Uluslararası Çelik ve Alüminyum Yapılar Konferansında (ICSAS 07) Temmuz 2007’de İngiltere’nin Oxford kentinde sunulmuştur...
FUNDAMENTAL PERIODS OF ECCENTRICALLY BRACED STEEL FRAMES WITH SHEAR LINKS

by
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Today one of the widely used earthquake resistant design procedures is Equivalent Lateral Force Procedure, in which determination of the design base shear of a building depends mainly on the fundamental period.

However, the fundamental period of a building that yet to be designed is not known at the beginning of the design process.
Hence, empirical period formulas are specified in most of the seismic codes. Generally, the form of these formulas is the following:

$$T = \alpha H^\beta$$

Here, $\alpha$ and $\beta$ are dependent on the structural type and material of the buildings. $H$ is the height of the building.
This general form is adopted by Goel and Chopra (1997) and they determined the constants $\alpha$ and $\beta$ for the upper and the lower bounds of the fundamental period by regression analysis of the measured data. They suggested that the lower bound is suitable for estimating the period conservatively, and the upper bound should be used for limiting the calculated period.
A study regarding the concentrically braced frames (CBFs) designed with a computer code is given by Tremblay (2005) in order to propose reasonable lower-bound period values.

Chrysanthakopoulos, Bazeos and Beskos (2006) have provided approximate formulae for determining by hand with a high enough accuracy the first three natural periods of steel unbraced and braced frames.
In the current codes and standards like ASCE 7-05, given approximate period ($T_a$) values are the fore mentioned lower bounds. In ASCE 7-05 the ratio between the upper and lower bound period values is represented by the coefficient $C_u$. 
THE USE OF APPROXIMATE PERIODS

- Fundamental period, which is used to determine the design base shear of a building that is yet to be designed, is not known at the beginning of the design process. Hence, $T_a$ value can be used to determine the base shear. Afterwards, resultant period value can be calculated by using the mechanical and geometrical properties of the building.

- For a designed building, the calculated period value shall not exceed the upper limit of $C_u \times T_a$. 
FINAL CHECKS IN EBF DESIGN

\[ T < C_u T_a \]

\[ \gamma_p = \frac{L}{e} \theta_p \leq 0.08 \]

\[ \theta_p = C_d \frac{\Delta}{h} \leq 0.02 \]

\( \Delta = \) maximum elastic story drift

\( C_d = \) deflection amplification factor

\( \theta_p = \) predicted maximum inelastic story drift ratio

\( \gamma_p = \) predicted maximum inelastic link rotation

\( L = \) span length

\( e = \) link length

\( T = \) fundamental period of the designed building (resultant period)

Rigid-Plastic Mechanism Assumption for Capacity Based Design (Elastic deformations are neglected in this assumption.)
Given final checks do not consider the economy of the design. A designer can calculate the fundamental period values of the building in the iterative design steps to reach a more economical design.

While repeating the design in iterations, spectral acceleration value in the last design step $S_a^\text{after}$, should be lower than that obtained from the preceding step $S_a^\text{before}$. In other words, the lateral forces to which the designed building will be subjected, should be lower than the forces used for the design, $S_a^\text{after}/ S_a^\text{before} \leq 1$. If a designer chooses to perform an economic design, in addition to the final checks, the ratio $S_a^\text{after}/ S_a^\text{before}$ should also be near unity, additionally.
In this study, all the designed frames satisfy the final checks. In addition, the design process is continued and repeated iteratively until the following economy condition is reached:

\[ 0.95 \leq \frac{S_a\text{after}}{S_a\text{before}} \leq 1 \]

Hence, for one frame geometry, two different frames are designed, the one satisfying the final checks and the other one satisfying both the final checks and the above condition. For the first design case, \( T_a \) is used to determine the design base shear; and the resultant period of the designed building is denoted as \( T \). For the iterative design case, the period value corresponding to the design base shear of the last iteration step is denoted as \( T'_1 \); and the resultant period of the designed building is denoted as \( T_1 \).
The investigations in the literature are related with the ratio of $T/T_a$. The period ratio of $T'/T_a$ for economic design has not been investigated so far systematically, known to the writers. Besides, little interest has been given to the EBFs, relatively to the other structural system types. In this study, this ratio is investigated systematically and tried to be given in terms of the building properties.
### Properties of the designed frames

<table>
<thead>
<tr>
<th>Period used for design</th>
<th>Num. of stories</th>
<th>Plan Area</th>
<th>Span Length</th>
<th>Link Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_a$</td>
<td>3</td>
<td>500 (m²)</td>
<td>700 (cm)</td>
<td>60 (cm)</td>
</tr>
<tr>
<td>$T'_1$</td>
<td>6</td>
<td>850</td>
<td>825</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>1200</td>
<td>950</td>
<td>100</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1075</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1200</td>
<td></td>
</tr>
</tbody>
</table>

Total number of frames = $2 \times 3 \times 3 \times 5 \times 4 = 360$
Fundamental period values of nearly the entire three storey building frames used in this study are in the constant spectral acceleration region of the design spectrum. Hence, the ratio $T'_1/T_a$ becomes unity. This means the design with the $T'_1$ value will not have economical advantage on the design with $T_a$. Thus, $T'_1/T_a$ ratios are not given here for three storey buildings, but *they are given for the remaining frames.*
For the building frames $T'_1/T_a$ ratios of which are bigger than 1, the design based on the period value of $T'_1$ will be more economical than the design with the period of $T_a$. 
Results of the parametric studies – $T'_1/T_a$ ratios – 6 storey frames

Fundamental period ratios of $T'_1/T_a$ for the designed 6-storey EBFs with the plan areas of (a) 500m$^2$ (b) 850 m$^2$ (c) 1200 m$^2$
Results of the parametric studies – $T'_1/T_a$ ratios – 9 storey frames

Fundamental period ratios of $T'_1/T_a$ for the designed 9-storey EBFs with the plan areas of (a) 500 m$^2$ (b) 850 m$^2$ (c) 1200 m$^2$
Regarding the 9-storey EBFs, there are more frames with the ratios of $T'_1/T_a$ below the unity. This is because the final check conditions dominate the design hence; economy condition is generally not effective. Namely, the number of the economic designs will be lower than that of the 6-storey frames.
Parametric studies are utilised to compare the below values obtained by the two design procedures:

- Frame weights
- Mean values of maximum inelastic base shears obtained under the scaled earthquake records corresponding to the link rotation capacity
- Coefficients of variation of the maximum inelastic base shears
Results of the parametric studies – 6 storey frames –

For the period ratios of $T'_1/T_a$ for all the designed 6-storey EBFs (a) frame weight ratios (b) ratios of mean inelastic maximum base-shears (c) COV values
Results of the parametric studies – 9 storey frames –

For the period ratios of $T'_1/T_a$ for all the designed 9-storey EBFs (a) frame weight ratios (b) ratios of mean inelastic maximum base-shears (c) COV values
Results of the parametric studies

–COMPARISON OF FRAME WEIGHTS –

$W_1$ is the weight of the frame designed with the period of $T'_1$ and $W_a$ is the weight of the same frame designed with the period of $T_a$. With the increasing $T'_1/T_a$ ratios, the frame weight ratios of $W_1/W_a$ decrease as expected. $W_1$ values can be 21% lighter than the $W_a$ values for 6-storey frames and 12% lighter for 9-storey frames.
Results of the parametric studies

–COMPARISION OF MAXIMUM INELASTIC BASE SHEARS –

$V_1$ is the mean value of the maximum inelastic base shears obtained for the 20 earthquakes for the frame designed with $T'_1$ and $V_a$ is for the frame designed using $T_a$. The general trend of $V_1/V_a$ is similar to that of the ratio of $W_1/W_a$ for both 6-storey and 9-storey frames. The lighter frames are subjected to the lower inelastic base shears. The decrease in max inelastic base shear can reach to 30% for a few frames, but it is generally smaller than 20%.
Obtained coefficient of variation values (COV) of the maximum inelastic base shears are lower than 0.1 for both 6-storey and 9-storey frames. However, slightly bigger COV values are obtained for the 9-storey EBFs.
Regarding the economic design, $T'_1$ values may be preferred for the design instead of the $T_a$ values for the 6-storey EBFs.

For 9-storey EBFs, there are more frames with the ratios of $T'_1/T_a$ below the unity. This is because generally final check conditions dominate the design hence; economic design condition may not be effective. Namely, the number of the economic designs will be lower for 9-storey frames.

For 3-storey buildings iterative design does not produce economical solutions, because of the constant spectral acceleration region of the design spectrum.
Thank you for your attention…