ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XXIII, NR. 1, 2016, ISSN 1453 - 7397

Considerations on Seismic Design of Installations using Natural Gas Fuel

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The paper presents issues relating to existing standards underlying seismic design restrictions for non-structural components (NSC) related to constructions. Are presented measures that can be implemented to maintain a high level of safety in case of earthquake, natural gas plants, which due to the flammability of fuel, carry some risk of fire or explosion. The purpose of this paper is to highlight the need for seismic design of facilities using natural gas fuel for new buildings but also to review the existing installations in buildings by taking mandatory measures.

Keywords: *seism, NSC, installation, natural gas, regulation, deterioration*

1. Introduction

Since the nineteenth century, sanitation problems and fires were the major risks for the construction of cities, and in the twentieth century has been demonstrated that with population and urbanization increase, earthquake represents an unacceptable risk. Seismic motion requires consideration of measures to protect life and health but also the property. The installations are part of building NSC and cover a wide range in building structures: plumbing and gas, electrical installations of low and / or medium voltage, low current electrical installations, heating, ventilation and air conditioning (HVAC), and equipment such as pumps, chillers, boilers, tanks, sprinkler systems for fire, etc.

In installations for buildings designing field, often is not pay enough attention to seismic constraints. Evidence for such purpose are the numerous disasters (Figure 1) recorded over the years (1971-San Fernando, 1977, Bucharest, 1994-Northridge 1995-Kobe, Kashemir 2005 Haiti 2010) [1], [2], [3], which has caused widespread disturbances namely, flooding due to water supply pipes breakage, fire caused by short circuit of electrical equipment, fires and explosions caused by damage to natural gas supply pipes [4].

San Fernando 1971 California 1994 Kashemir 2005

China 2008 Haiti 2010 Christchurch 2011

Figure 1. Seismic disasters over the years
(Sources: www.drgeorgepc.com, www.history.com, www.telegraph.co.uk, www.britannica.com, www.stuff.co.nz)

2. Trends evolution on seismic design of buildings installations

In seismic engineering, achievements were generally directed towards improving the structural safety and less to the NSC seismic one, even if damage to nonstructural elements or components can have the same types of consequences [5].

The first seismic design codes did not insist on NSC protection. However, in 1927 in an Annex to the Code UBC (Uniform Building Code) [6], [7] appears the first mention on NSC seismic protection, but makes no reference to their design and clamping, only to NSC elements stability insurance. These stipulations were introduced in 1935 as recommendations, becoming mandatory in 1961, and in 1988 were considered the main pipes, boilers, air conditioners, motors, pumps, etc. The year 1997 can be considered as the reference year for the seismic design of structural and nonstructural components when seismic requirements were revised significantly. Compared to previous documents, the new guidelines and rules of codes presents substantial technological improvements in seismic design. New concepts were introduced and there are highlighted technological advances that include: characterization methods for ground movement and zoning, engineering concepts based on performance, direct consideration of nonlinear structural responses and extension of codes provisions to existing buildings, and also structures and repair solutions after post-earthquake assessment. Several articles summarizes the importance of these revisions in which assessments are made regarding the new stipulations level based on new information on the pipes failure behavior of breaking at the magnitude of the latest earthquake, information that may influence the future codes [7], [8], [9], [10], [11], [12].

Since the frequency of earthquakes in Romania is quite high, our country is considered a major seismic risk area in terms of producing strong earthquake of Mw 6.0 - 7.0+ Mw. The most important seismic area in Romania is Vrancea, and the most important earthquakes in this area with magnitude over 6.5 Mw occurred in 1990 (6.9 Mw), 1986 (7.1 Mw) and 1977 (7.2 Mw). [13] In this respect, Seismic Evaluation Romanian codes both for existing buildings and also for those new built followed to introduce in national designing technical regulations key elements from assessment methodologies found in the designing codes and guides of the most advanced countries in this field, but also methods considered valuable in traditional practice in this field, in our country [14] [15], [16], [17], [18].

3. Seismic design principles for building installations

3.1. Design requirements imposed on seismic building installations

The goal for construction seismic design (structural and nonstructural elements) is to prevent any damage to earthquakes of low intensity, to reduce damage from earthquakes of medium intensity and prevent the collapse of all buildings parts to earthquakes of high intensity in order to avoid human lives losses.

For each NSC it is important to establish both seismic vulnerability and the consequences of a failure caused by seismic intensity, and also mitigation methods. NSC seismic response compared to structural elements, it has certain features which are due to various direct and indirect reactions to the earthquake. The assessment, planning and calculation methods to earthquake of NSC must be in accordance with the objectives considered for construction of buildings and realistic in relation to available resources.

In terms of seismic design of basic NSC in a building can be classified into two groups: sensitive components to deviation (vertical pipe sections) and sensitive components to acceleration (mechanical or electrical equipment, boilers, transformers, generators, air conditioning devices or vessels under pressure).

Damage and / or deformation of NSC susceptible to deviation are influenced by building profile deviation and those sensitive to acceleration by changing position in relation to the floor or wall to which they are attached can cause damage and / or deformation of the whole installation.

In seismic designing it is necessary that installations to be protected against the earthquake two effects (Fig.2.):
- The inertial forces direct effect;
- The indirect effect resulted from deformations imposed on NSC by the side relative movements of the attachment / contact points with the main structure [18].

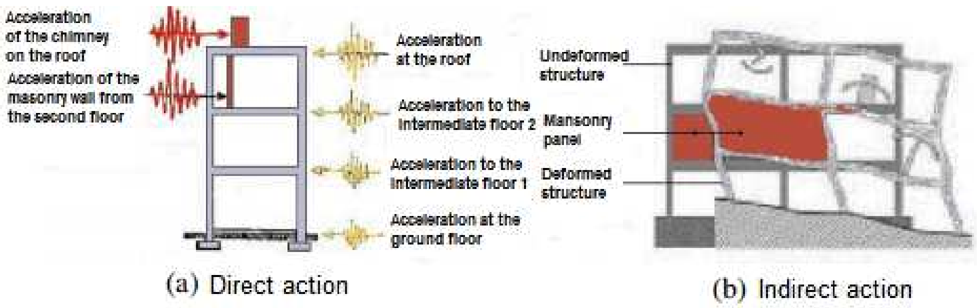


Figure 2. Earthquake action on NSC [18]

Through the direct effect of the earthquake on CNS, damage or breakage occurs due to exceeding its material and rollover resistance or movement caused by insufficient anchorage and even to anchorage absence.

The buildings of class I and II of importance, with certain facilities must be designed and executed so that to remain stable, to maintain their physical integrity and functionality under the forces and displacements caused by seismic action effects. From this point of view, the materials the installations are made of must meet certain mechanical and physical-chemical characteristics and their dimensions must satisfy the other requirements applicable to construction.

3.2. Principles and methods for assessing the NSC seismic force design

The Romanian regulations from 1963 to 2006, the stipulations relating to the seismic design set different values for the seismic force, reaching in 2006 to be differentiated according to specific values of self amplification factors (βNSC) and behavior factors (qNSC). According to the code in force [18], the design value of the seismic force for NSC depends on the NSC importance / role in the building operation, field the acceleration for design (ag) and features of elastic response spectrum, the field acceleration amplification at the NSC attachment level, self NSC dynamic amplification, seismic force reduction due to the NSC energy absorption capacity energy and its links to the main structure and the NSC total weight in operations.

To calculate the seismic design force resulted from the direct action of an earthquake on SNC, spectrums floor and equivalent static forces methods are used.

To determine the lateral movements of installations is necessary to analyze [19]:

- - Lateral displacement calculation the ultimate limit state (ULS) - determine component related to two different benchmarks on one or two different structures or sections and will be designed to take the relative movement;
- - Lateral displacement calculation serviceability limit state (SLS) - pipe systems that are attached to two adjacent sections for buildings of importance classes I and II.

4. The importance of seismic design of installations using natural gas fuel (IU-GNC)

Increasing importance of natural gas in the global economy occupying a significant percentage of the energy balance of countries with are energy sources consumers have made the installations using natural gas to be a viable option. [20]

The history of natural gas utilization worldwide showed that this is a safe fuel for domestic and industrial consumption applications when buildings, installations using natural gas fuel (IU-CNG) and devices using natural gas fuel are built, installed and maintained properly. The potential consequences of post-earthquake fire, demonstrates that natural gas is an important factor that contributes to the risk of post-earthquake fire. [21]

For gas supply systems design, manufacture and safely operation of, they must satisfy the essential quality requirements in construction. [18], [22], [23], [24], [25]. In drawing up the technical memorandum, an integral part of technical documentation for works execution in natural gas supply installations, are required some information on: location, geotechnical study, the importance category of works necessary to establish measures to avoid the gas infiltration in buildings, its evacuation from buildings and seismicity degree.[22], [18].

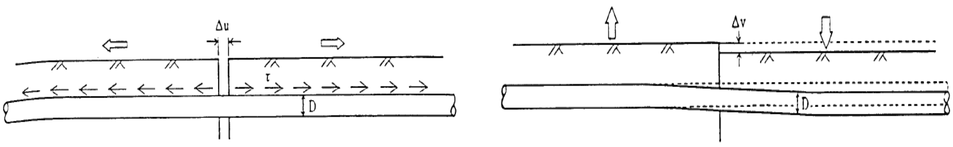
One of the main criteria of IU-CNG design is securing safe operating conditions and the continuity of natural gas supply. For this reason, improving the safety of the installation operation, together with the structural safety, represents a necessity for life and building protection. [26], [27], [28], [29], [30], [31], [32.]

In recent years, due to the difficult to predict seismic response of buildings with plan and elevation complex architectures, even under conditions of applying current stipulations related to NSC seismic design [18], the installations seismic risk increased. Thus, it is necessary to pay special attention to clamping / anchorage detail simultaneously with the resistance elements selection of which resistance capacity to be checked for different locations in Romania seismic intensity calculation.

A special attention should be paid to the seismic design of installations which equip buildings with vital functions, so they will remain in operation when earthquakes with shorter recovery period take place.

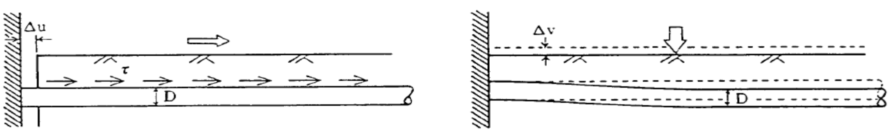
4.1. IU-GNC seismic response particularities

From the point of view of the IU-CNG, seismic acceleration to which pipe network is subjected to is much greater than the seismic acceleration of the land due to the fact that the installation is located above the building fixation level. Acceleration at floors level increases on building height, so that at the top level land it can be reached an acceleration amplification of 3 ÷ 4 times. [18]. Therefore IU-CNG seismic response depends on the dynamic characteristics of the building, the land motion and its position in the building. In Figure 3 [33] are presented models to assess the flexibility of buried pipelines.



horizontally vertically

a) Relative movement between to blocks at ground level



horizontally vertically

b) Movement of pipes encased in rigid structure

Figure 3. Pipes deformation caused by ground movement [33]
(Δu - horizontal deformability index, Δv - vertical deformability index, τ –ground restraint)

Pipes must be designed to withstand the expected strains and stresses induced by earthquakes. In general, the permissible tensile stress are in the range of 1-2% for steel pipes. Is recommended to use flexible couplings on long routes of pipelines. In general, the pipes must not be fastened differently from moving parts, rather they must move together with structure without additional strains. [33].

From the point of view of indirect seismic action, IU - CNG pipelines with structural multiple fastening are required through the deformations imposed by the movement of the building during the earthquake. Each of the attachment points have different movements and even out of phase from each other so that the intensity of these strains depends directly on the distances changing between attachment points during the earthquake. On the other hand, installations behavior varies depending on their own vibration period. Due to its own low damping it reaches to a situation of quasi-resonance, with very significant amplification of IU-GNC pipes movement at the level where these are seated.

It is necessary to pay attention to materials and equipment's that IU-CNG are made of so that their behavior does not fall in the brittle fracture.

The movement of structural and nonstructural elements with high massiveness produces the separation / detachment of pipes clamping elements that can or brake damage to that may cause the pipes damage or break. For this reason, measures are required to avoid IU- CNG full or partial exit from operation by interrupting the connections with external supply networks. Overall, IU-CNG pipeline rupture generates fire and / or explosion. Thus, in order to automatically interrupt the gas supply in buildings with high fire danger is recommended installing automated devices for interrupting the gas supply (Figure 4) in the supply grid. For buildings with low fire danger, there can be use manually operated closure devices [34].

Figure 4. Automatic device (valve) to stop natural gas supplies [34]

4. Conclusions

Regarding constructions, worldwide, there is a trend in increasing the safety level, especially for new buildings with large height regime. This increase is based on taking under consideration a higher level of seismic hazard of seismic action than the current one. The conditions set out in current regulations can contribute to increasing the safety level of the whole system, but cannot guarantee the operation continuity in all situations. In terms of preventing explosions caused by IU-

CNG operation disruptions in case of earthquake, a safety measure is represented by mounting automatic devices (valves) for gas supply automatic interruption inside the building, and introducing this as a mandatory requirement regardless of importance class of building in design regulations and rules.

Given that conventional seismic design based on the action of inertia force not entirely resolve the construction damage and hence the NSC damage, an installation design approach that takes into account the movement action is required.

In conclusion, Romania being a country with high factor of vulnerability to earthquakes, is required a controlled approach of design activities of installations with high explosion risk in case of earthquake.

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