TRANSFER OF THE SEISMIC MOTION FOR THE DESIGN AND ASSESSMENT OF COMPONENTS. A SIMPLIFIED APPROACH

Didier COMBESCURE\textsuperscript{1}, Pierre-Alain NAZE\textsuperscript{2}, Gildas POTIN\textsuperscript{3}, Celine DUJARRIC\textsuperscript{4}

ABSTRACT

The determination and the control of the seismic motion transferred to the mechanical components and their supporting structures represent a major issue for the seismic design of non-structural elements, the anchoring and qualification of equipment with a special emphasis for the strategical buildings and the industrial facilities. This paper presents the approach promoted in several French AFPS working groups in charge of writing guidelines for critical facilities (SEVESO industrial, hospital, school, emergency facilities).

Simple formulae are available in the literature to determine the seismic load to be considered for the design of the non-structural components and their supports (ASCE 07, Eurocode 8, etc...). Nevertheless these formulae have a limited domain of applicability and do not reflect the complexity of the seismic motion transferred to the components. On one hand, the transferred seismic motion in a real structure can be influenced by a large number of structure parameters such as the damping values and the ductility demand in the supporting structure. On the other hand, the real industrial structures may be very complex which requires to adopt simplified approach or to have tools to cross-checks the results of 3D finite element models.

The AFPS guidelines for the supporting structures of critical industrial facilities propose a simplified formula based on the work developed inside the French Association for Earthquake Engineering. The basis of this formula and the main assumptions are reminded in this paper. Comparisons between the simplified and the time-history approaches are also provided for several structures.

Keywords: Floor Response Spectra; Non structural elements

1. INTRODUCTION

The determination and the control of the seismic motion transferred to the mechanical components and their supporting structures represent a major issue for the seismic design of non-structural elements, the anchoring and qualification of equipment with a special emphasis for the strategical buildings and the industrial facilities. This paper presents the approach promoted in several French AFPS working groups in charge of writing guidelines for critical industrial facilities and for critical facilities (hospital, school, emergency facilities).

The AFPS guidelines for the supporting structures of critical industrial facilities propose a simplified formula based on the work developed inside the French Association for Earthquake Engineering (AFPS, 2000, 2001, 2011, 2013) and the German standard for nuclear facilities (KTA 2201). The basis of this formula and the main assumptions are reminded in this paper. Comparisons between the simplified and the time-history approaches are also provided for several structures. An application to ancillary buildings of ITER Fusion facility is presented.
2. INPUT DATAS NECESSARY FOR THE SEISMIC DESIGN OF THE EQUIPEMENTS AND THEIR SUPPORTS

The seismic motion which is transferred from the ground to the location of the supports and to the equipment can be fully defined if the following information is known:

- The seismic floor response spectra - which allows the inertial loads on the masses to be determined,
- The relative displacement anticipated between two interfaces of the equipment (for multi-supported system such as the piping systems).

Figure 1: Ground and floor response spectra for a multi-storey structure [AFPS 2013]

An example of floor response spectra in a multi-storey frame structure is given in Figure 1 and compared to the ground motion. The floor response spectra (FRS) exhibit some characteristics common to the ground response spectra:

- below the fundamental eigenfrequency of the building structure, the FRS is close to the ground response spectrum and the spectral acceleration becomes null at 0Hz;
- the seismic motion is amplified for the eigenmodes of the structure specially when their natural frequencies correspond to the amplified part of the ground response spectrum;
- above the cut-off frequency, the FRS is characterized by its ZPA (Zero Period Acceleration) and the seismic load becomes a static load.

The FRSs show also several specificities:
- the ratio between the spectral acceleration and the ZPA depends not only on the values of 
damping of the non-structural elements but also on the values of damping of the supporting 
structures. Lower these values of damping mean higher amplification;
- the ZPA and the cut-off frequency of the FRS may be lower than those of the ground, in 
particular in case of very flexible building structures or base-isolated structures.

3. DESCRIPTION OF A SIMPLIFIED METHODOLOGY TO GENERATE THE SEISMIC 
FLOOR RESPONSE SPECTRA

Simplified formulations are proposed for both the horizontal and the vertical floor response spectra. 
For equipment located on the roof or on an upper floor, as already explained, the ground seismic 
motion has to be modified because of the dynamic response of the building (Figure 1). The ground 
seismic motion can be reduced or amplified depending on the frequencies of the building. 
The proposed approach does not provide a FRS equal to the ground response spectrum at the base of 
the buildings. Only the ZPA is continuous. For the component which are directly fixed to the 
foundation level or close to the ground (3m or less below the first storey, first storey excluded), the 
envelop of the ground seismic response spectrum and the Floor Response Spectra at the equipment 
location can be used.

3.1 Horizontal floor response spectra

For the horizontal floor response spectra, the formulation is derived from the technical document CT 
30 of AFPS (AFPS, 2011) and improved in the guidelines for industrial buildings (AFPS, 2013). This 
simplified approach will enable evaluation of the acceleration to be applied statically to the weight of 
the equipment
The proposed fixed acceleration is based on an estimate of the maximum acceleration at the floor 
which supports the equipment and a dependent amplification factor to the ratio of periods of 
equipment (TE), the supporting structure (Tp) and the damping ratio of the building structure (D1) and 
of non-structural element (D2).
Simplified formulae are used to estimate response spectra which can be used to calc ulate the inertial 
forces to be applied at the center of gravity of the equipment: and deduce interface forces with the 
support structure for the design and verification of anchorage:

$$ F = M \times a_H $$

- \( M \) = mass of the equipment;
- \( a_H \) = absolute acceleration at the location of the support of the equipment:

$$ a_H = S_a(T_p, q_p, D_1) \times K_T(T_p, D_1, D_2) $$

- \( T_p \) = natural period of the building structure (f is the natural frequency associated to this 
period \( f = 1/T_p \));
- \( q_p \) = Reduction factor to take into account the non-linear behavior of the building structure, 
the support of the equipment and the equipment itself. \( q = 1 \) for SL-1 and \( q \geq 1.5 \) can be 
considered for accidental seismic load (EC8 or nuclear SL-2 spectra) depending on the 
ductility capacity of the structural elements. It is assumed that the equipment and its local 
support has the same ductility capacity than the building.
- \( D_1 \) is the damping factor for the building;
- \( D_2 \) is the damping factor for the equipment;
- \( S_a(T_p) \) = absolute acceleration (and not relative to the ground) at the period \( T_p \) and for the 
damping value \( D_1 \) of the building structure.
- **K\_T** = amplification factor taking into account the interaction between the equipment and the building.

  \( K_T \) is a function of the period \((T_E)\) or the natural frequency \((f_E)\) of the equipment, the period \((T_p)\) or the natural frequency \((f_p)\) of the building structure, the damping value of the equipment \(D_1\) and the damping value of the building \(D_2\).

  For a damping value of 5% for the equipment and 5% for the building structure, the amplification factor \(K_T\) is given by the following formulae:

  \[
  K_T = \begin{cases} 
  1 & \text{if } f_{\text{limit}} < f_E \\
  5n - \left[ (5n - 1) \left( \log \frac{1.2 \cdot f_n}{f_E} \right) / \log \frac{1.2 \cdot f_n}{f_{\text{limit}}} \right] & \text{if } 1.2 \cdot f_n < f_E \leq f_{\text{limit}} \\
  5n & \text{if } 0.8 \cdot f_n \leq f_E \leq 1.2 \cdot f_n \\
  5n \left( \frac{0.8 \cdot f_n}{f_E} \right)^2 & \text{if } f_E \leq 0.8 \cdot f_n 
  \end{cases}
  \]

  with:

  - \( f_1 \) to \( f_n \) : main eigenmodes of the building/support structure;
  - \( f_{\text{limit}} \) : limit frequency equal to 16.7 Hz \((T_{\text{limit}}=0.06 \text{ s})\) (ASCE, 2007);
  - \( n \): factor depending on \(D_1\) and \(D_2\) \((n=1 \text{ if } D_1=D_2=5\%)\).

In case of resonance between the building structure and the equipment, for 5% damping systems, the amplification factor is equal to \(K_T = 5\) (if \(n=1\)). If the equipment is rigid compared to the building structure, \(K_T\) can be taken equal to 1.

The floor response spectrum has the following shape (cf Figure 2-a). The results derived using the simplified method are typically equivalent to the accurate values derived from time-history analysis.

Close to the ground \((H<3\text{ m excluding the anchors to the first slab/roof})\), the shape of the floor response spectra is more similar to the ground floor response spectra. Since the proposed simplified shape is not continuous with the ground response spectrum at ground level (only the ZPA is continuous at \(z=0\)), the envelop of the soil response spectra and the floor response spectra have to be considered. At ground level, the effect of the ductility of the equipment or non-structural element and its support can be considered by dividing the elastic forces by the reduction factor (SL-2) or by using the design response spectra (EC8) which already includes the reduction factor.

The floor response spectrum strongly depends on the values of frequencies considered for the building:

- \( f \): the value of the frequency used to calculate \(S_a\) and so the ZPA at each level of the building can be identified with the more penalizing value (highest value for flexible building) of the fundamental eigenmode of the building (looking at the eigenmodes in Ox and Oy directions and soil conditions).
- \( f_1 \): the frequency defining the beginning of the plateau can be identified with the lowest value of the fundamental eigenmode of the building (looking at the eigenmodes in Ox and Oy directions and soil conditions).
- \( f_n \): the frequency defining the end of the plateau can be identified with the highest value of the last predominant eigenmode of the building (fundamental eigenmode for a simple structure or second or third significant eigenmode for a structure whose FRSs are driven by several eigenmodes).

If FRSs are available from a previous stage of design, such results can be used to determine the values of natural frequencies. The number of eigenmodes to be considered may also be determined by analysing the relative contribution of the eigenmodes onto the absolute acceleration or ZPA.
3.2 Determination of the absolute acceleration

The absolute acceleration or ZPA of the FRS can be calculated in a simplified way by completing the spectral acceleration from a response spectrum analysis with a static pseudo-mode (or missing mass):

\[ S_a(T_p) = a_N \left( 1 - \sum_i P_i \varphi_i(x, y, z) \right)^2 + \sum_i R_i^2 \left( T_{p,i} \right) P_i^2 \varphi_i(x, y, z)^2 \]  \hspace{1cm} (4)

The first term represents the ground motion corrected by the eigenmodes already included in the calculation. The second term represents the spectral acceleration calculated with the eigenmodes, in this case with a SRSS recombination. The characteristics of the eigenmodes can be derived with a FEM software or with a simplified formulae.

In case of regular building, the absolute acceleration is mainly a function of the elevation \( z \) of each floor with respect to the foundation and the total height \( H \) of the building. This absolute acceleration can be determined with a finite element model and time-history analysis. In the present methodology, some effect of the non linearities in the building structure and the equipment support onto the spectral acceleration is taken into account by including the coefficient \( q_p \).

For an eigenshape such as \((z/H)^\alpha\), the expression of \( S_a \) becomes:
\[ S_a\left(T_p\right) = a_N \sqrt{\left(1 - P_p \left(\frac{z}{H}\right)^\alpha\right)^2 + P_p^2 R_a^2\left(T_p\right)} \left(\frac{z}{H}\right)^{2\alpha} \] (5)

In the case of a response dominated by a single eigenmode, a conservative value of \(S_a\left(T_p, q_p\right)\) is given by:

\[ S_a\left(T_p\right) = \frac{a_N}{q_p} \sqrt{1 + P_p^2 R_a^2\left(T_p\right)} \left(\frac{z}{H}\right)^{2\alpha} \] (6)

with:

- \(a_N\) = ground acceleration (\(a_g\) with EC8 formalism);
- \(z\) = altitude of the roof or the slab with respect to the foundation;
- \(H\) = height of the building;
- \(P_p\) = participation factor of the fundamental eigenmode of the building structure:
  \[ P_p = \frac{2\alpha + 1}{\alpha + 1} \]
  \(\alpha = 1\) and \(P_p = 1.5\) for the framed structures;
  \(\alpha = 1.5\) and \(P_p = 1.6\) for the wall or diagonal trusses structures;
  \(P_p = 1\) for the system made by a lumped mass and a massless supporting structure (one mass type structure);
- \(R_a\) = spectral amplification factor of the spectral acceleration with respect to the ground acceleration \(a_N\) at the period \(T_p\) of the building structure. This value may be determined using the eigenfrequencies determined with a finite element model (modal analysis) or with a simplified model or using a « forfaitaire/inclusive » approach considering the maximum spectral acceleration of the EC8 soil response spectrum (\(R_a = 2.5\)) or of the SL-2 spectra (\(R_a = 2.34\) for the 5\% damping SL-2 spectra). A minimum value of 1 for \(R_a\) can be considered for the building structure with a low frequency fundamental mode (flexible or base-isolated building).

The realistic maximum values \(P_p = 1.6\) (obtained for \(\alpha = 1.5\)) and \(R_a\left(T_p\right) = 2.5\) give an absolute acceleration \(S_a\) of about 4\(a_N\) at the top of the building.

In case of isolated buildings, the formula is over conservative due to the fact that the first term is approximated by 1 and not its real value close to 0. For a rigid body motion (\(P_p = 1\) and \(\varphi = 1\)) as fundamental eigenmode, the formula becomes:

\[ S_a\left(T_p\right) = a_N R_a\left(T_p\right) \] (7)

### 3.3 Influence of damping:

For buildings with damping values different than 5\%, the correction factor from EC8 can be considered to modify the KT factor (value in case of resonance):

\[ n_1 = \frac{10}{\sqrt{5 + D_1}} \] (8)

where \(D_1\) is the damping factor for the building (see Table 1).

If \(R_a\) is known for 5\% damping (for EC8), the correction factor has also to be applied to \(R_a\). The expression to calculate the maximum acceleration becomes:
\[ S_a(T_p) = \frac{a_s}{q_p} \sqrt{1 + P_p^2 \left( \frac{n^2 R_{\phi}^2(T_p)}{H} \right)^{\frac{2a}{a_2}}} \] (9)

For the equipment with damping values different than 5%, a correction factor from random vibration theory can be considered for the KT factor with \( D_2 \) the damping factor for the equipment (see Table 2).

\[ n_2 = \sqrt{\frac{5}{a_2}} \] (10)

When both values of damping are different from 5%, the correction factor to be considered for the KT factor (see Table 3) is:

\[ n = n_1 \cdot n_2 \] (11)

Table 1. Values of \( n_1 \) for different values of damping for the building (\( D_1 \)) (\( D_2=5\% \) for the equipment)

<table>
<thead>
<tr>
<th>( D_1 )</th>
<th>( n_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>1.20</td>
</tr>
<tr>
<td>4%</td>
<td>1.05</td>
</tr>
<tr>
<td>5%</td>
<td>1.00</td>
</tr>
<tr>
<td>7%</td>
<td>0.91</td>
</tr>
<tr>
<td>10%</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Table 2. Values of \( n_2 \) for different values of damping for the equipment (\( D_2 \)) (\( D_1=5\% \) for building)

<table>
<thead>
<tr>
<th>( D_2 )</th>
<th>( n_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>1.58</td>
</tr>
<tr>
<td>4%</td>
<td>1.12</td>
</tr>
<tr>
<td>5%</td>
<td>1.00</td>
</tr>
<tr>
<td>7%</td>
<td>0.84</td>
</tr>
<tr>
<td>10%</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Table 3. Maximum values of \( KT=5n_1n_2 \) for sets of values of damping for building (\( D_1 \)) and equipment (\( D_2 \))

<table>
<thead>
<tr>
<th>( D_1 )</th>
<th>( D_2=2% )</th>
<th>( D_2=4% )</th>
<th>( D_2=5% )</th>
<th>( D_2=7% )</th>
<th>( D_2=10% )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>9.4</td>
<td>8.3</td>
<td>7.9</td>
<td>7.2</td>
<td>6.5</td>
</tr>
<tr>
<td>4%</td>
<td>6.7</td>
<td>5.9</td>
<td>5.6</td>
<td>5.1</td>
<td>4.6</td>
</tr>
<tr>
<td>5%</td>
<td>6.0</td>
<td>5.3</td>
<td>5.0</td>
<td>4.57</td>
<td>4.1</td>
</tr>
<tr>
<td>7%</td>
<td>5.1</td>
<td>4.5</td>
<td>4.2</td>
<td>3.9</td>
<td>3.4</td>
</tr>
<tr>
<td>10%</td>
<td>4.2</td>
<td>3.7</td>
<td>3.5</td>
<td>3.2</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Note that the values from Table 3 are similar than the values given in KTA standard (Figure 3)

Figure 3: Values of KT (noted V) for different sets of damping (KTA, 2012)
3.4 Vertical floor response spectra

In the vertical direction, the same approach than previously described can be followed. Amplification of the vertical seismic motion at mid-span of the beams and slabs can be easily reproduced with an adequate structural model.

Nevertheless, as it is recommended in (MEDDE, 2013), it is assumed that the transferred motion does not depend on the altitude in the building but depends only on its horizontal position (close to a wall or a column or at mid-span of a beam or a slab). The amplification of the vertical motion is due to the flexibility of the horizontal elements which are much higher than the vertical flexibility of the vertical elements. An amplification factor of 2 between the vertical structural elements and the center of the slabs and beams is considered for ceilings like in (MEDDE, 2013). If the natural frequency of the equipment is higher than twice the eigenfrequency of the slab (with the mass of the equipment), the same expression of spectral acceleration (or equivalent static acceleration) than (MEDDE, 2013) can be considered:

\[
S_a(T_p) = 2 \alpha_{v,N}
\]  

(12)

Note that except in West Indies, no ground vertical acceleration is considered in France.

4. ESTIMATION OF THE RELATIVE DISPLACEMENT FOR MULTISUPPORTED EQUIPMENTS

The multisupported equipment (piping for example) has to behave adequately in case of imposed relative displacement. For the equipment supported by a single slab (same storey and same building), the relative displacement may be neglected. For the equipment supported by two different slabs (different storeys or/and different buildings), the relative displacement can be estimated with the spectra displacement(s) at the frequency(ies) of the fundamental eigenmode(s) of the building(s).

For equipment supported by two different storeys of the same building, the relative displacement is equal to:

\[
\Delta u = \frac{L}{m} \Delta \phi . S_d
\]

(13)

\[ L/m = P_p \]

\[ S_d \]

L/m: participation factor of the fundamental eigenmode,
\[ \Delta \phi \]

Relative displacement between the two points for the fundamental eigenmode,
\[ S_d \]

Spectral displacement at the fundamental natural frequency.

For an equipment fixed, on one side, at the altitude z with respect to the foundation and, on the other side, on the foundation, the expression becomes:

\[
\Delta u = P_p \frac{z}{H} . S_{dH}
\]

(14)

For an equipment fixed on two different buildings, the relative displacement is equal to:

\[
\Delta u = \left[ \frac{L}{m} \Delta \phi . S_d \right]_{\text{building 1}} + \left[ \frac{L}{m} \Delta \phi . S_d \right]_{\text{building 2}}
\]

(15)

The spectra displacement has to be calculated without taking into account any reduction factor (q=1). For piping and cables fixed on equipment (for example, electrical cabinet or supporting structures of cable trays and HVAC, etc.), the spectral displacement can be determined conservatively using the floor response spectra proposed in the current paper (see Figure 4).

The relationship between displacement and pseudo-acceleration spectra is:

\[
S_d(f) = \frac{1}{(2\pi f)^2} S_a(f) = \left( \frac{L}{2\pi} \right)^2 S_a(f)
\]

(16)
It is important to note that the maximum values of spectral displacement and spectral velocity from the proposed approach give a good estimate of these quantities. The FRS may also be used as input data of seismic qualification testing campaigns.

5. APPLICATION TO AN ANCILLARY BUILDING OF ITER FUSION FACILITY

The approach has been applied to a large set of buildings part of the ITER Fusion facility which is under construction in France. The Tokamak complex which is nuclear building is surrounded by a large number of ancillary buildings. Some example of buildings is given in Figure 5. The main seismic requirement for these buildings and their equipment is the stability in case of the EC8 or the nuclear accidental earthquake. The building structures are calculated according the ASN guidelines. For the non-structural elements, in order to limit the delay and cost in the generation of the FRSs to be considered without jeopardizing the technical quality of the input data, the above-mentioned approach has been considered. This approach is very robust with respect to the potential changes in the design of the building and to the traceability of input datas for the seismic design of the non-structural elements and its anchors.

5.1 Implementation of the simplified approach through excel sheet

Excel sheets have been developed to apply easily the simplified approach (Figure 6). The Excel file contains two types of sheets:
- A first set of sheets (Figure 6a) which give the floor response spectrum for a set of input datas (position of the equipment in the building, damping and reduction factor for the building, damping for the equipment). The Ra factor comes from the second excel table and are calculated with the value of damping and frequency for the building from the second excel table.

- A second set of sheets (Figure 6b) which give the values of the soil response spectra for SL-2, SL-1 and EC8 seismic event. The soil response spectra are given for several values of damping. For a building characterized by its natural frequency, the values of spectral acceleration and Ra factor are provided. A lower bound equal to 1 has been considered for the Ra factor. The user is not allowed to modify these sheets but can check them.

![Floor response spectra](image1)
![Soil response spectra and Ra factor](image2)

Figure 6: Example of sheets giving the floor response spectra, soil response spectra and Ra factor

### 5.2 Application to Building 61

The Site Services Building 61 will accommodate and distribute industrial support services and systems, as required throughout the ITER site. The Building includes a Control Room and all necessary support services. The seismic loads for ITER project are defined through different response spectra (SL-1, SL-2, SL-3 and EC8) depending on the classification of the buildings (nuclear or non nuclear buildings). SL-2 and SL-3 are the most demanding spectra used for the design and the beyond design analysis of nuclear buildings. SL-1 is the investment protection seismic load. EC8 provisions are applicable for all structures for the protection of workers. The building is classified NSC and is designed considering EC8 spectra. The supports of the equipment are designed against SL-1 event in order to protect the investment.

Building 61 is essentially a single story steel framed, braced structure, which will accommodate the plant and equipment providing various services throughout the ITER site. Heavy items of equipment, mainly chillers and pumps, are installed directly onto the ground bearing slab of the building.

Assessment of the natural frequencies in Ox and Oy directions predicts values of frequency as below:
- 2.0 Hz in Ox direction
- 1.26 Hz in Oy direction

These values have been confirmed by the Building designer (Construction Design).

The floor response spectra corresponding to EC8 and SL-1 have been determined with the simplified formulae. A value of reduction factor of 4 has been considered for EC8 and a reduction factor of 1 for SL-1.

The values of horizontal spectral acceleration for 5% damping from the EC8 Soil Class C spectrum (horizontal direction) are:
- 5.76 m/s² in Ox direction (Ra=3.00)
- 3.63 m/s² in Oy direction (Ra=1.89)

The Zero Period Acceleration on the roof of building 61 for EC8 is estimated with formula (9):
\[ S_a(T_p) = \frac{1.92}{4.0} \times (1 + 1.6^2 \times 3.00^2 \times [1]^{2x1.5})^{0.5} = 2.35 \text{ m/s}^2 \text{ for Ox direction (EC8)} \]

\[ S_a(T_p) = \frac{1.92}{4.0} \times (1 + 1.6^2 \times 1.89^2 \times [1]^{2x1.5})^{0.5} = 1.53 \text{ m/s}^2 \text{ for Oy direction (EC8)} \]

The values of horizontal spectral acceleration from the 2% damping SL-1 spectrum (horizontal direction) are:
- 1.208 m/s² in Ox direction (Ra=1.53)
- 0.727 m/s² in Oy direction (Ra=0.94 considered as Ra=1.0)

The Zero Period Acceleration on the roof of building 61 for SL1 is estimated with formula (9):
\[ S_a(T_p) = \frac{0.77}{1.0} \times (1 + 1.6^2 \times 1.53^2 \times [1]^{2x1.5})^{0.5} = 2.05 \text{ m/s}^2 \text{ for Ox direction (SL1)} \]
\[ S_a(T_p) = \frac{0.77}{1.0} \times (1 + 1.6^2 \times 1.0^2 \times [1]^{2x1.5})^{0.5} = 1.45 \text{ m/s}^2 \text{ for Oy direction (SL1)} \]

Table 4: Equivalent static acceleration to be considered for building 61 (EC8 and SL1 - horizontal direction)

<table>
<thead>
<tr>
<th>ZPA of transferred motion</th>
<th>Acceleration for resonant equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa(T) – EC8</td>
<td>Sa(T) – SL1</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Roof</td>
<td>2.35 m/s²</td>
</tr>
<tr>
<td>Ground</td>
<td>1.92 m/s²</td>
</tr>
</tbody>
</table>

(*): At ground level, the maximum spectral acceleration for 5% damping is considered for the resonant equipment

The horizontal spectrum is generated using the previous value and assuming that the seismic response of the building will be dominated by its fundamental eigenmode in each direction (single degrees of freedom system). In order to have a unique floor response spectra in both horizontal direction, we will consider the frequency in Oy direction as \( f_1 = 1.26 \text{Hz} \) and the frequency in Ox direction as \( f_n = 2.0 \text{Hz} \). The horizontal spectra for SL-1 and Eurocode 8 (ULS) are given in figure 7.

The vertical spectra for the equipment fixed onto the roof and the ceilings is estimated with a value of amplification of 2 and a reduction factor of 1 which means a value of spectral acceleration equal to \( 2\times2/3\times0.77 = 1.02 \text{ m/s}^2 \) for SL-1 (no vertical acceleration for EC8). This value can be used on the whole surface of the roof since it is conservative for the points close to the vertical structural elements.

![Horizontal spectral acceleration (m/s²) for SL1](image1)

![Spectral acceleration (m/s²) for EC8](image2)

6. CONCLUSIONS

This paper has presented a simplified formula based on the work developed inside the French Association for Earthquake Engineering (AFPS) and the German standard for nuclear facilities (KTA 2201). The basis of this formula and the main assumptions are reminded in this paper. Comparisons between the simplified and the time-history approaches are also provided and give satisfactory results. Nevertheless several important aspects still need to be clarified and the approach improved. The continuity of the FRS and the ground seismic spectra is not insured at the ground level (except for the ZPA) and the spectral acceleration may be overestimated in some cases. A comparison with the proposals in EC8-1 (for design) and EC8-3 (FRS for the masonry buildings) also need to be done (EC8 2017). The conservatism due to the fact that a single plateau is considered may be reduced in
case of multi-modal structure. Last but not least, the way how the elastic FRS is transformed into a design FRS (including the effect of ductility, over-strength, etc...) is considered in an over-simplified way. The effects of the non-linearities which can be developed in both the non-structural elements (with its own ductility and overstrength) and the supporting structures need to be clarified through extensive non-linear analysis. Observations from instrumented structures in epicentral areas may also provide valuable information on the real seismic loads supported by the non-structural elements and its anchors.

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8. REFERENCES

AFPS technical reports are published on AFPS website, at the address:
http://www.afps-seisme.org/fre/PUBLI
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