CSI, 2012-05-12

Effect of Rigid Diaphragms on Buckling of a Cruciform Structure

Summary and conclusions:

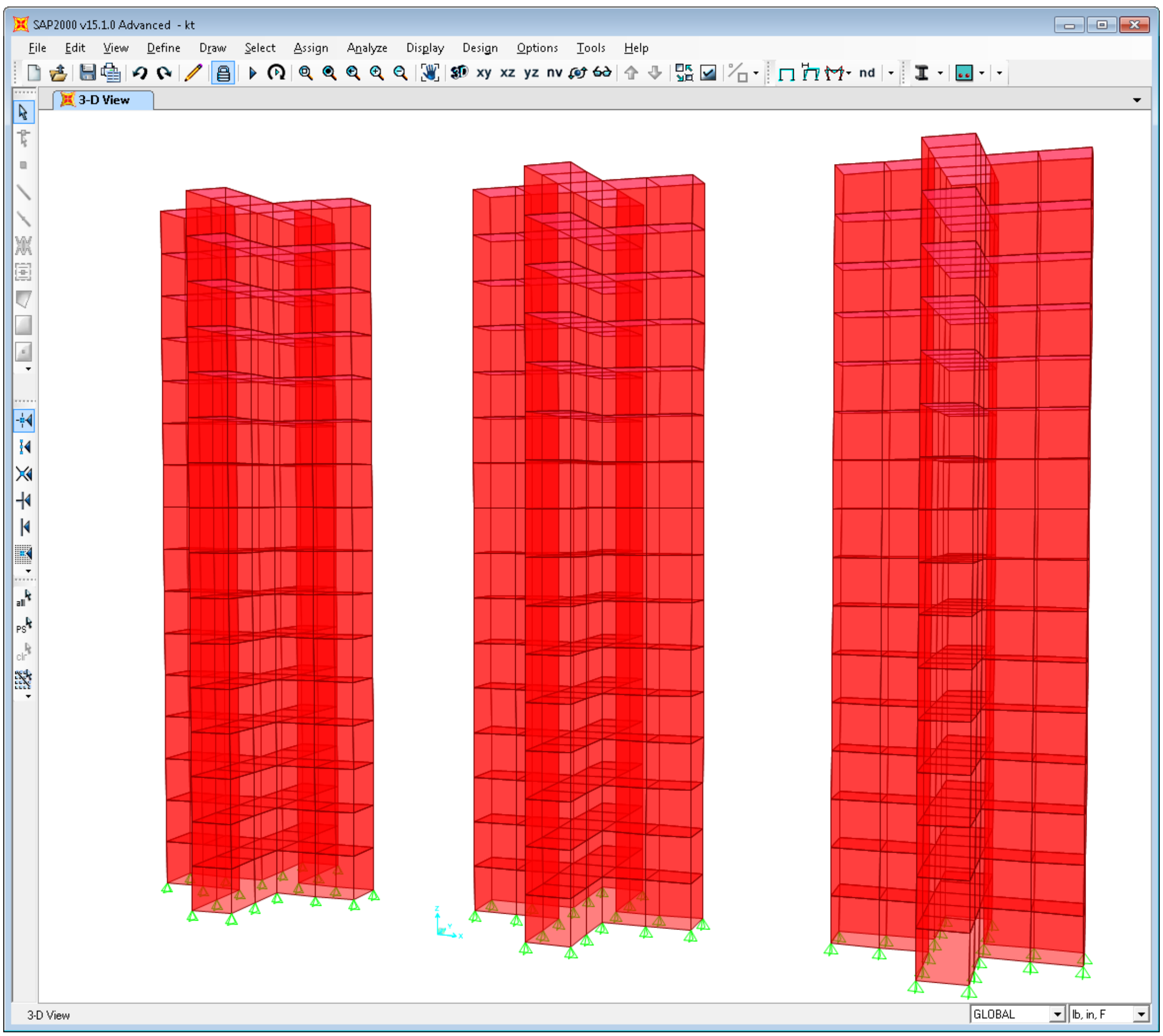
- A simple model of a tall cruciform building with vertical walls and flat slabs exhibits very different buckling behavior depending on whether or not rigid diaphragms are used for the floors.
- With rigid diaphragms, torsional buckling of the whole structure is one of the fundamental buckling modes.
- Without rigid diaphragms, torsional buckling occurs at a higher buckling factor.
- Making the slab stiffer in plane, but without using a diaphragm constraint, does not substantially change this behavior.
- The presence of the diaphragm constraint allows significant horizontal compressive stresses to develop in the walls. These are due to Poisson's effect under gravity load, and are sustained by the infinitely stiff horizontal diaphragm.
- Without the diaphragm, even with a very stiff slab, the Poisson stresses are less pronounced.
- The horizontal compressive stresses in the walls cause out-of-plane instability, tending to cause torsional buckling.
- With the diaphragm constraint, the corresponding tension in the slab is implicitly developed but no slab stresses are computed. Therefore, there is no tension stiffening included in the P-delta formulation.
- With the stiff or flexible diaphragm, the tension in the slab that resists the horizontal Poisson stresses is included in the P-Delta effect. This tension stiffening counteracts the softening due to the compressive stresses in the wall.
- Vertical compressive stresses do not have a counteracting tensile stress in the slab, and will tend to cause torsional and other types of buckling.
- To prove this analysis, setting Poison's ratio to zero causes the model with diaphragm constraints and the model with a stiff slab to be essentially identical, with a high torsional buckling factor.
- All conclusions above are for the particular model of this study. Whether or not they apply to any other model or real structure is a decision to be made by the engineer.
- Whether or not these horizontal stresses can be sustained in a real structure is a modeling decision for the engineer. However, the effect on behavior is very significant and must be considered carefully.

SAP2000 Model:

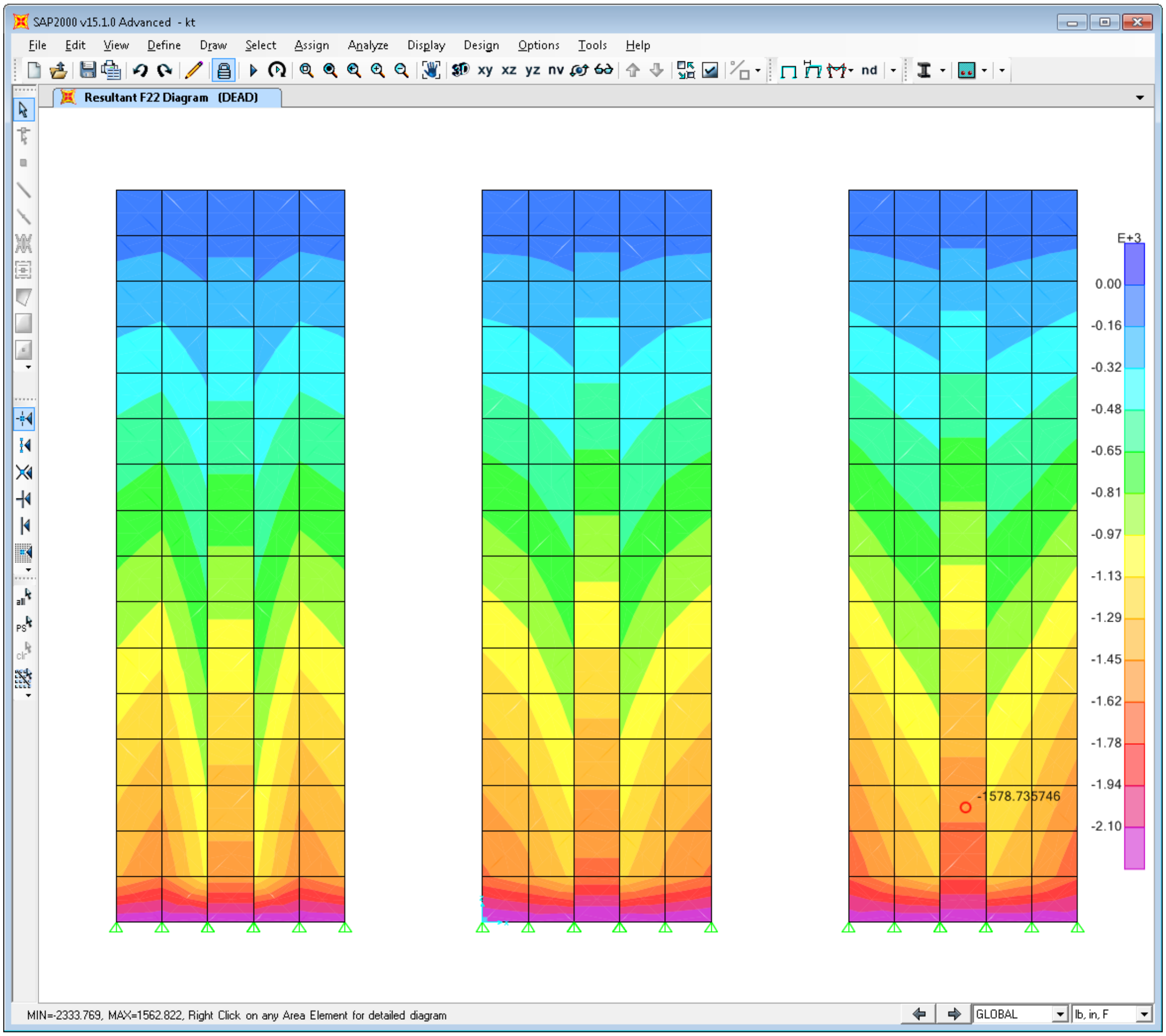
- All walls and floors are 12’ x 12’ x 8” concrete thin shell elements.
- 16 stories
- Buckling under self-weight load

Three similar structures:

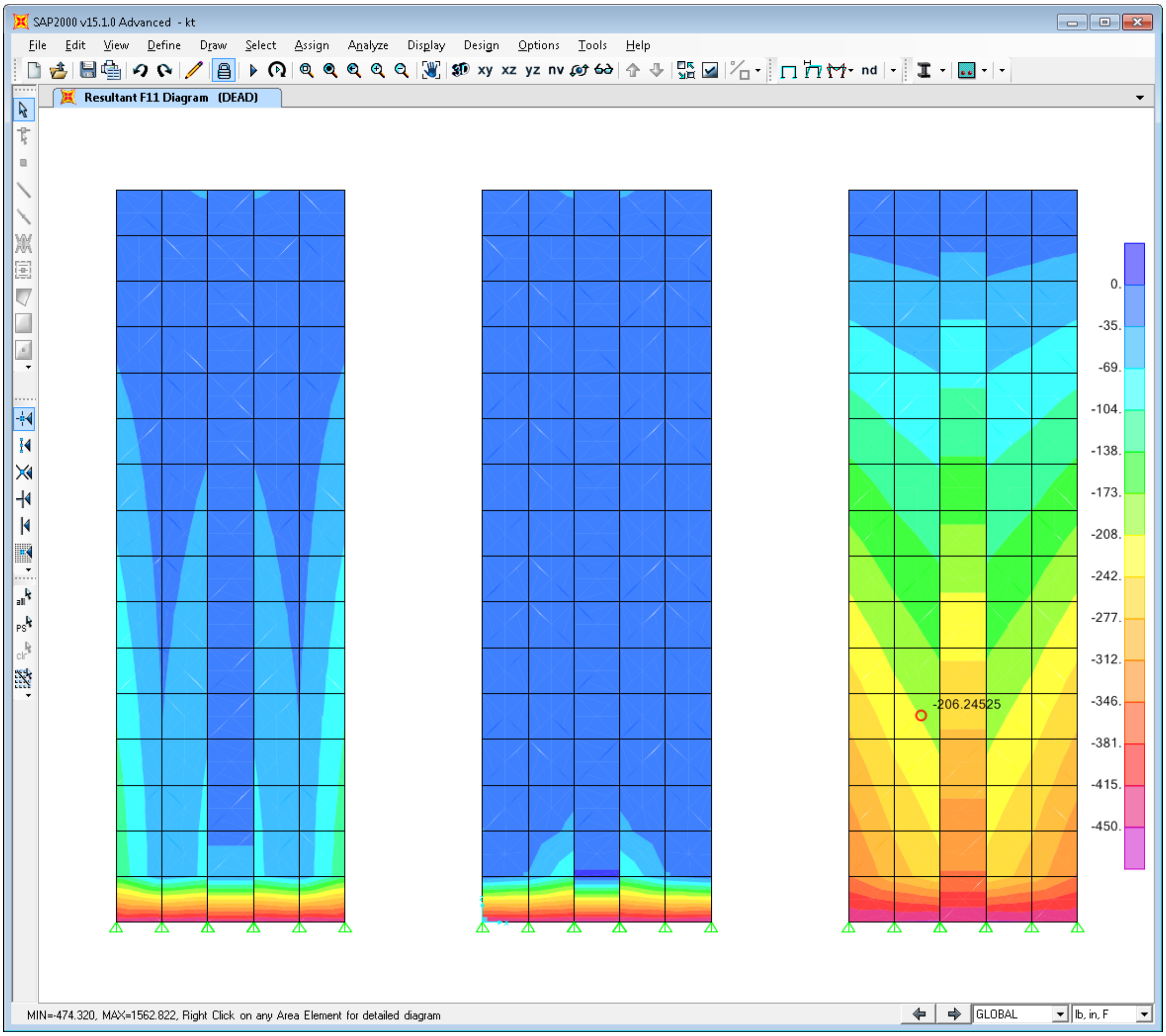
- Center – No modification
- Left – Slab stiffness modifiers of 1000 for F11, F22, F12
- Right – Diaphragm constraints



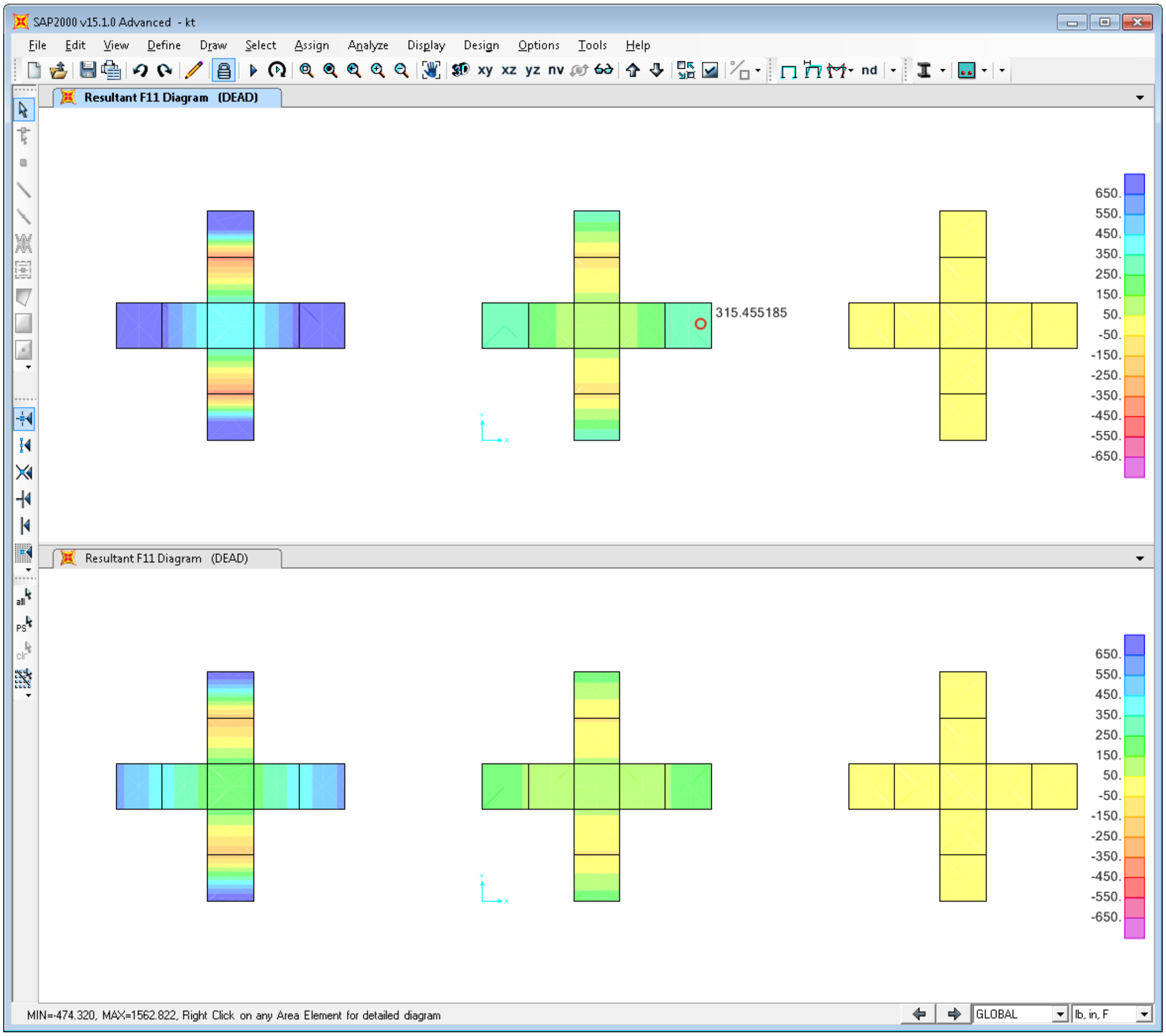
Vertical stresses under self-weight:



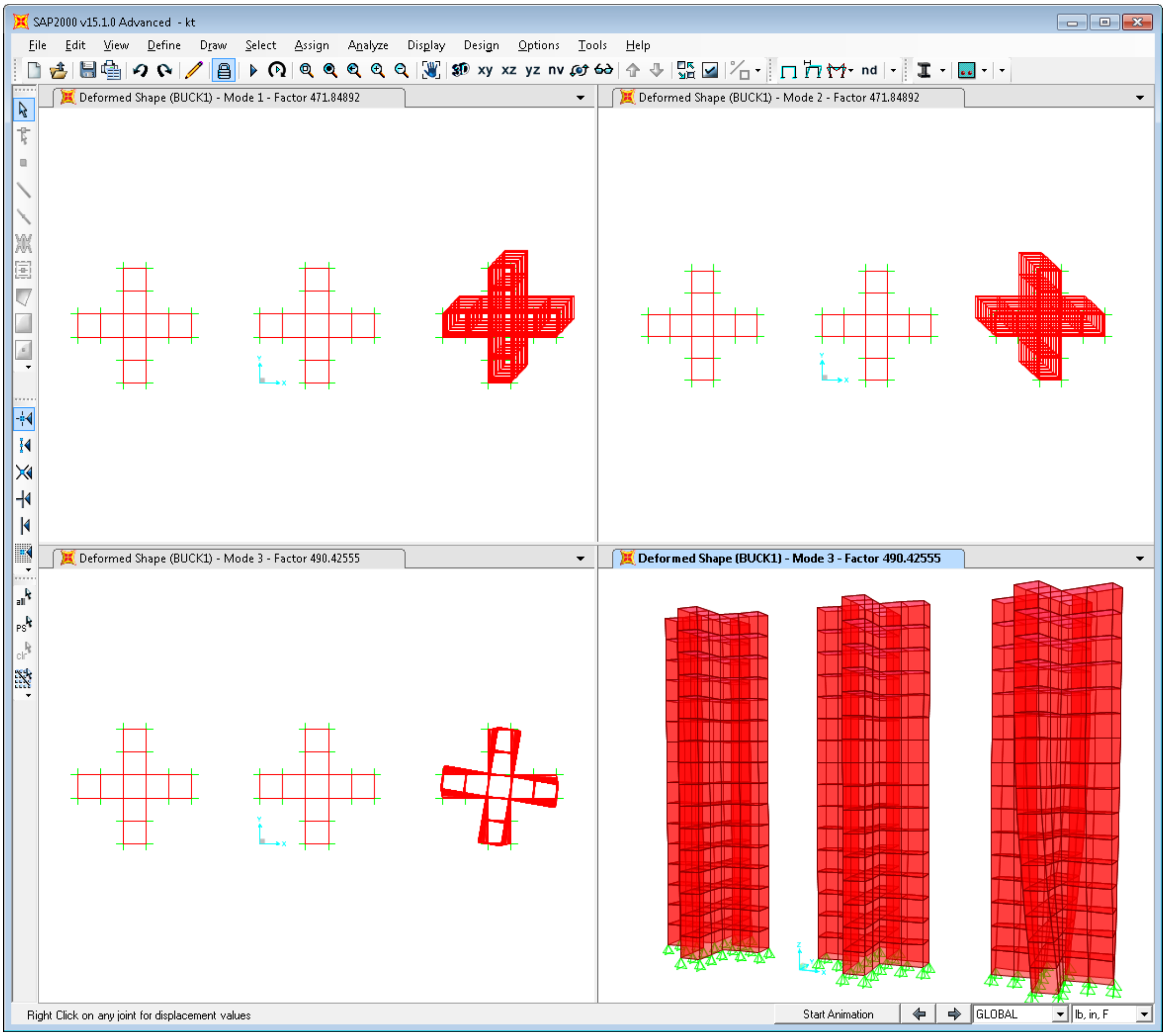
Horizontal stresses under self-weight:



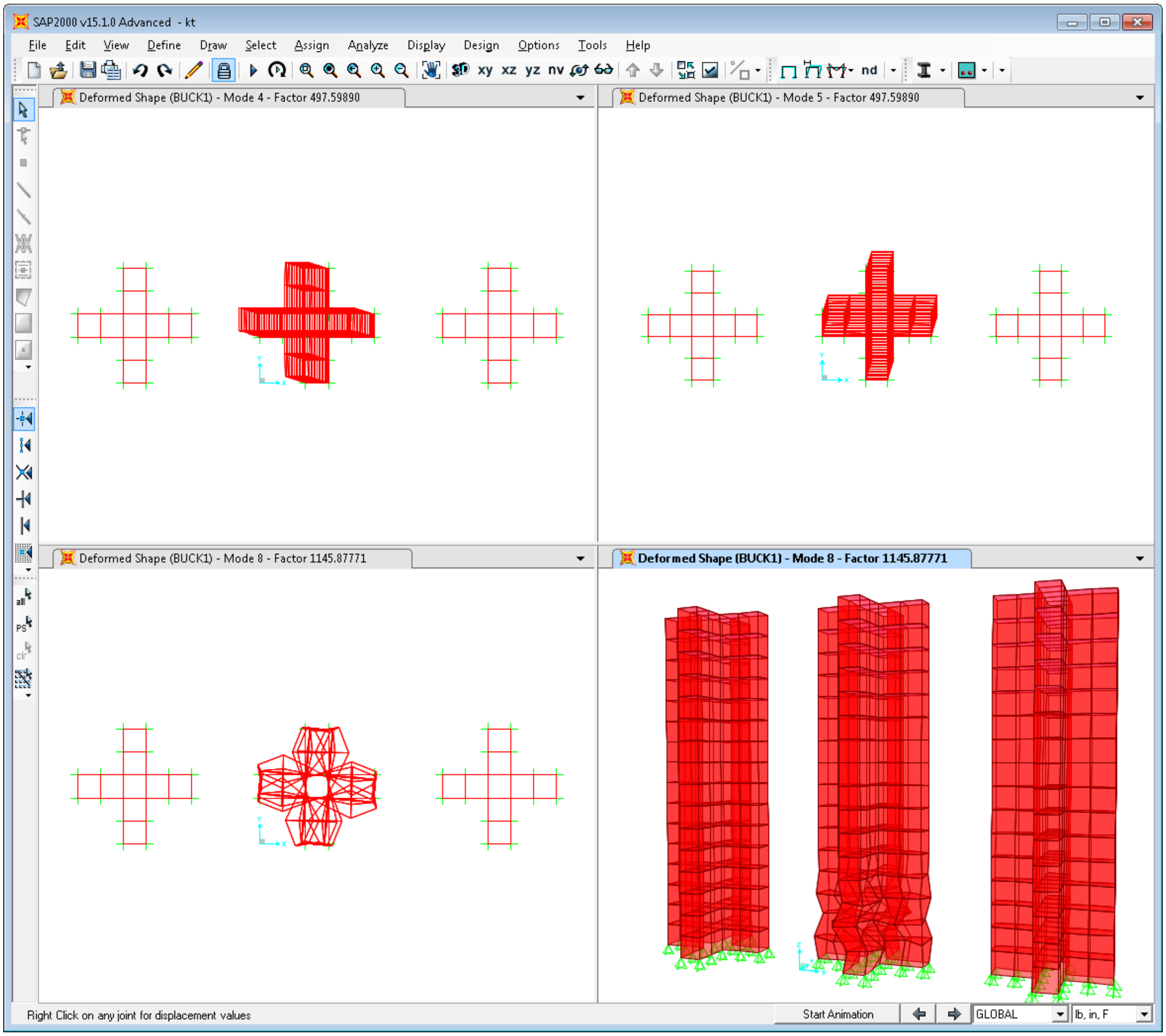
Slab stresses at Story 2 (top) and Story 8 (bottom):



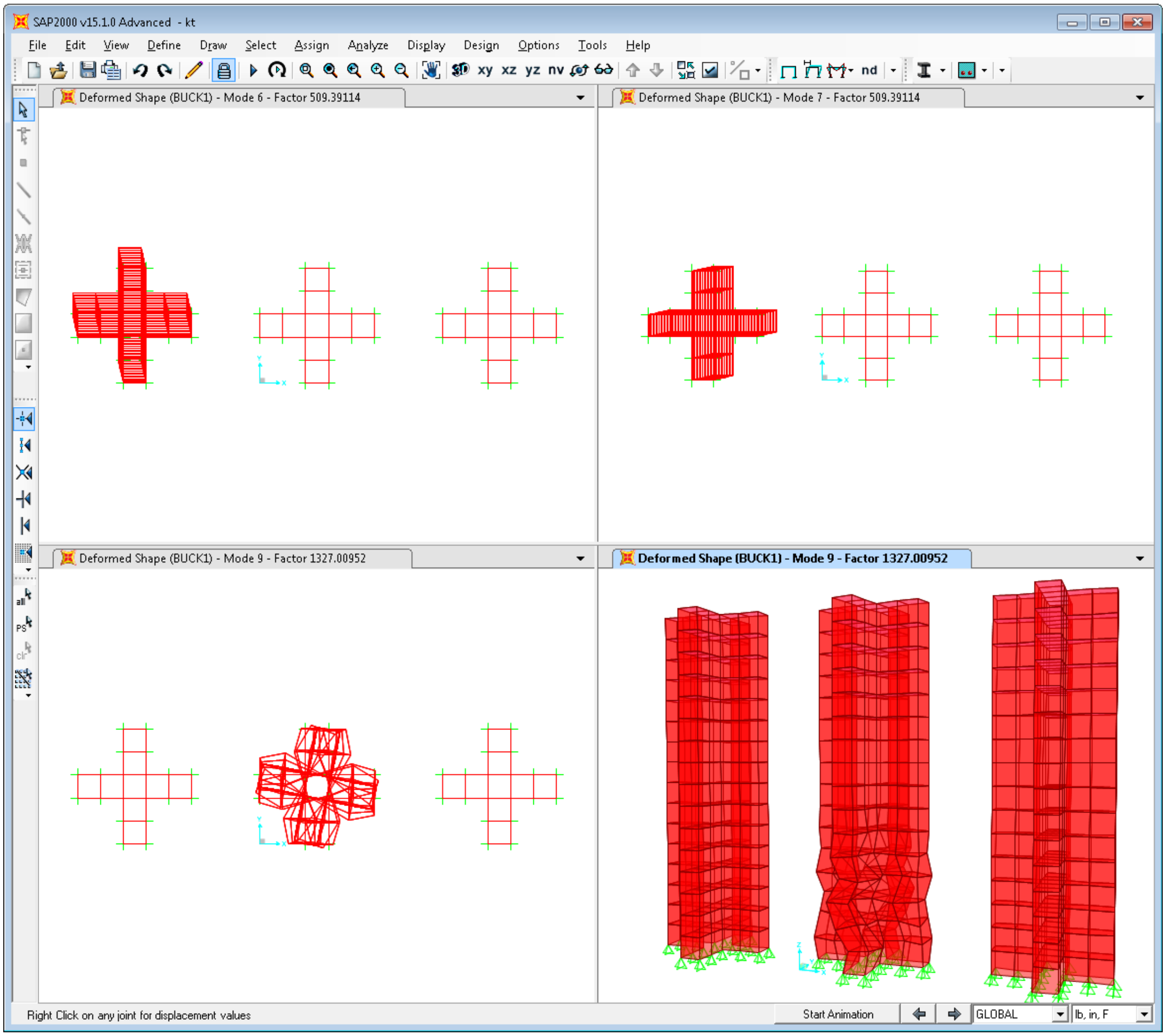
Buckling modes 1, 2, 3:



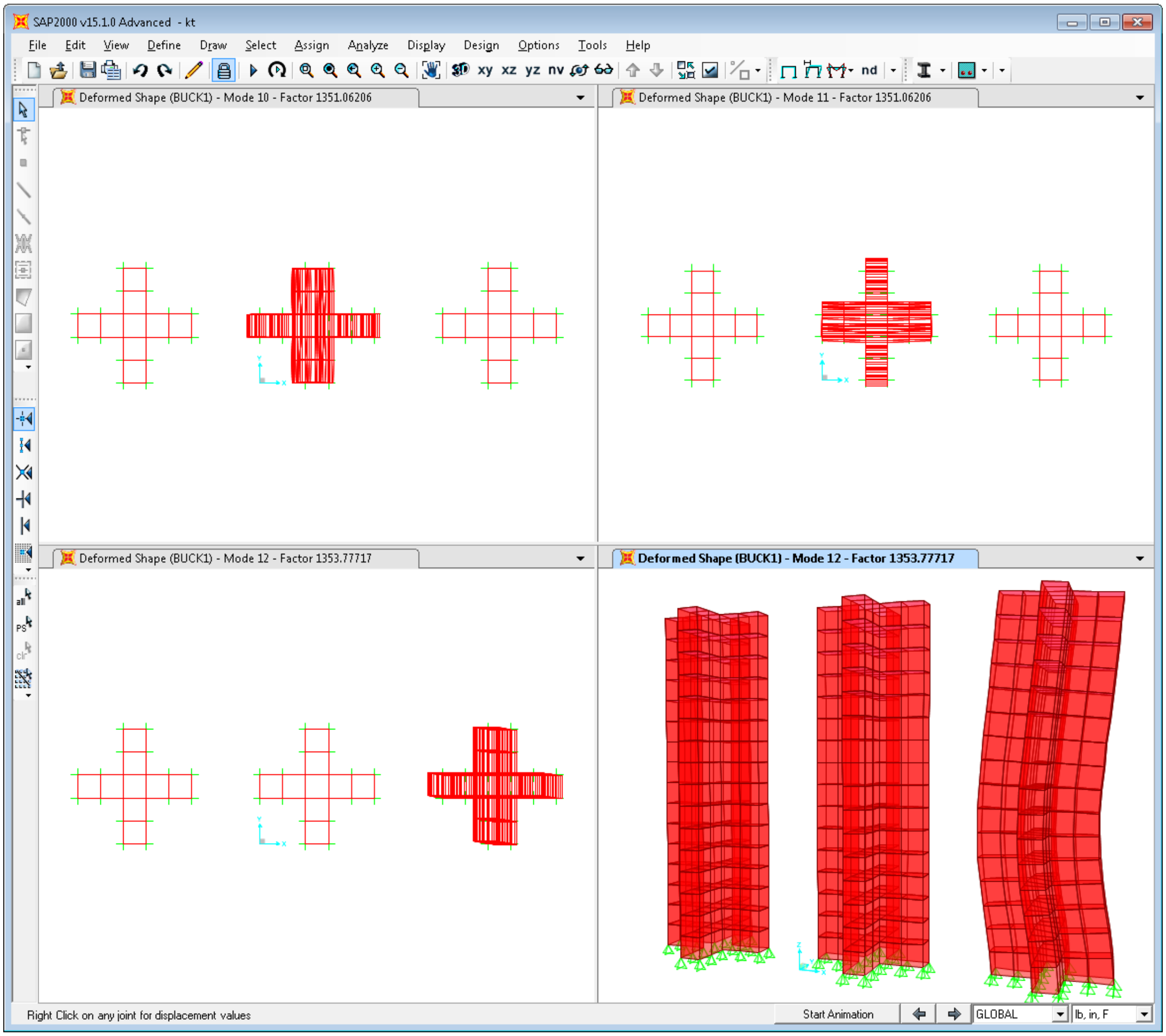
Buckling modes 4, 5, 8:



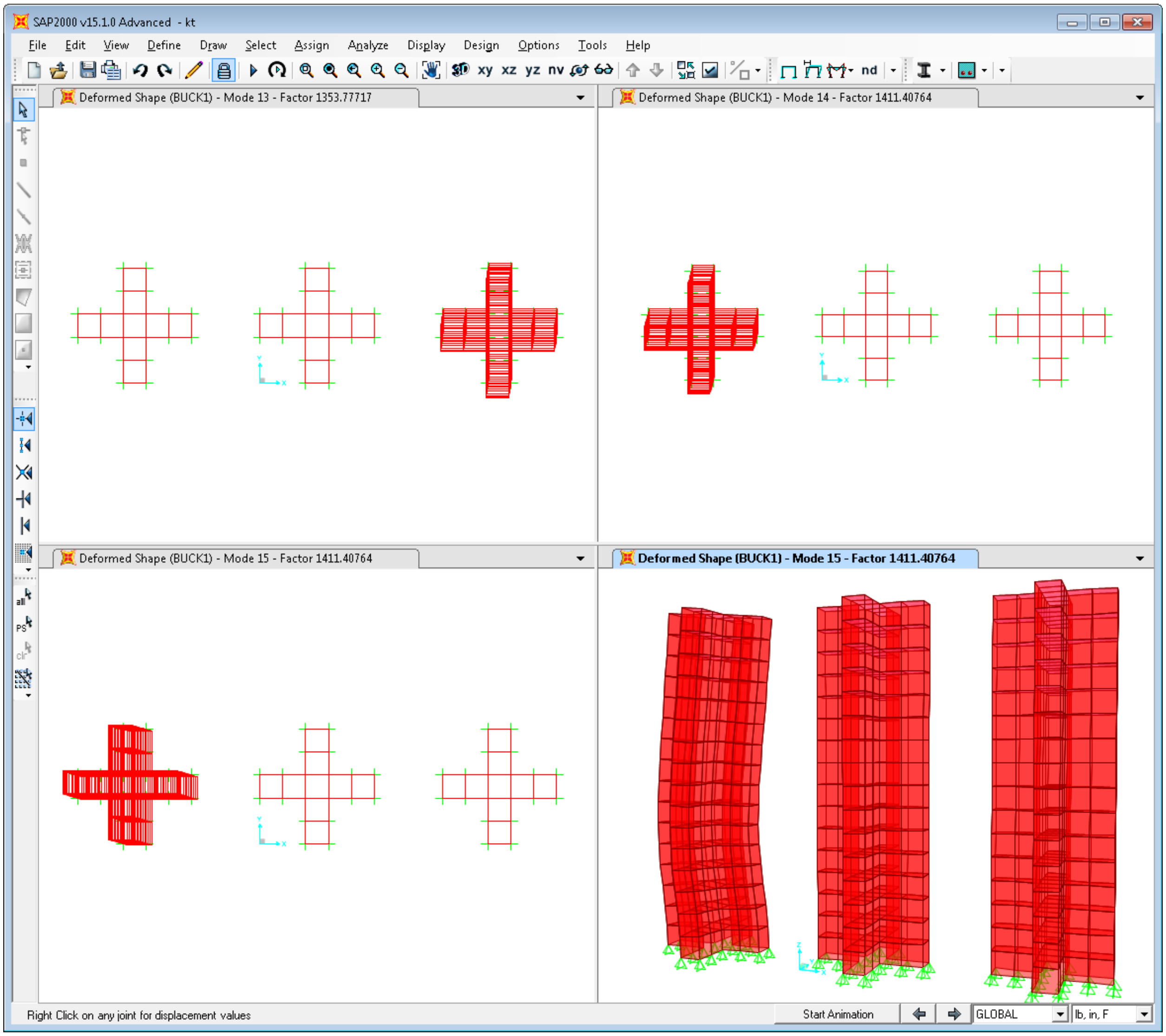
Buckling modes 6, 7, 9:



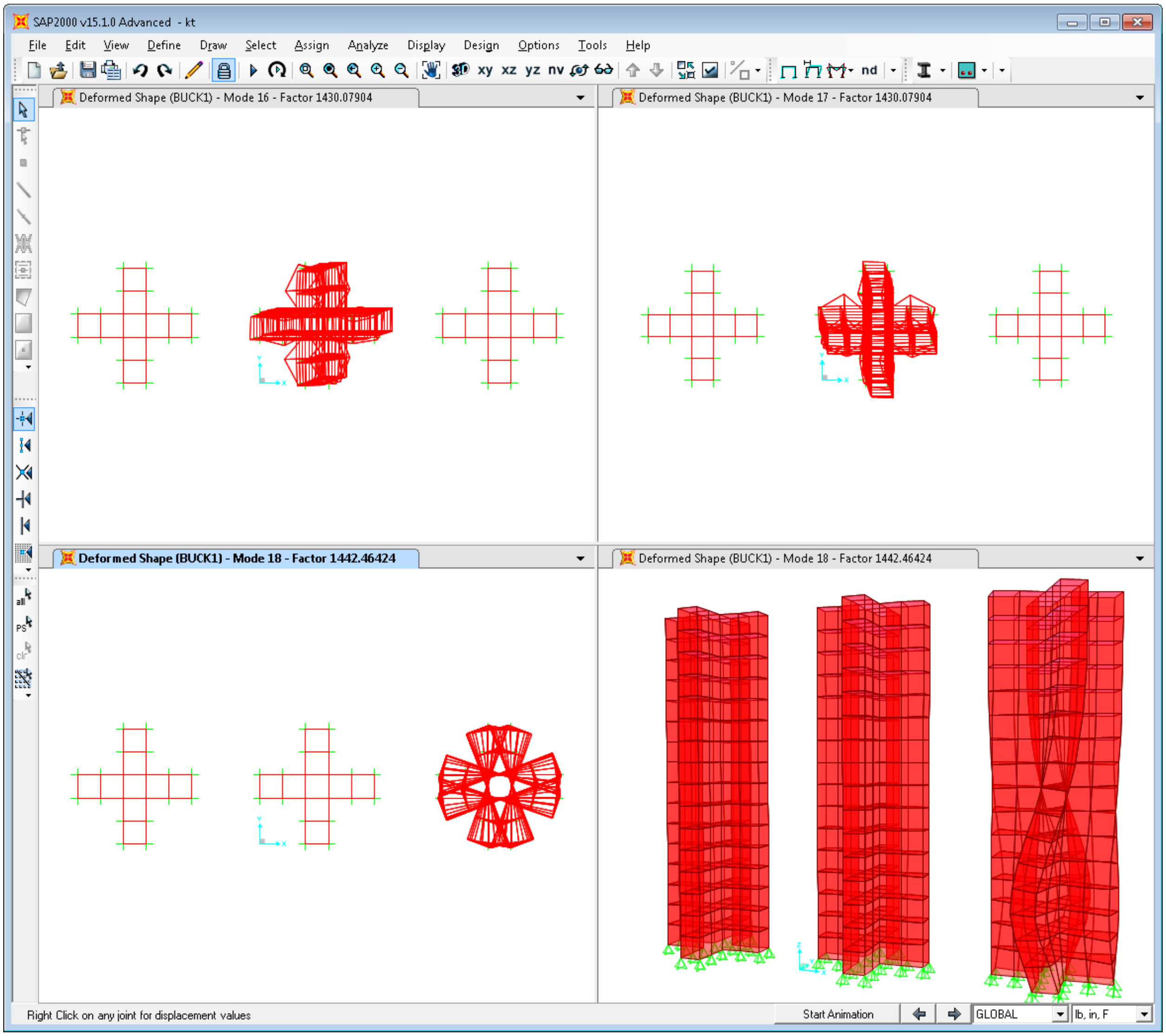
Buckling modes 10, 11, 12:



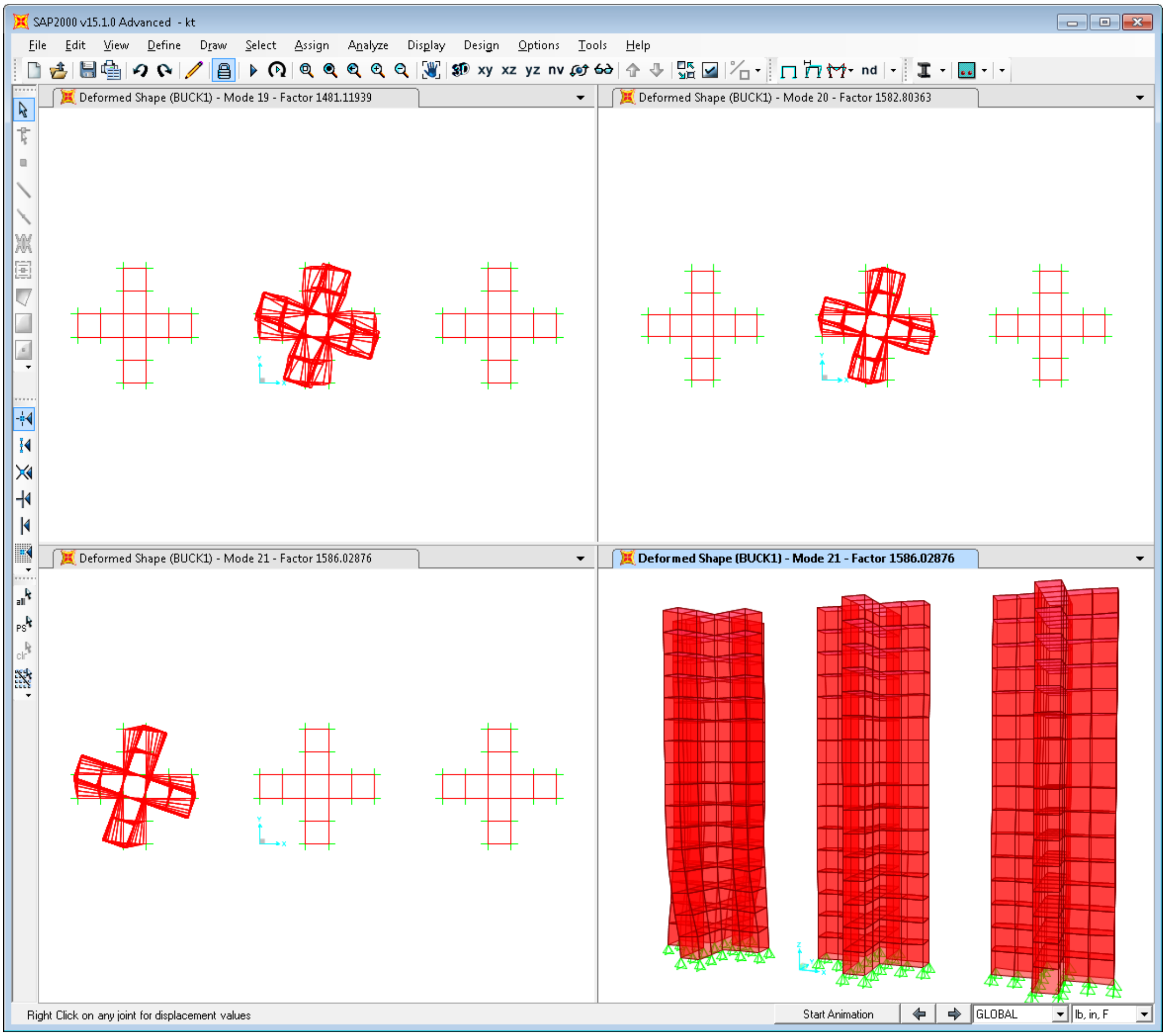
Buckling modes 13, 14, 15:



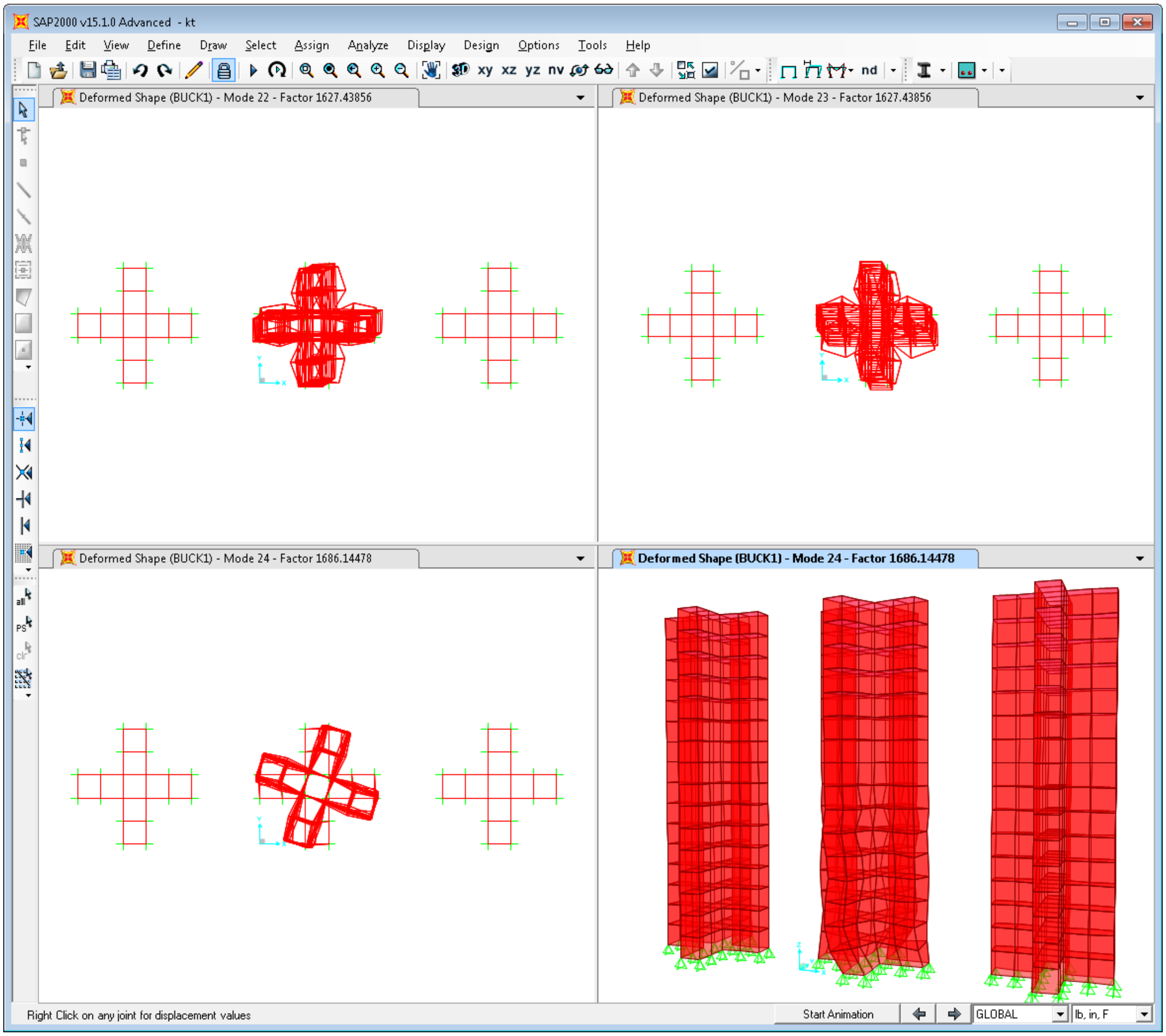
Buckling modes 16, 17, 18:



Buckling modes 19, 20, 21:



Buckling modes 22, 23, 24:



Buckling deformation of Stories 2 and 8:

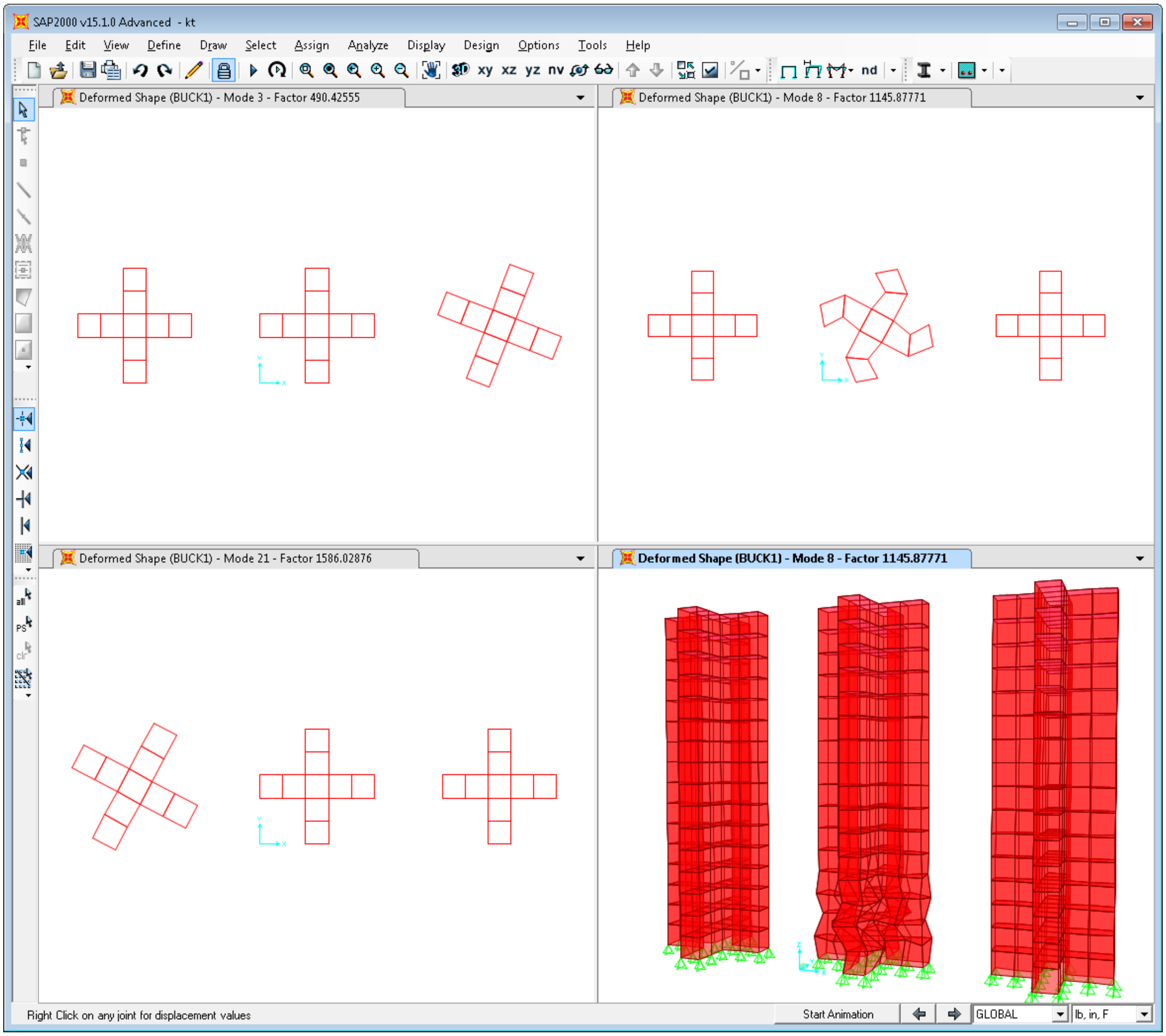


TABLE: Buckling Factors			
Mode	Factor	Tower	Type
1	472	Diaphragm	Bending-1
2	472	Diaphragm	Bending-1
3	490	Diaphragm	Torsion-1
4	498	Flexible	Bending-1
5	498	Flexible	Bending-1
6	509	Stiff	Bending-1
7	509	Stiff	Bending-1
8	1146	Flexible	Crunch-1
9	1327	Flexible	Crunch-2
10	1351	Flexible	Bending-2
11	1351	Flexible	Bending-2
12	1354	Diaphragm	Bending-2
13	1354	Diaphragm	Bending-2
14	1411	Stiff	Bending-2
15	1411	Stiff	Bending-2
16	1430	Flexible	Crunch-Bending-1
17	1430	Flexible	Crunch-Bending-1
18	1442	Diaphragm	Torsion-2
19	1481	Flexible	Crunch-Torsion-1
20	1583	Flexible	Crunch-Torsion-2
21	1586	Stiff	Torsion-1
22	1627	Flexible	Crunch-Bending-2
23	1627	Flexible	Crunch-Bending-2
24	1686	Flexible	Crunch-Torsion-3