS components and its supportive structure or incorrect implementation of connection details. Defining which A-NS component needs seismic consideration and designing reliable seismic connection should be considered in schema and design stage of a building design and built process. In developing countries, there are lots of deficiencies due to definition and categorization of A-NS components. In Iran there are no provisions for A-NS components other than chimney, parapets, penthouses and non-load bearing walls. Extensive damage to façades and windows and doors' frame and glasses were the result of this shortage. for those A-NS components within the scope of provisions and guidelines, however, designing seismic retrofitting detail in design stage in not mandatory, and there is no supervision in construction stage to inspect the accurate implementation of details if any exist. Even in developed countries, as U.S., in which A-NS components' seismic design considered in design stage and the seismic protection of them addressed on the building drafts, in many cases, the implementation of these details is completed without the benefit of a submittal review or any project-specific engineering (ATC, 2008). While some building inspectors routinely check for the presence of code-required bracing for piping and conduit, few inspect the anchorage of A-NS components, suspended ceilings and partitions and even fewer examine the seismic bracing on Building components. Therefore, even if appropriate details considered in schema, design process and construction drafts, incorrect implementation or inappropriate installation of them in construction stage will be result in failure. (Saghafi 1999 & 2004)

- The primarily focused of the code provisions for the A-NS components and their attachments is to reduce the threat to life safety. the functionality of buildings during or after seismic events is not directly addressed. In Bam earthquake, some buildings structurally intact were no longer functional because of non-structural damages-mostly the A-NS ones; such as down fall of ceiling, drift of treads and outpouring of cabinet's contents. Consequently, buildings such as Red Crescent Center and schools which could be used as an primarily settlement locations for earthquake-stricken people or Municipality and Governor buildings which are essential for managing rescue teams in such a crises, were useless. (Primary Bam Earthquake Report, 2003).

**Fig. 1:** Collapse of the external walls -no proper connection is observed. Emdad Khodro building (Photo by M. Hosseini).

**Fig. 2:** Collapse of the yard walls -no buttresses is observed. (Photo by M. Hosseini).
Fig. 3: Ceramic tiles Façade Failure.

Fig. 4: Severely damaged interior wall made of gypsum panels (Photo by M. Hosseini).

Fig. 5: Stone Tiles Façade's Failure (Photo by M. Hosseini).

Fig. 6: System design and built process model (source: Authors).

Fig. 7: Conventional Process Model and Suggested Process Model. (source: Authors).
• Seismic consideration of A-NS components both in code provisions and seismic design guidelines, are addressed in the last stage of design process and executive drafts, as finishing details. As a result, in most cases, they are neglected and postponed to be chosen in construction period. This, leads to personal decisions for selecting the kinds and the details of A-NS components. Thus, choosing the appropriate executive details would be base on contractor's personal decision and not on projects requirements. Choosing ceramic tiles for façade in Bam, which led to complete failure of building's veneer in earthquake, is one of the consequences. Furthermore, in developed countries, there is requirement for new A-NS components products to be tested and evaluated prior to use. These evaluations and standardizations are due to seismic feature of their original regions, however, in developing countries, as in Iran, imported A-NS components are used and mostly are not adopted by local jurisdictions.

• Many A-NS components are added to building after construction stage and mostly in utilizing stage such as door and windows glasses. A-NS components, even those within the scope of the code, are often added to a building after inspections are complete and beneficial occupancy has been granted. In addition, there are neither codes nor guides for interval inspection of A-NS components while utilizing in building lifeline. Consequently, proper details with correct implementations may not desirably performance without maintenance in long time. Rotten bolts and joints cause many doors and windows' frame failure and loosed screws causes many façade failures due to falling down stone tiles.

Conclusion:
The importance of A-NS component issues in seismic design and performance evaluation is now better recognized by researchers as well as practicing engineers. As a result of past earthquake losses and the level of investment in A-NS components, considerable attention has been paid in recent years to this subject area to develop a better understanding of the seismic behavior of them, in order to realistically assess their seismic vulnerability and performance, and to develop effective protection strategies.

This essay with studying A-NS components' seismic design necessity and Bam earthquake damages, tries to analyze the effects of conventional risk mitigation efforts. Based on the result of this study, two major efforts have been taken for reducing non structural components damages in earthquakes; 1) upgrading seismic design codes and 2) proposing new guidelines; however in both, considering seismic design of non-structural components is either restricted to slight part of design and as finishing details or mostly overlooked. Consequently, despite sophisticated seismic code provisions and guidelines in year 2003, we observed many damages to and from A-NS components and may continue to observe them again in such earthquakes.

However, as early appropriate building configuration decision in schema stage will have a great impact on the success of a building structure in an earthquake, similar appropriate decisions by the design team early in the design process will have a profound impact on the design of A-NS system and components.

Proposing seismic design details for new and on raise A-NS and based on the region seismic requirements, in which these components are used, should be mandatory in developing countries like Iran. Choosing appropriate seismic detail for those should be considered in primarily design stage and should be draw in construction drawings.

While functionality is not directly addressed in code provisions or guidelines, (in some states in U.S such as California, functionality is considered only for essential buildings such as hospitals and schools), for Being functional aftermath of earthquakes, discussion between design team about the seismic performance of building and its effect on seismic behavior of architectural A-NS components in design process is needed. Furthermore, appropriate design and proper executive details with poor implementation may not result in desirable way, however considering accuracy of implementation by inspectors in construction stage, may prevent damages cause of implementation stages. In addition, desirable performance of A-NS components in a seismic event, needs consideration on repair or replacement of the damage joints or rotten components in building's lifeline.

In conclusion, for preventing A-NS failure in earthquakes, it is necessary to be considered these components in all stage of design and implementation system. We need proper seismic perspectives in Schema, appropriate Design and executive details, proper Construction, implementation and supervisions, and correct installations of architectural non-structural components in Utilize stag. (figure 7).

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