SUPERPOSE- An Excel Visual Basic Program for Fracture Modeling Based on Stress Superposition Method

USER GUIDE

Sait Ozkaya

This user guide explains details of preparing and running the SUPERPOSE program and adjustment of results by changing parameters. In addition to this user guide, a slide set is also presented showing how to run the program step by step.

1. Modules of SUPERPOSE Program

The SUPERPOSE program consists of the following modules

1-Data import modules. There are two macros to import structural grid data into Excel. These are:

a- GRDECL to import grid data in Eclipse format

b- ZMAPDAT to import structural surface grid in ZMAP format.

2- Main routine. The main program has two subprograms

a- QUADARCH subprogram: calculates principal curvature direction and magnitudes and local stress tensor related to curvature, layer thickness and mechanical layer characteristics.

b-ADDTENSOR subprogram: calculates principal composite stress magnitude and directions by superposing regional stress and local tensile stress tensors.

The program outputs the possible location, length, and strike of fractures in addition to various other intermediate results.

2. GRDECL Module

This is one of the two data import routines into Excel. The purpose is to import structural grid from an ECLIPSE input file. The .grdecl file must be saved originally or opened and saved as a text file using Wordpad or a similar program otherwise program cannot read the file

The input file must have the format in Table U1. It must contain “SPECGRID”, “GRIDUNIT” , “COORD” and “MAPAXES” keywords. Other key words, following data and comment lines starting with dash are ignored. The “SPECGRID” keyword must be followed by nx: number of columns and ny: number of rows. Number of grid points is nx+1 in x direction and ny+1 in y direction. The total number of cells is (nx+1) times (ny+1). The maximum total number in the present program is 1,000,000.

The “GRIDUNIT” keyword must be followed by M or FEET (if preceded by quotation, the quotation mark is ignored). If it is FEET, the coordinates and elevation data are converted to meters. The program always imports data in meters. ”COORD” keyword must be followed by x, y and z coordinates of grid cells. Only the first 3 numbers are imported the rest are ignored. These are x and y UTM coordinates \and elevation z. x and y coordinates must be arranged so that the grid is scanned row by row.

If MAPAXES key word is specified in the input file, followed by coordinates of the origin, the x and y grid coordinates are given as increments. The program uses two parameters (XDIR and YDIR) to decide orientation of the x and y axes. If xdir is 1, then origin is on the left and the grid x increments are added so that x axis is positive to the right, otherwise the origin is on the right and grid increments are subtracted and x axis is positive to the left. The same logic applies to the y axis. Z is always positive downward XDIR and YDIR parameters are irrelevant if the Eclipse file does not include the MAPAXES key word.

In the example in figure U1, xdir is 1 and ydir is -1. The origin is at the upper left corner. Positive X is to the right and positive Y is from top to bottom. Positive z is downward . The program continues reading coordinates line by line until the "\" backslash symbol is encountered. Any additional data beyond are ignored. The input data for the GRDECL program must be placed in an Excel tab in cells B15 to B21 **(**Table U2**).** If MAPAXIS key work is not specified, XDIR ad YDIR must be set to 1.

The GRDECL program allows two filters. It is possible to trim the grid from left and right sides by setting "*imin"* and "*imax"* and top or bottom by setting "*jmin"* and *"jmax"*. Imax is nx+1 and jmax is ny+1 where nx and ny are the grid size in x and y direction in the original '.grdecl" file. The QUARCH program calculates curvature in a large window to capture structural arching. It is therefore advisable to decimate the original grid so that the coarse grid has a large cell size. This may also help speed the program and improve accuracy if the original grid is too large. The parameters "*stepx*" and "*stepy*" are used to decimate the grid. A step size of 4 means every forth cell is taken and the 3 intermediate cells are skipped. The last line in the input parameter table is the file name. Full path must be specified for the program to find the original grid file.

The imported structural grid data for the top horizon of the reservoir is placed in cells starting with B33 (Table U3). Output parameters are placed on the same Excel tab in cells starting with L15 (Table U4). The output parameters are original number cells in x and y directions ("*nxorig*" and "*nyorig*"); the maximum number of cells in the decimated coarse grid ("*nxmax*", "*nymax*'), and minimum and maximum values of UTM coordinates and elevation.

3. ZMAPDAT Module

This is the second of the two data import routines into Excel. The purpose is to import structural grid from a Zmap.dat input file format. The ZMAPDAT routine reads only the topmost grid as a structural horizon and places into an Excel template.

The input file must have the format in Table U5. It must contain @FILENAME followed by three lines of numerical data separated by comma, and another @ followed by elevation data. Other key words, following data and comment lines starting with "!| are ignored.

The following parameters are extracted from the format data:

Number of fields in the elevation data section (5 in this example).

Missing value (0.1e31 in this example)

Field width (7 in this example)

Number of grid cells in x direction (nx=486 in this example)

Number of grid cells in y direction (ny=519 in this example)

Starting and end values of East UTM (144510.0 and 265750.0 in this example)

Starting and end values of North UTM coordinates (15347500 and 1664250.0 in this example)

Some programs place first number grid cells in y direction followed by number of grid cells in x direction. Find $dx1=(utme_{max}-utme_{min})/nx$ and also $dx2=(utmn_{max}-utmn_{min})/ny$. dx1 must be equal to dx2. Otherwise swap nx and ny.

The elevation data is arranged with origin on the upper left corner. Positive x is to the right and positive y is top down. The elevation data is stacked row by row with increasing x. The stack starts at top row and goes down with decreasing y values. The total number of grid cells is 1000x1000. Each of the million cells contain three values, x, y coordinates and elevation. Since SUPERPOSE routine has elevation positive downward, the negative elevation values are converted to positive values.

The input parameters for the ZMAPDAT program must be placed in an Excel tab in cells B15 to B21 **(**Table U6**).** The program allows two filters. It is possible to trim the grid from left and right sides (by setting "*imin* "and "*imax"* and top or bottom by setting "*jmin"* and *"jmax"*. The SUPERPOSE program calculates curvature in a large window to capture structural arching. It is therefore advisable to decimate the original grid so that the coarse grid has a large cell size. This may also help speed the program and improve accuracy if the original grid is too large. The parameters "*stepx"* and "*stepy"* are used to decimate the grid. A step size of 4 means every forth cell is taken and the 3 intermediate cells are skipped.

The grid file may be arranged column by column or row by row. Use the next parameter <DIROP> to specify if the data is arranged in .DAT file column by column (y direction, dirop=1) or row by row (x direction dirop=2). The origin is always upper left corner. Y is always listed downward (columns) and x is listed from left to right (rows). The last line in the input parameter table is the file name. Full path must be specified for the program to find the original grid file.

Some program export depth as negative values. SUPERPOSE expects positive values for depth. If zmap elevations are negative use option 1 for Z+down parameter to convert to positive.

The imported structural grid data for the top horizon of the reservoir is placed in cells starting with B33 (Table U7). Output parameters are placed on the same Excel tab in cells starting with L15 (Table U8). The output parameters are original number cells in x and y directions (“*nxorig”* and “*nyorig’*); the maximum number of cells in the decimated coarse grid (“*nxmax”,” nymax”*), and minimum and maximum values of UTM coordinates and elevation.

4. Superpose Main Program

The main program calls two subprograms, QUADARCH and ADDTENSOR subroutines. QUADARCH calculates principal curvatures within a sliding window. ADDTENSOR subroutine, calculates (i) local stress tensor related to arching, (ii) rotates it to the common reference frame of the regional stress tensor, (iii) adds the local and regional stress tensors,(iv) finds the principal stress and directions of the superposed composite stress. The program also decides whether tensile of shear fractures could form and if so generates sticks to represent these fractures.

Parameters for the main program are as shown in Table U9. The parameters must be placed in an Excel tab at exactly the same row and columns as indicated. The data in form of East UTM (x), North UTM (y) and Depth (z) must be placed in the same Excel template under the parameter table in the same row and columns as in Table U10. The imported data from GRDECL or ZMAPDAT can be directly copies into these cells.

4.1 QUADARCH Subroutine

4.1.1 Parameters

The top 12 parameters in Table U9 are needed for QUADARCH routine. A brief description is given below. Some of the critical aspects of the program are explained further down.

The number of grid cells in x and y directions (“*nxmax”* and ”*nymax”)* must be taken from the output of the GRDECL or ZMAPDAT modules. The following two additional parameters “*nxin”* and “*nyin”* are usually the same as *nxmax* and nymax but are introduced to test the program on a small subset of grid data before a full-fledged execution.

The minimum x,y z values. The minimum of x,y coordinates (“*xmin”, “ymin”* and “*zmin”*) are subtracted from actual data before curvature calculation to reduce the round off error as curvatures are usually extremely small numbers. The two following parameters: “*nxpts”* and “*nypts”*, decide the window size for curvature calculation. Young modulus and thickness are (E and thick) are needed for calculation of stress from curvature.

4.1.2 Window Size

Window size has an important bearing on the curvature. Small window captures small wavelength folding, and large window size captures large structural arching. A large window of at least a few km wide must be used to avoid local irregularities of the structural surface. The width and height are calculated by multiplying “*nxpts”* and “*nypts”* by grid size. If all cells are selected when importing data by GRDECL or ZMAPDAT modules, the grid size is the original grid size. However, if only every k^{th} grid is selected, the grid size will be equal to original grid size multiplied by steps jumped. Therefore the two pairs of parameter to consider when setting the window size for curvature calculation: “*stepx”* and “*stepy”* in GRDECL or ZMAP and “*nxpts”* and “*nypts”* in QUADARCH subprogram.

The maximum number of cells for curvature window is 501 both for “*nxpts”* and “*nypts”*. Normally, 5 to 15 cell s are sufficient. If all the data is imported, and grid size is small, “*nxpts”* and “*nypts”* will have to be set to a large number. This will considerably slow the program. A trade-off is to select every 4^{th} or 5^{th} grid data to import and use a small number like 5 to 15 for “*nxpts”* and “*nypts”*.

Large windows smooth out local structural variations and the average curvature is small. Large window also makes the edge effect conspicuous. The curvature calculated is assigned to the center point of the window. If a large curvature is present at the edge of the grid, the high curvature is somewhat shifted away from the edge.

4.1.3 Local tensile stress from curvature

The following two parameters are used to calculate curvature related stress. These are Young’s modulus (E) and layer thickness (thick). Radius of curvature is also required for calculation of local tension. Two tensile stress values (u_{xx} ad u_{yy}) are calculated corresponding to the two principal curvatures. Reciprocal of principal curvatures are taken as corresponding radius of curvature.

Calculation of stress from curvature is based on flexural slip model of folding. Each layer is separated from layers above and below by bedding surfaces, which allow beds to slide relative to each other freely. Anticlinal arching creates tension on the top surface of the layer and compression at the bottom. There is a neutral surface somewhere in the middle of the layer where neither tension nor compression is present. The QUADARCH program only calculates the stress at the top of a layer. The amount of stress is proportional to layer thickness. If the layer thickness is small, the curvature related tension is also small and fractures may not form.

Obviously, the simple formula and dependence of stress on layer thickness cannot address complex interactions in nature. Therefore, the fracture models from the SUPERPOSE program must be considered only as index models and must be calibrated to actual fracture models.

4.2 ADDTENSOR Subroutine

This is the second main subroutine of the SUPERPOSE program. It superposes local stress from curvature to regional stress and finds principal stresses and directions of the resultant composite stress tensor.

4.2.4 Parameters

The parameters for the ADDTENSOR subprogram are listed in Table U9. These are (i)maximum and minimum horizontal regional effective stress; angle of Sxx from geographic X axis (east positive) towards Y (north positive); (ii) Internal friction angle for Coulomb failure envelope; (iii) unconfined compressive strength MPa and (iv) Hoek-Brown failure criterion coefficient, m. These are the essential parameters for (i) defining regional stress tensor; (ii)rotating local tensile stress tensor; (iii)superposition of the two tensors and determining if tensile or shear fractures form and if so their strike and length. It should be reminded again that the effective regional stress must be input.

4.2.5 Fracture length and spacing

One tensile or two conjugate shear fractures are generated in each cell that meets the conditions. This is obviously symbolic as noted earlier. In general fracture spacing is proportional to layer thickness among other factors. Observations in many Middle East Fields show, fractures are clustered and the degree of clustering increases with increasing layer thickness. In massive reservoirs, tensile or shear fractures cluster in fracture corridors that may extend for several hundred meters or kilometers. The width, length and spacing of fracture corridors are proportional to layer thickness. The SUPERPOSE program provides two length multipliers: “*lendex”* for tensile and “*lendshr”* for shear fractures. The multiplier can be used to adjust fracture/ fracture corridor length according to layer thickness. The program also allows showing every nth fracture skipping (n-1) fractures in between. For tensile fracture n is given by “*cizlimex”* and for tensile fractures by “*cizlimsh”* parameters. Skipping some fractures makes it possible to adjust fracture /fracture corridor spacing to layer thickness.

Both length index and fracture skipping may also be used to calibrate the fracture model form SUPERPOSE with actual fracture corridor mapped from borehole images and other well and seismic data.

The fracture length can be indexed to window size of curvature. Small window reflect fine details in curvature and translate into large number of short fractures. Large windows that cover large areas yield a small number of long fractures. The program can be run at two or three different levels with increasing window size, frequency and length of fractures. The results can be superimposed to generate a composite fracture model with short and long fractures.

4.2.6 Results

The SUPERPOSE program outputs the following for every grid

Length, strike and UTM coordinates of the center point for each tensile and shear fracture stick

UTM coordinates of the two end points of each tensile and shear fracture stick

The end point coordinates cane be recast in different formats and exported to program like Petrel for display and further processing such as upscaling.

4.2 Limitations

The program can handle up to 500x 500 grid cells within reasonable time.