Applied Numerical Modeling in Geomechanics – 2020 – Billaux, Hazzard, Nelson & Schöpfer (eds.) Paper: 13-03
©2020 Itasca International, Inc., Minneapolis, ISBN 978-0-9767577-5-7

Pre-processing and meshing FE-models with *Griddle*/Rhino: Applications on complex geometries from salt mine drifts

G. Maniatis & S. Fahland
Federal Institute for Geosciences and Natural Resources (BGR), Germany

1 INTRODUCTION

Research in radioactive waste disposal often includes extensive numerical modeling and one of the most demanding tasks in a three-dimensional model is the development of a good quality mesh. Depending on the size of the model, this task can be time consuming and will often require compromises on the amount of geometrical detail that the final numerical model will contain. Normally, generic, three-dimensional numerical models are designed to consist of solids defined by flat or somewhat simple and smooth surfaces avoiding sharp angles between them. Such models can be usually meshed by using the built-in meshing tools that most numerical software provide. However, implementing real geometries for example from drifts and rooms in salt mines drifts including the surrounding geological structures into numerical models increases the complexity of the 3D mesh dramatically. In such cases, more powerful pre-processing and meshing tools are required.

Here we report on a methodology for meshing more complex, real geometries from salt mine drifts by using *Griddle* (Itasca 2016), an interactive general-purpose surface remesher and volume mesh generator that works as a plug-in for the Rhinoceros 3D CAD Software. Parts of the method include importing the geometries, identifying and removing or improving problematic areas, assembling the model geometry, meshing the model's surfaces and finally produce a volume mesh that can be then imported to a numerical analysis software.

2 IMPORT, PREPARATION AND MESHING WITH *GRIDDLE*/RHINO

The drift geometries from a German salt mine that were used for this application were available in the common .dwg file format. The file contains polygon meshes that represent drift geometries from wider areas of the salt mine. Prior to importing the .dwg file into Rhino (McNeel & Associates 2016) the appropriate length units have to be set for the model and the layout in the properties menu. Since there is no way to import only the area of interest, the entire geometry contained in the file is imported into Rhino. The area of interest is then selected, and the rest of the model can be deleted or moved to another layer. Practical experience has shown that it is highly advisable to move the areas of interest i.e. the polygon meshes of the drift that is going to be remeshed with *Griddle* as close as possible to the beginning of the coordinate system. In this way errors are avoided, and the best possible geometrical accuracy can be achieved when assembling the geometry as well as meshing the model.

The initial polygon meshes contained in the .dwg file we have used were derived from 3D scans and surveying campaigns in the salt mine, and therefore they were not designed for numerical modeling purposes (Fig. 1). As expected, they contain several types of errors and defects, which have to be found, analyzed and repaired with the mesh-check and mesh-repair tools in Rhino. In addition, the area of the salt mine we are modeling consists of several polygon meshes that are not joined with each other.

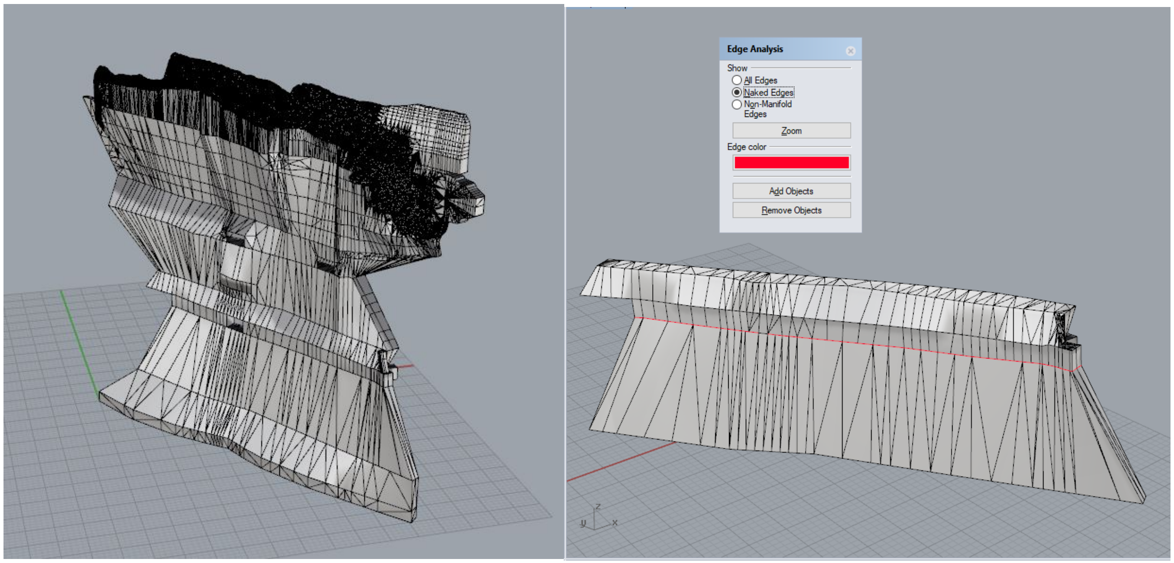

Figure 1. The initial polygon meshes contained in the .dwg file (left) were derived from 3D scans and surveying campaigns in the salt mine. Therefore, they contain defects and cannot be readily used for numerical modeling purposes. Typical mesh defects (right) include non-conformal meshes and naked mesh edges (in red).

The most common problems identified by Rhino's mesh repair tools are openings (i.e. missing surface elements) in the mesh and "naked edges" at the edges of open polygon meshes. These are repaired by using the interactive tools provided in the Rhino toolkit (i.e. "FillMeshHole" and "PatchSingleFace") and by connecting open polygon meshes to create closed ones at a later stage of the model preparation respectively.

Other errors and defects in the imported mesh include pairs of surface element faces that intersect each other, single duplicate surface element faces and degenerate faces. All the above problems can be handled by using the respective mesh repair tools in Rhino. Extended and more complex areas consisting of duplicate (i.e. identical) surface meshes are another persistent defect in the initial mesh geometries that can be solved mostly by using mesh Boolean operations in Rhino.

However, in some areas of the imported meshes there are extensive and tightly overlapping mesh surfaces that share no identical nodes and therefore cannot be cleaned by using standard Boolean operations. To precisely locate and remove these areas without affecting the rest of the model we developed an algorithm within the Grasshopper plugin, which is available for Rhino. This algorithm searches for the closest neighboring vertices of two partially overlapping meshes and removes or separates them from the rest of the model.

After carrying out the mesh corrections and repairs described above, the polygon meshes are joined to create closed ones, taking care to avoid or to correct non-conformal meshes along the matched mesh edges. The mesh normals of the new meshes require being consistent and can be unified by using the appropriate tools. The new surface meshes are then checked once again with Rhino's onboard tools for conformity and proper intersections and then they are ready to be used as the base for the final meshing with the GSurf and Gvol tools available in *Griddle*. In order to define the size of the model and to construct its sides on which the boundary conditions are applied later, we enclose the meshes into a bounding box which also gets a surface mesh by using the simple onboard meshing command in Rhino.

We then proceed with the generation of the final mesh for the model. First, we use _GSurf, *Griddle*'s surface remesher that offers the options of all-triangle, quad-dominant or all-quad surface meshes. For this model, we choose a quad-dominant surface mesh with uniform elements sizes for the surface of the rooms and the model boundaries (Fig. 2). The MinEdgeLength and MaxEdgeLength values are therefore set equal to one meter and the ridge angle value is set at the typical 20 degrees. The surface mesh for the boundary surfaces of the model is generated in the same way but with a uniform element size of 10 meters to allow for coarser mesh away from the center of the model.

GVol is *Griddle*'s volume mesher that can create a tetrahedral or a hex-dominant mesh using surface meshes created with GSurf. GVol requires properly connected input surface meshes that do not contain duplicate, overlapping, intersecting triangles and quadrilaterals. Therefore, a last check of the surface meshes created with GSurf is carried out with Rhino's mesh repair tool before we proceed with the generation of the volume mesh. We prefer a hex-dominant volume mesh for the model (Fig. 2.), which will then be saved as an .f3grid file. This file format can be imported for further pre-processing and numerical analysis into JIFE, BGR's own Java Application for Interactive non-linear Finite-Element analysis in Multiphysics as well as other numerical programs such as *FLAC3D* (Itasca 2012).

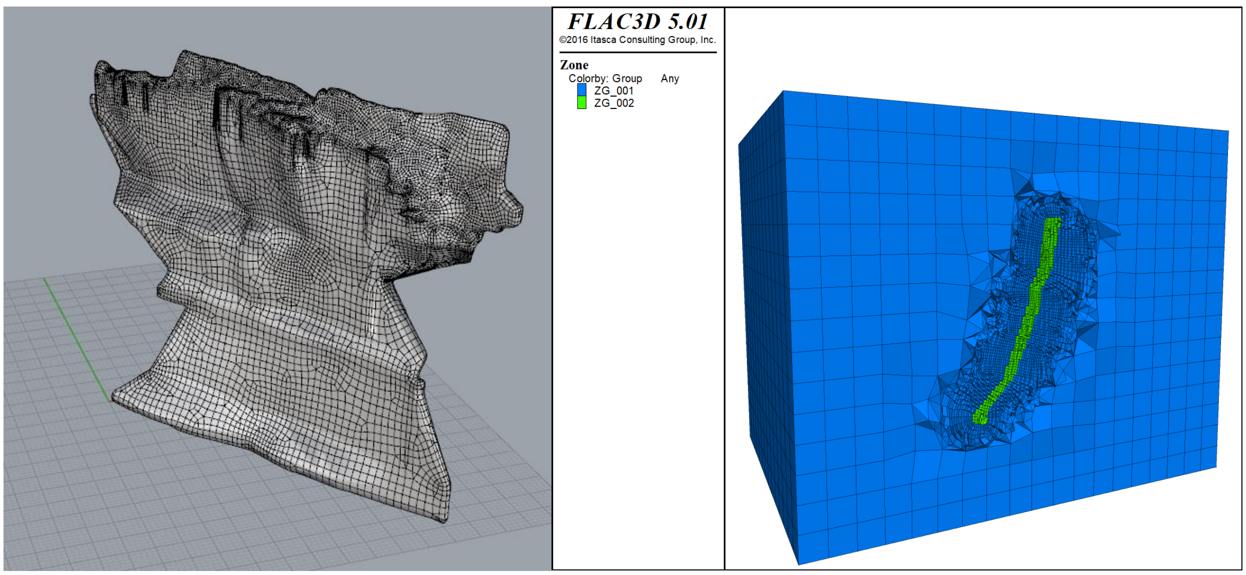

Figure 2. Generated mesh with GSurf (left) and the resulting volume mesh with GVol (right) with the resulting zones for the different areas of the model.

3 DISCUSSION AND CONCLUSIONS

The results of the surface mesher, GSurf, and the volume mesher, GVol, are depicted in Fig 2. As expected, the volume mesh is built with Brick (B8), Wedge (W6), Tetrahedral (T4) and Pyramid (P5) elements because the input mesh surfaces contained quadrilaterals. The entire model consists of approx. 417 thousand elements. In Figure 2 it is apparent that the volume mesh is divided into two zones, one representing the area of the rooms (green) and one for the surrounding rocks (blue) which can be assigned different material properties at the following stages of pre-processing. Another feature that is visible in Figure 2 is how *Griddle* distributes the change from the high mesh density at the center of the model where the rooms are located towards the boundaries of the model. A practical solution for the rather abrupt change in the mesh density seen in Figure 2 would be the use of concentric surfaces between the center and the boundaries of the model. Gradually increasing the mesh density from such one surface to the next one would obviously distribute the change of mesh density more evenly.

Our case study shows that mesh generation with *Griddle* in Rhino provides a straightforward method for complex geometries. Existing data can be easily imported in Rhino and remeshed with *Griddle* to produce volume meshes that can be moved across different platforms of numerical software.

4 REFERENCES

Itasca Consulting Group, Inc. 2012. *FLAC3D – Fast Lagrangian Analysis of Continua in 3 Dimensions, Ver. 5.0 User's Manual*. Minneapolis: Itasca.

Itasca Consulting Group, Inc. 2016. *Griddle Ver. 1.0 User's Guide*. Minneapolis: Itasca.

Robert McNeel & Associates. 2016. Rhinoceros 5 for Windows User's Guide, Robert McNeel & Associates.