Seismic Protection of Fire Sprinkler and Other Mechanical Systems: Best Practices from Turkey

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SUMMARY

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

Today engineers can design buildings depending on expected seismic forces. However, an unacceptable mistake is to neglect the importance of seismic restraint for non-structural systems. This is crucial especially 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.

This paper includes basic information about earthquakes and examples of seismic restraint design and applications for some selected buildings in Turkey; an office, a shopping center and a residence. Followed buildings codes are IBC 2003 and Turkish Code 1997.

INTRODUCTION

The purpose of this paper is to point out the importance of seismic protection for mechanical and electrical systems in buildings and facilities. These systems are the essential bases for a building and/or facility to be functional after and sometimes even during an earthquake. There is no scientific hypothesis in this work. Instead, this work first covers basic information about earthquakes and how they affect our buildings; then shows the empirical calculations of seismic forces and a comparison between the Turkish Local Code and the International Building Code; and finally demonstrates ways to keep our mechanical and electrical systems safe. The ultimate purpose of this work is to support the awareness for importance of seismic protection for non-structural systems in buildings.

Seismic forces can be calculated thru globally accepted building codes. The most widely used building code today is IBC (International Building Code) which has joined the previous ones (UBC, BOCA etc). Except Japan, almost the rest of the world is using IBC when dealing with non-structural seismic design. The reason is that many local codes (including Turkish Code) are technically weak in terms of seismic protection for mechanical and electrical systems. Once the seismic force assumed to act on a mechanical component (piping, equipments etc) is calculated, the next step is to make the necessary precaution. This can be done either by fixing it to the structure in an experienced and accepted way or by restraining it with help of specifically designed and manufactured seismic hardware (snubber, isolator, steel cable, bracket etc). In both cases, it is a must to calculate the forces and design protection system.
EARTHQUAKES AND DAMAGES ON MECHANICAL SYSTEMS

Earthquakes are non-predictable natural disasters caused by three reasons: volcanic action, collapse of an underground hole, or a ground layer motion which is called “tectonic action”. The first 2 are not as critical as the last one, since these happen seldom and affect rather smaller areas. Tectonic earthquakes, on the other hand, are more critical because of their strong and devastating effects on wide areas.

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.

The above paragraph shows a very possible situation. But if we have a fire sprinkler system, strong enough to resist the seismic forces, we don’t need to be afraid of these kinds of situations. The same is for all mechanical and electrical systems. We have to consider the non-structural aspects when constructing our buildings and facilities. If we don’t, the followings can happen:

Figure 1. Examples of earthquake damages;  a) A sheared pipe,  b) A broken sprinkler head,  c) Collapsed emergency battery racks,  d) Ripped body of a chiller by the connected pipe.
BUILDING CODES AND SEISMIC FORCES

Just like the weather forecasts, seismic forces can not be known exactly. Instead, these can be calculated with empirical formulas, based on observations on past earthquakes. A very detailed formula can be found in IBC 2003 (Equation 1),

\[ F_p = \frac{0.4 a_p S_{DS} W_p}{R_p} \left( 1 + \frac{z}{h} \right) \]  

(1)

where \( F_p \) is the design seismic lateral force, \( a_p \) is the component amplification factor, \( S_{DS} \) is the design spectral response acceleration at short periods, \( W_p \) is the component operating weight, \( R_p \) is the component response modification factor, \( I_p \) is the component importance factor, \( z \) is the height in structure at point of attachment of component, and \( h \) is the average roof height of structure.

The formula in the local Turkish Code 1997, on the other hand, is much less detailed, thus weak (Equation 2),

\[ f_e = w_e A_0 I \left( 1 + \frac{H_I}{H_N} \right) \]  

(2)

where \( f_e \) is the design seismic lateral force, \( w_e \) is the component operating weight, \( A_0 \) is the ground acceleration, \( I \) is the building importance factor, \( H_I \) is the height in structure at point of attachment of component, and \( H_N \) is the average roof height of structure. In addition to this, there is a statement in the local Turkish Code to double the calculated force for fire suppression systems, emergency energy systems, and boilers of central heating systems.

Sample calculations

A sample seismic force calculation for a rigidly mounted transformer can be found below. The design lateral seismic force has been calculated both per IBC 2003 and Turkish Code 1997.

Physical characteristics of the sample equipment (same for both calculation methods):
\( W_p \): Operating weight of the equipment (is equal \( w_e \) in Turkish Code); taken as 5,000 kg
\( z \): Height in structure at point of attachment of component (is equal \( H_I \) in Turkish Code); taken as 30 m (assuming the 10th floor of a building with 3 m floor height)
\( h \): Average roof height of structure (is equal \( H_N \) in Turkish Code) taken as 45 m (assuming the building has 15 floors with 3 m floor height)

Parameters of IBC 2003 calculation (taken from tables in IBC 2003):
\( F_p \): Design seismic lateral force; this will be the result of the calculation
\( a_p \): Component amplification factor; taken as \( I \) for rigid mounted equipments
\( S_{DS} \): Design spectral response acceleration at short periods; taken as 1,1 for Istanbul
\( R_p \): Component response modification factor; taken as 2,5 as a moderate value
\( I_p \): Component importance factor; taken as \( I \) for non-critical equipments
\[ F_p = \frac{0.4 a_p S_{DS} W_p}{R_x / I_p} \left(1 + 2 \frac{z}{h}\right) = \frac{0.4 \cdot 1 \cdot 1.1 \cdot 5.000}{2.5} \left(1 + 2 \cdot \frac{30}{45}\right) = 2.053 \text{ kgf} \]

Parameters of Turkish Code 1997:

- \( f_e \): Design seismic lateral force; this will be the result of the calculation
- \( A_0 \): Ground acceleration; taken as 0.4 for Istanbul
- \( I \): Building importance factor; taken as 1 for non-critical buildings

\[ f_e = w_e A_0 I \left(1 + \frac{H_I}{H_N}\right) = 5.000 \cdot 0.4 \cdot 1 \cdot \left(1 + \frac{30}{45}\right) = 3.333 \text{ kgf} \]

Assuming a circulation pump with the same physical characteristics of the sample transformer is vibration isolated. In this case, the result of Turkish Code does not change, whereas the result of IBC multiplies by 2.5 since we have to take the \( a_p \) value as 2.5 for vibration isolated equipments.

Assuming a fire pump with the same physical characteristics of the sample transformer, which shouldn’t be vibration isolated. This time we come up with 3.080 kgf in IBC, since we have to take the \( I_p \) value as 1.5 for life safety equipments. On the other hand, the result is 6.666 kgf in Turkish Code, since the Turkish Code says double the force for life safety equipments.

Table 1. Seismic force comparisons between IBC 2003 and Turkish Code 1997.

<table>
<thead>
<tr>
<th>NON-STRUCTURAL EQUIPMENT</th>
<th>Seismic Force (kgf) per IBC 2003</th>
<th>Seismic Force (kgf) per Turkish Code 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer (non isolated)</td>
<td>2.053</td>
<td>3.333</td>
</tr>
<tr>
<td>Circulation pump (vibration isolated)</td>
<td>5.133</td>
<td>3.333</td>
</tr>
<tr>
<td>Fire pump (non isolated)</td>
<td>3.080</td>
<td>6.666</td>
</tr>
</tbody>
</table>

As seen in the above sample calculations, IBC 2003 gives more accurate results compared to Turkish Code 1997. The reason is that, there are more parameters in the IBC formula. It is obvious that a less detailed formula will give less detailed results. This, at the end will give either too low or too high results.

**SEISMIC RESTRAINT DESIGN**

Seismic restraint design for mechanical systems can be split into 2 groups:

1) Floor mounted, suspended or wall mounted equipments.
2) Suspended pipes, ducts, electrical cable trays etc.

Floor mounted equipments can either be rigidly mounted to the floor or to concrete pads or they can be mounted on vibration isolators with snubbers or directly on seismic isolators. If there is a need for vibration isolation (for a chiller for instance), rigid mounting cannot be done. If the equipment needs to be restrained, it is less expensive to use seismic isolators instead of using 2 different hardware, open springs and snubbers. Suspended equipments can also either be rigidly restrained if there is no need for vibration isolation or they can be hanged with vibration hangers and also restrained with seismic cables. Wall mounted
equipments rarely need vibration isolation. Thus it is enough to rigidly mount them to the wall with anchors strong enough to resist the calculated seismic force.

Suspended pipes, ducts and electrical cable trays are critical, since those are subject to sway and damage both themselves and other systems close to them. Therefore, it is a must to brace these systems. The bracing (called seismic bracing, sway bracing or cable bracing) is a matter of design. The non-structural seismic engineer has to determine the points of bracing on a layout drawing. Many building codes (including IBC) and standards (including SMACNA) directs to put lateral bracing at each 12 meters and longitudinal bracing at each 24 meters. However, depending on the installation conditions, these distances can be less. In other words, seismic cable bracing points must be determined depending on seismic calculations.

Figure 2 shows a general concept of determining the cable bracing points on a pipe/duct/electrical cable tray layout system. It also shows an alternate way of bracing (45° angles) instead of having lateral (transverse) and longitudinal braces separately. The installation details of seismic cables can be seen in Figure 3.

Figure 2. Seismic cable bracing for suspended pipe/duct/electrical cable tray lines.

Figure 3. Seismic cable bracing details for suspended pipes.
SEISMIC RESTRAINT APPLICATIONS FROM TURKEY

Tekfen Tower – Office Building: This is a 32 floor high class office building. The main HVAC equipments are located on top of the building right over a VIP office floor. This made it difficult to avoid vibration and noise. In order to achieve this, all equipments have been vibration isolated by using seismic isolators (Figure 4) and all pipe supports have been installed with vibration hangers and seismic cables (Figure 5).

![Figure 4. Applications of seismic isolators in Tekfen Tower for; a) Pumps, b) Boilers.](image)

Kanyon Levent – Shopping Center: This is a building complex of shopping center, office tower and residence blocks. The main HVAC equipments have been vibration isolated with seismic isolators (Figures 6a) and pipes have been braced with seismic cables (Figure 6b).
Figure 6. Applications of seismic isolators (a) and seismic cables (b) in Kanyon Levent Sisli Plaza – Residence Tower: This is a premium class residence tower. All main HVAC equipments have been vibration isolated with seismic isolators and pipes have been braced with seismic cables. A seismic brace layout drawing of fire sprinkler system is shown in Figure 7.

Figure 7. Seismic cable bracing layout drawing for Sisli Plaza Residence.
CONCLUSION

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 (for instance the Turkish Local Code) in terms of non-structural seismic protection must be taken into consideration carefully. Necessary precautions should be determined in the local codes and standards. As for Turkish code writers, the global level of awareness for seismic protection of non-structural systems should be reached.

ACKNOWLEDGEMENTS

Many thanks to my father Ceyhan Kalafat, PM of Tekfen Tower, for giving me my first job; my ex-boss Olgun Sonmez and Werner Stebner, VP of Amber/Booth, for opening me a door in seismic world; Robert E. Simmons for my training, to my colleagues Sarper Arun, Erkan Selek, Murat Kantarci, Okan Sever and others for being in my team; Prof. Mustafa Erdik, Prof. Abdurrahman Kilic and Prof. Ahmet Arisoy for their academic support; Celal Okutan, the founder of TTMD, and all other TTMD and MMO workers for their support.

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