Seismic Design of School Buildings in Colorado and other Low to Moderate Hazard Areas: Is the International Building Code adequate?

EERI School Initiative Webinar

May 29, 2014

Rob Jackson, P.E., SECB
Overview

- Seismic Design Category A (1 % lateral load) is intended for use only in the lowest areas of seismic risk. The use of SDC A is not appropriate for buildings in low to moderate risk areas.

- The use of a 1% lateral load is arbitrary and is not based on the seismic hazard maps.

- SDC A is being used in low to moderate areas of seismic risk based on soil classification.
Overview

- The use of 1 % can be lower by a factor of 3 to 10 when compared to the mapped values and the usual equivalent lateral force procedures.
- The seismic design of schools is not required to be any different than for ordinary buildings where SDC A is allowed.
- There are currently two spectral acceleration thresholds for the use of SDC A, one based on spectral ground accelerations only and the other based on the accelerations and on the soil classification.
Societal risk
Arbitrary......

The following are excerpts from the 2003 NEHRP Provisions Commentary:

• “The 1 percent value has been used in other countries as a minimum value for structural integrity. For many structures, design for the wind loadings specified in the local building codes normally will control...However, many low-rise, heavy structures or structures with significant dead loads resulting from heavy equipment may be controlled by the nominal 1 percent acceleration.”

• “The selection of 1 percent of the building weight as the design force for Seismic Design Category A structures is somewhat arbitrary. This level of design lateral force was chosen as being consistent with prudent requirements for lateral bracing of structures to prevent inadvertent buckling under gravity loads and also was believed to be sufficiently small as to not present an undue burden on the design of structures in zones of very low seismic activity.”
Colorado’s Earthquake and Fault Map
Isoseismal map of the 1882 $M_w$ 6.6 earthquake.
Known Colorado Quaternary Faults and Maximum Credible Earthquakes.

Figure from “The Challenges of Evaluating Earthquake Hazard in Colorado” by Vince Matthews
Aug. 23. 2011 Mineral VA M5.8
Aug. 23, 2011 Trinidad CO M5.3
Quaternary faults used in the national seismic hazard maps

Figure 2. Quaternary faults used in the national seismic hazard maps.
NEHRP Region 1 (SDC A) Boundary

Region 1 has been defined by NEHRP for Site Class B as being any area where $S_s \leq 0.25$ and $S_1 \leq 0.10$.

The boundaries of Region 1 for Site Classes C and D are then determined by applying the site coefficients and keeping the same upper limit of $S_s \leq 0.25$ and $S_1 \leq 0.10$. 
**Seismic Design Category, IBC 2012**

### TABLE 1613.3.3(2)
VALUES OF SITE COEFFICIENT $F_i$ *a*

<table>
<thead>
<tr>
<th>SITE CLASS</th>
<th>$S_i \leq 0.1$</th>
<th>$S_i = 0.2$</th>
<th>$S_i = 0.3$</th>
<th>$S_i = 0.4$</th>
<th>$S_i \geq 0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>1.7</td>
<td>1.5</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>D</td>
<td>2.4</td>
<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>E</td>
<td>3.5</td>
<td>3.2</td>
<td>2.8</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>F</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
</tr>
</tbody>
</table>

*a.* Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, $S_i$.

*b.* Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

### TABLE 1613.3.5(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD (0.2 second) RESPONSE ACCELERATIONS

<table>
<thead>
<tr>
<th>VALUE OF $S_{sa}$</th>
<th>I or II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{sa} &lt; 0.167g$</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>$0.167g \leq S_{sa} &lt; 0.33g$</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>$0.33g \leq S_{sa} &lt; 0.50g$</td>
<td>C</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>$0.50g \leq S_{sa}$</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

### TABLE 1613.3.5(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

<table>
<thead>
<tr>
<th>VALUE OF $S_{sa}$</th>
<th>I or II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{sa} &lt; 0.067g$</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>$0.067g \leq S_{sa} &lt; 0.133g$</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>$0.133g \leq S_{sa} &lt; 0.20g$</td>
<td>C</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>$0.20g \leq S_{sa}$</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>
Breakpoint values for use of SDC A

\[
S_{DS} = 0.167 = \frac{2}{3} \times F_A \times S_S \\
S_S = 0.25 / F_A \\
S_{D1} = 0.067 = \frac{2}{3} \times F_V \times S_1 \\
S_1 = 0.10 / F_V
\]

<table>
<thead>
<tr>
<th>Site Class</th>
<th>(F_A)</th>
<th>(S_S) (for SDC B or higher)</th>
<th>(F_V)</th>
<th>(S_1) (for SDC B or higher)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.8</td>
<td>0.31313</td>
<td>0.8</td>
<td>0.12563</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0.2505</td>
<td>1</td>
<td>0.1005</td>
</tr>
<tr>
<td>C</td>
<td>1.2</td>
<td>0.20875</td>
<td>1.7</td>
<td>0.05912</td>
</tr>
<tr>
<td>D</td>
<td>1.6</td>
<td>0.15656</td>
<td>2.4</td>
<td>0.04188</td>
</tr>
<tr>
<td>E</td>
<td>2.5</td>
<td>0.1002</td>
<td>3.5</td>
<td>0.02871</td>
</tr>
</tbody>
</table>
## Selected Front Range Spectral Acceleration Values, Site Class C

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1996 NSHMP</td>
<td>2002 NSHMP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>City</td>
<td>$S_S$</td>
<td>$S_1$</td>
<td>$S_S$</td>
<td>$S_1$</td>
</tr>
<tr>
<td>Aurora (80011)</td>
<td>0.186</td>
<td>0.057</td>
<td>0.207</td>
<td>0.055</td>
</tr>
<tr>
<td>Boulder (80302)</td>
<td>0.233</td>
<td>0.061</td>
<td>0.239</td>
<td>0.059</td>
</tr>
<tr>
<td>Castle Rock (80104)</td>
<td>0.192</td>
<td>0.059</td>
<td>0.216</td>
<td>0.057</td>
</tr>
<tr>
<td>Colo Springs (80903)</td>
<td>0.18</td>
<td>0.06</td>
<td>0.21</td>
<td>0.059</td>
</tr>
<tr>
<td>Denver (80202)</td>
<td>0.199</td>
<td>0.058</td>
<td>0.22</td>
<td>0.057</td>
</tr>
<tr>
<td>Ft. Collins (80521)</td>
<td>0.212</td>
<td>0.058</td>
<td>0.226</td>
<td>0.057</td>
</tr>
<tr>
<td>Golden (80401)</td>
<td>0.222</td>
<td>0.061</td>
<td>0.234</td>
<td>0.059</td>
</tr>
</tbody>
</table>
### Minimum of SDC B required if either $S_5 > 0.20875$ or $S_1 > 0.05912$

<table>
<thead>
<tr>
<th>Site Class C:</th>
<th>1996 NSHMP</th>
<th>2002 NSHMP</th>
<th>2008 NSHMP</th>
<th>2012 IBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>$S_5$</td>
<td>$S_1$</td>
<td>$S_5$</td>
<td>$S_1$</td>
</tr>
<tr>
<td>Greeley (80620)</td>
<td>0.18</td>
<td>0.054</td>
<td>0.194</td>
<td>0.052</td>
</tr>
<tr>
<td>Lakewood (80226)</td>
<td>0.211</td>
<td>0.06</td>
<td>0.226</td>
<td>0.058</td>
</tr>
<tr>
<td>Littleton (80120)</td>
<td>0.2</td>
<td>0.059</td>
<td>0.222</td>
<td>0.058</td>
</tr>
<tr>
<td>Pueblo (81001)</td>
<td>0.167</td>
<td>0.059</td>
<td>0.19</td>
<td>0.059</td>
</tr>
<tr>
<td>Trinidad (81082)</td>
<td>0.208</td>
<td>0.059</td>
<td>0.243</td>
<td>0.068</td>
</tr>
<tr>
<td>Average</td>
<td>0.199</td>
<td>0.059</td>
<td>0.219</td>
<td>0.058</td>
</tr>
</tbody>
</table>

**Variation of the Average from Site Class C breakpoint values**

- $-4.60\%$  
- $-0.60\%$  
- $4.80\%$  
- $-1.70\%$  
- $-5.90\%$  
- $-11.20\%$  
- $-6.60\%$  
- $3.80\%$
Colfax and Colorado Blvd 2012 IBC

Design Maps Summary Report

Report Title: Colfax and Colorado Blvd

Building Code Reference Document: ASCE 7-10 Standard
(which utilizes USGS hazard data available in 2008)

Site Coordinates: 39.74°N, 104.94°W

Site Soil Classification: Site Class C – “Very Dense Soil and Soft Rock”

Risk Category: I/II/III

USGS-Provided Output:

- $S_s = 0.179$ g
- $S_{hs} = 0.214$ g
- $S_{ds} = 0.143$ g
- $S_{s1} = 0.058$ g
- $S_{hs1} = 0.098$ g
- $S_{ds1} = 0.066$ g
Colfax and Broadway 2012 IBC

Design Maps Summary Report

Report Title: DENVER COLFAX AND BROADWAY
Sat May 24, 2014 15:58:41 UTC

Building Code Reference Document: ASCE 7-10 Standard
(which utilizes USGS hazard data available in 2008)

Site Coordinates: 39.74°N, 104.99°W

Site Soil Classification: Site Class C – “Very Dense Soil and Soft Rock”

Risk Category: 1/II/III

USGS–Provided Output:

\[
S_s = 0.182 \text{ g} \quad S_{ns} = 0.218 \text{ g} \quad S_{os} = 0.146 \text{ g}
\]

\[
S_1 = 0.058 \text{ g} \quad S_{n1} = 0.099 \text{ g} \quad S_{o1} = 0.066 \text{ g}
\]
Colfax and Wadsworth 2012 IBC
1988 UBC Zone Map (yellow)
SDC A boundary (Site Class B) (red)
Colorado Population Density

Source: U. S. Census Bureau
Census 2000 Summary File 1
Population by census tract.
$V_{S30}$ and Site Class
Factors influencing the use of Seismic Design Category A

- SDC B or higher
- SDC A

Risk Category
- Site (soil) class

Hazard Map
- Societal resistance to seismic design
- Hazard Map cutoff criteria
Colorado policy recommendations on the seismic design of schools

**Colorado Earthquake Hazard Mitigation Council:**
- SDC A shall not be used for schools in Colorado
- Design shall be for a minimum of SDC B.
- Where SDC B is already required, increase to SDC C.
- Exemptions for non-structural attachments do not apply.

**Western States Seismic Policy Council:**
- Increase the Risk Category of schools from III to IV and require a minimum of SDC C.
1613.5.2 Site class definition. .... Any assignment of site class NOT based on soil shear wave velocity, measured for the top 100 feet of the soil profile, shall comply with the following limitations:

• No site shall be assigned as Site Class A, B, or C when bedrock has an overburden depth greater than 15 feet, as measured from the top of bedrock to the finished grade.
• No site shall be assigned as Site Class A or B when bedrock has an overburden depth less than or equal to 15 feet, as measured from the top of bedrock to the finished grade.
• When the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be used unless the building official or geotechnical data that Site Class E or F soil is likely to be present at the site.

1613.5.6.3 Seismic design category, minimum. All buildings and structures in the City and County of Denver shall satisfy the requirements of seismic design category B, as a minimum.
Code change recommended

A code change to the IBC is recommended to *(eliminate Seismic Design Category A or)* allow the use of SDC A ONLY in areas of lowest seismic risk and to increase the Risk Category of schools from III to IV.
Structures permitted to be designed for Seismic Design Category A

\[ S_1 \leq 0.04 \text{ and } S_\varsigma \leq 0.15 \]
Quotes

“Civilizations exist based on geologic consent subject to change without notice.”  - William Durant

“Earthquake mitigation must be perceived as a ‘fundamental good.’”  - Frank McClure