Modeling of flying buttresses with rigid blocks

1.1 Flying Buttress

The flying buttress is a specific form of buttress composed of an arched structure that extends from the upper portion of a wall to a pier of great mass, in order to convey to the ground the lateral forces that push a wall outwards. These forces arise from vaulted ceilings of stone, and from wind-loading on roofs [1].

The flying buttresses of Notre-Dame Cathedral (Paris, France) are shown in Figure 1. A schematic cross section is shown in Figure 2. The Notre Dame Cathedral Paris didn't originally have flying buttresses included in its design. But after the construction of the cathedral began, the thinner walls (popularized in the Gothic style) grew ever higher and stress fractures began to occur as the walls pushed outward. The cathedral's architects, to fix the problem, built supports around the outside walls. Later additions continued the pattern. The Notre-Dame Cathedral was among the first buildings in the world to use the flying buttress [2].

Figure 1 Buttresses of Notre-Dame Cathedral.

214 ANDREW J. TALLON

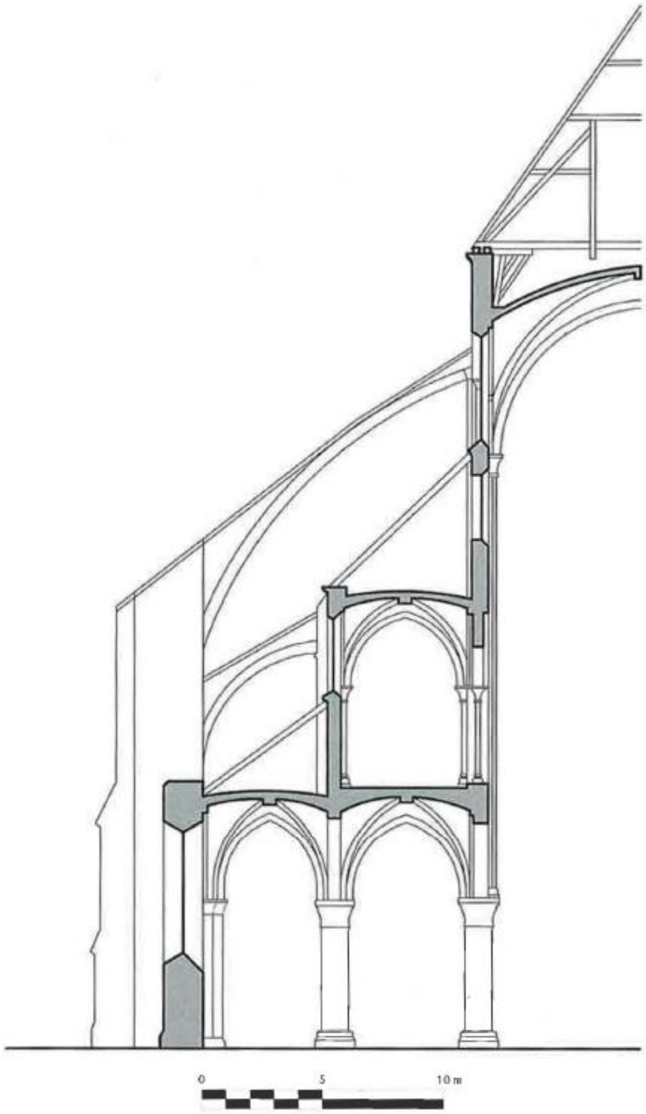

Figure 15.2 Paris, Notre-Dame, reconstruction section through S6, showing vaults though S5

Figure 2 Cross-section of flying buttresses of Notre-Dame Cathedral [3].

1.2 Modeling Procedure

The span of the arch is approximately 11 m and the height is 34 m. The buttresses are modelled as 1 m thick blocks (approximately equal to the true thickness). The gothic arch at the top represents the continuous vault; so, its weight is multiplied by 6 m, the bay spacing, so that the correct outward push is applied to the pillars. The geometry is simplified compared to the true geometry (Figure 1 and Figure 2). The *3DEC* model is shown in Figure 3.

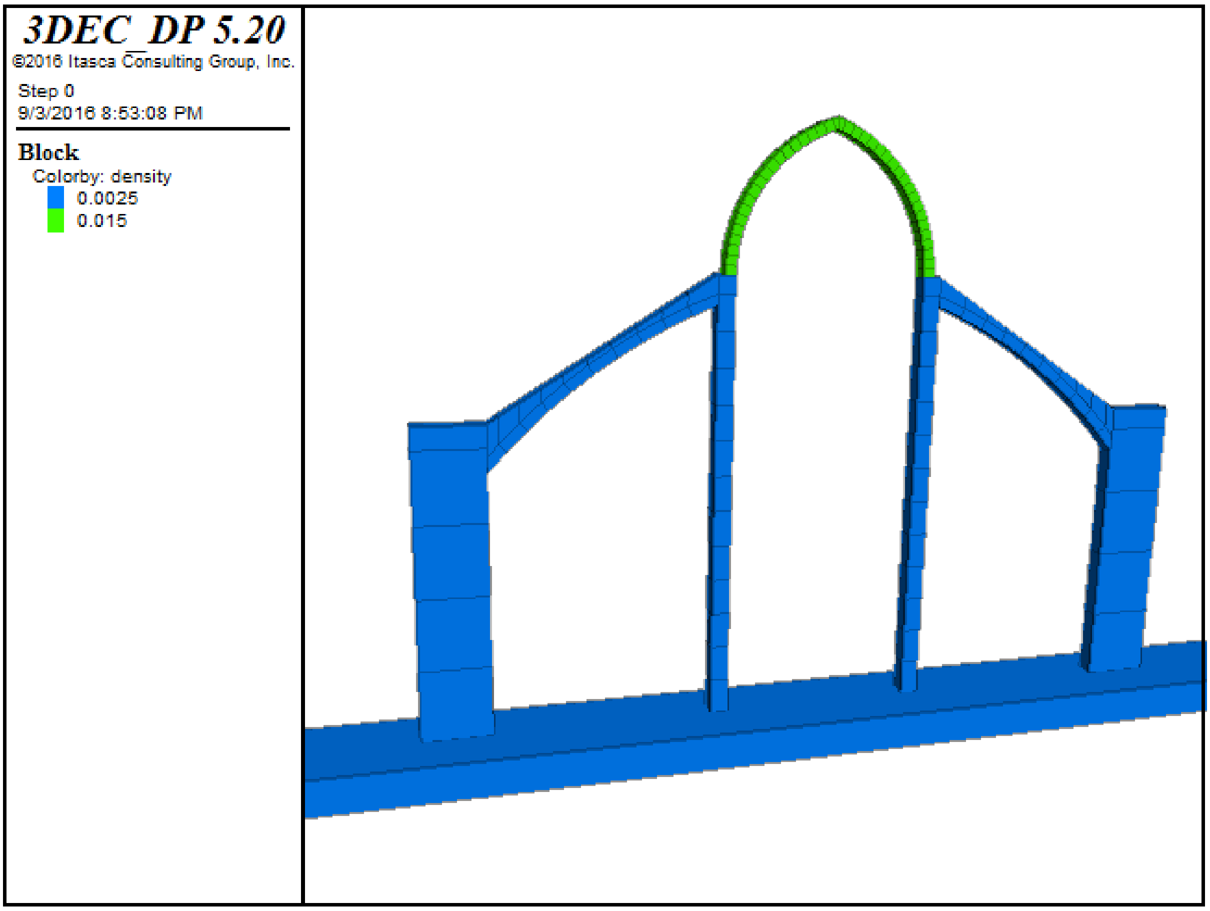

Figure 3 3DEC model of flying buttresses.

The density of the blocks is set to 2500 kg/m^3. As explained above, the density of the arch is set to six times this value (15,000 kg/m^3). The joint friction is set to 35° — except the joints between the pillars and the buttresses, which were given infinite strength (elastic).

1.3 Solution and Results

The model is configured to be dynamic to ensure accurate calculate of moments of inertia for the blocks. However, since only a static solution is required, the dynamic calculation is set to off (high damping will be present). Gravity is turned on and the model with buttresses is solved to equilibrium. Displacements are shown in Figure 4. The same model is then run without buttresses. The model is stopped after 20,000 steps due to obvious collapse. The evolution of failure is shown in Figure 5.

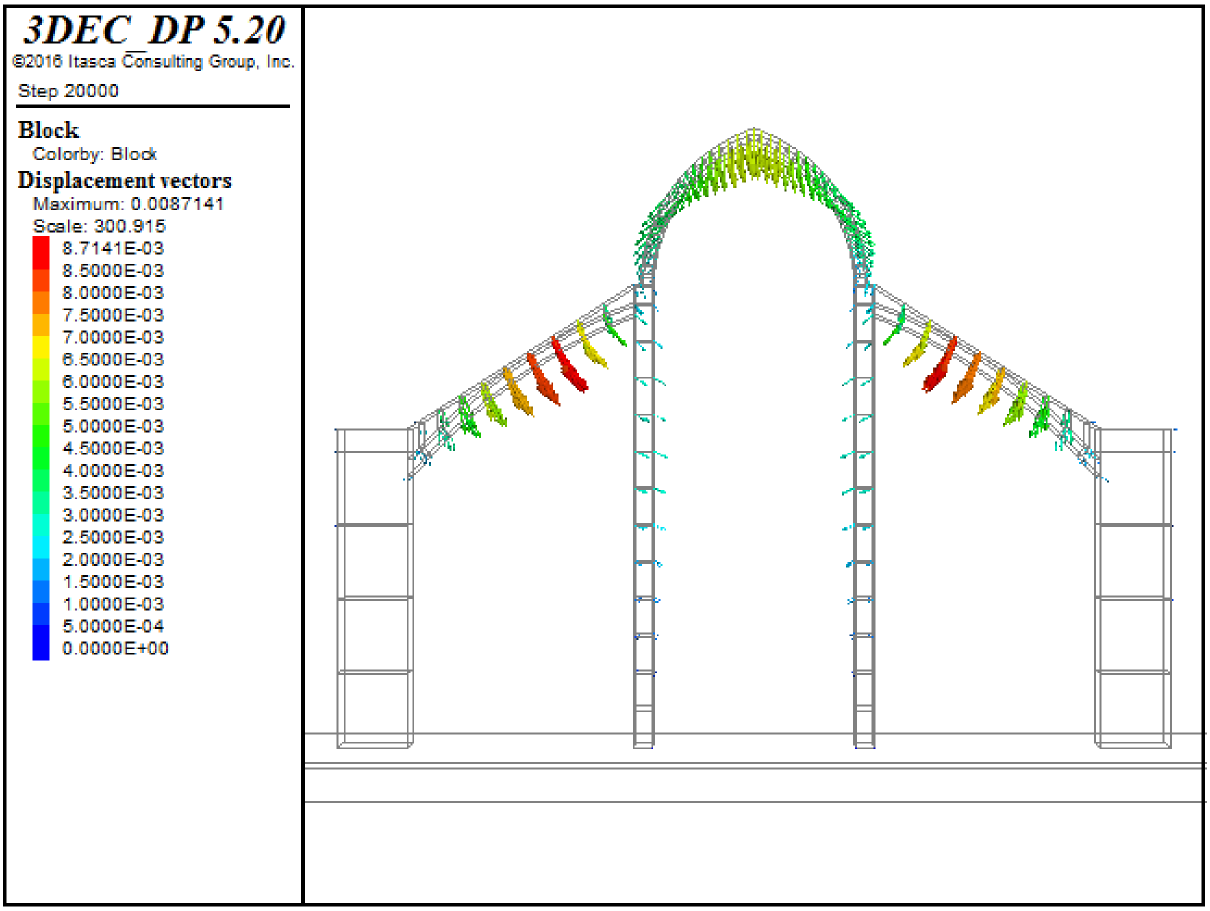

Figure 4 Displacements in the model with flying buttresses.

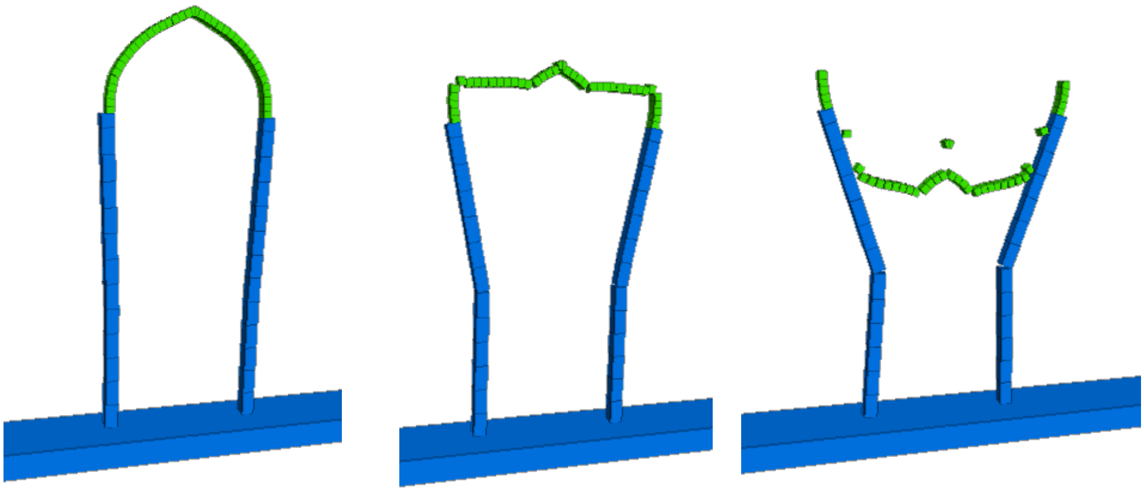

Figure 5 Evolution of failure of the arch with no buttresses.

1.4 References

[1] *A Dictionary of Architecture*, James Stevens Curls, Editor. 1999: Oxford. pp. 113–114.

[2] http://www.notredamecathedralparis.com/

[3] Tallon, A.J., 2011. "Rethinking Medieval Structure," in *New Approaches to Medieval Architecture*, R. O. Bork, W. W. Clark, A. McGehee (eds.), Routledge.