Towards a Model for Simulating Driving Rain on an Inclined Roof during Wind Gusts and Heavy Rain Intensity.

A.W.M. van Schijndel
Eindhoven University of Technology
P.O. Box 513, 5600MB, Eindhoven Netherlands, A.W.M.v.Schijndel@tue.nl

Abstract: The roof of a well known shopping place in Amsterdam collapsed during a storm with heavy rain showers in 2002. One of the main problems was the malfunction of the draining system. Another problem was that driving rain water apparently washed over edges that where designed to hold the water. This short paper presents the progress of using Comsol to simulate the height of the water near the edges of an inclined roof during heavy rainfall and wind gusts. It is concluded that the combined application modes of Incompressible Navier-Stokes (ns) and Moving Mesh (ale) seems promising in simulating the height of the water near the edges of an inclined roof during heavy rainfall and wind gusts. However there are still a lot of features to be implemented before more realistic simulation results can be obtained.

Keywords: Driving Rain, Wind, Ponding, Comsol

1. Introduction

The roof of the well known shopping place in Amsterdam collapsed during a storm with heavy rain showers in 2002. Figure 1 shows the damage.

Figure 1. The damage of the roof.

One of the main problems was the malfunction of the draining system. Another problem was that driving rain water apparently washed over edges that where designed to hold the water. The latter is the motivation to following key research question: Can we simulate the height of the water near the edges of an inclined roof during heavy rainfall and wind gusts? This paper presents the progress in using Comsol to simulate this problem. The research approach was as follows. A literature research was started and it was found out that the Shallow Water Equations (SWEs) could do the job. The present 2D SWE Comsol model was studied and this model was adapted for this purpose. However, numerical stable results were not obtained so far and it was decided to start developing a model analog to the boiling water model which is based two application modes: Incompressible Navier-Stokes (ns) and Moving Mesh (ale).

2. Modeling problem

Figure 2 visualizes the height of the water on an inclined roof during rainfall and wind [1].

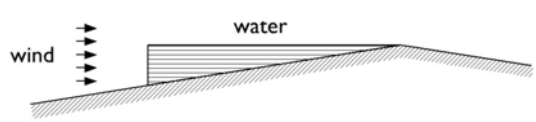

Figure 2. The height of the water on an inclined roof due to wind and rain

A currently ongoing study on this problem is presented by de Borst [1]. At the appendix an overview of all possible combinations is presented [1]. For further reading, see references [2-4].

3. Use of COMSOL Multiphysics

The geometry is shown in figure 3.

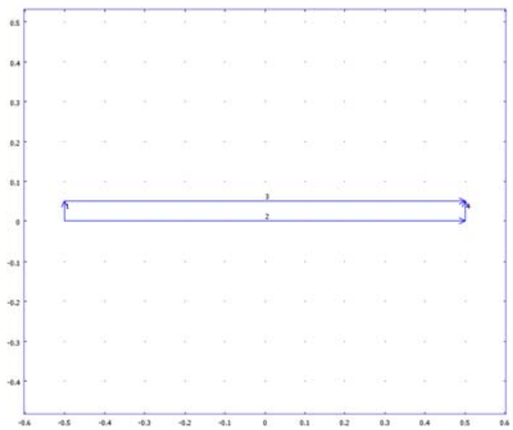

Figure 3. The initial geometry and boundaries

The following tables provide information on the Comsol model:

Table I Scalar Expressions

Name	Expression	Unit	Description
grav_x	g*sin(phimax)	m/s^2	Gravity vector, x component
grav_y	-g*cos(phimax)	m/s^2	Gravity vector, y component

Table II Application Mode Properties ALE

Property	Value
Default element type	Lagrange - Quadratic
Smoothing method	Winslow
Analysis type	Transient
Allow remeshing	Off
Defines frame	Frame (ale)
Original reference frame	Frame (ale)
Motion relative to	Frame (ref)
Weak constraints	On
Constraint type	Non-ideal

Table III Boundary Settings ALE

Boundary	1, 4	2	3
Type	Mesh displacement	Mesh displacement	Mesh velocity
constrcoord	global	global	local
Mesh velocity (veldeform)	{0;0}	{0;0}	{u*nx+ v*ny;0}
Defflag	{1;0}	{1;1}	{0;0}
veldefflag	{0;0}	{0;0}	{1;0}
weakconstr	0	0	1

Table IV Subdomain Settings ALE

Subdomain	1
Shape functions (shape)	shlag(2,'lm1') shlag(2,'lm2') shlag(2,'x') shlag(2,'y')
Integration order (gporder)	4 4
Subdomain initial value	**1**
Spatial coordinate (x)	xinit_ale
Spatial coordinate (y)	yinit_ale

Table V Application Mode Properties NS

Property	Value
Default element type	Lagrange - P_2 P_1
Analysis type	Transient
Corner smoothing	Off
Frame	Frame (ale)
Weak constraints	On
Constraint type	Non-ideal

Table VI. Boundary Settings NS

Boundary	1-2, 4	3
Type	Wall	Stress
walltype	slip	mvwall
Stress (Fbnd)	{0;0}	{30*(1-exp(-t/3));0}
Velocity of the tangentially moving wall (uvw)	0	0.01

Table VII Subdomain Settings NS

Subdomain	**1**
Shape functions (shape)	shlag(2,'lm3') shlag(2,'lm4') shlag(1,'lm5') shlag(2,'u') shlag(2,'v') shlag(1,'p')
Integration order (gporder)	4 4 2
Constraint order (cporder)	2 2 1
Density (rho)	rho (=1000)
Dynamic viscosity (eta)	nu (=0.001)
Volume force, x-dir. (F_x)	grav_x*rho
Volume force, y-dir. (F_y)	grav_y*rho

Table VIII. Solver Settings

Analysis type	Transient
Auto select solver	On
Solver	Time dependent
Solution form	Automatic
Symmetric	auto
Adaption	Off

Table IX. Direct (UMFPACK)

Parameter	**Value**
Pivot threshold	0.1
Memory allocation factor	0.7

Table X. Time Stepping

Parameter	**Value**
Times	0:0.2:20
Relative tolerance	0.001
Absolute tolerance	0.0010
Times to store in output	Specified times
Time steps taken by solver	Free
Manual tuning of step size	Off
Initial time step	0.0010
Maximum time step	1.0
Maximum BDF order	5
Singular mass matrix	Maybe
Consistent initialization of DAE	Backward

systems	Euler
Error estimation strategy	Exclude algebraic
Allow complex numbers	Off

4. Results

4.1 Default model

The main parameters of the default model are summarized:

(1) Water is used as material;
(2) Transient simulation from initial height to steady state;
(3) The roof inclination is modeled by ‘inclined gravity’ (angle is zero, i.e. horizontal);
(4) The upper boundary is moving wall boundary with a wind induced stress of 30 N/m^2.
(5) Other boundaries are modeled as slipping walls.

The results of the default model with a small length of a horizontal roof (1m) are presented below. Figure 4 shows the basic mesh. Figure 5 presents the height of the water

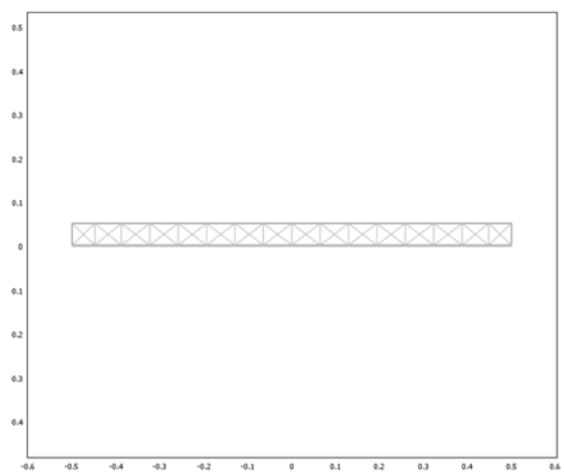

Figure 4. The initial mesh

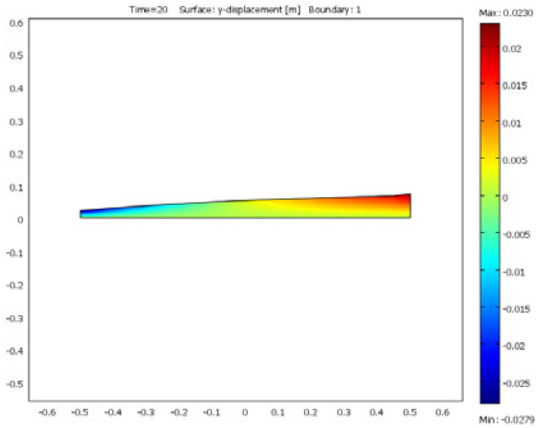

Figure 5. The height of the water

Although not very realistic yet, this model provided stable results. The strategy was to improve the model to a more realistic case, step-by-step. This is shown in the remainder of this Section.

4.2 Increased roof length model

A first improvement was to increase the length of the horizontal roof to the size of the compartments (10 m). However stable results were only obtained for a roof length up to 4 m. Figure 6 shows the results.

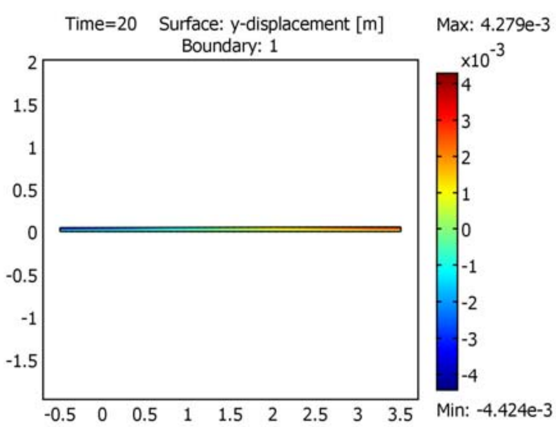

Figure 6. The height of the water for a horizontal roof with a length of 4 m

4.3 Other models under investigation

The next features are currently under investigation and are not fully implemented yet due to numerical stabilization problems:

(a) Inclined roof
(b) In and outflow of water at the left and right hand side of the domain;
(c) A water flow (load) distribution at the top;
(d) Increase of the dimensions to a more realistic roof;
(d) Friction at the bottom wall
(f) 3D modeling

5. Conclusion

It is concluded that combined application modes of Incompressible Navier-Stokes (ns) and Moving Mesh (ale) seems promising in simulating the height of the water near the edges of an inclined roof during heavy rainfall and wind gusts. However there are still a lot of features to be implemented before more realistic simulation results can be obtained.
It is also concluded that this works seems to be the first attempt to model the mentioned subject using Comsol. Feedback from the Comsol community is therefore more than welcome.
Furthermore if it would be possible to obtain realistic results, there would also be a great opportunity to combine this model with a structural mechanics model of the roof construction. The latter would provide a new and unique tool to reduce the risk of roof failures.

6. References

[1] Borst, J, de, 2009, ‘een oriëntatie op het gedrag van waterlagen op platte daken’ (A study on the behavior of water layers on flat roofs), Concept master thesis, Eindhoven University of Technology,
[2] Vambersky, J.N.J.A., 2006, Roof failures due to ponding a symptom of underestimated development, HERON 51 pp83-96
[3] Yoon, Y.N., Wenzel, H.G., 1971, Mechanics of Sheet Flow under simulated Rainfall, Journal of the Hydraulics Division, ASCE; 98 (6).
[4] A.F., Turner, A.K., Crow, F.R., Ree, W.O., 1966, Runoff from impervious surfaces under conditions of simulated rainfall, Transactions of the ASAE; Volume 9;

Appendix

Visualization of possible combinations of roof angles and wind and water profiles[1] (although the comments are in Dutch the reader can get a good impression of all possibilities)