Technical Memorandum

ITASCA Consulting Group, Inc.

Date: June 17, 2009

To: *PFC3D* users

From: Itasca Consulting Group, Inc.

Re: Benchmarking the ball/wall contact detection performance improvement in *PFC3D* 4.0 Release 143

1.0 SUMMARY

Most granular flow applications involve complex container surfaces, which are currently imported in *PFC3D* as a set of triangular faces, acting as moving boundaries and undergoing large displacement with respect to the ball characteristic diameter. Although *PFC3D* has proved to be a powerful tool to model such systems, several modifications to the contact detection logic between standard walls and balls have been implemented in PFC3D4.0-143 to improve its performance for models containing large numbers of wall elements. This note compares the results of a test case model that has been run both with PFC3D40.-142 (R142) and PFC3D4.0-143 (R143). The results show a significant speedup (a factor of 7 for the problem considered) from R142 to R143.

2.0 BENCHMARK TEST MODEL

We consider the case of a rotating cylindrical drum (see Figure 1) filled partially with particles. The drum is modeled using 3 different descriptions of the geometry, each with an increasing number of triangles (416, 5532 and 10544 triangles). For each case, the balls are generated within the cylinder, and then allowed to settle under gravity until a state of static equilibrium has been reached. Then, one rotation of the drum is performed, at a rotational speed of 60 RPM about the x-axis, corresponding to 1s of physical time. Figure 2 shows the settled configurations before the rotation starts.

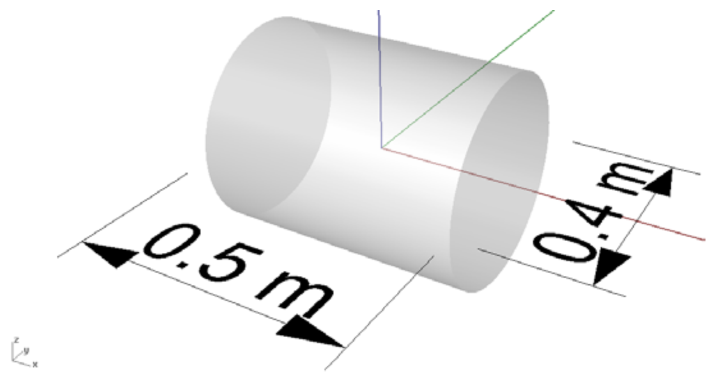

Figure 1 Container geometry

The test model is described as follows.

- **Drum geometry:**
    - Diameter 0.4 m
    - Drum height 0.5 m
    - Rotational velocity: 60 RPM about x-axis
- **Ball properties:**
    - 5000 balls
    - Uniform radii distribution between 4.9 mm and 5.1 mm
    - Ball density of 2600 kg/m3
    - Local damping set to 0
- **Contact properties:**
    - Linear contacts, kn = ks = 10^6 N/m
    - Global viscous damping:
        - normal critical ratio 0.8 with notension on
        - shear critical ratio 0.0
- **Modeling procedure:**
    - Particles settle under gravity
    - Rotation starts
    - Total physical time simulated during rotation of the drum: 1s

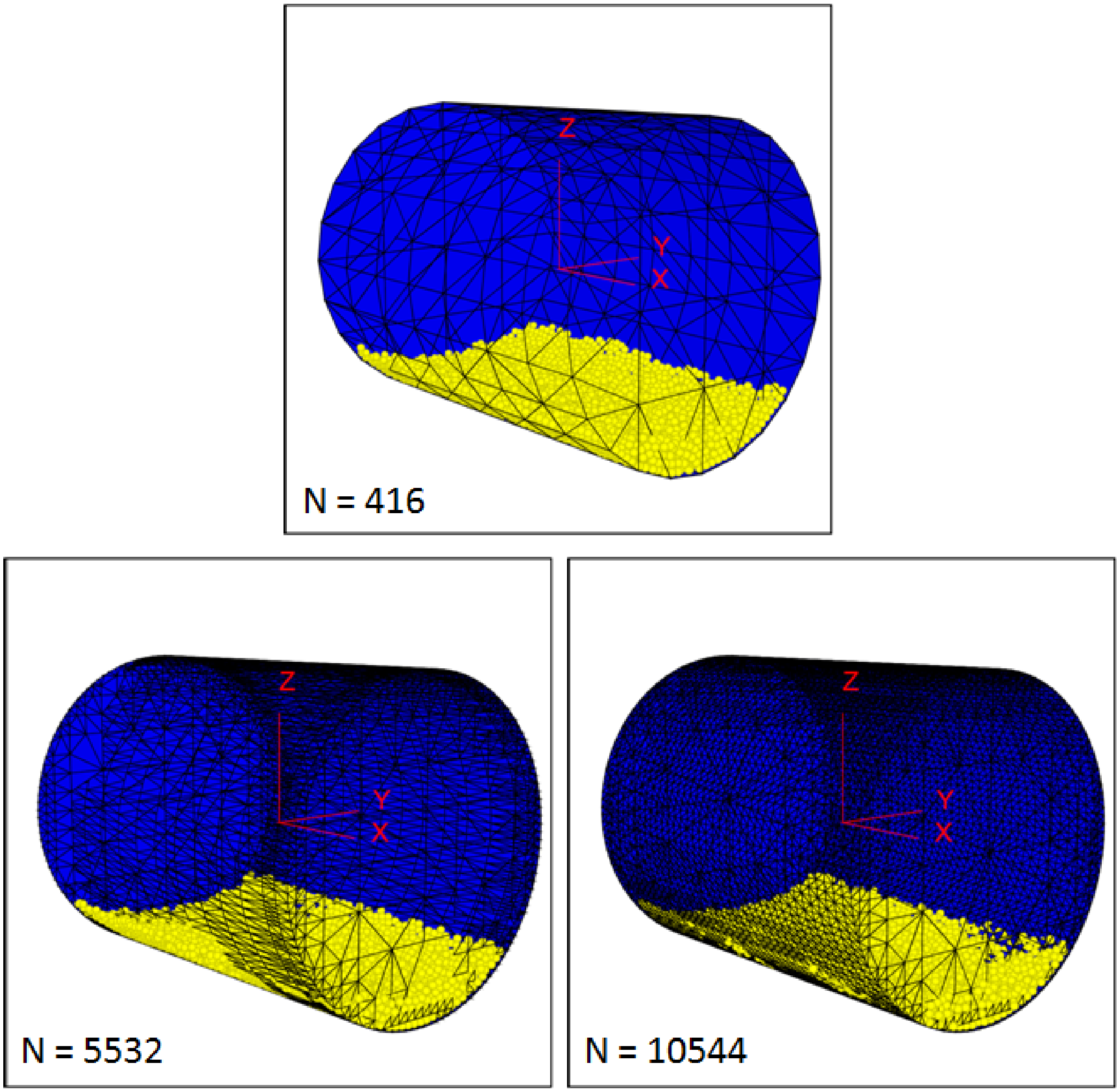

Figure 2 The three container descriptions using triangular facets. Settled configurations before rotation starts.

3.0 RESULTS

All simulations discussed below were obtained with the same machine, running Windows XP 32-bit on a PENTIUM 4 (3.40 GHz) processor. The simulation is run for the 3 representations of the container, with releases R142 and R143. Each simulation is performed as follows.

- First, the balls are allowed to settle under gravity (with a maximal SOLVE ratio of 10^{-5}).
- Then we record:
  - the computation time necessary to perform one revolution of the cylinder (1s of physical time with a rotational speed of 60 RPM),
  - the number of ball/ball contacts (total and active),
  - the number of ball/wall contacts (total and active), and
  - the total kinetic energy of all balls as a representative physical quantity.

Note that the values reported here are instantaneous quantities, sampled after one rotation of the drum, rather than averages of those quantities over a certain period of time. The relative speedup between R142 and R143 is computed as:

$$RS(N) = \frac{t_{R142}(N)}{t_{R143}(N)} \tag{1.1}$$

where N is the number of walls, and t_{R142} and t_{R143} are the computation times retrieved after one revolution of the drum with R142 and R143, respectively.

The ball configurations after 1 revolution of the drum are shown in Figure 3. Although small differences may be noted, they appear to be comparable between R142 and R143 for all cases.

Figure 4 plots the speedup with respect to the number of triangular walls defining the container shape. The computation time is reduced by a factor of approximately 3 for $N = 416$, and larger than 7 for $N \geq 5000$. Due to the details of the code modification (which are not described in this note), it is believed that this reduction factor is an increasing function of the number of balls in the model, which means that the reduction would have been even more significant with a larger number of balls.

Figures 5 and 6 show, respectively, the number of ball/ball and ball/wall contacts (total and active) after 1 revolution of the container, and Figure 7 plots the total kinetic energy of the balls with the number of triangular walls, obtained with R142 and R143. None of these quantities show significant differences between R142 and R143. We can notice a comparable evolution of the speedup and the total number of ball/wall contacts between Figure 4 and Figure 7, which underlines that the modifications in R143 are related to the ball/wall contact detection logic.

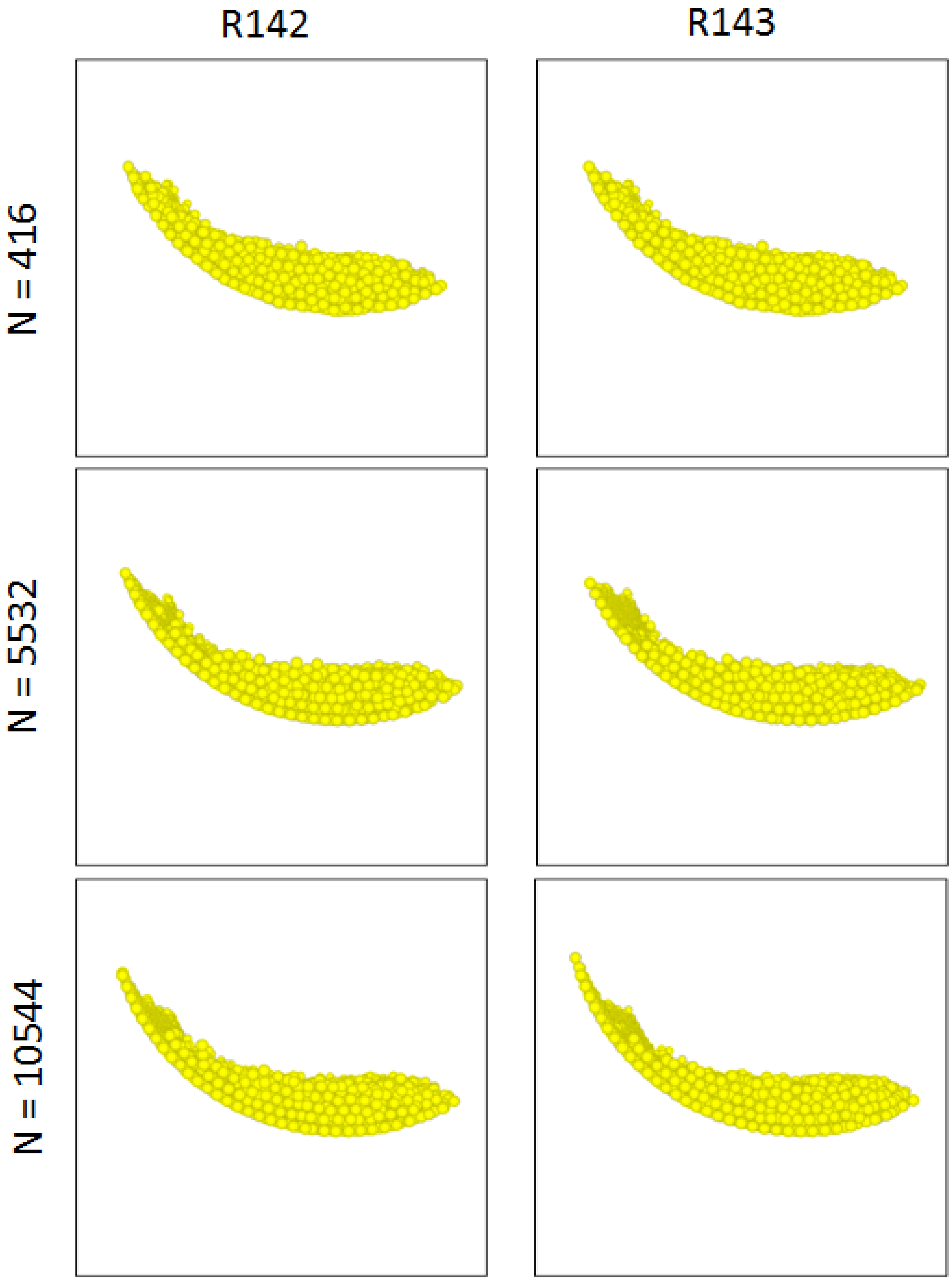

Figure 3 Ball configurations after 1 second rotation (1 complete revolution)

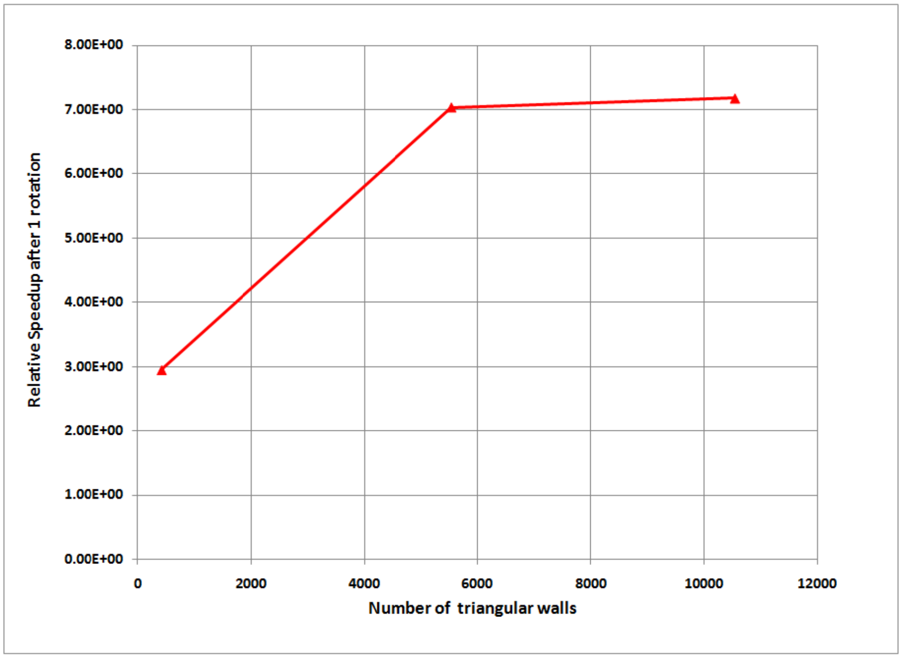

Figure 4 Evolution of the relative speedup between R142 and R143 with the number of triangular walls defining the container

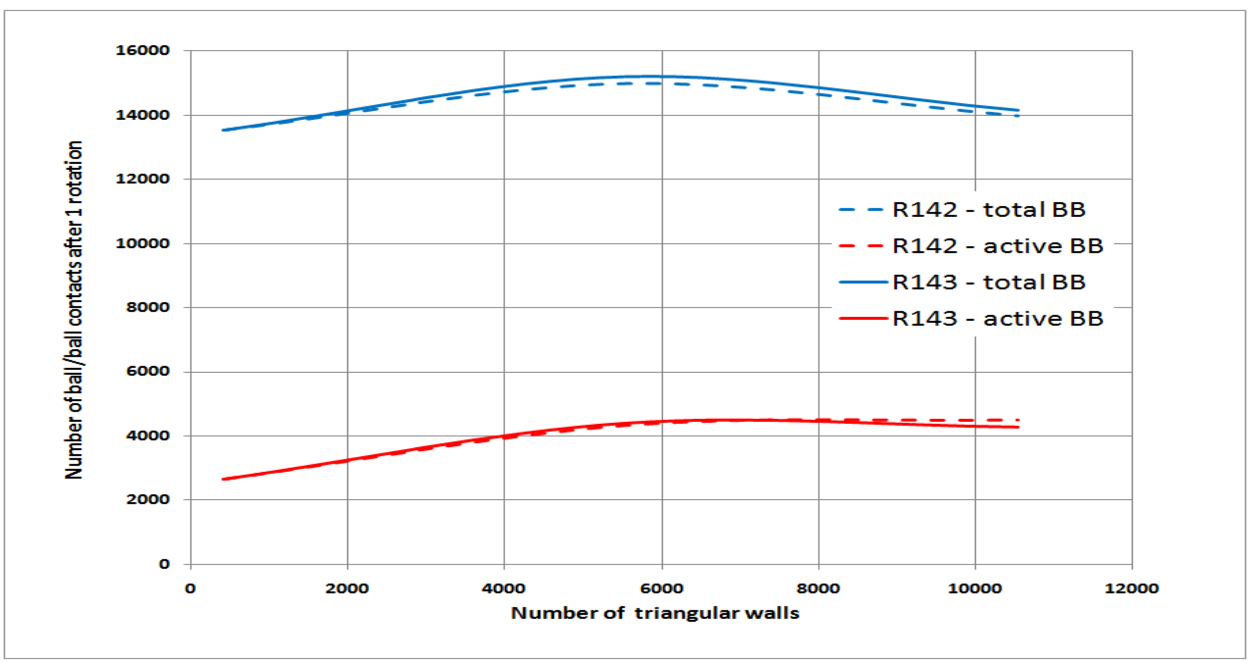

Figure 5 Evolution of the number of ball/ball contacts (total and active) after 1 revolution of the cylinder

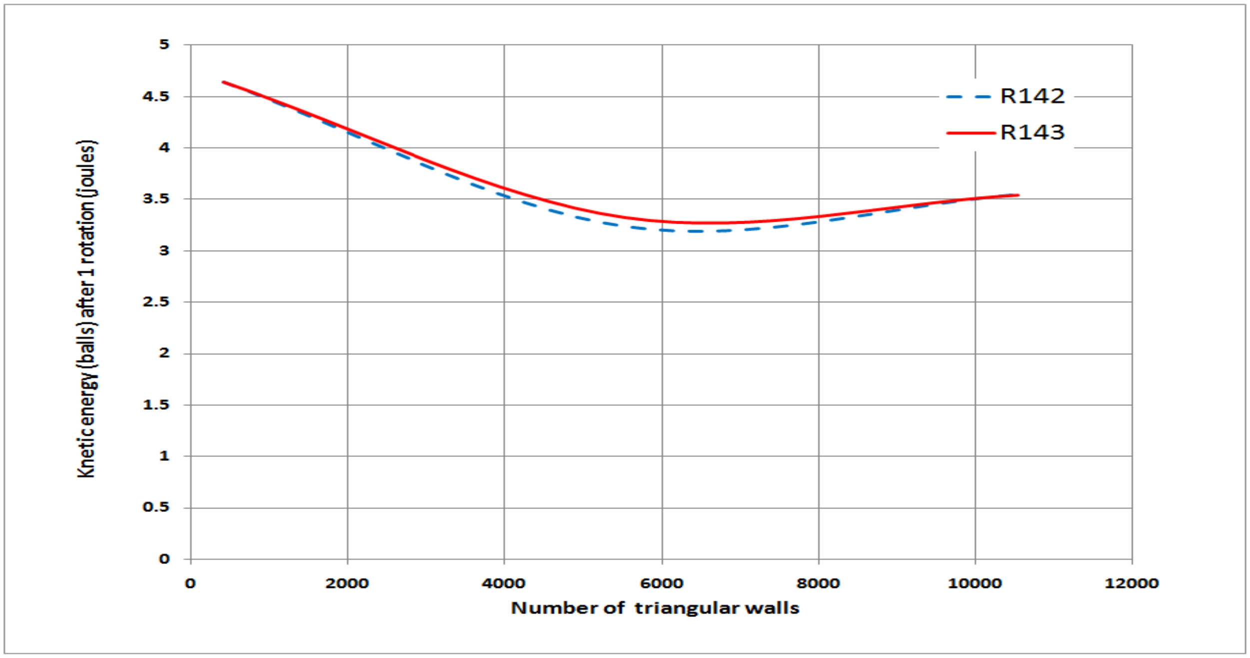

Figure 6 Evolution of the total kinetic energy of all balls after 1 revolution of the cylinder

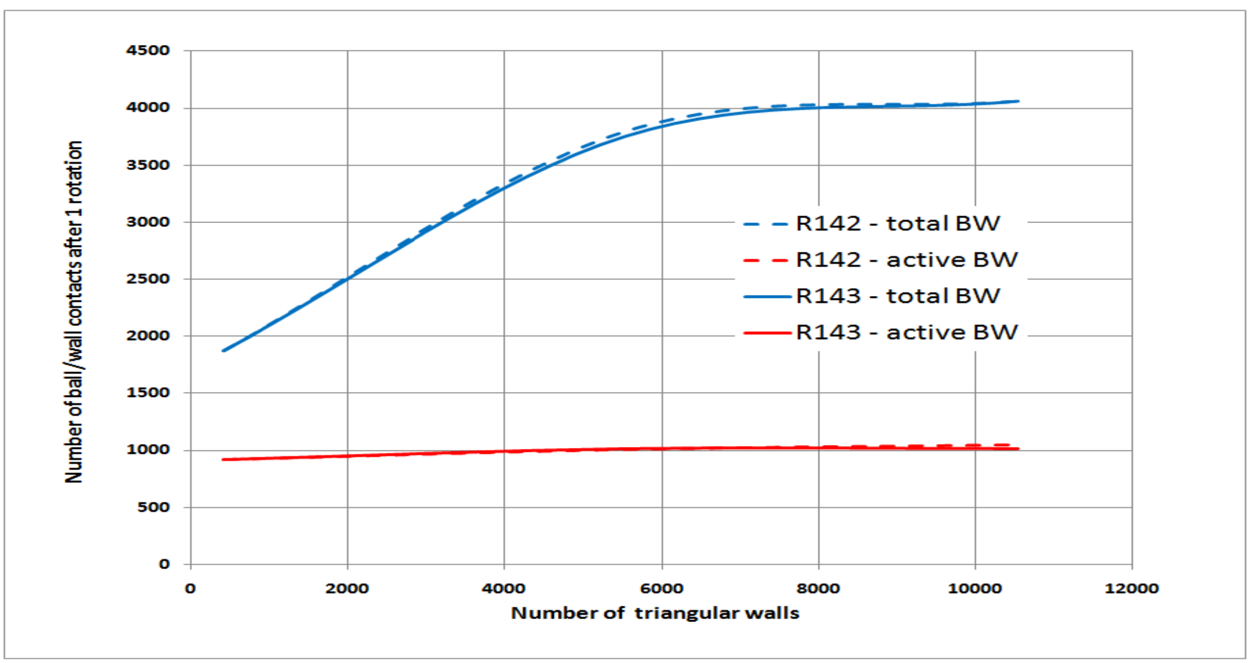

Figure 7 Evolution of the number of ball/wall contacts (total and active) after 1 revolution of the cylinder

4.0 CONCLUSIONS

Two principal conclusions can be drawn from the results shown above.

1. There is a significant increase of *PFC3D* efficiency between R142 and R143 for problems with standard walls that are undergoing large motion with respect to the particles. For this particular rotating drum geometry, with a container composed of 10544 triangular walls and a total of 5000 balls in the model, a speedup of 7 is obtained. The speedup is an increasing function of both the total number of ball/wall contacts and the number of balls in the model; thus, even better speedup may be obtained for models involving larger numbers of balls.

2. The modifications in R143 do not affect the results.

Problems containing large numbers of 3-noded standard walls to represent complex shaped moving surfaces will benefit greatly from this improvement. Note that the use of general walls will provide an additional speedup relative to the use of standard walls.