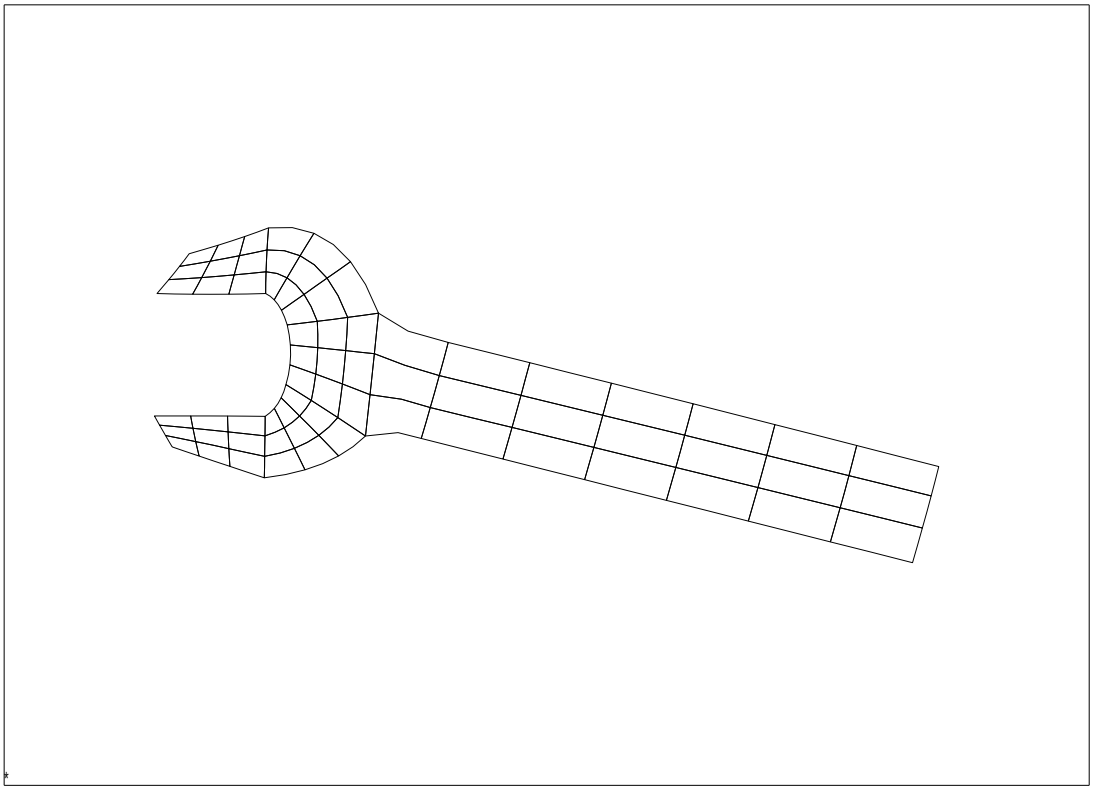
Z88®

The compact Finite Elements System



Version 15.0

Z88®

A modular, compact und fast
Finite Element Program in ANSI-C
for all Windows, LINUX, UNIX and
macOS computers

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WELCOMES TO Z88®!

This Open Source version of Z88® for UNIX and Windows is protected by the GNU General Public License, see next pages.

Z88® is compact and fast and was developed for PCs initially. Today, Z88® runs properly on PCs with Windows starting with Windows95 to Windows10, LINUX, UNIX and macOS computers, however. Simple to compile and to install. Handling is simple. Z88® comes with online-help and a user-friendly command processor. Successfully proved by countless Windows, UNIX and LINUX installations worldwide. For static calculations in mechanical engineering and building & construction industries. Absolutely transparent for the user as input and output are handled by text files. Z88® has deliberately been designed as a compact and fast system. Thus, its use is restricted to static calculations. Z88® does not want to compete with professional FEA programs for workstation or mainframes wich can do really everything, but are hardly payable and complicated to operate. While you are still puzzling about installation and start of some programs of this genre also in the PC class, you have already calculated the first examples with Z88®. The Z88® system may operate with English or German language depending on your setting (ENGLISH or GERMAN) in the file Z88.DYN. The edition 15 differs from the former edition 14 in these topics:

- The sources are modified for Windows10 and macOS Sierra 10.12.3.
- The LINUX and MacOS sources come with my own vector font system. Thus, the former used GtkGLExt lib (always causing trouble!) is skipped.
- New is the Bernouilli/Timoshenko beam element 25.

Z88® for Windows comes ready-to-run for 32 bit Windows and for 64 bit Windows, however. For LINUX and macOS you are to install some additional free software. You may compile Z88® for other UNIX versions on your own computer.
If you already have FEA experiences, you can start at once. If you are a beginner in this area, i would recommend secondary literature. Here are a few choices:

- *Zienkiewicz, O.C.; Taylor, R.L.: The Finite Element Method, Volumes 1-3, 5th edition, Butterworth- Heinemann and John Wiley & Sons, 2000*
- *Bathe,K.J.: Finite Elemente Procedures. Prentice Hall, 1995*
- *Rieg,F.; Hackenschmidt, R., Alber-Laukant, B.: Finite Element Analysis for Engineers. Carl Hanser Verlag, München Wien 2014.* ISBN 978-1-56990-487-9, www.hanserpublications.com

If you'll improve Z88® please give me your feedback. If you want to compile Z88® for LINUX the GCC compiler along with the *GTK+* and the *OpenGL* library *Mesa* should work fine. If you want to compile Z88® for macOS load *XCode*, *XQuartz* and *MacPorts* with *gtk2, pkgconfig, glw* and *libGLU*. If you want to compile Z88® for Windows any kind of C or C++ compiler should work fine – i've tested Visual Studio 2015 from Microsoft.
And because Z88® is bound to the GNU General Public License you are to present your improvements and modifications to the public including the source code – that's a point of honor. Promote the idea of the free software according to GNU-GPL! Please see **www.z88.de**.

And if you want to get a really powerfull, full-featured and up-to-date FEA system: Load our *Z88Aurora*® at no charge which is developed by my team and me.

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Bayreuth, April 2017

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<one line to give the program's name and a brief idea of what it does.>
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Yoyodyne, Inc., hereby disclaims all copyright interest in the program
`Gnomovision' (which makes passes at compilers) written by James Hacker.

<signature of Ty Coon>, 1 April 1989
Ty Coon, President of Vice

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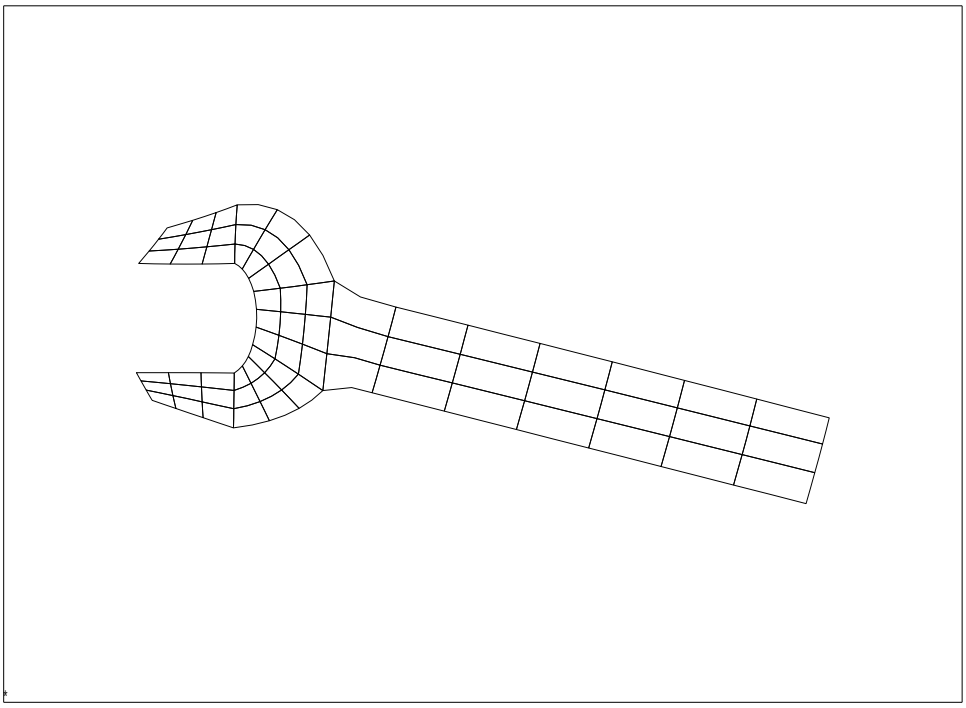
TABLE OF CONTENTS

1 THE FINITE ELEMENTS PROGRAM Z88



1.1 GENERAL OVERVIEW OF FEA PROGRAM Z88

The Z88 philosophy:

+ Fast and compact: Developed for PC, no ported mainframe system
+ Flexible and transparent: Controlled by text files
+ "Small is beautiful" - a modular system vs. monolithic monsters
+ *native* Windows, LINUX and MacOS programs, no emulation
+ Windows and UNIX programs use the same computing and graphic kernels
+ Full data exchange from and to CAD systems with DXF-Interface
+ mesh import from NASTRAN, COSMOS and ANSYS (via Z88ASY.PL)
+ online-help under Windows and UNIX
+ Simplest installation: No subdirectories, no change of system files
+ Under UNIX: Automatic control and cumulative runs possible

Always compare FE calculations with analytical rough calculations, results of experiments, plausibility considerations and other tests without exception!

In this manual, UNIX always means UNIX and LINUX and MacOS.

Keep in mind that sign definitions of Z88 (and also other FEA programs) differ from the usual definitions of the analytical technical mechanics from time to time .

Z88 is a complex computer program. How Z88 deals with other programs and utilities etc. is not predictable. I cannot give any advice and support here! You should switch off at first all other programs and utilities. Run Z88 "purely" and then start further programs step-by-step. Z88 uses only documented operating system calls of Windows and UNIX!

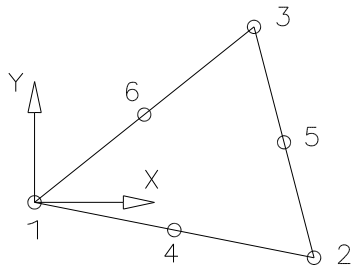
1.1.1 SUMMARY OF THE Z88 ELEMENT LIBRARY:

(You will find the exact description of the element library in chapter 4.)

Twodimensinal problems: Plane stress, plates, beams, trusses

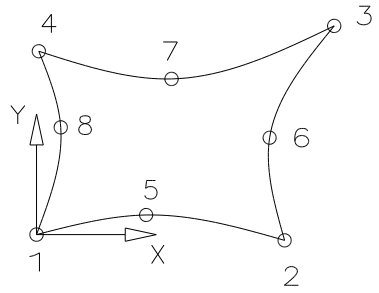
Plane Stress Triangle Element No. 3

- Shape functions quadratic
- Quality of displacements very good
- Quality of stresses in the centre of gravity good
- Computing effort: average
- Size of element stiffness matrix: 12 × 12



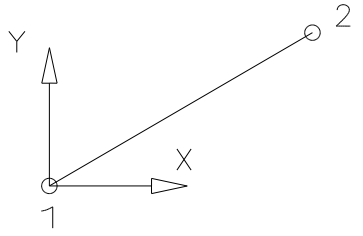
Plane Stress Isoparametric Element No. 7

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Quality of stresses in the Gauss points very good
- Quality of stresses in the corner nodes good
- Computing effort: High
- Size of element stiffness matrix: 16 × 16



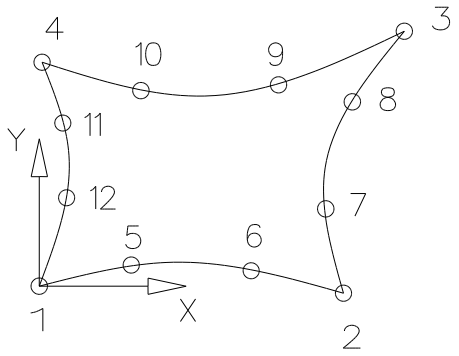
Truss No. 9

- Linear function
- Quality of displacements exact (Hooke 's law)
- Quality of stresses exact (Hooke ' s law)
- Computing effort: Minimal
- Size of element stiffness matrix: 4 × 4



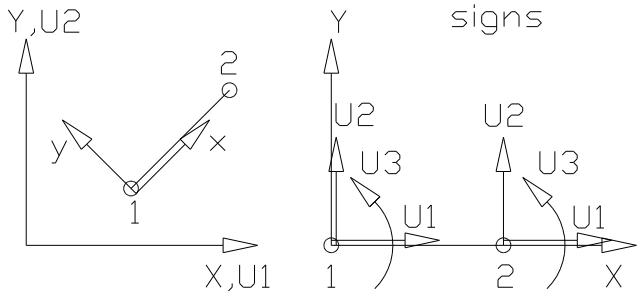
Plane Stress Isoparametric Element No. 11

- Cubic Isoparametric Serendipity element
- Quality of displacements excellent
- Quality of stresses in the Gauss points excellent
- Quality of stresses in the corner nodes good
- Computing effort: Very high
- Size of element stiffness matrix: 24 × 24



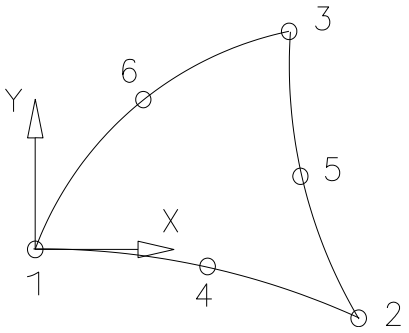
Beam No. 13

- Linear function for tensile stress, cubic function for bending stress
- Quality of displacements exact (Hooke 's law)
- Quality of stresses exact (Hooke ' s law)
- Computing effort: Low
- Size of element stiffness matrix: 8 × 8



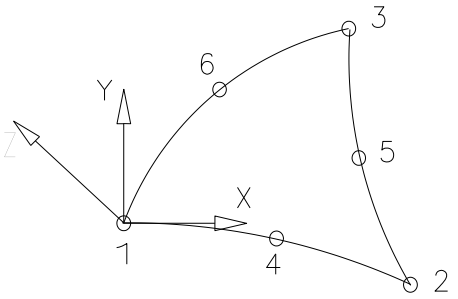
Plane Stress Isoparametric Element No. 14

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Quality of stresses in the Gauss points very good
- Quality of stresses in the corner nodes good
- Computing effort: medium
- Size of element stiffness matrix: 12 × 12



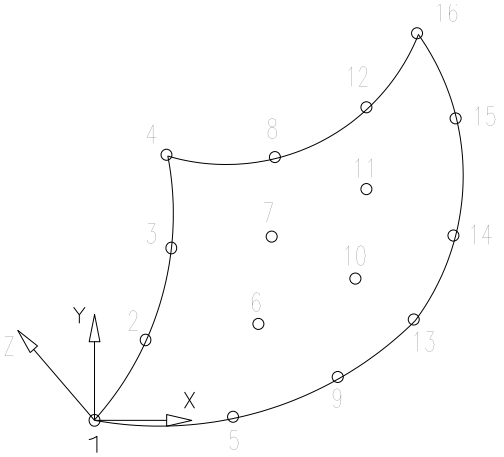
Isoparametric Plate Element No. 18

- Quadratic Isoparametric Serendipity element following Reissner- Mindlin's theory
- Quality of displacements very good
- Quality of stresses in the Gauss points good
- Quality of stresses in the corner nodes acceptable
- Computing effort: medium
- Size of element stiffness matrix: 18 × 18



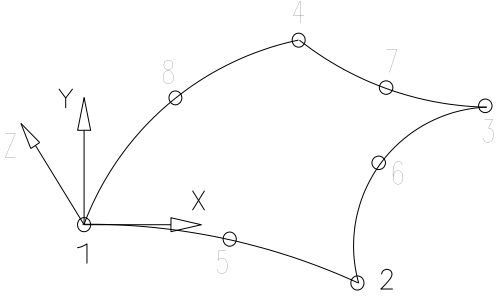
Isoparametric Plate Element No. 19

- Cubic Isoparametric Lagrange element following Reissner-Mindlin's theory
- Quality of displacements very good
- Quality of stresses in the Gauss points very good
- Quality of stresses in the corner nodes good
- Computing effort: High
- Size of element stiffness matrix: 48 × 48



Isoparametric Plate Element No. 20

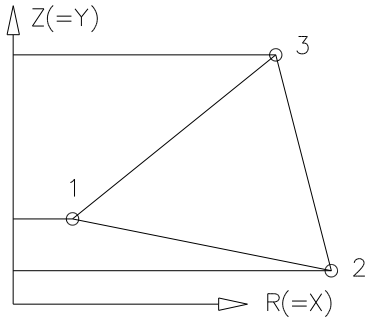
- Quadratic Isoparametric Serendipity element following Reissner-Mindlin's theory
- Quality of displacements very good
- Quality of stresses in the Gauss points good
- Quality of stresses in the corner nodes quite good
- Computing effort: medium
- Size of element stiffness matrix: 24 × 24



Axisymmetric problems:

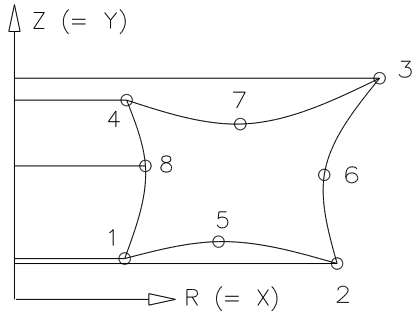
Torus No. 6

- Linear function
- Quality of displacements average
- Quality of stresses in the corner nodes inaccurate
- Computing effort: Low
- Size of element stiffness matrix: 6 × 6



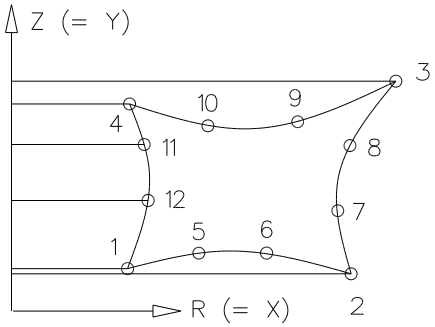
Torus No. 8

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Quality of stresses in the Gauss points very good
- Quality of stresses in the corner nodes good
- Computing effort: High
- Size of element stiffness matrix: 16 × 16



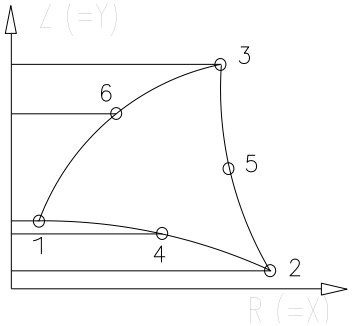
Torus No. 12

- Cubic Isoparametric Serendipity element
- Quality of displacements excellent
- Quality of stresses in the Gauss points excellent
- Quality of stresses in the corner nodes good
- Computing effort: Very high
- Size of element stiffness matrix: 24 × 24



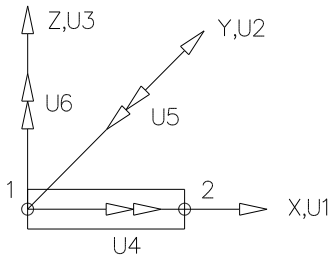
Torus No. 15

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Quality of stresses in the Gauss points very good
- Quality of stresses in the corner nodes good
- Computing effort: High
- Size of element stiffness matrix: 12 × 12



Cam No. 5

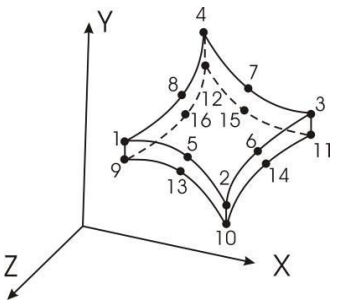
- Linear function for torsion and tensile stress, cubic function for bending stress
- Quality of displacements exact (Hooke 's law)
- Quality of stresses exact (Hooke ' s law)
- Computing effort: Low
- Size of element stiffness matrix: 12 × 12



Shell problems:

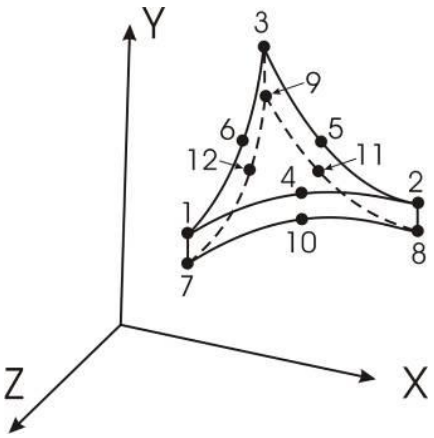
Shell No.21

- curvilinear, isoparametric Serendipity volume shell element
- isoparametric transformation
- arbitrary curvature of element possible
- good calculation of both displacements and stresses
- Stresses in the corner nodes (good for an overview) or in the Gauss points (substantially more exact)
- Computing effort: high
- Size of element stiffness matrix: 48×48



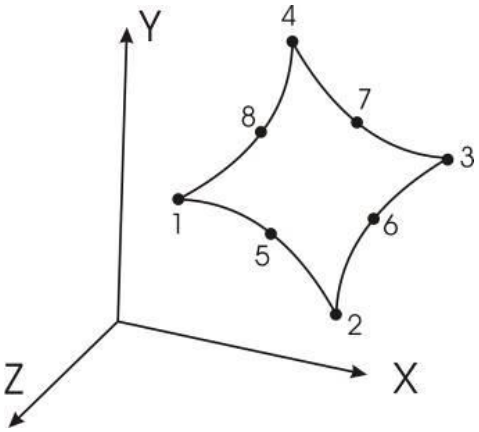
Shell No.22

- curvilinear, isoparametric Serendipity volume shell element
- isoparametric transformation
- arbitrary curvature of element possible
- good calculation of both displacements and stresses
- Stresses in the corner nodes (good for an overview) or in the Gauss points (substantially more exact)
- Computing effort: average
- Size of element stiffness matrix: 36×36



Shell No.23

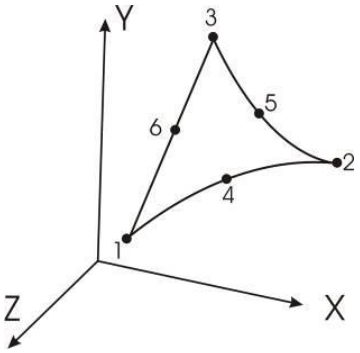
- curvilinear, isoparametric Serendipity shell element
- Shape functions quadratic
- isoparametric transformation
- all nodes in one plane
- good calculation of both displacements and stresses
- Stresses in the corner nodes (good for an overview) or in the Gauss points (substantially more exact)
- Computing effort: high
- Size of element stiffness matrix: 48×48



Shell No.24

- curvilinear, isoparametric Serendipity shell element
- Shape functions quadratic

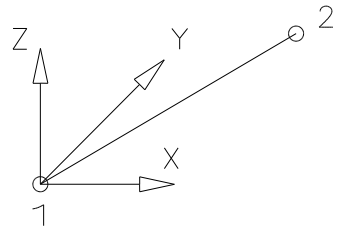
- isoparametric transformation
- all nodes in one plane
- good calculation of both displacements and stresses
- Stresses in the corner nodes (good for an overview) or in the Gauss points (substantially more exact)
- Computing effort: average
- Size of element stiffness matrix: 36×36



Spacial problems:

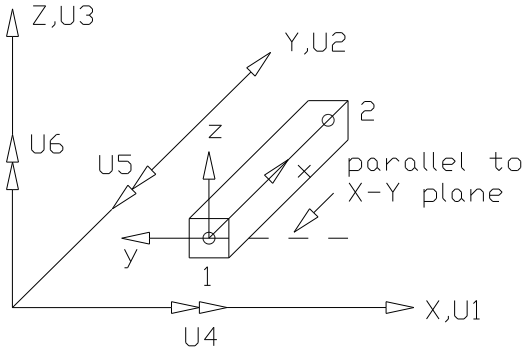
Truss No. 4

- Linear function
- Quality of displacements exact (Hooke 's law)
- Quality of stresses exact (Hooke ' s law)
- Computing effort: Minimal
- Size of element stiffness matrix: 6 × 6



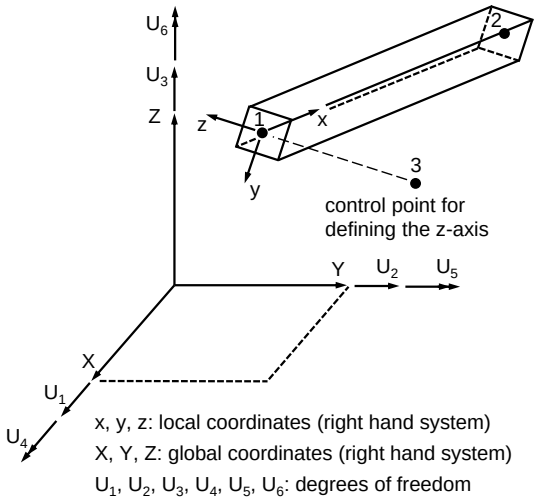
Beam No. 2

- Linear function for tensile stress, cubic function for bending stress
- Quality of displacements exact (Hooke 's law)
- Quality of stresses exact (Hooke ' s law)
- Computing effort: Low
- Size of element stiffness matrix: 12 × 12



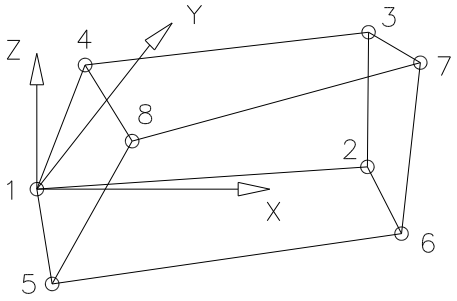
Beam No. 25

- Linear function for tensile stress, cubic function for bending stress
- Quality of displacements exact (Hooke's law)
- Quality of stresses exact (Hooke's law)
- Computing effort: Low
- Size of element stiffness matrix: 12 × 12
- Arbitrary definition of the orientation of the cross section in 3D possible
- Control point for defining the orientation
- Theory of Bernoulli and theory of Timoshenko can be used



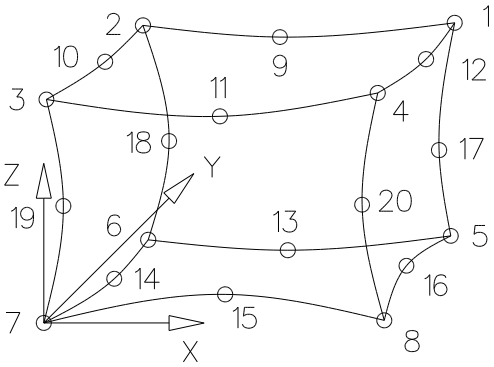
Hexahedron No. 1

- Linear shape functions
- Quality of displacements average
- Stresses in the Gauss points useable
- Stresses in corner nodes inaccurate
- Computing effort: very high
- Size of element stiffness matrix: 24 × 24



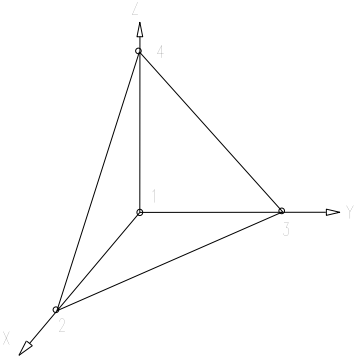
Hexahedron No. 10

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Stresses in the Gauss points very good
- Stresses in corner nodes good
- Computing effort: extremely high
- Size of element stiffness matrix: 60 × 60



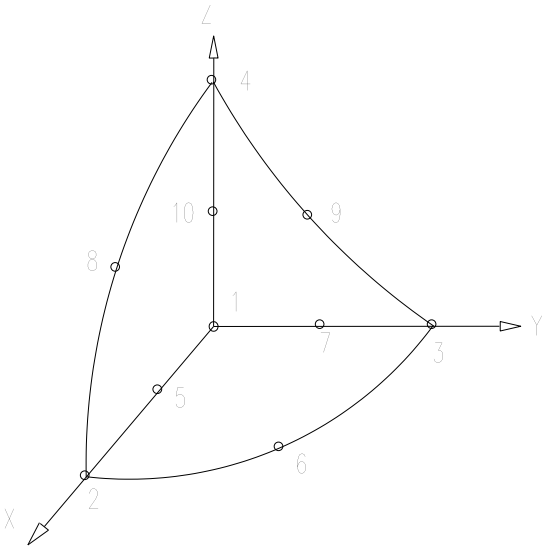
Tetrahedron No. 17

- Linear shape functions
- Quality of displacements bad
- Stresses in the Gauss points inaccurate
- Stresses in corner nodes very inaccurate
- Computing effort: medium
- Size of element stiffness matrix: 12 × 12



Tetrahedron No. 16

- Quadratic Isoparametric Serendipity element
- Quality of displacements very good
- Stresses in the Gauss points very good
- Stresses in corner nodes good
- Computing effort: very high
- Size of element stiffness matrix: 30 × 30



1.1.2 THE Z88 EXECUTABLES:

Overview:
Z88 always exclusively works at the tasks required at the moment. Thus, Z88 is no gigantic, monolithic program, but consists of several separate running modules according to the UNIX philosophy "Small Is Beautiful". They are loaded into the main memory according to your requirements, execute their tasks and release the main memory again. In this way Z88's achieves its enormous speed and faultlessness beating many other FE programs! The Z88 modules communicate by files, cf. Chapter 3. **Remark:** UNIX = LINUX, UNIX & MacOS.

Short description of the modules:

I. The Solver

The linear **solver** Z88R is the heart of any FEA system. It reads the general structure data Z88I1.TXT, the boundary conditions Z88I2.TXT and the file for surface and pressure loads Z88I5.TXT along with the integration order file Z88INT.TXT, the elements parameter file Z88ELP.TXT and the material definitions file Z88MAT.TXT with associated *.TXT material data files. For the operation of the solver, the file Z88MAN.TXT is processed. Basically, the Z88 input files can be created by CAD converter Z88X, by 3D-converter Z88G, by mesh generator Z88N, by editor or word processor system or by a mixed procedure, e.g. by CAD and editor. The solver generates prepared structure data Z88O0.TXT and processed boundary conditions Z88O1.TXT, calculates the element stiffness matrices, compiles the total stiffness matrix, scales the system of equations, solves the (huge) system of equations and stores the displacements in Z88O2.TXT. Thus, the main task of every FEA system, the calculation of displacements, is solved. Thereupon the stresses are calculated and stored in Z88O3.TXT; afterwards the nodal forces are calculated and stored in Z88O4.TXT. Furthermore, the solver generates two files Z88O5.TXT and Z88O8.TXT, which are used for the communication with Z88 Aurora.

Z88 features two different solvers:

- A so-called *Cholesky solver without fill-in.* It is easy to handle and very fast for small and medium structures. However, like any direct solver Z88F reacts badly on ill-numbered nodes but you may improve the situation with the Cuthill-McKee program Z88H. It is your choice for small and medium structures, up to 20,000 ... 30,000 degrees of freedom.
- A so-called *sparse matrix iteration solver*. It solves the system of equations by the method of conjugate gradients featuring SOR-preconditioning or preconditioning by an incomplete Cholesky decomposition depending on your choice. This solver deals with structures with more than 100,000 DOF at nearly the same speed as the solvers of the large and expensive commercial FEA programs as our tests showed. In addition, a minimum of storage is needed. This solver is your choice for large structures with more than 150,000 … 200,000 DOF. FE-structures with ~ 5 million DOF are no problem for it if you use a 64 bit operation system (Windows or LINUX or MacOS) along with the 64 bit version of Z88 and about 6 GByte of memory. *This very stable and approved solver works always, thus, you may use it as your standard solver.*

II. The link to CAD programs

The **CAD converter Z88X** converts DXF files from CAD systems into Z88 input files (mesh generator input file Z88NI.TXT, general structure data Z88I1.TXT, boundary conditions

Z88I2.TXT, surface and pressure loads Z88I5.TXT) or, and this is the real goodie, also converts Z88 input files into DXF files. You may not only produce input data in the CAD system and then use in Z88, but you can also complete Z88 entry files which are always simple ASCII files, e.g. by text editor, by word processing, by EXCEL or e.g. by your own special programs and then convert the data sets back into the CAD system by CAD converters Z88X. In the CAD system you can add more informations, then push the data again to Z88. This flexibility is unique!

The **3D converter Z88G** reads FEA input files following the COSMOS or the NASTRAN format and generates the Z88 input files Z88I1.TXT, Z88I2.TXT and Z88I5.TXT automatically. You may produce COSMOS or NASTRAN data files by various CAD programs. However, Z88G is properly tested with CREO by Parametric Technology, USA. Thus, you may directly use CREO 3D models with Z88! In addition, you may convert ANSYS PREP7 files by my Perl converter Z88ASY.PL (which is very easy to modify) into Z88 files.

The **Cuthill-McKee program Z88H** was mainly designed for use with Z88G. It allows the re-numbering of finite elements meshes and may heavily decrease the memory needs for meshes generated by automeshers i.e. CREO.

III. The mesh generator for ordered meshes

The **mesh generator Z88N** reads the super structure data Z88NI.TXT and computes the general structure data Z88I1.TXT. In principle, the mesh generator file Z88NI.TXT has the same construction as the file of the general structure data Z88I1.TXT. It can also be generated by CAD converters Z88X, by editor or word processor system or with a mixed procedure.

IV. The postprocessors

The **plot program Z88O** plots deflections and stresses. Operating in 3D mode, you may use wireframe or hidden line scenes or scenes with lighting.

All modules of Z88 request Memory dynamically:

The user can define this in the file Z88.DYN. Z88 is delivered with default values which you may and also should change if necessary. This is possible at any time. The Z88 modules are genuine 32 bit or 64 bit programs and request their memory by operating system calls via *calloc*. The header file Z88.DYN provides how much memory shall be requested. You can request all virtual memory (virtual memory = main memory + swap area), which is provided by the operating system. **Therefore there is no limit for the size of the Z88 finite element structures!** You can also fix the language for Z88 in the file Z88.DYN: keywords *ENGLISH* or *GERMAN*.

Multitasking of Z88:

Absolute multitasking is possible under Windows and UNIX, i. e. several Z88 modules or other genuine Windows programs can run parallel. Make sure that you do not overlap the windows (put them side by side), as if the Z88 modules have once started they are not evaluating WM_PAINT signals for speed reasons. This means, that, although the Z88 programs are properly working, displays and window images can be destroyed if you enlarge, reduce, move or cover Z88 windows by other programs. This does not have any influence on the computing results and only by this trick the outstanding speed of Z88 can be gained. Keep

in mind that big space structures, e.g. with 20 nodes hexahedrons, can put very heavy load on your computer which can slow down the machine totally. Thus, let Z88 run alone and do not start any memory eaters like the various office programs.

Hints for the start of Z88:

Windows:
All Z88 modules can be started directly via Explorer, from a group which contains the various Z88 modules or via *Start* > *Run*. It suffices to call the Z88-Commander Z88COM for launching all other modules.

LINUX/UNIX:
Launch the modules directly from a UNIX shell, from the Z88-Commander Z88COM, or, as an extended possibility, e.g. for large night runs, from a shell-script (*sh, bash, ksh* etc.). **You have all the unlimited liberties of the UNIX operating system.** All modules except Z88COM and Z88O can be started in text mode from consoles, but naturally also in an X window. As GKT+ programs the Z88-Commander Z88COM and the plot program Z88O are to start from an X-term. **LINUX**: For a convenient use of Z88, fire up your X-Window-manager, open an X-term and launch Z88COM. **MacOS**: Start the *Terminal* (Finder > Go > Utilities > Terminal) and launch Z88COM. Put Z88COM and the Terminal, which started Z88COM, side-by-side or over-and-under to see both.

The Input and Output of Z88:

The input and output files are generated either by an editor (e.g. the *editor* or *notepad* of Windows, UNIX tools like *vi, emacs, joe*), word processor program (e.g. *WinWord* etc.), spreadsheet program (e.g. *Excel*) or via CAD converter Z88X directly in a CAD program, which can read and write DXF files (e.g. *AutoCAD*). Or import ANSYS, COSMOS or NASTRAN data files produced by *CREO* into Z88 by use of the 3D converter Z88G (NASTRAN and COSMOS) or the stand-alone *Perl* program Z88ASY.PL for ANSYS.

For the user this means maximum flexibility and transparency, as the input and output files of Z88 are quite simple ASCII text files. You can fill the files by arbitrary tools or by hand, and also by self-written programs, of course. Only make sure to meet the Z88 conventions for the respective file structure cf. Chapter 3.

You can modify output files as you like, enlarge them with your own comments, reduce them to the essential or use them as input for other programs.

Dimensions, i. e. measurement units, are not used explicitly. You can work in optional measurement systems, e.g. in the Metric or Imperial measurement system. Use inches, Newtons, pounds, tons, millimeters, meters, yards - whatever you prefer. But make sure to keep the one chosen measurement units throughout all computations of this structure. Example: You want to work with mm and N so Young's modulus must be used in N/mm^2.

Note:
The Z88 input files read *always*:

+ Z88G.COS	COSMOS data file from 3D-CAD system for 3D-converter Z88G
+ Z88G.NAS	NASTRAN data file from 3D-CAD system for 3D-converter Z88G

+ Z88ASY.ANS ANSYS PREP7 data file for Perl program Z88ASY.PL
+ Z88X.DXF Exchange file for CAD programs and for CAD converter Z88X
+ Z88NI.TXT Input file for the mesh generator Z88N
+ Z88I1.TXT Input file (general structure data) for the solver Z88R
+ Z88I2.TXT Input file (boundary conditions) for the solver Z88R
+ Z88I5.TXT Input file (surface and pressure loads) for the solver Z88R
+ Z88MAN.TXT Input file: parameters for the solver Z88R
+ Z88ELP.TXT Input file: element parameters for the solver Z88R
+ Z88INT.TXT Input file: integration orders for the solver Z88R
+ Z88MAT.TXT Input file: material groups für den Solver Z88R
+ (number).TXT Input file: material data for the solver Z88R

The Z88 output files read *always*

+ Z88O0.TXT Prepared structure data for documentation purposes
+ Z88O1.TXT Prepared boundary conditions for documentation purposes
+ Z88O2.TXT Computed displacements
+ Z88O3.TXT Computed stresses
+ Z88O4.TXT Computed nodal forces

These file names are expected from the Z88 modules and they must reside in the same Directory as the Z88 modules. You cannot allocate your own names for data sets. Of course, you may rename the Z88*.* files after all calculations have been done and save them in other directories.

Making:

You may allways create the mesh generator file Z88NI.TXT, the general structure data file Z88I1.TXT, the boundary conditions file Z88I2.TXT and the file for surface and pressure loads Z88I5.TXT by hand using an editor or the like.

Using automatic generation consider the following possibilities:

CAD system	*creates*	*converter*	*creates*	*mesh generator*	*creates*
CREO	Z88G.COS Z88G.NAS	**Z88G**	Z88I1.TXT, Z88I2.TXT, Z88I5.TXT	not necessary	files still exist
CREO	Z88ASY.ANS	**Z88ASY.PL**	Z88I1.TXT, Z88I2.TXT, Z88I5.TXT	not necessary	files still exist
AutoCAD	Z88X.DXF	**Z88X**	Z88NI.TXT	**Z88N**	Z88I1.TXT
AutoCAD	Z88X.DXF	**Z88X**	Z88I1.TXT, Z88I2.TXT, Z88I5.TXT	not necessary	files still exist

Z88 protocol files:

The Z88 modules always store protocol files .LOG, e.g. Z88R.LOG documents the steps or errors of the calculation of Z88R. Look at the various .LOG files in case of doubt. They also document the current memory needs. **UNIX:** If different users work in the same Z88 directory, make sure to have the proper permissions for the .LOG files, too. Use *umask*.

Printing of Z88 files

Is not supported by the Z88-Commanders. You print them by the Explorer of **Windows** or by an editor or word processing program. Make a screen dump by *Shift – Print* and paste it anywhere.
Use the printing routines of the **LINUX** operating system or print by using an editor like *gedit* or *OpenOffice*. Make screen dumps by *GIMP*.
On **MacOS** computers you may print the Z88 files by *TextEdit*, use the utility *screencapture* or make a screen dump by *Cmd – Shift – 3*.

Which Z88 finite Element types can be produced automatically?

element type	*function*	*COSMOS NASTRAN ANSYS (Z88G and Z88ASY.PL)*	*DXF (Z88X)*	*super element (Z88N)*	*creates FE (Z88N)*
Hexahedron No.1	linear	No	Yes	Yes	Hexa No.1
Hexahedron No.10	quadratic	No	Yes	Yes	Hexa No.10 & No.1
Tetrahedron No.16	quadratic	Yes	Yes	No	-
Tetrahedron No.17	linear	Yes	Yes	No	-
Plane stress No.3	quadratic	No	Yes	No	-
Plane stress No.7	quadratic	Yes	Yes	Yes	Plane stress No.7
Plane stress No.11	cubic	No	Yes	Yes	Plane stress No.7
Plane stress No.14	quadratic	Yes	Yes	No	-
Torus No.6	linear	No	Yes	No	-
Torus No.8	quadratic	Yes	Yes	Yes	Torus No.8
Torus No.12	cubic	No	Yes	Yes	Torus No.8
Torus No.15	quadratic	Yes	Yes	No	-
Plate No.18	quadratic	Yes	Yes	No	-
Plate No.19	cubic	No	Yes	No	-
Plate No.20	quadratic	Yes	Yes	Yes	Plate No.19 & No.20
Shell No.21	quadratic	No	Yes	Yes	Shell No.21
Shell No.22	quadratic	No	Yes	No	-
Shell No.23	quadratic	Yes	Yes	No	-
Shell No.24	quadratic	Yes	Yes	No	-
Truss No.4	exact	No	Yes	No	-
Truss No.9	exact	No	Yes	No	-
Beam No.2	exact	No	Yes	No	-
Cam No.5	exact	No	Yes	No	-
Beam No.13	exact	No	Yes	No	-

All Z88 files:

Name	Type	Direction	Purpose	change, modify	MS-Win	UNIX
Z88.DYN	ASCII	Input	Memory & Language header file	Yes,Recom.	Yes	Yes
Z88G.COS	ASCII	Input	COSMOS to Z88	Yes, 1)	Yes	Yes
Z88G.NAS	ASCII	Input	NASTRAN to Z88	Yes, 1)	Yes	Yes
Z88ASY.ANS	ASCII	Input	ANSYS PREP7 to Z88	Yes, 1)	Yes	Yes
Z88X.DXF	ASCII	In/Output	DXF from and to Z88	Yes, 1)	Yes	Yes
Z88NI.TXT	ASCII	Input	mesh generator input file	Yes	Yes	Yes
Z88I1.TXT	ASCII	Input	general structure data	Yes	Yes	Yes
Z88I2.TXT	ASCII	Input	constraints	Yes	Yes	Yes
Z88I5.TXT	ASCII	Input	surface and pressure loads	Yes	Yes	Yes
Z88MAN.TXT	ASCII	Input	parameters for solver Z88R	Yes	Yes	Yes
Z88ELP.TXT	ASCII	Input	element parameters for Z88R	Yes	Yes	Yes
Z88INT.TXT	ASCII	Input	integration orders for Z88R	Yes	Yes	Yes
Z88MAT.TXT	ASCII	Input	material groups for Z88R	Yes	Yes	Yes
(number).TXT	ASCII	Input	material data for Z88R	Yes	Yes	Yes
Z88O0.TXT	ASCII	Output	processed structure data	Possible	Yes	Yes
Z88O1.TXT	ASCII	Output	processed constraints	Possible	Yes	Yes
Z88O2.TXT	ASCII	Output	computed displacements	Possible	Yes	Yes
Z88O3.TXT	ASCII	Output	computed stresses	Possible	Yes	Yes
Z88O4.TXT	ASCII	Output	computed nodal forces	Possible	Yes	Yes
Z88O5.TXT	ASCII	Output	for internal use of Z88O	No 1)	Yes	Yes
Z88O8.TXT	ASCII	Output	for internal use of Z88O	No 1)	Yes	Yes
Z88O.OGL	ASCII	Input	Color header file Z88O MS-Win	Possible	Yes	No
Z88.FCD	ASCII	Input	Fonts, Colors, Dimens. UNIX for Z88COM and Z88O	Possible	No	Yes
Z88COM.CFG	ASCII	Input	configuration file Z88COM	No 2)	Yes	No

(1) in principle yes, but not necessary, automatically produced
(2) only if needed

Remark: UNIX = LINUX, UNIX and MacOS

1.2 HOW TO INSTALL Z88 FOR WINDOWS

Remark: We could of course use the standard installation routines or ready-to-run installation tools for Z88, but as there are no hidden .DLL files, no .INI files are to be modified and no subdirectories are created, we leave it alone. You will see, Z88 installs quite simply:

Windows in five steps:

Please note: These executables will run properly under Windows 8.1 and 10. Tip: Load the free *Classic Shell* from http://www.classicshell.net/ to get a really nice Start button.

1st step: Extract the Z88 zip file to C:

Assuming that you have extracted the file **Z88V15OS.ZIP** from the Internet to C: . Then you'll see these subdirectories:

C:/Z88V15OS

- /BIN
  - /WIN32 — Z88 ready-to-run 32 Bit Windows
  - /WIN64 — Z88 ready-to-run 32 Bit Windows
  - /UNIX64 — Z88 ready-to-run 64 Bit LINUX*
  - /MAC — Z88 ready-to-run 64 Bit MacOS*
- /DOCU
  - this manual in German and English
- /MAKE
  - /MAKE_WIN_32 — *nmake* files for MS Visual Studio Windows 32 Bit
  - /MAKE_WIN_64 — *nmake* files for MS Visual Studio Windows 64 Bit
  - /MAKE_UNIX_64 — *make* files for GCC 64 Bit LINUX
  - /MAKE_MAC — *make* files for XCODE 64 Bit MacOS
- /SRC
  - /name_of_executable, e.g. Z88R
    - /COMMON — sources needed by Windows and UNIX
    - /UNIX — sources for UNIX only
    - /WIN — sources for Windows only
- /EXAMPLES
    - /name_of_sample
- /PERL
  - some support Perl scripts, see chp. 2.7

* *If you have installed the necessesary libs – more for testing purposes. I recommend that you'll compile the sources new from scratch which is fairly easy by the Make files. If you want a great ready-to-run FEA system: Better install our Z88Aurora!*

2nd step: Make Z88 ready to run:

Create a link on the Windows Desktop (Windows key, right mouse button > new) to
C:\Z88V15OS\BIN\WIN64\Z88COM.EXE or
C:\Z88V15OS\BIN\WIN32\Z88COM.EXE

3rd step: Enter your favourite editor in Z88

You may produce all input files either by a CAD program which can read and generate DXF files in cooperation with the CAD converter Z88X or also write by editor because Z88 operates with ASCII files, however. An editor for looking at the Z88 results is also very useful. So you should define it: Suitable editors are under Windows *editor* from *Start* >

Programs > Accessories.
Launch the Z88 commander, choose *File > Define Editor*. Assume you want to work with Notepad: enter in textfield *Editor Name* any text, e.g. MY-NOTEPAD, enter in textfield *Editor Call, if nes. Path*. the program name *notepad*. Further example: Word for Windows. You must find out where Word for Windows is located. Go ahead: *Start > Find > Files or Folders* : *winword.exe*. Let's assume WinWord is located in C:\MSOffice\Winword. Thus, you could enter in Z88COM: *Word4Windows* and *C:\MSOffice\Winword\winword* . **Make sure when using Winword that you work and save in plain text mode!**

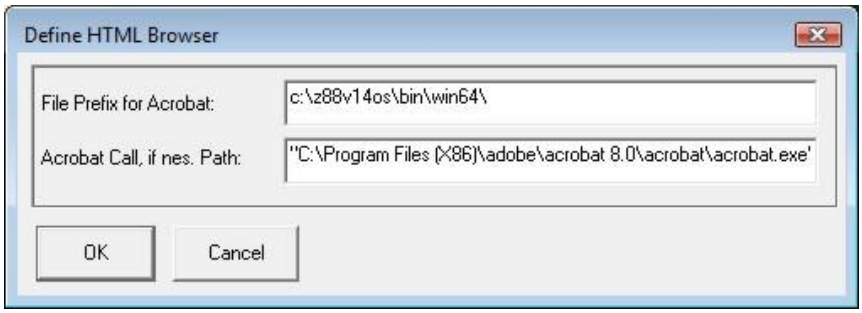
4th step: Add an Internet Browser or PDF Viewer for Z88's OnLine help:
Integrate your favourite Internet Browser into Z88. This may be *Firefox, MS Internet Explorer* or *Chrome*. Or use a PDF Viewer like *Acrobat Reader*. Note: The help files (Z88MANE.PDF for English, Z88MANG.PDF for German) are stored on your hard disk. Thus, you don't need any internet connection when running Z88.

(1) The next step is very important: Z88 must be able to start the Browser! Either you must put it into the PATH or enter the PATH in Z88COM or copy the whole Browser into the Z88 directory. State at first where your Internet browser is located. Use *Start > Find > Files or Folders*. The Microsoft Internet Explorer is called *iexplore.exe*, Firefox is called *firefox.exe*. Note down the found path.

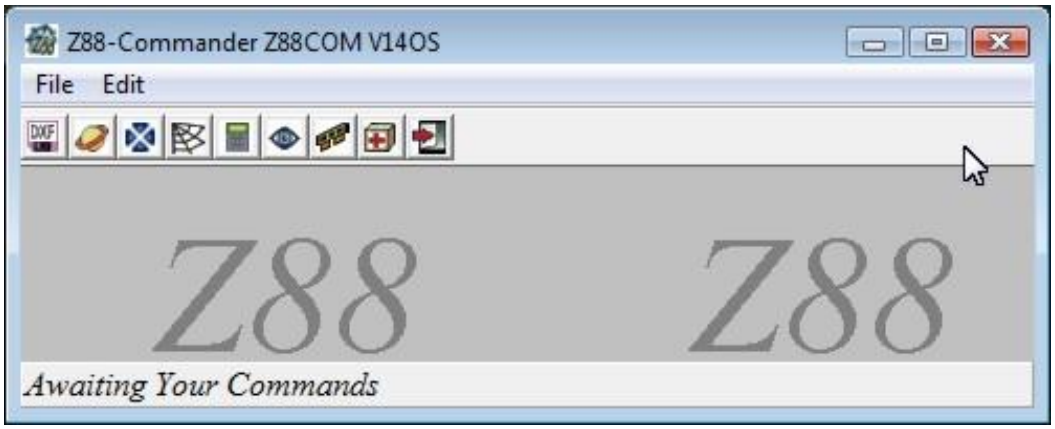
1st possibility: Type in path into the PATH variable: *Start > Settings > Control Panel > System > Advanced > Environment*. Example: The Internet Explorer is located in Windows: *c:\Program Files\Internet Explorer*. Let us assume your previous PATH variable looks as follows: `H:\VisualStudio6\Tools\WinNT;C:\Hugo;`
Separate the items by semicolons. And now:
`H:\VisualStudio6\Tools\WinNT;C:\Hugo;c:\Program Files\Internet Explorer;`
Logoff and login again.

2nd possibility: Enter path in Z88COM directly. If the path contains blanks then put the path into double quotes. For example:
`"C:\Program Files\Mozilla Firefox\firefox.exe"`
`"C:\Program Files (X86)\Adobe\Reader 9.0\Reader\AcroRd32.exe"`

(2) Take into account that most Internet-Browsers immediatelly try to contact the Internet. Now they are to load a local PDF file. Thus, various file prefixes depending on the used Browser must be fixed. For Microsoft Internet Explorer and Firefox the prefix is *file:Z88 path*.
See, for example, the entries for Adobe Acrobat Reader:



5th step: Launch Z88:
Z88 is ready to run. You may fire away immediatelly by launching the Z88 commander Z88COM and using the OnLine help system. Proceed with example 5.1.



Notes for the Z88-Commander Z88COM

It starts all Z88 modules, provided that you don't want to start them stand-alone (which is possible any time and without any restrictions), permits the immediate editing of all input and output files and calls the online-help.

Z88COM files your entries for the Internet-Browser and editor in a file Z88COM.CFG. If this file should be destroyed accidentally, you can edit Z88COM.CFG by hand:
1st line: Editor name
2nd line: Editor call
3rd line: Browser prefix
4th line: Browser call
Example:
Word4Windows
C:\MSOffice\Winword\Winword
File:c:\Z88V15OS\docu
C:\Program Files\Internet Explorer\iexplore.exe

... And how do you remove Z88 ?

Simply delete all files in the directory containing Z88. Then delete the directory if necessary. You should delete the links we made for Windows in chapter 1.2. That's all !

And how to compile Z88 for Windows?

If you want to add improvements to Z88 you will need to compile the package. Every Windows C or C++ compiler should work properly. I tried the compiler from Microsoft (Visual Studio 2015). For MS Visual Studio see the directories *make\make_win_64* and *make\make_win_32* for ready-to-go *nmake* files. You may run them, for example, by *nmake -f z88r.nm* in a Visual Studio command prompt .

Make sure to have the files *Z88.DYN*, *Z88COM.CFG* and *Z88O.OGL* in the same directory were you did the compilation i.e. where your executables are located. Otherwise, you don't need to wonder about fancy error massages. And the proper input files should exist here, too.

Use the following compiler defines to define the number of bytes for every operating system and any precision:

	Number type	Win32	Win64	LINUX32	LINUX64 MacOS
Operating system	./.	FR_WIN FR_XWIN32	FR_WIN FR_XWIN64	FR_UNIX FR_LINUX	FR_UNIX FR_LINUX
	Pointer	4	8	4	8
FR_XINT	Integer	4	4	4	4
FR_XLONG	Integer	4	4	4	8
FR_XLOLO	Integer	4	8	8	8
FR_XDOUB	Float	8	8	8	8
FR_XQUAD	Float	8	8 / 16[1)]	12 / 16[1)]	12 / 16[1)]

You may choose any precision by using the FR_ compiler defines. For example: You want to compile the sources for Vista 64 Bit. The integers should hold 8 Bytes memory each and the floats should hold 8 Bytes memory each, too:

FR_WIN FR_XWIN64 FR_XLOLO FR_XDOUB

Hint [1)] : depending on your compiler you may give further compiler flags

1.3 HOW TO INSTALL Z88 FOR LINUX, UNIX AND MACOS

Assuming that you have extracted the file **Z88V15OS.ZIP** from the Internet to your home directory. Then you'll see these subdirectories:

~/Z88V15OS

- /BIN
  - /WIN32 Z88 ready-to-run 32 Bit Windows
  - /WIN64 Z88 ready-to-run 32 Bit Windows
  - /UNIX64 Z88 ready-to-run 64 Bit LINUX*
  - /MAC Z88 ready-to-run 64 Bit MacOS*
- /DOCU
  - this manual in German and English
- /MAKE
  - /MAKE_WIN_32 *nmake* files for MS Visual Studio Windows 32 Bit
  - /MAKE_WIN_64 *nmake* files for MS Visual Studio Windows 64 Bit
  - /MAKE_UNIX_64 *make* files for GCC 64 Bit LINUX
  - /MAKE_MAC *make* files for XCODE 64 Bit MacOS
- /SRC
  - /name_of_executable, e.g. Z88R
    - /COMMON sources needed by Windows and UNIX
    - /UNIX sources for UNIX only
    - /WIN sources for Windows only
- /EXAMPLES
  - /name_of_sample
- /PERL
  - some support Perl scripts, see chp. 2.7

[*] *If you have installed the necessesary libs – more for testing purposes. I recommend that you'll compile the sources new from scratch which is fairly easy by the Make files. If you want a great ready-to-run FEA system: Better install our Z88Aurora!*

I suggest to set the file access rights to 777: *chmod 777 **

Now you may compile Z88 at first for MacOS, LINUX or UNIX. This is fairly easy as you will see below.

MacOS, LINUX or UNIX installation in 6 steps:

1st Step: Switch to the proper make-directory:

- Go to */Z88V15OS/make/make_unix_64* or */Z88V15OS/make/make_mac*. Take care to do this as a normal user and that you have read/write/execute permissions. This should be true for your home directory or an underlying subdirectory. Of course, it's all possible as root, too, but then paths must be adjusted. Again: Make sure that all permissions are properly set. Use *umask* if necessary.

2nd Step: Compile Z88 for MacOS, UNIX or LINUX:
You need: C compiler, make, X11, GTK+2, OpenGL. Any UNIX-C or C++ compiler should work. I've tested Xcode 8.2.1 with MacOS Sierra 10.12.3 and the GNU gcc compiler with Ubuntu 16.04 and OpenSuSe 13.1.

- For MacOS: run the *make* files, for example *make -f z88r.mk.gccmac*
  Make sure that Xcode along with its command line tools is properly installed.
  These or similar libraries must be installed on your system:
  - XQuartz (www.xquartz.org → for an X11 subsystem on MacOS)
  - MacPorts (www.macports.org → to install GTK+ and OpenGL)
  - then run the *port* command:
    sudo port install gtk2
    sudo port install pkgconfig
    sudo port install glw
    sudo port install libGLU

- For LINUX: run the *make* files, for example *make -f z88r.mk.gcc64*
  These or similar libraries must be installed on your system:
  - x11-devel (X11 development library)
  - mesa-devel (OpenGL development library : GL and GLU)
  - gtk+-devel (GTK+ development library : GTK+ 2.0)

- UNIX systems: modify the Makefiles (*.mk.*) if necessary.
-
- The following Makefiles for LINUX are included:

	for the solver	other moduls	GTK+ moduls
MacOS 64-Bit	*z88r.mk.gccmac*	*z88g.mk.gccmac*	*z88com.mk.gccmac*
		z88h.mk.gccmac	*z88o.mk.gccmac*
		z88n.mk.gccmac	
		z88x.mk.gccmac	

LINUX 64-Bit	*z88r.mk.gcc64*	*z88g.mk.gcc64*	*z88com.mk.gcc64*
		z88h.mk.gcc64	*z88o.mk.gcc64*
		z88n.mk.gcc64	
		z88x.mk.gcc64	

3rd step: Enter your favourite Internet Browser or PDF Viewer and Editor into Z88:
You should have installed a browser or PDF reader on your system in order to display the Z88 online help. Use any internet browser e.g. *Firefox:* Edit the header file *Z88.FCD*. Be sure to enter the proper browser prefix (keyword CPREFIX) matching your browser. The prefix tells the browser to load a specific PDF file from your machine rather from the Internet. For example *Firefox*: *file:///home/frank/Z88V15OS/docu/*, assuming that the Z88 PDF files (Z88MANE.PDF for English, Z88MANG.PDF for German) are located in the directory */home/frank/Z88V15OS/docu.*
You may use any ASCII editor. I like *gedit.* Edit *Z88.FCD* if necessary.The Apple editor *TextEdit* (Finder > Go > Application > TextEdit) is predefined in Z88.FCD – be shure to operate *TextEdit* in plain text mode (TextEdit > Preferences > Plain Text)! The Apple browser *Safari* for the online help is predefined in Z88.FCD. You may change later both the editor and browser in the file *Z88.FCD* to, for example, *emacs* and *Firefox* (if installed). Be shure to put commands with more than one token as *open –a safari* in *: **open –a safari**

4th step: Adjust system variables:
Allow the Z88 programs to start in your favourite directory. Modify your file *.bash_profile* :

- *export PATH=$PATH:.* (mind the dot after the colon!)

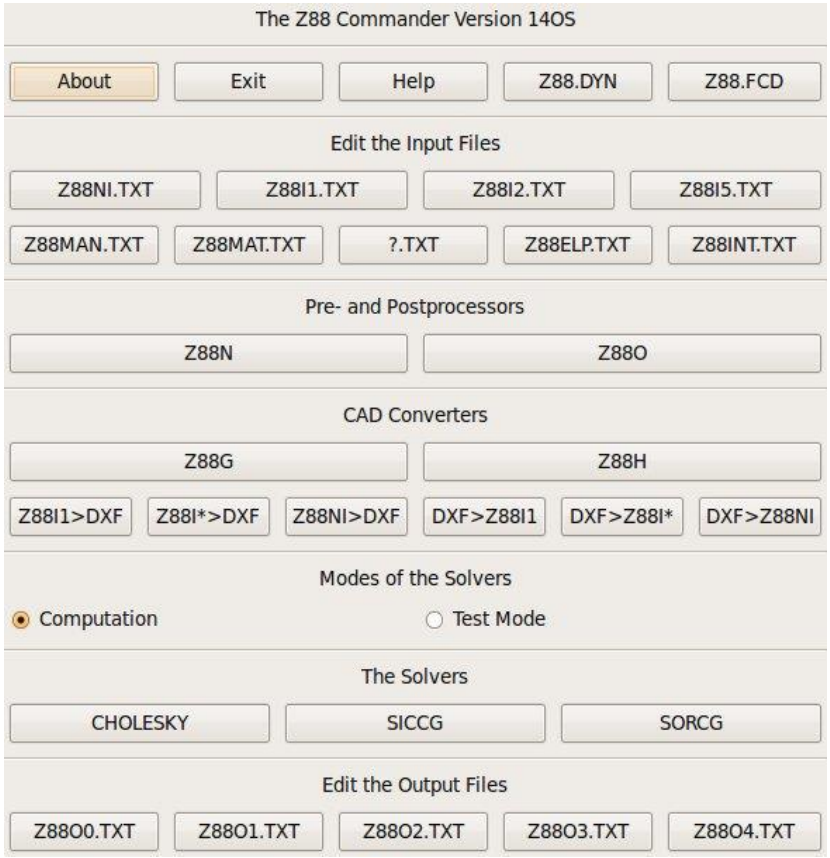
If you've got a „GERMAN" or another non-angloamerican LINUX or MacOS then adjust the system variable LANG in every case in *.bash_profile* to:

- *export LANG=C*
- *export LC_NUMERIC=C*

Otherwise, the dots in the Z88 files are wrong interpreted and the plot program Z88O prints fancy wrong colours – typically a red background. Why? Because the thousands in Great Britain and the USA are delimited by commas and the decimal point is the dot but in Germany and other European countries the thousands are delimited by dots and the decimal point is the comma!
LANG=C or LANG=en: 1.000 reads 1. (correct!)
LANG=de : 1.000 reads 1000. (wrong!)
To make the variable LANG work, log off and log on again.

5th step: Adjust Z88's language:
Enter into the file Z88.DYN either the keyword ENGLISH or GERMAN. ENGLISH is default, thus, you may skip this step.

6th step: Run Z88:
LINUX: Start an X-term and launch Z88COM.
MacOS: Start Terminal.app and launch Z88COM.
Put Z88COM and the X-term or Terminal.app, which started Z88COM, side-by-side or over-and-under to see both. The X-term or Terminal.app is used for console input/output for the text-mode programs Z88R, Z88N, Z88X, Z88G, Z88H.



If you are not pleased with my choice of colours and fonts, then edit the header file *Z88.FCD*. Be sure to store the original *Z88.FCD* file in order to have a ready-to-run file if something goes wrong as Z88COM and Z88O cannot run without a correct *Z88.FCD*.

... And how do you remove Z88?

Simply delete all files in the directory containing Z88. Then delete the directory if necessary.

1.4 DYNAMIC MEMORY Z88

HEADER FILE Z88.DYN

All Z88 modules allocate memory dynamically. Although Z88 is delivered with default values in Z88.DYN the user may and should modify the values for best operation of Z88. The file Z88.DYN is there to be modified .

The language is defined also in Z88.DYN. Enter into a line, best located between DYNAMIC START and NET START, the key word **ENGLISH** or **GERMAN**.

Z88.DYN starts with the key DYNAMIC START and ends with DYNAMIC END. There is a section for the mesh generator (NET START, NET END), a common section for all modules (COMMON START, COMMON END) and an additional section for the Cuthill McKee program (CUTKEE START, CUTKEE END). Blank lines or comments are optional, only the uppercased keywords are recognized. After the keyword follows an integer value, separated by at least one blank. The order of the keywords is optional.

A proper modification of Z88.DYN is definitely a good idea.

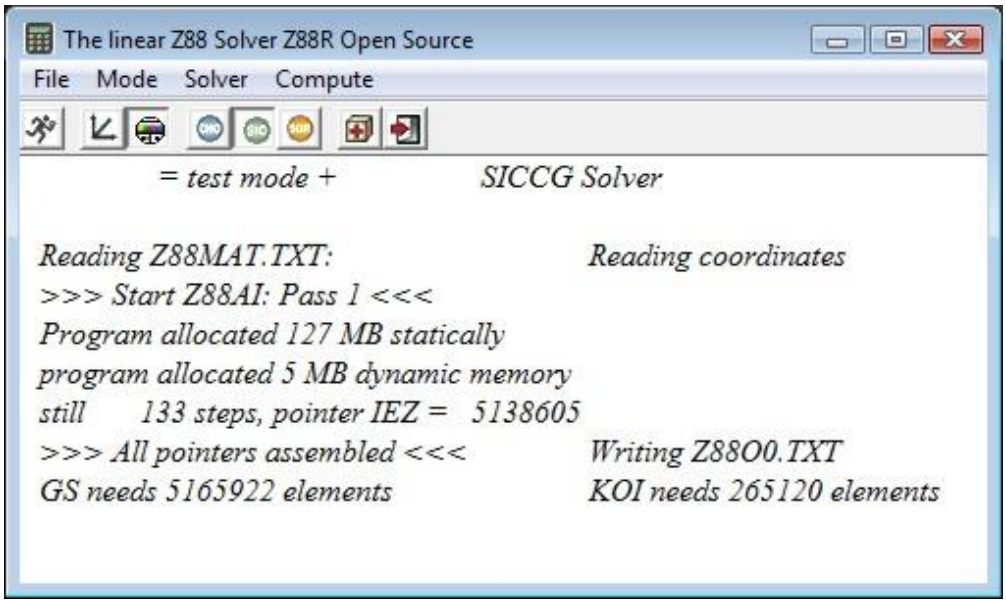
However, do not request unnecessarily much memory since this causes speed losses, especially when using virtual memory.

Test the memory needs for large structures. Proceed as follows depending on the solver:

I) Test run - II) modify Z88.DYN,if necessary - III) solver run

I) Test run:

Windows: Z88R > Mode: Test mode > Solver: Cholesky | SICCG | SORCG > Compute: Run
UNIX: z88r -t -choly | -siccg | -sorcg



See the necessary memory MAXGS and MAXKOI, Windows. Looks similar on UNIX systems.

For the Cholesky solver, MAXGS and MAXKOI will do. However, the procedure for the sparse matrix solver SICCG and SORCG is quite tricky because you must define in addition memory for MAXIEZ for the assembly of the sparse matrix. There is no way to pre-determine the needed memory but Z88R tells you if MAXIEZ was too small. Then, increase MAXIEZ in Z88.DYN and run Z88R again. Thus proceed for large structures for Z88 in 3 or more steps:
I)
1: run Z88R in test mode
2: if Z88R completed properly proceed with step II
3: if Z88R stopped because of lack of MAXIEZ increase MAXIEZ in Z88.DYN and run Z88R again. Repeat this step until Z88R completes properly in test mode.
II) Modify Z88.DYN: read off the values for MAXGS and MAXKOI and adjust Z88.DYN, if necessary. Now memory is proper adjusted for Z88R in computation mode. Of course, the other entries for MAXK (max. number of nodes), MAXE (max. number of elements) must fit properly.

Attention: For safety reasons, please add always 3 to each minimum value.
III) Run Z88R in computation mode. Be sure to use the same mode you've used in test mode!
Windows: Z88R > Mode: Computation > Solver: Cholesky | SICCG |
SORCG > Compute: Run
UNIX: z88r -c -choly | -siccg | -sorcg

Make sure that your swap space is sufficient. Adjust if necessary:
Windows: *Start > Settings > Control Panel > System > Performance > Virtual Memory > Change*. UNIX: Depending on the various UNIX operating systems the swap partition can be easily extended dynamically or an additional swap file must be created or the swap area must be deleted and a new swap area created with extended size.

There are no limits for the size of the structures for Z88. The maximum size is limited only by virtual memory of your computer and your imagination! However, for very large structures you may use Z88 with 64 Bit integers and pointers (i.e. the 64 Bit Z88 versions for Windows Server or Vista 64 bit or LINUX 64-Bit or MacOS) to avoid overflows of internal loop counters etc.

The Z88 modules check whether the predefined memory is sufficient for the current problem or if limits are reached and stop if necessary. At commentless breakdown of a Z88 module check the accompanying .LOG file. Often the value for MAXKOI was too small! Caution UNIX: If Z88 modules refuse to start, check the permissions of the .LOG files. The .LOG files record the memory needs. Some more memory is needed for the program, local arrays and stack which one can neglect for Windows or UNIX.
The Z88 32 Bit versions for Windows deal with

- Floating point numbers with Doubles = 8 bytes
- Integers and pointers with Longs = 4 bytes.

The Z88 64 Bit versions for Windows and LINUX deal with

- Floating point numbers with Doubles = 8 bytes
- Integers and pointers with Longs = 8 bytes.

However, on several UNIX machines you may compile (compiler switches and compiler directive FR_XQUAD) the solver modules using

- Floating point numbers with long Doubles = 16 bytes = 128 bit
- Integers with long Longs = 8 bytes = 64 bit.

Attention: 64 Bit Integers are usefull for very large structures i.e. > 2 ~ 3 mio. of DOF for avoiding internal overflows. However, using 128 Bit floats is much more time-consuming

than 64 Bit floats. Test runs with a SUN FIRE V890 with quad precision at my institute at the University of Bayreuth, Germany, caused five to ten times more CPU time than double precision! Thus, I recommend using 64 bit integers and 64 bit floats on larger computers.
The general description follows for Z88.DYN:

DYNAMIC start

Adjusting Language:

ENGLISH or **GERMAN**. If nothing is entered or the entry is wrong, English language is used automatically.

Section Mesh Generator:

NET START

MAXSE Maximum number of internal nodes for FE mesh generation. Must be clearly higher than produced FE nodes.

MAXESS Maximum number of super elements

MAXKSS Maximum number of super nodes

MAXAN Maximum number of nodes which can meet a super element. The default of 15 has proven well even for complex space structures with Hexahedrons No.10. May be increased in case of doubt.

NET END

Common Data:

COMMON START

MAXGS Maximum number of entries in the the total stiffness matrix. Actual number GS is recorded by Z88F and Z88I1.

MAXKOI Maximum number of entries in the coincidence vector = number nodes per element * number of finite elements. Example: 200 finite elements No.10 = 20 nodes per element * 200 = 4000. At mixed structures take the element type with most nodes and multiply by the number of elements. Required number of NKOI is recorded by Z88R.

MAXK Maximum number of nodes in the structure.

MAXE Maximum number of elements in the structure.

MAXNFG Maximum number of degrees of freedom in the structure.

MAXMAT Maximum number of material entries in the structure.

MAXJNT Maximum number of integration order groups in the structure.

MAXPEL Maximum number of element parameter groups in the structure.

MAXPR Maximum number of surface and pressure loads

MAXRBD Maximum number of boundary conditions (used only by Z88O)

MAXIEZ For the sparse matrix solver SICCG and SORCG only. Z88R uses a vector with the size of MAXIEZ. There is no way to pre-determine the needed memory but Z88R tells you if MAXIEZ was too small. In this case you must increase MAXIEZ and launch Z88R again.

MAXGP Maximum number of Gauss points (used only by Z88O)

COMMON END

For the Cuthill-McKee program:

CUTKEE START

MAXGRA maximum degree of nodes

MAXNDL steps of the algorithm

CUTKEE END

DYNAMIC END

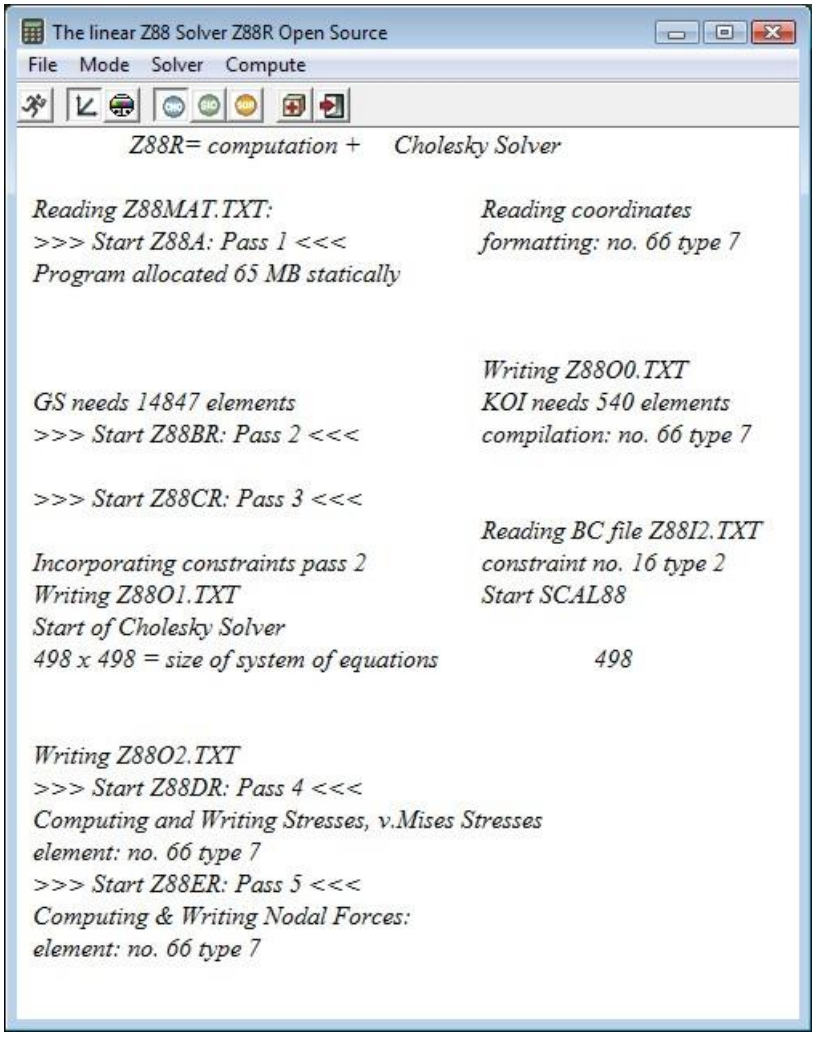
2 THE Z88 MODULES

2.1 THE SOLVER Z88R

2.1.1 Z88R: THE CHOLESKY SOLVER

NOTE: Always compare FEA calculations with analytical rough calculations, results of experiments, plausibility considerations and other tests without exeption!

The so-called *Cholesky solver* with so-called Jennings storage is easy to handle and very fast for small and medium structures. However, like any direct solver Z88R in Cholesky mode reacts badly on ill-numbered nodes but you may improve the situation with the Cuthill-McKee program Z88H. Z88R in Cholesky mode is your choice for small and medium structures, up to 20,000 ... 30,000 degrees of freedom. Typical application: truss and beam models, plane continuum elements.



Note: The files Z88I1.TXT, Z88I2.TXT and Z88I5.TXT mentioned here are described more precisely in chapter 3.

(1) Test Mode
Windows: Z88R > Mode: Test Mode > Solver: Cholesky > Compute > Run
UNIX: z88f –t –choly or via Z88COM

Input files:
See (2) Compute Mode

Output files:
Z88O0.TXT processed structure data for documentation
Only the file Z88O0.TXT (processed structure data for documentation) is produced along with the memory needs for total stiffness matrix and coincidence vector plotted on the screen. Use this mode for

- Checking the memory needs for MAXGS and MAXKOI.
- Checking if Z88R interprets Z88I1.TXT correctly and, as requested, puts the data in Z88O0.TXT.

(2) Compute Mode

Windows: Z88R > Mode:Computation > Solver: Cholesky > Compute: Run
UNIX: z88f –c –choly or via Z88COM

Input files:

- Z88I1.TXT general structure data
- Z88I2.TXT boundary conditions, constraints
- Z88I5.TXT surface and pressure loads), if needed
- Z88MAT.TXT material definitions and one or more material files in .TXT format
- Z88ELP.TXT element parameters
- Z88INT.TXT integration orders
- Z88MAN.TXT solver parameters
-

Output files:

- Z88O0.TXT processed structure data for documentation
- Z88O1.TXT processed boundary conditions for documentation
- Z88O2.TXT deflections
- Z88O3.TXT stresses
- Z88O4.TXT nodal forces

2.1.2 Z88R: THE SPARSE MATRIX ITERATION SOLVER

NOTE: Always compare FEA calculations with analytical rough calculations, results of experiments, plausibility considerations and other tests without exeption !

Z88R, when in sparse matrix mode, solves the system of equations by the method of conjugate gradients featuring SOR preconditioning or preconditioning by an incomplete Cholesky decomposition depending on your choice. This solver needs a minimum of storage. It is your choice for structures with more than 20,000 ~ 30,000 DOF. On 64 Bit machines, structures with millions of DOF are no problem. However, its use is more difficult than Z88R in Cholesky mode. It computes the deflections, stresses and nodal forces.

(1) Test Mode
Windows: Z88R > Mode: Test Mode > Solver: SICCG or SORCG > Compute > Run
UNIX: z88f –t –siccg or –sorcg or via Z88COM

Input files:
See (2) Compute Mode

Output files:
Z88O0.TXT processed structure data for documentation
Only the file Z88O0.TXT (processed structure data for documentation) is produced along with the memory needs for total stiffness matrix and coincidence vector plotted on the screen. Use this mode for

- Checking the memory needs for MAXGS and MAXKOI.
- Checking if Z88R interprets Z88I1.TXT correctly and, as requested, puts the data in Z88O0.TXT.

An iteration solver uses only the so-called non-zero elements – which results in an absolute minimum of storage requirements. It builds the following pointers for the lower part of the total stiffness matrix GS:

- Pointer vector IP points to the diagonal elements GS(i, i)
- Pointer vector IEZ points to the column index GS(x, j)

Example (ref. Schwarz, H.R: Methode der finiten Elemente) : Let the lower part of GS be:

GS(1,1)					
GS(2,1)	GS(2,2)				
	GS(3,2)	GS(3,3)			
GS(4,1)			GS(4,4)		
GS(5,1)		GS(5,3)		GS(5,5)	
	GS(6,2)		GS(6,4)		GS(6,6)

GS results in the following vector of non-zero elements:

GS(1,1)	GS(2,1)	GS(2,2)	GS(3,2)	GS(3,3)	GS(4,1)	GS(4,4)
GS(5,1)	GS(5,3)	GS(5,5)	GS(6,2)	GS(6,4)	GS(6,6)	

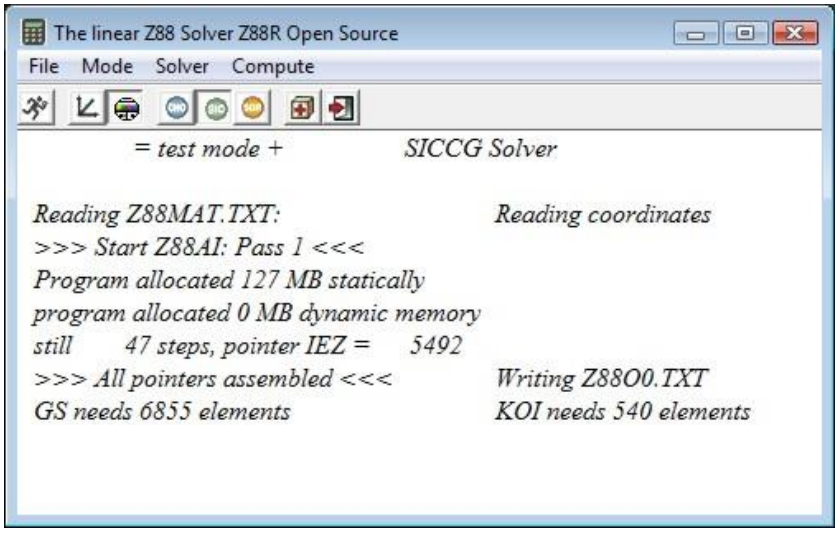
IEZ will result in:

1	1	2	2	3	1	4	1	3	5	2	4	6

and IP:

1	3	5	7	10	13

The pointer IEZ holds MAXIEZ elements, ref. Memory definition file Z88.DYN. You must allocate memory MAXIEZ for the assembly of the sparse matrix. There is no way to pre-determine the needed memory but Z88R tells you if MAXIEZ was too small. Then, increase MAXIEZ in Z88.DYN and run Z88R again.



Z88R tells you how much memory for GS (= MAXGS) and for KOI (= MAXKOI) you must allocate; adjust this in Z88.DYN. See an example of Z88.DYN:

```
COMMON START
    MAXGS   5200000 ← adjust before running Z88R Comp.mode
    MAXKOI   270000 ← adjust before running Z88R Comp.mode
    MAXK      46000
    MAXE      27000
    MAXNFG   137000
    MAXMAT       32
    MAXPEL       32
    MAXJNT       32
    MAXIEZ  5200000 ← adjust before running Z88R Test mode
COMMON END
```

Thus, proceed for large structures for Z88 in 3 or more steps:
1: run Z88R in Test mode
2: if Z88R completed properly, read off the values for MAXGS and MAXKOI and adjust Z88.DYN, if necessary. Now the memory is properly adjusted for running Z88R in Computation mode.
3: if Z88R in Test mode stopped because of lack of MAXIEZ increase MAXIEZ in Z88.DYN and run Z88R in Test mode again. Repeat this step until Z88R completes properly.

(2) Compute Mode

Windows: Z88R > Mode:Computation > Solver: SICCG or SORCG > Compute: Run
UNIX: z88f –c –siccg or –sorcg or via Z88COM

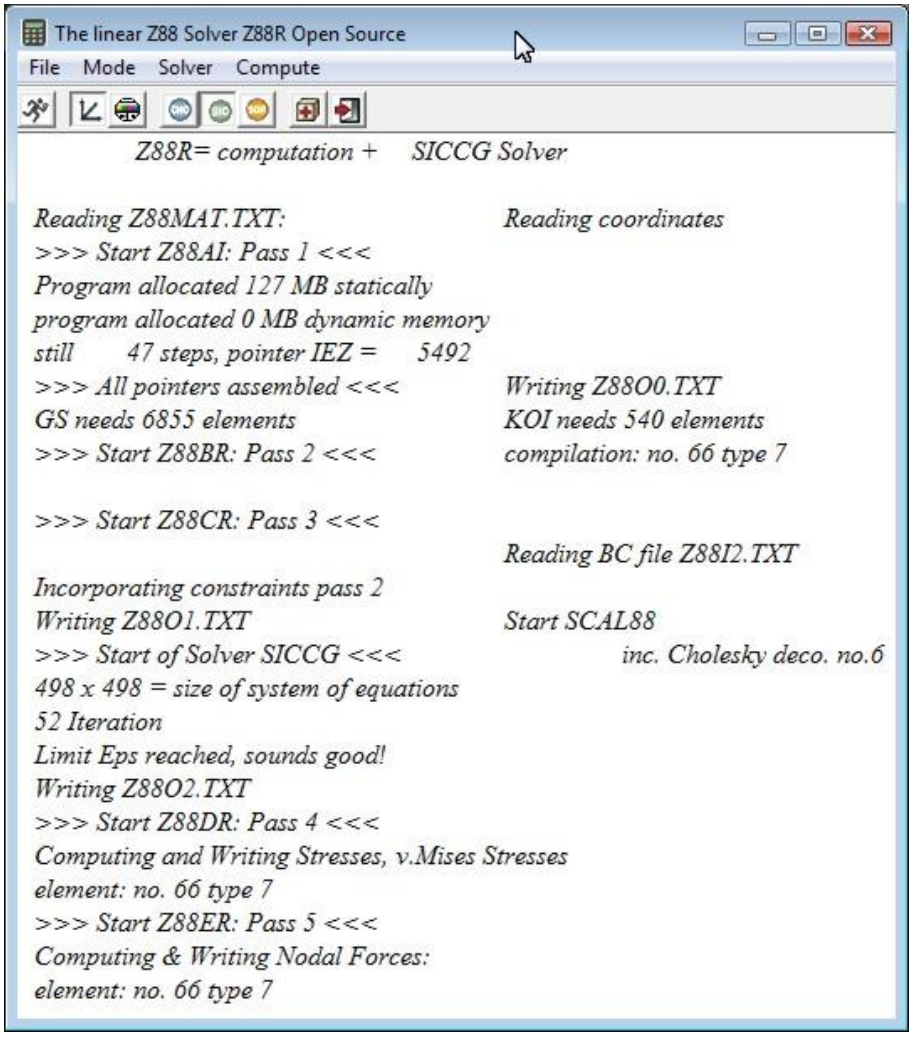
Input files:

- Z88I1.TXT general structure data
- Z88I2.TXT boundary conditions, constraints
- Z88I5.TXT surface and pressure loads), if needed
- Z88MAT.TXT material definitions and one or more material files in .TXT format
- Z88ELP.TXT element parameters
- Z88INT.TXT integration orders
- Z88MAN.TXT solver parameters

Output files:

- Z88O0.TXT processed structure data for documentation
- Z88O1.TXT processed boundary conditions for documentation
- Z88O2.TXT deflections
- Z88O3.TXT stresses
- Z88O4.TXT nodal forces

The Sparse Matrix Iteration Solver Z88R in Computation mode computes the element stiffness matrices, compiles the total stiffness matrix, incorporates the boundary conditions, scales the system of equations and solves the (huge) system of equations by the conjugate gradient algorithm. Preconditioning is done for better convergence. Choose your favourite pre-conditioner: Either a *SOR* step or a so-called incomplete Cholesky decomposition (*shiftet incomplete Cholesky decomposition SIC*). Default is *SIC* preconditioning because the main parameter, the so-called shift factor α is easy to handle. The *SOR* preconditioning needs only ~ 2/3 of the memory of SIC but the SOR parameter ω cannot be determined *a-priori*.



In addition you must supply 4 entries in the solver parameter file Z88MAN.TXT:

```
SOLVER START
   MAXIT            10000
   EPS              1e-007
   RALPHA           0.0001
```

```
   ROMEGA           1.1
SOLVER END
```

- termination criterion: maximum count of iterations(for example 10000) reached
- termination criterion: residual vector < limit *Epsilon* (for example 1e-7)
- parameter for the SIC convergence acceleration. Shift factor *Alpha* (from 0 to 1, good values may vary from 0.0001 to 0.1). For further information consult the literature)
- parameter for the SOR convergence acceleration. Relaxation factor *Omega* (from 0 to 2, good values may vary from 0.8 to 1.2).

Note: The files Z88I1.TXT, Z88I2, Z88I5.TXT, Z88MAN.TXT, Z88MAT.TXT, Z88INT.TXT and Z88ELP.TXT are described more precisely in chapter 3.

2.1.3 WHICH SOLVER SHOULD I USE?

Roughly spoken: Use the simple and reliable Cholesky solver Z88R –choly for small structures. The sparse matrix iteration solver Z88R *–siccg or –sorcg* works *always* even for very large structures.

Solver	Type	Number of DOF	Memory needs	Notes
Z88R –t/c -choly	Cholesky Solver without Fill-In	up to ~ 30.000	medium to high	running Z88H first is recommended
Z88R –t/c -siccg or -sorcg	Conjugated gradients solver with pre-conditioning	no limits (tested with more than 12 Mio. DOF on a normal PC)	an absolute minimum	a very stable and reliable solver for very large structures

2.1.4 SOME NOTES ON STRESSES CALCULATION

The results are presented in the file Z88O3.TXT. The stress calculation is controlled via the file Z88MAN.TXT, see chapter 3. It defines, among other things:

- Calculation of the stresses at the Gauss points or at the corner nodes
- Additional calculation of radial and tangential stresses for elements No. 3, 7, 8, 11, 12, 14 and 15.
- Calculation of von Mises stresses for continuum elements No. 1, 3, 6, 7, 10, 11, 12, 14, 15 ~ 24.

2.1.5 SOME NOTES IN NODAL FORCES CALCULATION

The results are presented in Z88O4.TXT. The nodal forces are calculated separately for each element. If several elements meet a node, one gets the complete nodal force for this node by adding the nodal forces of all accessing elements. These results are presented further down in the nodal force file Z88O4.TXT.

2.2 THE MESH GENERATOR Z88N

The mesh generator Z88N can produce 2-dimensional and 3-dimensional meshes. Z88N reads the mesh generator input file Z88NI.TXT and writes the general structure data file Z88I1.TXT.
For the description of Z88NI.TXT see chapter 3.

A mesh generation is sensible and permitted only for continuum elements:

Super structure	**Finite element structure**
Plane stress element No.7	Plane stress element No.7
Torus No.8	Torus No.8
Plane stress element No.11	Plane stress element No.7
Torus No.12	Torus No.8
Hexahedron No.10	Hexahedron No.10
Hexahedron No.10	Hexahedron No.1
Hexahedron No.1	Hexahedron No.1
Plate No.20	Plate No.20
Plate No.20	Plate No.19
Shell No.21	Shell No.21

Mixed structures e.g. containing Plane Stress Elements No.7 and Trusses No.9, cannot be processed.

In such a case let the mesh generator process a super structure containing only Plane Stress Elements No.7 without any Trusses No.9. Run Z88N. Then convert with the CAD converter Z88X the file Z88I1.TXT generated by the mesh generator Z88N to the DXF file Z88X.DXF. Start your CAD programm, import Z88X.DXF and insert the trusses, in addition you can also define the constraints on the fly. Export the drawing to Z88X.DXF, run Z88X again and generate Z88I1.TXT (general structure data) and optionally Z88I2.TXT (boundary conditions).

Mode of operation of the mesh generator:
The generation of FE meshes proceeds as follows: The continuum is described by super elements (short SE), which practically corresponds to a quite rough FE structure. Super elements can be: Hexahedrons No.10, Plane Stress Element No.7 and Plane Stress Element No.11 as well as Toruses No.8 and Toruses No.12 and Plates No.20.

The super structure then will be subdivided. This is done super element wise, starting with SE 1, SE 2 up to the last SE. SE 1 produces the finite elements (short FE) 1 to j, SE 2 the FE j+1 to k, SE 3 the FE k+1 to m and so on. Within the SE the direction of the local coordinates determines the nodal numbers and the element numbers of the FE structure. Definition:

- Local x axis runs in direction of local nodes 1 and 2
- Local y axis runs in direction of local nodes 1 and 4
- Local z axis runs in direction of local nodes 1 and 5

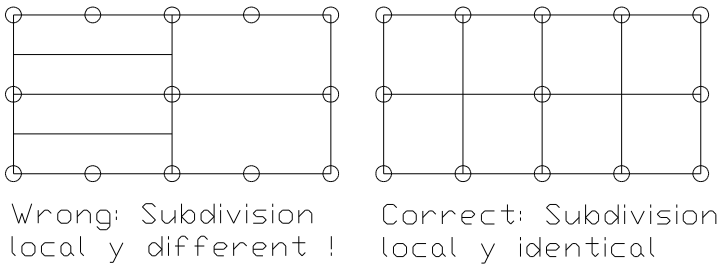
Super structures in space are subdivided first in z, then in y and for the end in x direction i. e. the FE element numbers start along the z direction. To plane and axially symmetric structures applies analogously: The numbering starts along the y axis or for axially symmetric elements

along the z axis (cylinder coordinates!).

Along the local axes can be subdivided as follows:

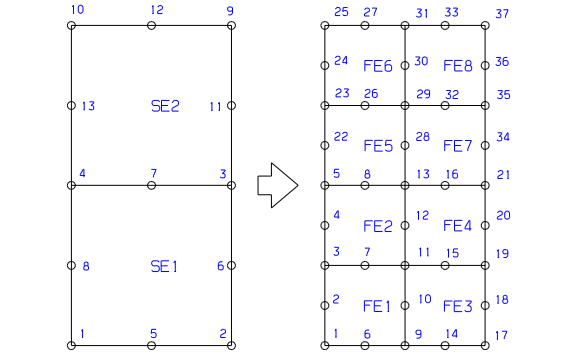
- Equidistant
- Increasing geometrically from node 1 to 4 or 5: Mesh becomes rougher
- Decreasing geometrically from node 1 to 4 or 5: Mesh becomes finer

It is obvious, that for lines or areas, which two super elements share, the super elements must be subdivided exactly the same! The mesh generator doesn't check this and then generates useless or totally mad FE meshes. Example:



Because the local axes x, y and z are defined by the location of the local nodes 1, 4 and 5, it is possible to generate almost arbitrary numberings for nodes and elements of the FE structure by corresponding construction of the coincidence list in the mesh generator input file Z88NI.TXT.

Example for the generation of a FE structure with 8 FE Plane Stress Elements No.7 from a super structure with 2 Plane Stress Elements No.7 (looks the same with Toruses No.8):



Coincidence of 1st superelement: 1-2-3-4-5-6-7-8
Coincidence of 2nd superelement: 4-3-9-10-7-11-12-13

Specials:

The mesh generator checks which nodes are already known at the production of new FE nodes. It needs for this check a trap radius (a computer cannot meet a floating point number exactly). This trap radius is provided for all 3 axes per default 0.01. Modify the trap radiuses when processing very small or very large numerical values.

In addition the mesh generator determines for each super element, which other super elements meet this super element. For Plane Stress Elements No.7 and No.11 or Toruses No.8 and No.12 this can be at the most 8 other SE. This maximum number MAXAN is provided in Z88.DYN per default 15. Theoretically, Hexahedrons No.10 can meet 26 other elements (6 areas, 8 corners, 12 edges). Practice has proved, that even complicated space structures with MAXAN = 15 worked fine. If in doubt increase MAXAN in Z88.DYN.

Attention mesh generator Z88N: The generator can generate input files easily which blast all limits of the FE solver. Generate therefore at first rougher FE structures, check the results then refine if necessary. A good starting point: Produce approx. 5 ~ 10 times more finite elements than super elements.

Note mesh generator Z88N: If the coordinate flag KFLAGSS is set in the mesh generator input files Z88NI.TXT, i.e. input values are polar or cylindrical coordinates, then the mesh generator output files Z88I1.TXT normally have Cartesian coordinates and KFLAG is set to 0. If you set the coordinate flag output KFLAG to 1, however, then the coordinates are polar or cylindrical in the output file Z88I1.TXT and KFLAG is set to 1 in Z88I1.TXT.

2.3 THE OPENGL PLOT PROGRAM Z88O

You may illuminate a structure with three different light sources or plot with hidden lines, both the undeflected and the deflected structure. You may plot stresses and X, Y and Z deflections with a color range. You may plot a limited range of nodal or element numbers - a nice feature especially for large structures. A printer or plotter feature is not included into Z88O - and why - just do a screen shot by *Shift-Print* into the clipboard and proceed with Windows' program Paint or Corel Paint.

Z88O uses OpenGL so your computer must be able to deal with OpenGL graphics. This is true for all newer Windows machines and a quite cheap graphics card will do well. Anyway, it's always a good idea to control the system settings - sometimes you may turn on OpenGL hardware acceleration. On LINUX systems you should install the genuine NVIDIA graphics driver from www.nvidia.com if you've got a NVIDIA graphics card – the speed will increase heavily in contrast to the standard LIXUX graphics driver.

Of course, you may define your choice of colors, the light features, material properties, the polygon offset in the parameter files Z88O.OGL (for Windows) and Z88.FCD (for LINUX/UNIX and MacOS). Be careful with changes in Z88O.OGL (Windows) or Z88.FCD (UNIX/LINUX and MacOS): You should have some proper knowledge about OpenGL if you want to change light effects etc. Otherwise you may pull a long face because nothing will work as you wish. Some hints are included into Z88O.OGL and Z88.FCD, however, i cannot give here an introduction into OpenGL. Consult the two basic books „OpenGL Programming Guide" and „OpenGL Reference Manual" from Addison-Wesley.

Start of Rendering: When Z88O was launched the OpenGL subsystem is started and prepared to go. You'll start rendering with the very first *Run* pushbutton.

Needed Files:	**Super Struktures**	**undeflected FE Struktures**	**deflected FE Struktures**
Z88NI.TXT	yes	no	no
Z88I1.TXT	no	yes	yes
Z88I2.TXT	no	yes for displaying the boundary conditions	yes for displaying the boundary conditions
Z88I5.TXT	no	yes for displaying the surface and pressure loads	yes for displaying the surface and pressure loads
Z88O2.TXT	no	no	yes
Z88O5.TXT	no	yes for displaying the stresses in the Gauss points	no
Z88O8.TXT	no	yes for displaying the stresses in the corner nodes or the average element stresses	yes for displaying the stresses in the corner nodes or the average element stresses

Z88 deals with these files

Rendering with Z88O: For fastest operation Z88O connects the nodal points - and only the corner points- with straight lines, although for Serendipity elements the edges of the elements are square or cubic curves. However, especially illuminated scenes need a huge amount of computational power. Please keep in mind: If a part renders pretty fast in your CAD system, CREO for example, and the same part renders quite slowly in Z88O - this is normal business because CAD systems are „drawing“ only some outline curves. In contrast, FEA system have to render *every* finite element i.e. compute the normal vectors for any element surface, compute light effects for every tetrahedron etc. Hidden line scenes put very heavy load on the CPU, too.

What can i plot with Z88O? Nearly everything if the solver Z88R was run which stored the deflection file Z88O2.TXT and the three stress files Z88O3.TXT (for you to check the stresses), Z88O5.TXT and Z88O8.TXT (for Z88O). Even for trusses you may plot the „von Mises“ stresses (i.e. tensile stresses) with different colors. Only beams No.2 and No.13 and cams No.5 allow only the plotting of deflections and nothing more. Why? Because you must compute for beams and cams also the stress concentration factor which is impossible for a FEA system which deals with a *whole structure of beams*. Of couse, you may compute the stresses in a chamfer by putting a FE mesh around it. But this needs either plane stress elements or 3D elements but neither beam elements nor cam elements.

Plot of stresses: The kind of plotting the stresses within FEA programs is truly of philosophical character. As a matter of fact, numerous experiments and computer studies at the *Institute of Engineering Design and CAD* of the University of Bayreuth, Germany, showed, that some very expensive and well-known professional FEA programs produced *incorrect stress plots* in some situations! The best way is the computation of stresses directly in the Gauss points. However, this is odd for OpenGL in some modes so i decided for the following way after a lot of experiments:

- *von Mises/principla/Tresca stresses in corner nodes.* In fact, the stresses are computed not really in the corner nodes which would lead to very wrong results especially for very tapered elements but in Gauss points laying in the near of the current corner nodes. Stresses are computed for just the same number of Gauss points like the number of corner points. Because often a node is linked to more than one element the stresses are computed to a mean value from the „corner node“ stresses of all linked elements. This results in pretty balanced stress shadings which are mostly somewhat lower than the maximum stresses in the Gauss points, however. The value of the order of integration INTOS in the integration orders file Z88INT.TXT has no meaning but INTOS should be greater than 0.
- *von Mises/principla/Tresca stresses as a mean value for each element.* The stresses are computed in the Gauss points of the current element, added and then divided by the current number of Gauss points. This results in a mean value for the *von Mises/principla/Tresca stress* per element. The value of the order of integration INTOS in the integration orders file Z88INT.TXT is important and INTOS must be greater than 0.
- *von Mises/principla/Tresca stresses in Gauss points.* This is most accurate but delivers not always very pretty pictures. INTOS must be greater than 0.

Z88O may show these stresses after a run of Z88R – but only one type of stress:

- *von Mises stresses*
- *Rankine or principal stresses*
- *Tresca stresses*

Thus, if you have computed the *von Mises* stresses with a Z88R run Z88O will show the *von Mises* stresses. If you want to see now the *Tresca* stresses you must leave Z88O. Edit

Z88MAN.TXT, enter the proper parameter and re-run Z88R. Then start Z88O again. This looks awkward but don't you know before starting the FE computations which type of stresses is suitable and correct for your task?

Plot of deflections: You may plot the undeflected or the deflected structure. The enlargement factor is adjustable, with 100 as the default value for X, Y and Z. In addition, you may plot the deflections for X, for Y or for Z with color shading. This is a pretty nice feature for large spatial structures. You may plot the shaded colors for stresses or for the deflections or the hidden line display or the wire frame display with the deflected structure. The display of the stresses in Gauss points in only possible for undeflected structures.

	3D	2D	BC	undef.	deflec.	nodes	elem.
Light	+	+	+	+	+	-	-
Hidden Line	+	-	+	+	+	o	-
Wire Frame	+	+	+	+	+	+	+
Stresses in corner nodes	+	+	-	+	+	-	-
Stresses aver. elements	+	+	-	+	+	-	-
Stresses in Gauss points	+	+	-	+	-	-	+
Deflections X	+	+	-	+	+	-	-
Deflections Y	+	+	-	+	+	-	-
Deflections Z	+	+	-	+	+	-	-

combination of the different modes of Z88O

Hints for the user for Zooming, Panning and Rotating:

1. You may work without limitation with the special keys for Windows (see below) or the pushbuttons for UNIX. You should use the special keys or the pushbuttons for precise zooming, panning and rotating. This is the default mode. Mouse navigation is turned off.
2. With Z88O you may use mouse navigation: Under Windows, press the mouse icon. Under UNIX, press the pushbutton *Keyboard/ Mouse*: Now you can
   - zoom with the left mouse button pressed
   - pan with the middle mouse button pressed
   - rotate with the right mouse button pressed

This option fits well for limited zooming- and panning ranges and for fast but quite unprecise rotating. You may in addition use the special keys or pushbuttons but this mixed mode is not a real feature and may lead to unpredictable results because Z88O uses different calculations for both modes.

Special key strokes for Windows, LINUX and MacOS:

Key Windows & LINUX	**Key MacOS**	**Function**
PRIOR	fn + ↑	increase zoom
NEXT	fn + ↓	decrease zoom
CURSOR LEFT	←	panning X
CURSOR RIGHT	→	panning X
CURSOR UP	↑	panning Y
CURSOR DOWN	↓	panning Y
HOME		panning Z
END		panning Z
F2	fn + F2	rotate around X axis
F3	fn + F3	rotate around X axis
F4	fn + F4	rotate around Y axis
F5	fn + F5	rotate around Y axis
F6	fn + F6	rotate around Z axis
F7	fn + F7	rotate around Z axis
F8	fn + F8	reset all rotations to 0

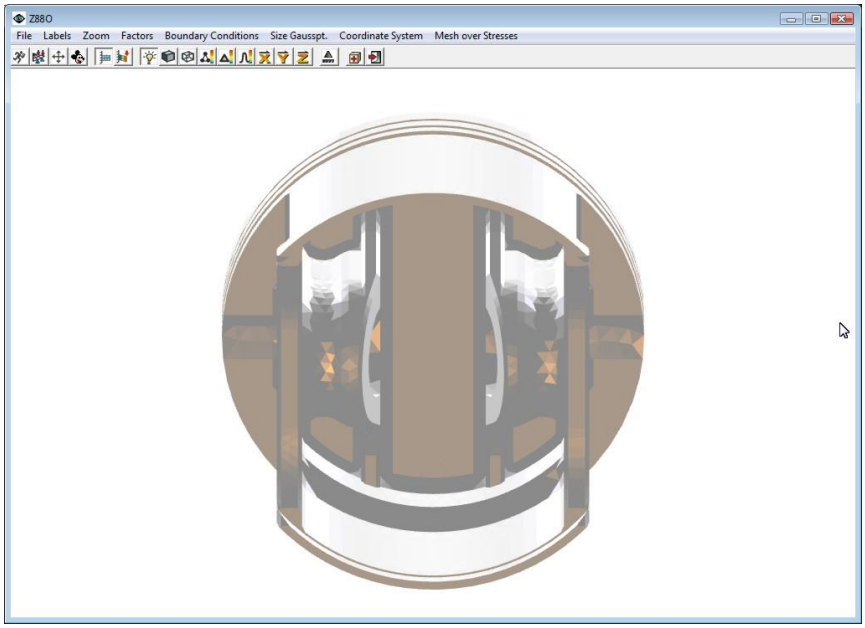
Special hints for MacBook:

Start Z88COM. Goto X11 > Preferences > Input: activate „emulate three button mouse"

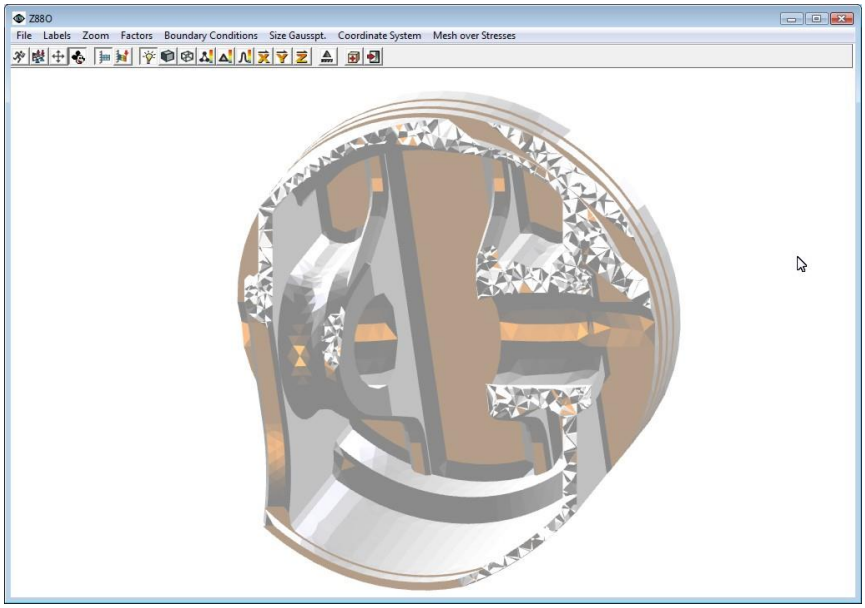
- Zoom in/out: move with touchpad pressed
- Panning: *alt* + move with touchpad pressed
- Rotating: *cmd* + move with touchpad pressed

USB-plugged three button mice operate just like the Windows version, see manual

The „coordinate system“: OpenGL works with a *Clipping Volume*, i.e. with a kind of cube, defined by *Xmin* and *Xmax* in horizontal direction, by *Ymin* and *Ymax* in vertical direction and *Zmin* (points towards the user) and *Zmax* (points away from the user). If you use a too-large zoom factor or if you are panning the structure too near to you then the range of *Zmin* is exceeded and parts of the structure are laying outside the viewing volume. This offers a nice chance to look into a structure. Otherwise, change the value of Z*min* (default entry is –100) to lower values, e.g. -1000: use *Factors > Z limit towards you*. The following screenshots are showing the situation:



Windows: piston of a BMW engine (motorcycle F650GS) Zlimit: default value –100.



Windows: piston of a BMW engine (motorcycle F650GS) Zlimit is –10, piston has slash cut.

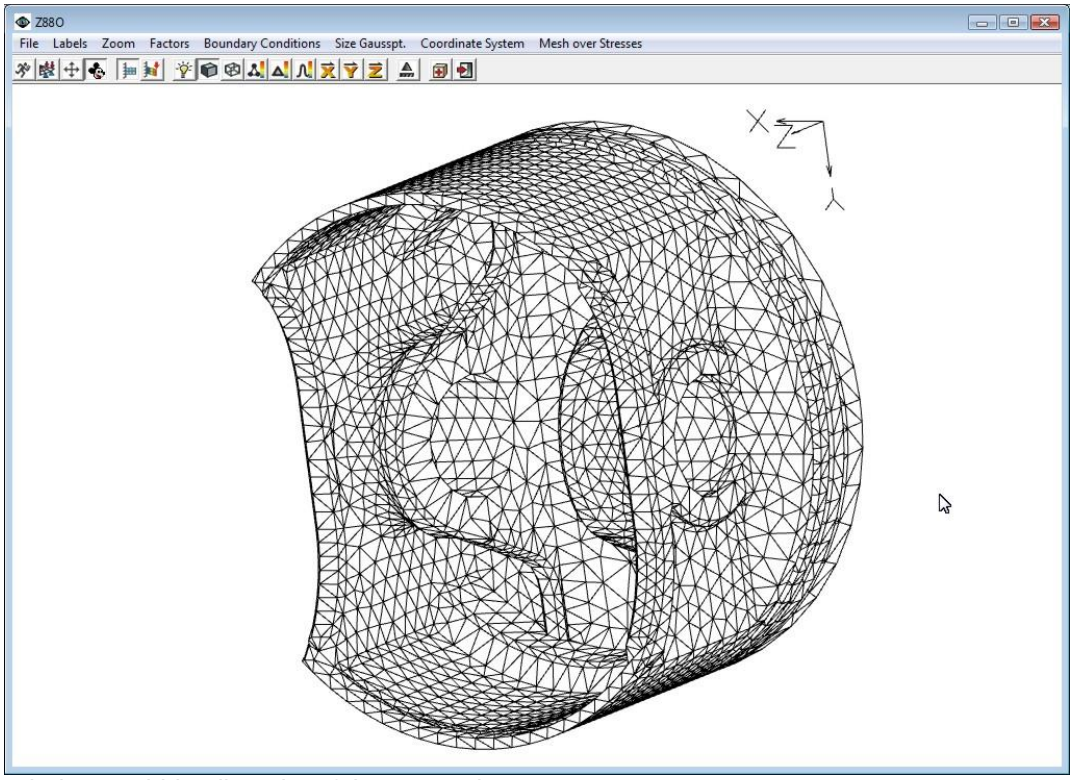
The menu items of Z88O:
Name of Structure File: Windows: the diskette icon. UNIX: the *File* pushbutton
Choose the structure file here. Enter name, if necessary with path. The new stucture is loaded. You'll start rendering with the icon *Go* or with the *Run* pushbutton. This mode exists only for a first entry control of an undeflected structure. Please keep in mind: To use *all* display modes, Z88O needs the files Z88I1.TXT (structure data), Z88I2.TXT (boundary conditions), Z88I5.TXT (surface and pressure loads, if given), Z88O2.TXT (the computed deflections), Z88O5.TXT (stresses from Z88D) and Z88O8.TXT (stresses from Z88D).

Deformation Modes of the Structure: the proper icons or pushbuttons
Plots the undeflected structure or the deflected structure. You may do all other rendering operations with the undeflected structure or the deflected structure. Exception: displaying the Gauss stresses in a *deflected* structure is not possible.
Caution Deflected: The user must have executed a calculation of displacements before using this function. Do a FEA run with Z88R before using Z88O. Otherwise, some old files Z88O2.TXT (displacements) from earlier Z88 runs are opened causing totally wrong results!

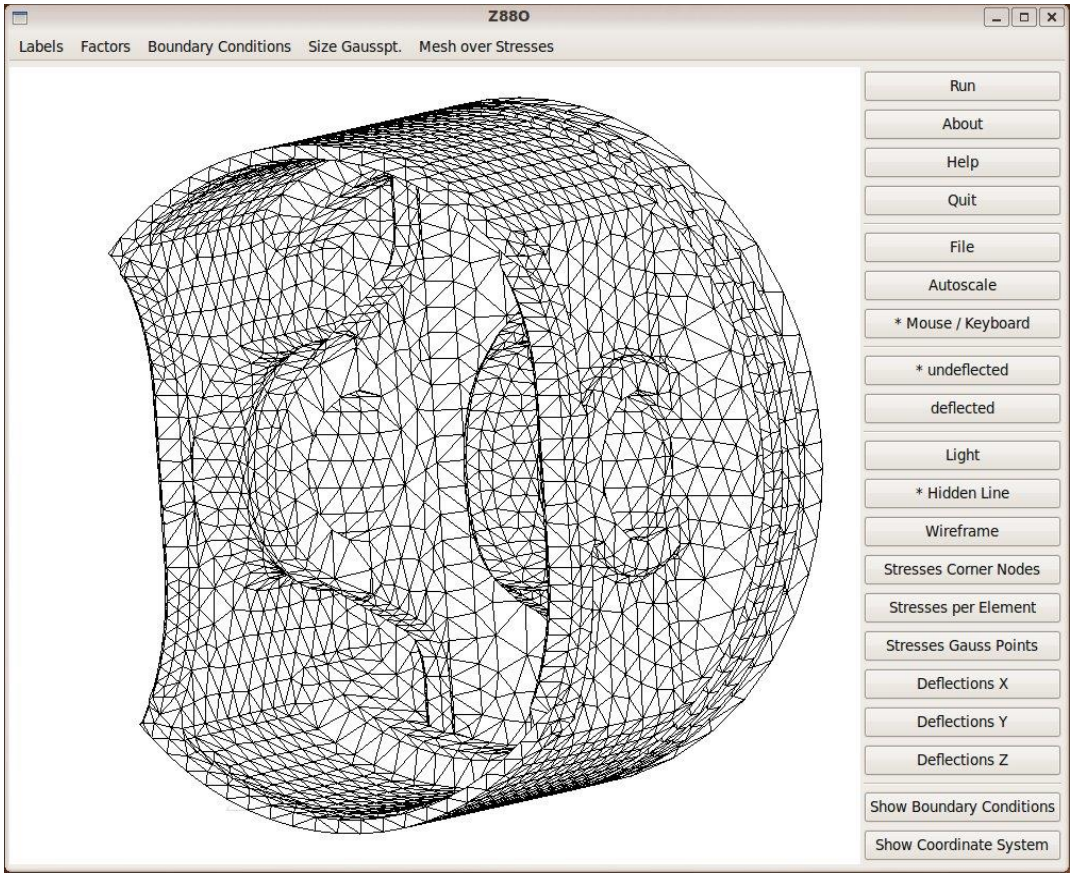
Choice of the 3D effects: the proper icons or pushbuttons
1. **Light on**. The structure is illuminated with three light sources. You may modify the features of the light sources by editing the header files Z88O.OGL (Windows) and Z88.FCD (UNIX).
2. **Hidden Lines**. For spatial structures the finite elements mesh is rendered with hidden lines. For 2D struktures the pure finite elements mesh is drawn (there is nothing to hide). In this mode you cannot see *all* desired nodal and elements labels because some labels are hidden. The polygon offset can be edited in the header files Z88O.OGL (Windows) and Z88.FCD (UNIX).
3. **Wire Frame**. *All* lines are plotted, thus, this is the proper mode for 2D struktures and very simple 3D structures. Only in this mode you can see *all* desired nodal and elements labels.

4. The ***von Mises/principla/Tresca*** **stresses of the corner nodes** are plotted. In fact, the stresses are computed not really in the corner nodes which would lead to very wrong results especially for very tapered elements but in Gauss points laying in the near of the current corner nodes. Stresses are computed for just the same number of Gauss points like the number of corner points. Because often a node is linked to more than one element the stresses are computed to a mean value from the „corner node" stresses of all linked elements. This results in pretty balanced stress shadings which are mostly somewhat lower than the maximum stresses in Gauss points, however. The value of the order of integration INTOS in the file Z88INT.TXT has no meaning but INTOS should be greater than 0.
5. The ***von Mises/principal/Tresca*** **stresses as a mean value for each element** are plotted. The stresses are computed in the Gauss points of the current element, added and then divided by the current number of Gauss points. This results in a mean value for the *von Mises/principal/Tresca stress* per element. The value of the order of integration INTOS in the file Z88INT.TXT is important and INTOS must be greater than 0.
6. The ***von Mises/principal/Tresca*** **stresses in the Gauss points** are plotted. This is the most accurate mode but leads not always to very nice pictures. You may change the size of the Gauss points in the menu. The value of the order of integration INTOS in the header file Z88INT.TXT is important and INTOS must be greater than 0.
7. Plot of the displacements for X with color shading
8. Plot of the displacements for Y with color shading
9. Plot of the displacements for Z with color shading

For pos. 4. to 9. the color range may be edited in the header files Z88O.OGL (Windows) and Z88.FCD (UNIX).



Windows: Hidden line plot of the BMW piston.



LINUX and MacOS: Hidden line plot of the BMW piston.

Drawing Node and Element Numbers: *Labels > No Labels, Nodes, Elements, Label all*
Plot the element numbers or the node numbers or skip numbering. You can define ranges *from-to*, e.g. plot the nodal numbers from 11 to 19 or plot the element 3, i.e. from 3 to 3. Z88O recalls your entries even if you change to *No Labels*. In *Label all* mode the element and node numbers you have chosen before are plotted. If you want to see all numbers again but you have forgotten how many nodes and elements are in your structure you may enter a very high number e.g. *from 1 to 10000000*. Z88O computes then the exact number. Please remember that you'll only get rendered all desired labels on the surfaces if you are in *Wire Frame* mode. The other modes may hide some labels. And labels inside a structure are usually covered by the tetrahedron and hexahedron surfaces.

Zooming:
Keyboard: *PRIOR* and *NEXT*
mouse navigation on: *left mouse button pressed*

Panning:
Keyboard: X: *CURSOR LEFT* and *CURSOR RIGHT*
Y: CURSOR UP and *CURSOR DOWN*
Z: HOME and *END*
mouse navigation on: *middle mouse button pressed*

Rotating:
Keyboard: F2~F7: rotate in 10° steps. F8 resets to 0.
Menu: *Faktors > Rotations 3D*
mouse navigation on: *right mouse button pressed*

Enlarging Deflections:
Menu: *Factors > Deflections > FUX, FUY, FUZ*

Some remarks on stresses:
If you did before a stress calculation with Z88R (this is possible and useful for all element types except for beams No.2, No.13 and cams No.5), then you may plot the *von Mises/principal/Tresca* stresses either in the corner nodes or as mean values per each element or in the Gauss points. And before running the stress processor Z88D you really had to calculate the displacements by running Z88F or one of the sparse matrix solvers. Thus, the sequence is:

1. Edit the parameter file Z88MAN.TXT. Mind the entry for ISFLAG: 1= *von Mises* stresses, 2= *principal* stresses, 3=*Tresca* stresses.
2. Define in the file Z88INT.TXT the number of Gauss points: 2nd entry INTOS
3. run solver Z88R.
4. run Z88O, if you want to plot stresses.

Automatic Scaling: the appropriate icon or pushbutton
The Autoscale function takes care that structures will completely fit on the screen. Autoscale activates automatically if a new structure is loaded.

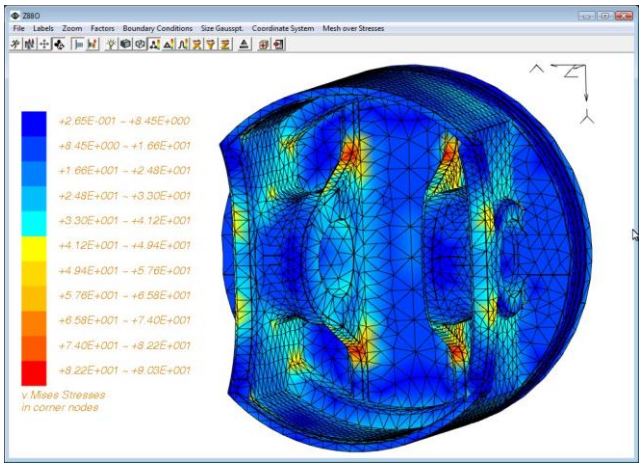
Menu item **Boundary Conditions**:
You may choose which boundary conditions to show. Sometimes you may want to hide some BCs for a better overview. You may also change the size of the BCs points.

Menu item **Size Gausspts.**:
You may change the size of the Gauss points to get a nice picture.

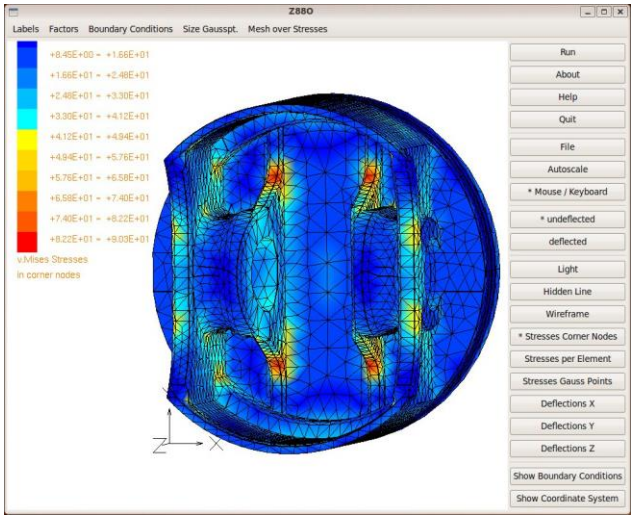
Menu item **Coordinate System**:
You may switch on or off the coordinate system. Default is on.

Menu item **Mesh over Stresses**:
For 3D structures you may switch on or off the mesh i.e. the hidden line display over the stresses display. Default is on. For very large structures you should switch off *Mesh over Stresses* because this means heavy computing load.

Height Ratio FYCOR: Files Z88O.OGL and Z88.FCD
The height ratio can be adjusted to the monitor customization. Therefore, the entry FYCOR exists in Z88O.OGL (Windows) or Z88.FCD (UNIX/LINUX and MacOS). Load a perfectly circular or perfectly square structure and modify FYCOR until this structure is plotted perfectly circular or square on your monitor. Please keep in mind that FYCOR is loaded with the start of Z88O, so you must re-launch Z88O after a modification in the files. You need to make this modification only once.



Windows: plot of the von Mises stresses in the corner nodes of the BMW piston. Mesh over Stresses is switched on.



LINUX and MacOS: plot of the von Mises stresses in the corner nodes of the BMW piston. Mesh over Stresses is switched on.

2.4 THE CAD CONVERTER Z88X

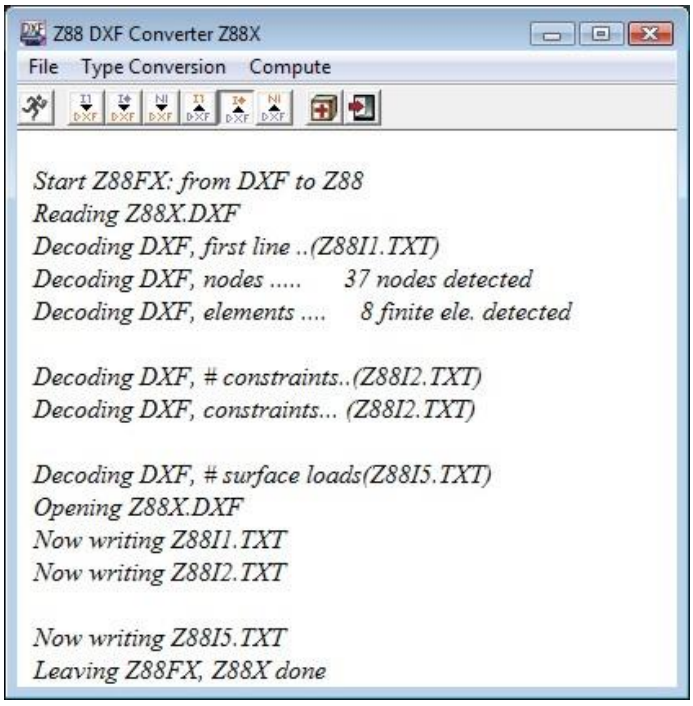
2.4.1 OVERVIEW Z88X

The CAD converter Z88X works in two directions:

(I) You design your component in a CAD system and generate Z88 data. You cover in the CAD system your component with a FE mesh or a super-structure following certain rules which follow below, and add if necessary boundary conditions and material informations. Then make your CAD system generating a DXF file and start the CAD converter Z88X. The Z88 entry files are produced by Z88X and you can start with the FE analysis.

Windows:

Z88X, > Type Conversion > 4 from Z88X.DXF to Z88I1.TXT
Z88X, > Type Conversion > 5 from Z88X.DXF to Z88I . TXT (default)*
Z88X, > Type Conversion > 6 from Z88X.DXF to Z88NI.TXT
... and > Compute > Go



UNIX:

z88x -i1fx (Z88X.DXF to Z88I1.TXT, "I1 from X")
z88x -iafx (Z88X.DXF to Z88I . TXT, "I all from X",)*
z88x -nifx (Z88X.DXF to Z88NI.TXT, "NI from X")
... or use the Z88 Commander with the proper option for Z88X

(II) Convert your Z88 entry files into CAD data. This is very interesting for Z88 data sets already existing, for controls, for completions of the FE structure, but also for plotting the FE structure by CAD program.

Windows:

Z88X, > Type Conversion > 1 from Z88I1.TXT to Z88X.DXF
Z88X, > Type Conversion > 2 from Z88I . TXT to Z88X.DXF*
Z88X, > Type Conversion > 3 from Z88NI.TXT to Z88X.DXF
... and > Compute > Go

UNIX:
z88x -i1tx (Z88I1.TXT to Z88X.DXF, "I1 to X")
z88x -iatx (Z88I . TXT to Z88X.DXF, "I all to X",)*
z88x -nitx (Z88NI.TXT to Z88X.DXF, "NI to X")
... or use the Z88-Commander with the proper option for Z88X
Since the converter is completely compatible in both directions, you can execute the possibilities I and II in succession as you wish. You will not find any data loss!

That makes a most interesting variant:
(III) Mixed Operation, e.g.
- Component-and super-structural layout done in CAD program
- Conversion CAD → Z88
- Meshing in Z88
- Conversion Z88 → CAD
- Complete FE structure in CAD e.g. with not-mesh generator capable elements
- Conversion CAD → Z88
- Conversion Z88 → CAD
- Installation of the boundary conditions in CAD
- Conversion CAD → Z88
- FE analysis in Z88
- Etcetera

Which CAD systems can cooperate with Z88 ?
Any CAD systems which can import (read) and export (write) DXF files. However, we cannot guarantee any success as some of the CAD guys are changing their DXF definitions from month to month. Z88 has been intensively tested together with the different AutoCAD and AutoCAD LT versions for Windows of Autodesk, and AutoDesk's DXF guidelines have been regarded as the inventor of the DXF interface, according from AC1009 to AC1024. Choose AutoCAD R12 DXF format, if in doubt, but AutoCAD 2011 DXF works, either.

The general philosophy of a CAD -FEA data interchange:
CAD files containe nondirectional informations. It is only a wild collections of lines, points and texts, stored in the order of its production to make things worse. Basically, a FEA system needs topological information which most CAD systems cannot supply. The FEA system must know that these and those lines form a finite element and that these and those points are included in this element. This could be made on principle if one would design in the CAD system in a quite firmly predefined order. Experiments showed that, indeed, this is possible for very simple components, but it will not work for complex components. And, yes, this is what one wants to do in practice: FE analysis on complex structures! These difficulties are known for a long time and appear at the data interchange of CAD-NC data likewise. As a proper work-around, integrated CAD-FEA systems do exist which are only to acquire at a very high price. Another attempt enlarges (better: blows up) the CAD system by e.g. additional modules or macros to such an extend, that partly utilizable FEA data can be produced. This is done frequently. It bears the disadvantage that it neither works well for all CAD programs nor works quite exactly even for the same products of one CAD program manufacturer. Another attempt does nothing in the CAD system. The FEA system, however, contains a kind of mini- or semi-CAD system, in order to process or rework the raw and totally useless CAD data into FEA data, but only by massive support of the operator. The disadvantage is here, that the operator must master two CAD systems, and the integrated semi-CAD system has not got the performance and power of the real CAD system.

Z88 solves these difficulties as follows:

1: FROM CAD SYSTEM TO Z88:

1.1 in the CAD system:

Remark: This point case 1.1 will be explained in greater detail in chapter 2.4.2. This is a summary.

(1) Design your component. Order and layers as you like.
(2) Define the FEA structure or the super structure by lines and points. Any order and layers, therefore unproblematic and fast.
(3) Number the nodes with the TEXT function on the layer Z88KNR. Any order, therefore unproblematic and fast.
(4) Write the element information with the TEXT function on the layer Z88EIO. Any order, therefore unproblematic and fast.
(5) Outline each element with the LINE function on the layer Z88NET. The only section with firm work rules and orders (because of the topological informations).
(6) Write general information on the Layer Z88GEN.
(7) Define the boundary conditions on the layer Z88RBD.
(8) Define the surface and pressure loads (if needed) on the layer Z88FLA.
(9) Export or store your 3-D model or 2-D drawing under the name Z88X.DXF.

1.2 in Z88: Starts the CAD converter Z88X

You can choose depending on your input data whether

- *A mesh generator file Z88NI.TXT or*
- *A file of the general structure data Z88I1.TXT or*
- *A complete Z88 data set with Z88I1.TXT, Z88I2.TXT and Z88I5.TXT*

is produced. Everything else runs automatically.

1.3 in Z88: Starts other Z88 modules

Run the FE analysis by starting the different Z88 modules at your choice:

- *Mesh Generator Z88N*
- *Plot Program Z88O*
- *Solver Z88R*

2: FROM Z88 TO CAD PROGRAM

2.1 in Z88: Input files Z88xx.TXT

You have produced the input files

- *Mesh generator file Z88NI.TXT or*
- *File of the general structure data Z88I1.TXT or*
- *complete Z88 data set with Z88I1.TXT, Z88I2.TXT and Z88I5.TXT*

either by an editor, a word processing program, EXCEL or an own routine or by modifying data files that came from the CAD converter Z88X.

2.2 in Z88: Launch CAD converter Z88X

Define which Z88 input files shall be converted. The DXF-file produced by Z88X is Z88X.DXF. If the input files contained polar- or cylindrical coordinates, they are converted into cartesian coordinates.

2.3 in the CAD system:
Import the DXF file Z88X.DXF. Save the loaded model or drawing under a valid CAD name (e.g. at AutoCAD name.DWG) and work with the drawing. You can switch off and switch on the different Z88-layers as you like.

2.4.2 Z88X IN DETAIL

Proceed in the following steps and reserve the following layers
Z88GEN: Layer for *general information* (1st input group in the mesh generator input file Z88NI.TXT and general structure data file Z88I1.TXT).
Z88KNR: Layer including the node numbers.
Z88EIO: Layer including the *element information* like element type and in the case of mesh generator input file Z88NI.TXT control information for the mesh generator.
Z88NET: Layer containing the *mesh* which was drawn or outlined in defined order.
Z88RBD: Layer containing the contents of the *boundary conditions* file Z88I2.TXT.
Z88FLA: Layer containing the *surface and pressure loads* as defined for Z88I5.TXT

A further layer, **Z88PKT**, is produced by Z88X if you convert from Z88 to CAD. It shows all nodes with a *point marker* in order to better recognize the nodes. For the reverse step, from CAD to Z88, it is completely insignificant.

1st step: Design your component in the CAD system as usual. You do not need to maintain a definite order and you can use any layers. It is highly recommended to put symbols on one layer, edges on another layer, dimensions on a third layer, invisible lines and centre lines on a fourth layer and so on. This enables you to remove all unnecessary information in the next step.

2nd step: Plan your mesh subdivision that means suitable finite element types and their distribution. Subdivide the FE structure or the super structure into elements by lines, insert **all** points which are not yet existing (for example intersection points or end-points of lines are usable). Any order and layer. However, it is recommended not to use the Z88-layers like Z88NET, Z88GEN, Z88PKT, Z88KNR, Z88EIO and Z88RBD. Better define any new layer for this or use already available layers from step 1.

3rd step: Define the Z88-Layer Z88KNR and make it the active layer. Catch or trap every FE node, which were already defined in the 1st step by your construction or have been completed in the 2nd step, and number them. Write to every node **P blank node-number** e.g. *P 33*, with the TEXT function of the CAD program. Be very careful to snap exactly the node and attach the number exactly to the node's location. Take your time! With the snap modes of AutoCAD (intersection point, end-point, point etc.) this works well. Choose any order of the work sequence as you like, you can well number the node 1 (*P 1*), then the node 99 (*P 99*) and then node 21 (*P21*). However, the numbering of the nodes must make sense and must be meaningful for an FE analysis. *You* define which node in node 99 and which other node reads 21.

4th step: Define the Layer **Z88EIO** and make it the active layer. Write the element information with the TEXT function anywhere (of course, it looks nicer with the element info's placed in middle of the respective finite element or super element). The order of the work sequence is up to you. You can describe element 1 first, step to the attaching element 17 and then proceed with element 8. However, your element choice and description must make sense for an FE analysis. The following information has to be written:

For all finite element types from 1 to 25:

FE Element number Element type
Write into one line, separate each item by at least one blank.

Example: An Isoparametric Serendipity Plane Stress Element No.7 is supposed to get the element no. 23. Write e.g. into the middle of the element with the TEXT function *FE 23 7*

For super elements 2-dimensional No. 7, 8, 11, 12 and 20:

SE
Element number
Super element type
Type of the finite elements to be produced by meshing
Subdivision in local x direction
Type of subdivision in local x direction
Subdivision in local y direction
Type of subdivision in local y direction
Write into one line, separate each item by at least one blank.

Example: Subdivide an isoparametric Serendipity Plane Stress Element with 12 nodes (Element type 11) used as super-element into finite elements of type 7, i.e. isoparametric Serendipity Plane Stress Elements with 8 nodes (Element type 7). Subdivide in local x direction three times equidistantly and subdivide in local y direction 5 times ascending geometrically. The super element is supposed to have the number 31. Write e.g. into the middle of the element with the TEXT function: *SE 31 11 7 3 E 5 L* (e or E for equidistant is equivalent)

For super elements 3-dimensional Hexahedrons No.10 and Shells No.21:

SE
Element number
Super element type
Type of the finite elements to be produced by meshing
Subdivision in local x direction
Type of subdivision in local x direction
Subdivision in local y direction
Type of subdivision in local y direction
Subdivision in local z direction
Type of subdivision in local z direction
Write into one line, separate each item by at least one blank.

Example: Subdivide an Isoparametric Serendipity Hexahedron with 20 nodes (Element type 10) as super element into finite elements of the type Isoparametric Hexahedrons with 8 nodes (Element type 1). Subdivide equidistantly three times in local x direction, 5 times ascending geometrically in local y direction and subdivide equidistantly 4 times in local z direction. The super element is supposed to have the number 19. Write e.g. into the middle of the element with the TEXT function:
SE 19 10 1 3 E 5 L 4 E (e or E for equidistant is equivalent)

5th step: Define the Layer **Z88NET** and make it the active layer. You need concentration for

this step, because a firm and rigid work sequence must now be kept because of the topological information. One of the most important information, the coincidence, is defined in this step that means which elements are defined or outlined by which nodes. Choose a proper colour which differs well from the colours used till now and remove all superfluous information by switching off unused layers. Select the **LINE command** and select the proper snap options e.g. points, **intersection points** and, if necessary, end-points.

Start at the first element. For Z88 the first element is the element with which you start now, that means the one which you have chosen for your first element (*SE 1 or FE 1*). Select the node you want to be the first node of this element (this can be e.g. globally the node 150) and draw a line to the node which shall be the second node of this element (this can be e.g. globally the node 67). From there, draw a line to the third node of this element (this can be e.g. globally the node 45). Connect all required nodes with lines and draw at last a line to the starting point, the first node, and then quit the LINE function.

Then you do the same with the second element. Remember: **You determine with this order which of the elements will be the real second element now**. In the previous 4th step you have only defined what kind of element the second element is. You determine here **how** the element is defined topologically.

The third element follows and so on. If you should make a mistake at the outlining of an element then delete all previous lines of this element (e.g. with an UNDO function) and start again at the first point of the element in question. But if you notice now just outlining element 17 that you have made a mistake at element 9, then you must delete all lines of the elements 9 to 17 and restart with element 9.

For your comfort, you must keep the following outline orders which partly differ from the orders shown at the element descriptions when entering the coincidence by hand. Z88X then sorts internally correctly.

Example: The coincidence for the element type 7 is as follows in the element description: First the corner nodes, then the middle nodes, reads 1-2-3-4-5-6-7-8. The coincidence list must look like this in the Z88 input files. However, for Z88X' use for comfortably outlining the elements the order is 1-5-2-6-3-7-4-8-1 (left picture), respectively A-B-C-D-E-F-G-H-A (right picture):

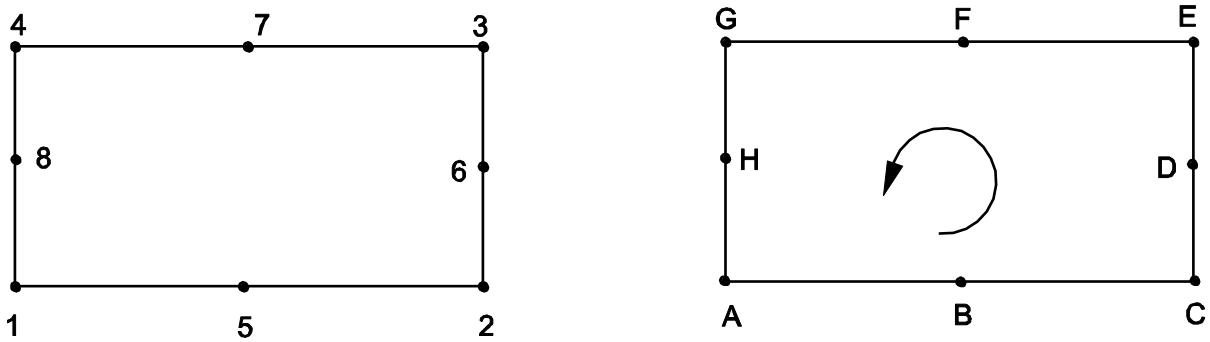
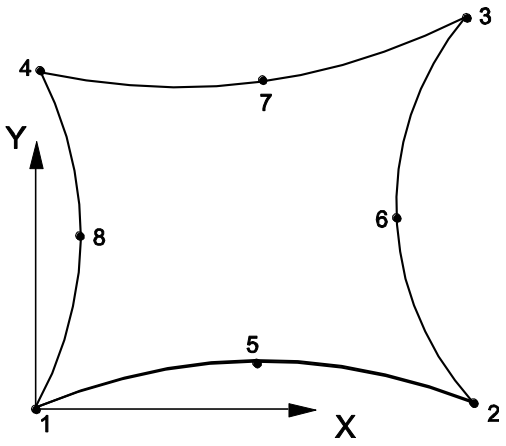


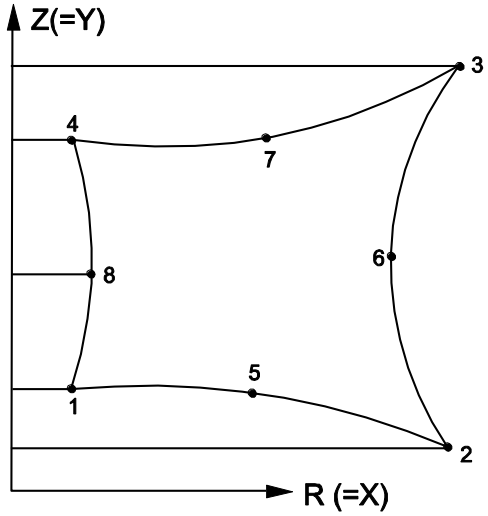
Figure 1: Example for correct outline orders

Following the CAD outline orders for all elements:

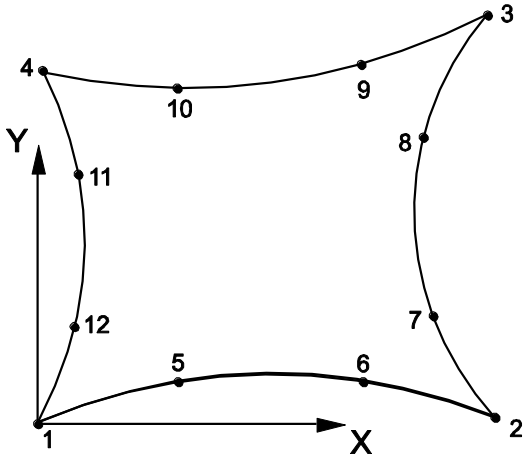
Element No. 7, No. 20 and No. 23: 1 - 5 - 2 - 6 - 3 - 7 - 4 - 8 - 1



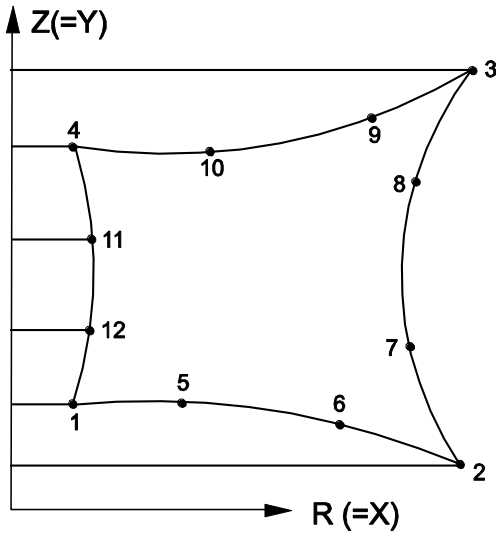
Element No. 8: 1 - 5 - 2 - 6 - 3 - 7 - 4 - 8 - 1



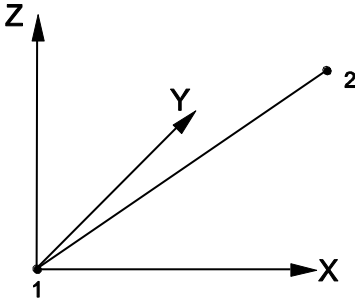
Element No.11: 1 - 5 - 6 - 2 - 7 - 8 - 3 - 9 - 10 - 4 - 11 - 12 - 1



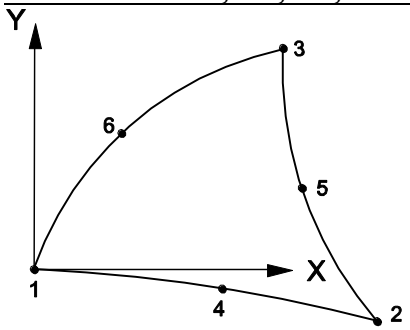
Element No.12: 1 - 5 - 6 - 2 - 7 - 8 - 3 - 9 - 10 - 4 - 11 - 12 - 1



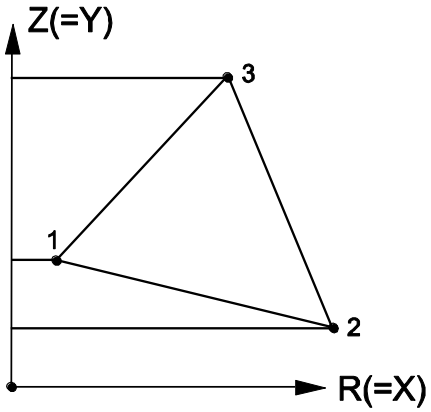
Element No. 2, 4, 5, 9, 13, 25: Line from node 1 to node 2



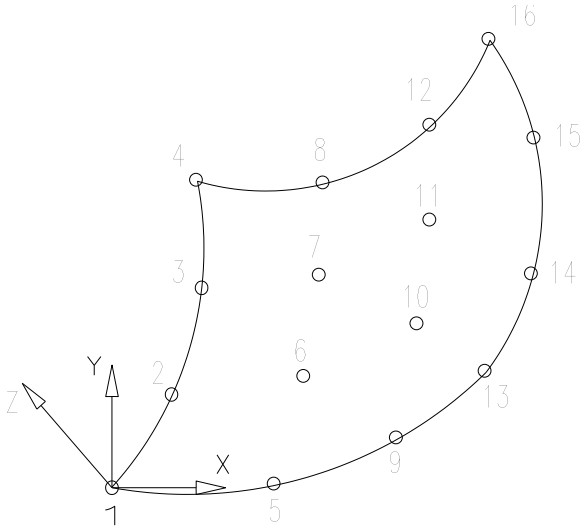
Element No. 3, 14, 15, 18 and 24: 1 - 4 - 2 - 5 - 3 - 6 - 1

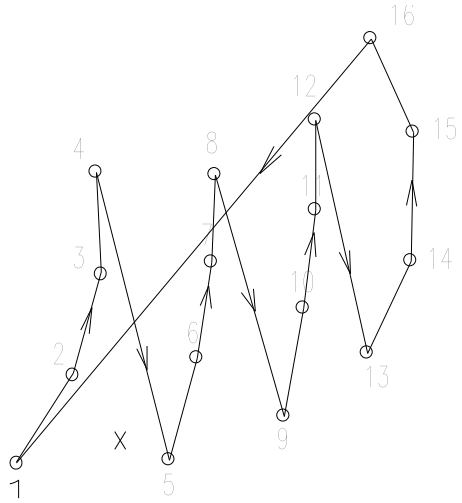


Element No.6: 1 - 2 - 3 – 1



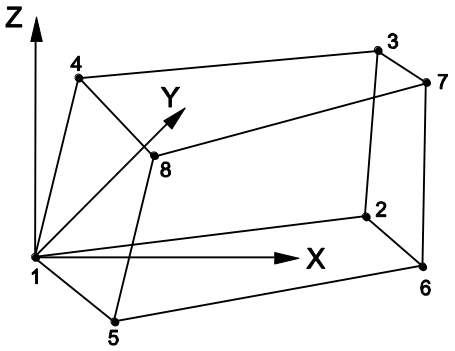
Element No.19: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10 - 11 - 12 - 13 - 14 - 15 - 16 – 1





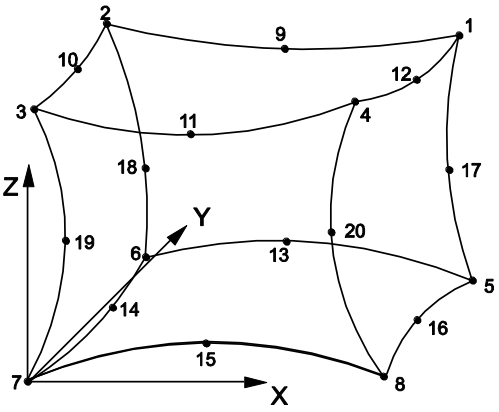
Element No.1:

Upper plane: 1 - 2 - 3 - 4 - 1, quit LINE function
Lower plane: 5 - 6 - 7 - 8 - 5, quit LINE function
1 - 5 , quit LINE function
2 - 6, quit LINE function
3 - 7, quit LINE function
4 - 8 , quit LINE function



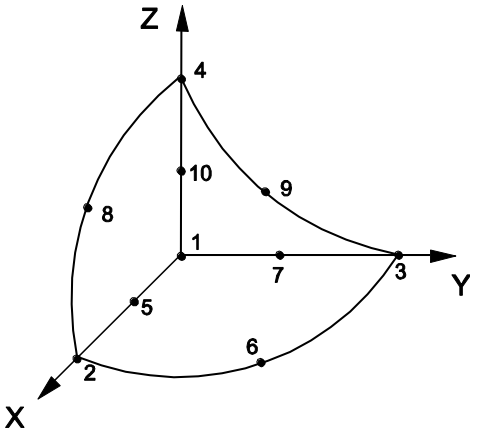
Element No.10:

Upper plane: 1 - 9 - 2 - 10 - 3 - 11 - 4 - 12 - 1, quit LINE function
Lower plane: 5 - 13 - 6 - 14 - 7 - 15 - 8 - 16 - 5, quit LINE function
1 - 17 - 5 , quit LINE function
2 - 18 - 6, quit LINE function
3 - 19 - 7, quit LINE function
4 - 20 - 8 , quit LINE function

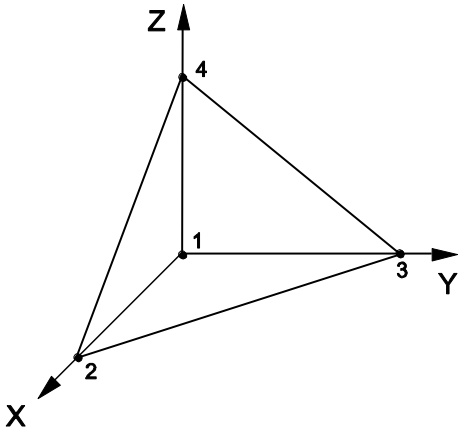


Element No.16:

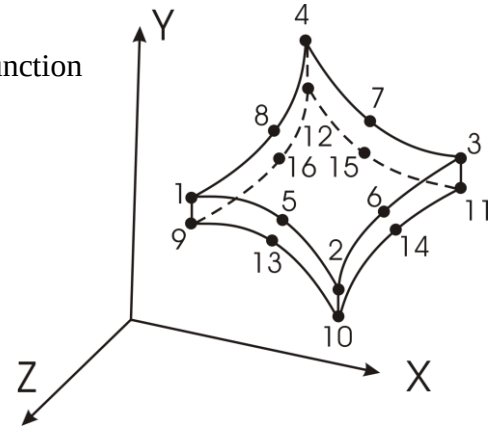
XY-Plane: 1 - 5 - 2 - 6 - 3 - 7 - 1, quit LINE function
2 - 8 - 4 quit LINE function
3 - 9 - 4, quit LINE function
1 - 10 - 4, quit LINE function



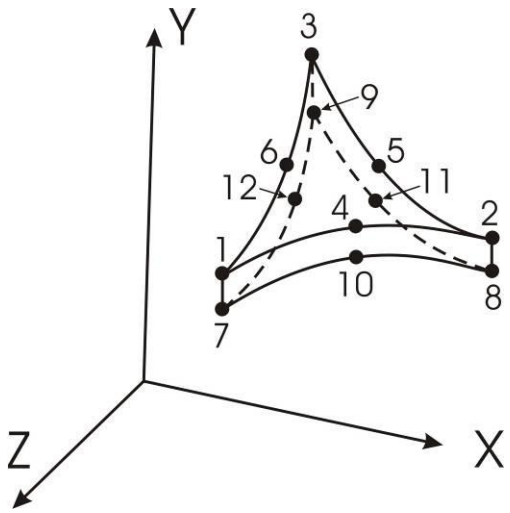
Element No.17:
XY-Plane: 1 - 2 - 3 - 1, quit LINE function
2 - 4, quit LINE function
3 - 4, quit LINE function
1 - 4, quit LINE function



Element No. 21:
Upper plane: 1 - 5 - 2 - 6 - 3 - 7 - 4 - 8 - 1, quit LINE function
Lower plane: 9 - 13 - 10 - 14 - 11 - 15 - 12 - 16 - 9,
quit LINE function
1 - 9, quit LINE function
2 - 10, quit LINE function
3 - 11, quit LINE function
4 - 12, quit LINE function



Element No. 22:
Upper plane: 1 - 4 - 2 - 5 - 3 - 6 - 1,
quit LINE function
Lower plane: 7 - 10 - 8 - 11 - 9 - 12 - 7,
quit LINE function
1 - 7, quit LINE function
2 - 8, quit LINE function
3 - 9, quit LINE function



6th step: Define the layer **Z88GEN** and switch it active. Write with the TEXT function into any place of your drawing:

6.1 general information, i.e. the first input group of the general structure data Z88I1.TXT or the mesh generator file Z88NI.TXT.
In case of Z88I1.TXT (i.e. FE mesh):

Z88I1.TXT
Dimension of the structure
Number of nodes
Number of finite elements
Number of degrees of freedom DOF
Coordinate flag (0 or 1)

Write into one line, separate each item by at least one blank. **Definitely write in the layer Z88GEN.**

Example: 3-dimensional FE structure with 150 nodes, 89 finite elements, 450 degrees of freedom. Input with cylindrical coordinates. Thus:
Z88I1.TXT 3 150 89 450 1

In case of Z88NI.TXT (i.e. super structure):

Z88NI.TXT
Dimension of the structure
Number of nodes
Number of super element
Number of degrees of freedom DOF
Coordinate flag for super elements (0 or 1)
Trap radius header flag (mostly 0)
Coordinate flag for finite elements (0 or 1)
Write into one line, separate each item by at least one blank.

Example: 2-dimensional super-structure with 37 nodes, 7 super elements, 74 degrees of freedom. Polar coordinates for the super elements, use default for trap radius, and use default (= cartesian coordinates) for coordinate flag for the finite elements. Thus:
Z88NI.TXT 2 37 7 74 1 0 0

Write into one line, separate each item by at least one blank. **Make sure to write in the layer Z88GEN.**

7th step: Define the Layer **Z88RBD** and activate it. Write with the TEXT function into a free space (well into any place of your drawing):

7.1 number of the boundary conditions, i.e. the first input group of the boundary condition file Z88I2.TXT

Z88I2.TXT Number of the boundary conditions

Write into one line, separate each item by at least one blank. **Make sure to write in the layer Z88RBD.**

Example: The structure has 10 boundary conditions, e.g. two loads and eight constraints i.e. support reactions. Thus *Z88I2.TXT 10*

7.2 Boundary conditions, the second input group of the boundary condition file Z88I2.TXT

RBD
Number of the boundary condition
nodal number
Degree of freedom
Header flag force/displacement (1 or 2)
Value

Write into one line, separate each item by at least one blank. **Make sure to write in the layer Z88RBD.**

Example: The structure shall be a truss-framework. Node 1 shall be fixed in Y and Z, node 2 fixed in X and Z. Nodes 7 and 8 have a load of 30,000 N each in Z direction, pointing down. Node 19 is fixed in X and Z and node 20 is fixed in Y and Z. Thus

RBD 1 1 2 2 0
RBD 2 1 3 2 0
RBD 3 2 1 2 0
RBD 4 2 3 2 0
RBD 5 7 3 1 -30000
RBD 6 8 3 1 -30000
RBD 7 19 1 2 0
RBD 8 19 3 2 0
RBD 9 20 2 2 0
RBD 10 20 3 2 0

8th step: if surface and pressure loads are defined: create the layer **Z88FLA** and activate it. Write with the TEXT function into any place of your drawing:

8.1 Number of surface and pressure loads
i.e. the first input group of the surface and pressure loads file Z88I5.TXT
Z88I5.TXT number of surface and pressure loads
Write into one line, separate each item by at least one blank. **Make sure to write in the layer Z88FLA.**
Example: The structure features 12 surface loads. Thus: *Z88I5.TXT 12*

8.2 Surface and pressure loads
i.e. the second input group of the surface and pressure loads file Z88I5.TXT
FLA number of the surface and pressure load

The following entries depend on the element type with surface and pressure load:

→ Plain stress element No.7 and 14 and Torus elements No.8 and 15:
Element number with surface load
Pressure, positive if pointing towards the edge
Tangential shear, positive in local r-direction
3 nodes of the loaded edge

Example: The plain stress element 97 is the third element with surface load. The load should be applied onto the edge defined by the corner nodes 5 and 13 and by the mid node 51. One surface load is applied normally to the edge with 100 N/mm and the other surface load is

applied tangentially and positive in local r direction with 300 N/mm (defined by the two corner nodes). Thus: *FLA 3 97 100. 300. 5 13 51*

→ Hexahedron No.1:
Element number with surface and pressure load
Pressure, positive if pointing towards the surface
Tangential shear, positive in local r direction
Tangential shear, positive in local s direction
4 nodes of the loaded surface

Example: The hexahedron 356 is the 34th element with surface loads. The load should be applied onto the surface defined by the corner nodes 51, 34, 99 and 12. The first surface load is pressure with 100 N/mm. The second surface load is applied tangentially and positive in local r direction with 200 N/mm. The third surface load is applied tangentially and positive in local s direction with 300 N/mm. Thus:
FLA 34 356 100. 200. 300. 51 34 99 12

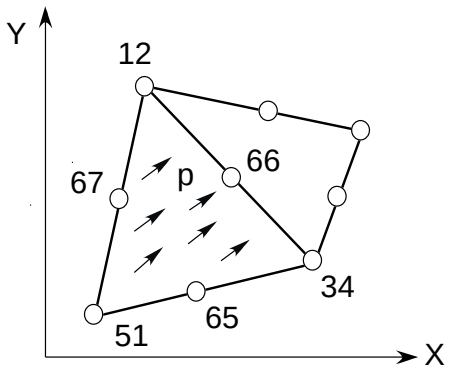
→ Hexahedron No.10, Shells No. 21 and No. 22:
Element number with surface and pressure load
Pressure, positive if pointing towards the surface
Tangential shear, positive in local r direction
Tangential shear, positive in local s direction
8 nodes of the loaded surface

→ Tetraeder No.17:
Element number with surface and pressure load
Pressure, positive if pointing towards the surface
3 nodes of the loaded surface

Example: The Tetrahedron element 356 is the 35th element with pressure load and shall be loaded on the surface defined by the corner nodes 51, 34 and 12 by a pressure of 100 N/mm^2. Thus:
FLA 35 356 100. 51 34 12

Tetraeder Nr.16:
Element number with surface and pressure load
Pressure, positive if pointing towards the surface
6 nodes of the loaded surface

Example: The Tetrahedron element 888 is the 36th element with pressure load and shall be loaded on the surface defined by the corner nodes 51, 34 and 12 and the middle nodes 65, 66 and 67 by a pressure of 100 N/mm^2. Thus:
FLA 36 888 100. 51 34 12 65 66 67



→ Plate elements No.18, 19 and 20, Shells No. 23 and 24:
Element number with pressure load
Pressure, positive if pointing towards the surface

Separate each item by at least one blank. **Make sure to write in the layer Z88FLA.**

9th step: Export (store) your model or drawing under the name **Z88X.DXF** in the DXF file format. For precision of decimal positions take the default value which the CAD program suggests. Then you may import this file into Z88 Aurora.

Note: You may convert Z88 input decks Z88I1.TXT, Z88I2.TXT, Z88I5.TXT or Z88NI.TXT to Z88X.DXF for input for AutoCAD. Because this functionality is only implemented for control purpose it is not anymore callable from Z88A Aurora V3 and V4; in contrary to open source Z88 V13 and freeware Z88 Aurora V1.
Thus, launch Z88X outside Aurora V4 from a command line interpreter , i.e. Windows DOS prompt or a UNIX shell in Aurora's binary directory. Be sure to have Z88I1.TXT, Z88I2.TXT, Z88I5.TXT or Z88NI.TXT in Aurora's binary directory. Then proceed as follow:

z88x -i1tx convert Z88I1.TXT to Z88X.DXF
z88x -iatx convert Z88I1.TXT, Z88I2.TXT and Z88I5.TXT to Z88X.DXF
z88x -nitx convert Z88NI.TXT to Z88X.DXF

Z88X will generate a file Z88X.DXF, and you may load this DXF file into AutoCAD. Vice versa, if you wish, you may convert DXF files named Z88X.DXF outside Z88 Aurora V2 into the Z88 solver decks:

z88x -i1fx convert Z88X.DXF to Z88I1.TXT
z88x -iafx convert Z88X.DXF to Z88I1.TXT, Z88I2.TXT and Z88I5.TXT
z88x -nifx convert Z88X.DXF to Z88NI.TXT

If you want to convert Z88 text files as Z88X.DXF to CAD, you can choose the text size which applies to all texts like node numbers, element numbers etc. This is very important from time to time because there is no possibility in e.g. AutoCAD to change the text size *globally* afterwards. Have some tries until you have found the suitable text size for the respective Z88 file. Simply call Z88X once more with another text size:

z88x -i1tx | -iatx | -nitx | -i1fx | -iafx | -nifx -ts number

Caution: Use the Z88X keywords **"P number, FE values, SE values, FLA, RBD,**

Z88NI.TXT, Z88I1.TXT, Z88I2.TXT and Z88I5.TXT" only where they are really needed. Take care that they do not appear in other drawing captions!

2.4.3 EXAMPLE 1 FOR Z88X: FINITE ELEMENTS STRUCTURE

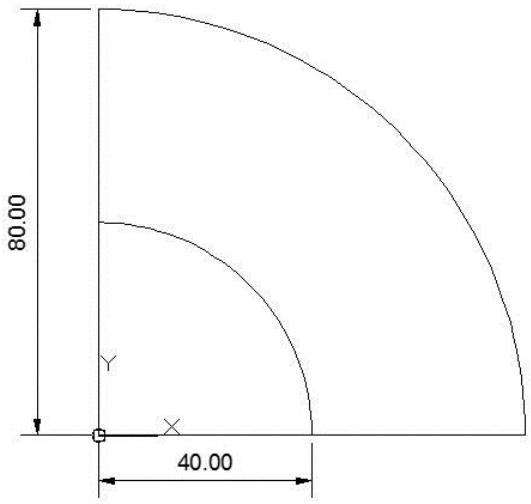
Consider a pipe under internal pressure of 1,000 bar (=100 N/mm^2). Inside diameter of the pipe is 80 mm, outside diameter of the pipe is 160 mm. The length is 40 mm. If one chooses the supports cleverly, a quarter of the pipe is enough to reflect the problem.

Such structures are best suited for polar coordinates. The internal pressure of 1,000 bar corresponds to a force of 251,327 N while the edge load is:

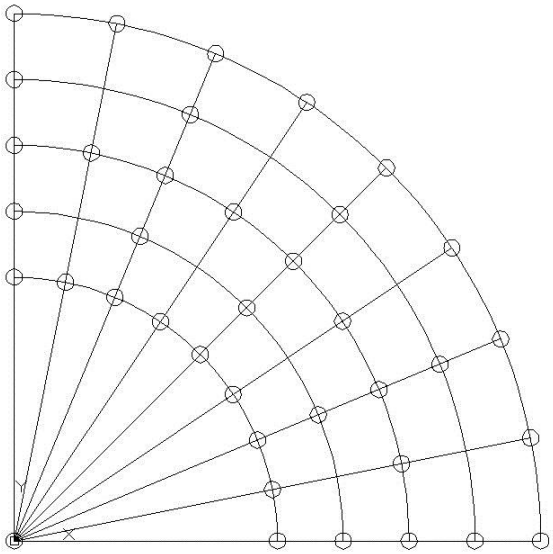
$$q = \frac{F}{\ell} = \frac{F}{r \times \varphi} = \frac{251327}{40 \times \pi/2} = 4000\,N/mm$$

1st step: Design your component in the CAD system as usual. You do not need to maintain a definite order and you can use any layers. It is highly recommended to put symbols on one layer, edges on another layer, dimensions on a third layer, invisible lines and centre lines on a fourth layer and so on. This enables you to remove all unnecessary information in the next step. For this example you may enter the main data by command line. Recall AutoCAD's numeric data formats:

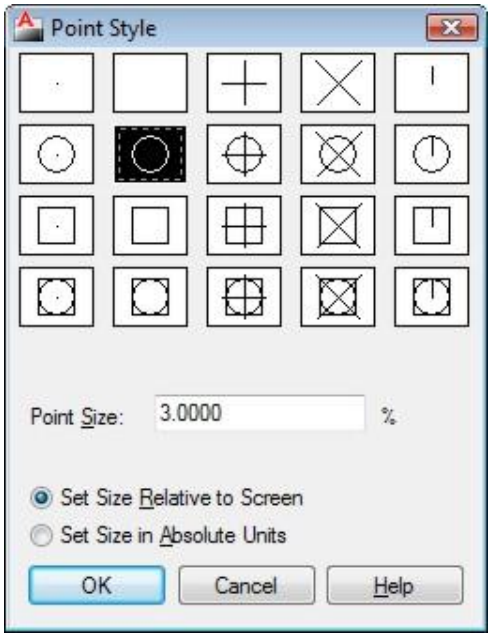
- absolute cartesian coordinates: X,Y
- relative cartesian coordinates: @DeltaX,DeltaY
- absolute polar coordinates: Radius<Winkel
- relative polar coordinates: @Radius<Winkel



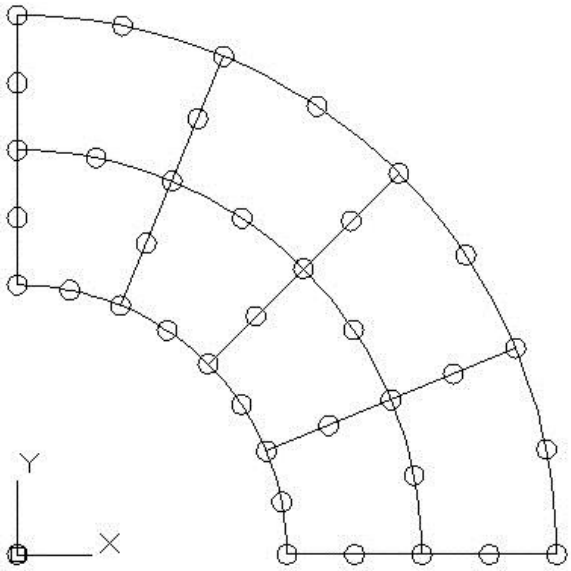
2nd step: Plan your mesh subdivision that means suitable finite element types and their distribution. Subdivide the FE structure or the super structure into elements by lines, insert **all** points which are not yet existing (for example intersection points or end-points of lines are usable). Any order and layer. However, it is recommended not to use the Z88-layers like Z88NET, Z88GEN, Z88PKT, Z88KNR, Z88EIO, Z88FLA and Z88RBD. Better define any new layer for this or use already available layers from step 1.



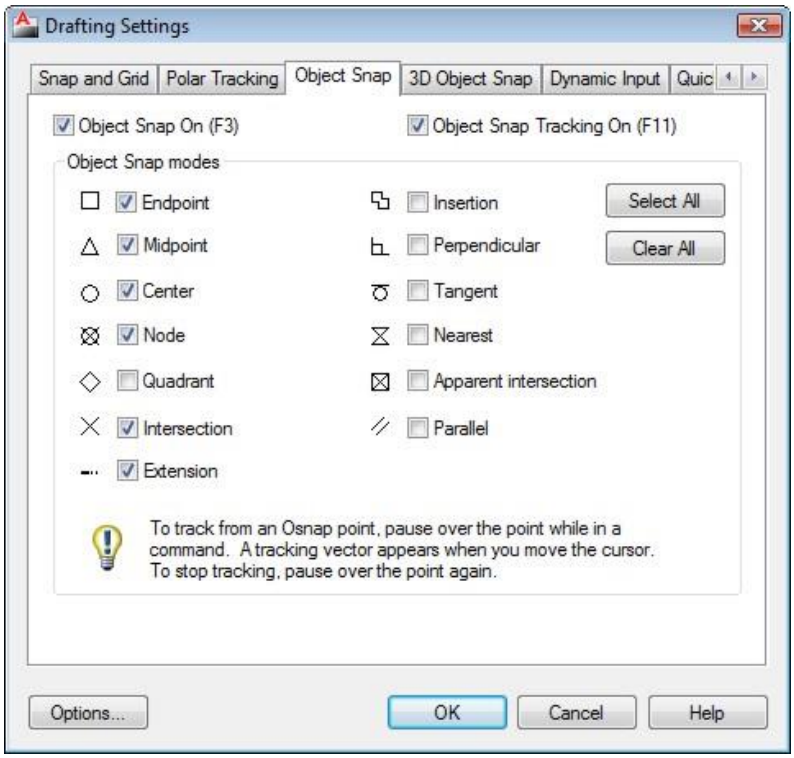
Take care to set nice looking points. Use the AutoCAD command DDPTYPE:

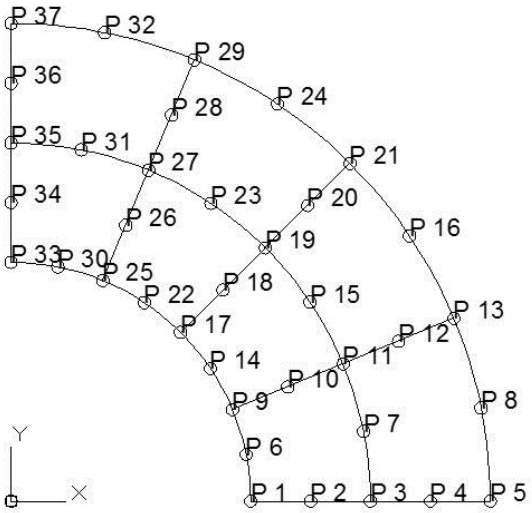


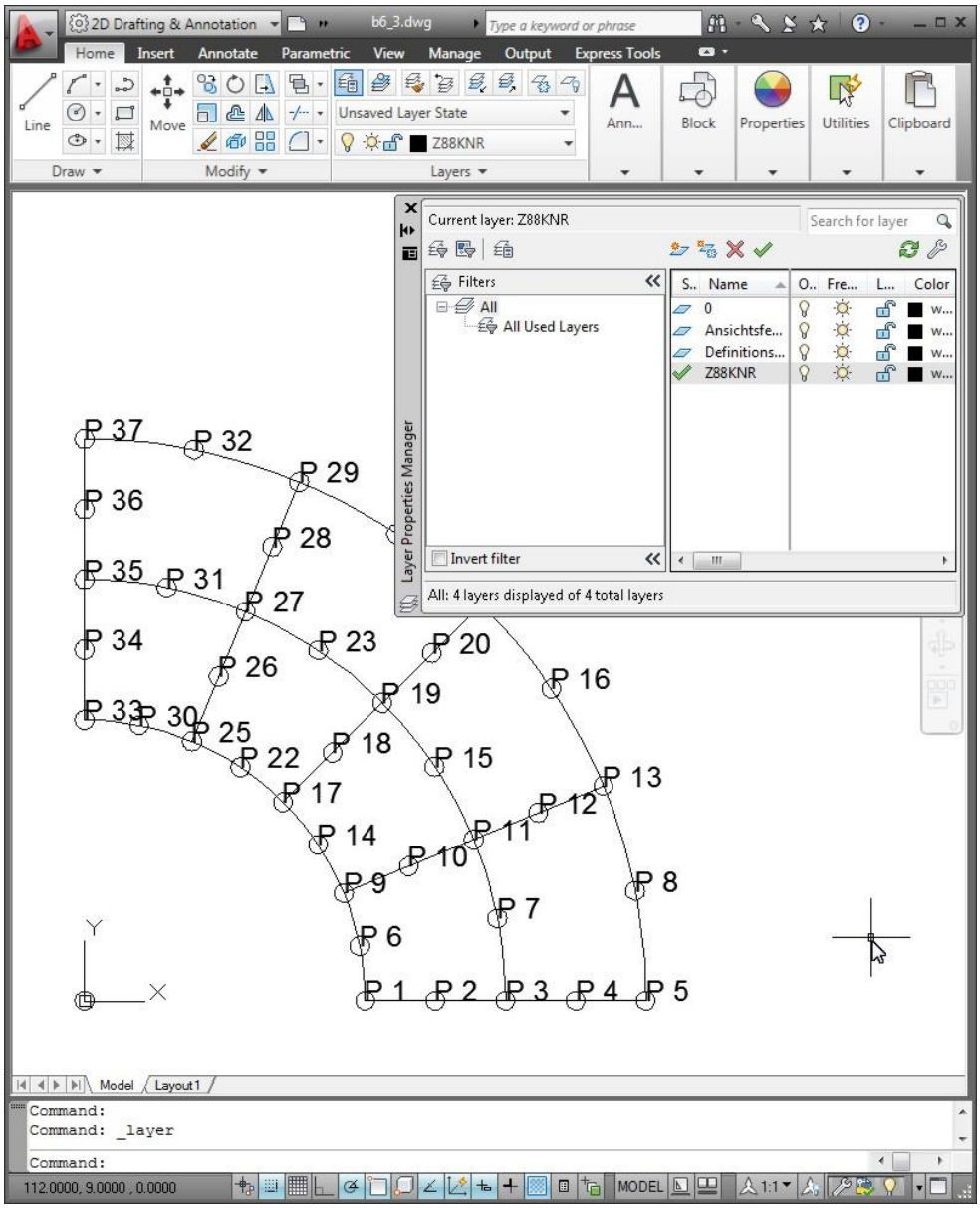
Now you may delete any auxiliary lines, arcs etc. to see the true FE structure:



3rd step: Define the Z88-Layer Z88KNR and make it the active layer. Catch or trap every FE node, which were already defined in the 1st step by your construction or have been completed in the 2nd step, and number them. Write to every node **P blank node-number** e.g. *P 33*, with the TEXT function of the CAD program. Be very careful to snap exactly the node and attach the number exactly to the node's location. Take your time! With the snap modes of AutoCAD (intersection point, end-point, point etc.) this works very well. Choose any order of the work sequence as you like, you can well number the node 1 (*P 1*), then the node 99 (*P 99*) and then node 21 (*P21*). However, the numbering of the nodes must make sense and must be meaningful for an FE analysis. *You* define which node is node 99 and which other node is 21.





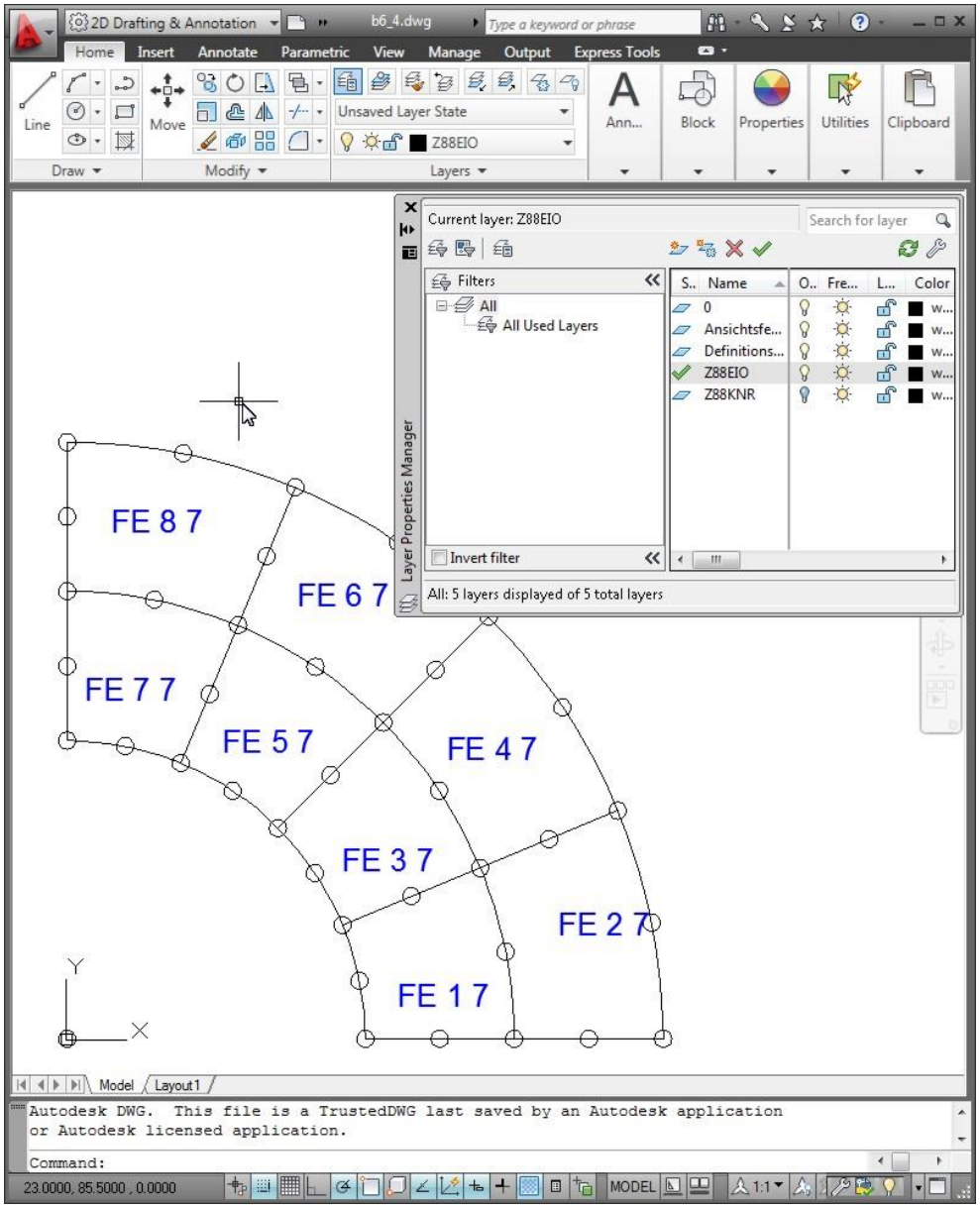


4th step: Define the Layer **Z88EIO** and make it the active layer. Write the element information with the TEXT function anywhere (of course, it looks nicer with the element

info's placed in middle of the respective finite element or super element). The order of the work sequence is up to you. You can describe element 1 first, step to the attaching element 17 and then proceed with element 8. However, your element choice and description must make sense for an FE analysis. The following information has to be written:

FE Element number Element type

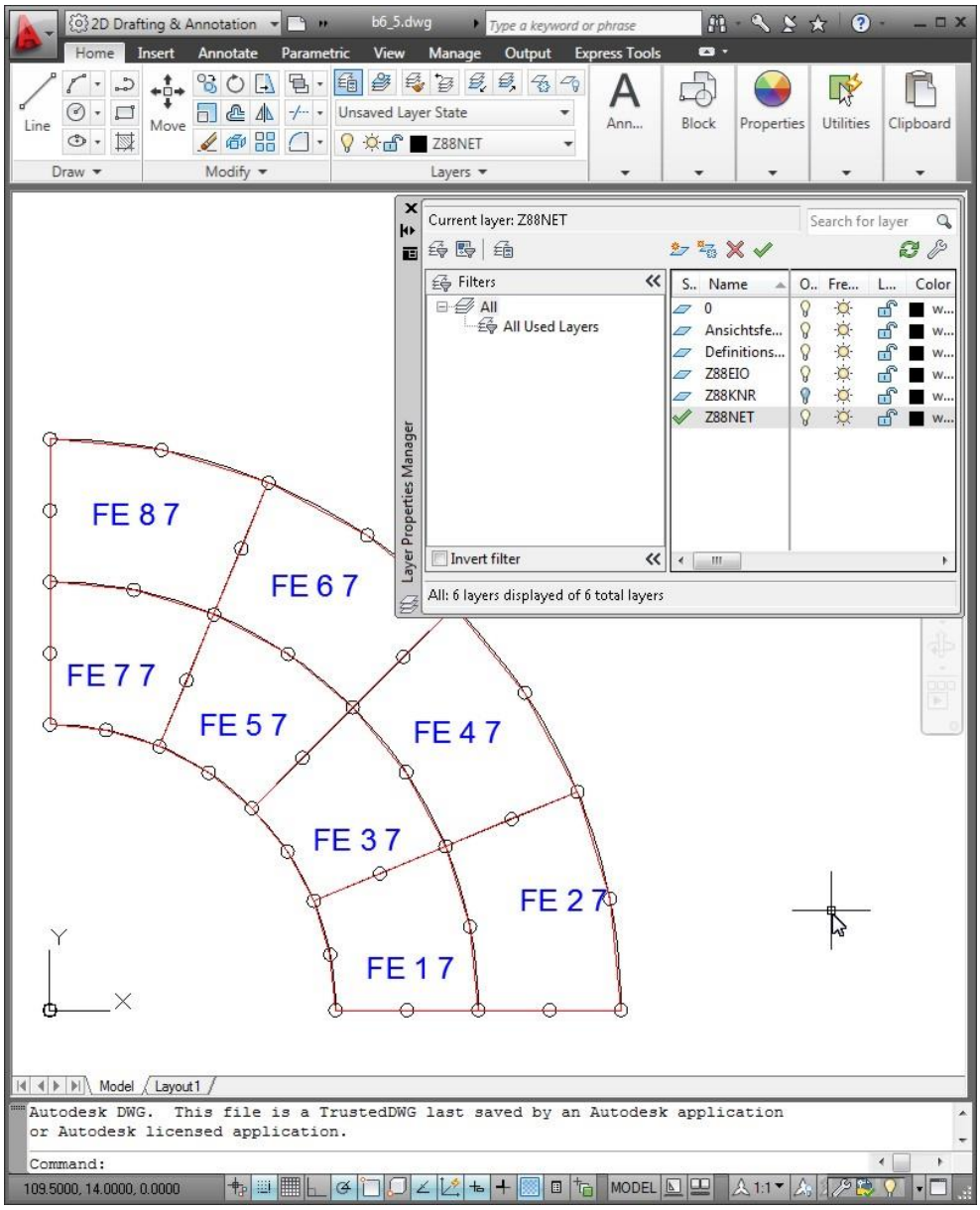
It might be a good idea to use another colour for the objects of layer Z88EIO – here, blue. However, you don't need to. For better information, the former layer Z88KNR is switched off.



5th step: Define the Layer **Z88NET** and make it the active layer. You need concentration for this step, because a firm and rigid work sequence must now be kept because of the topological information. One of the most important information, the coincidence, is defined in this step that means which elements are defined or outlined by which nodes. Choose a proper colour which differs well from the colours used till now and remove all superfluous information by switching off unused layers. Select the **LINE** command and select the proper snap options e.g. points, intersection points and, if necessary, end-points.

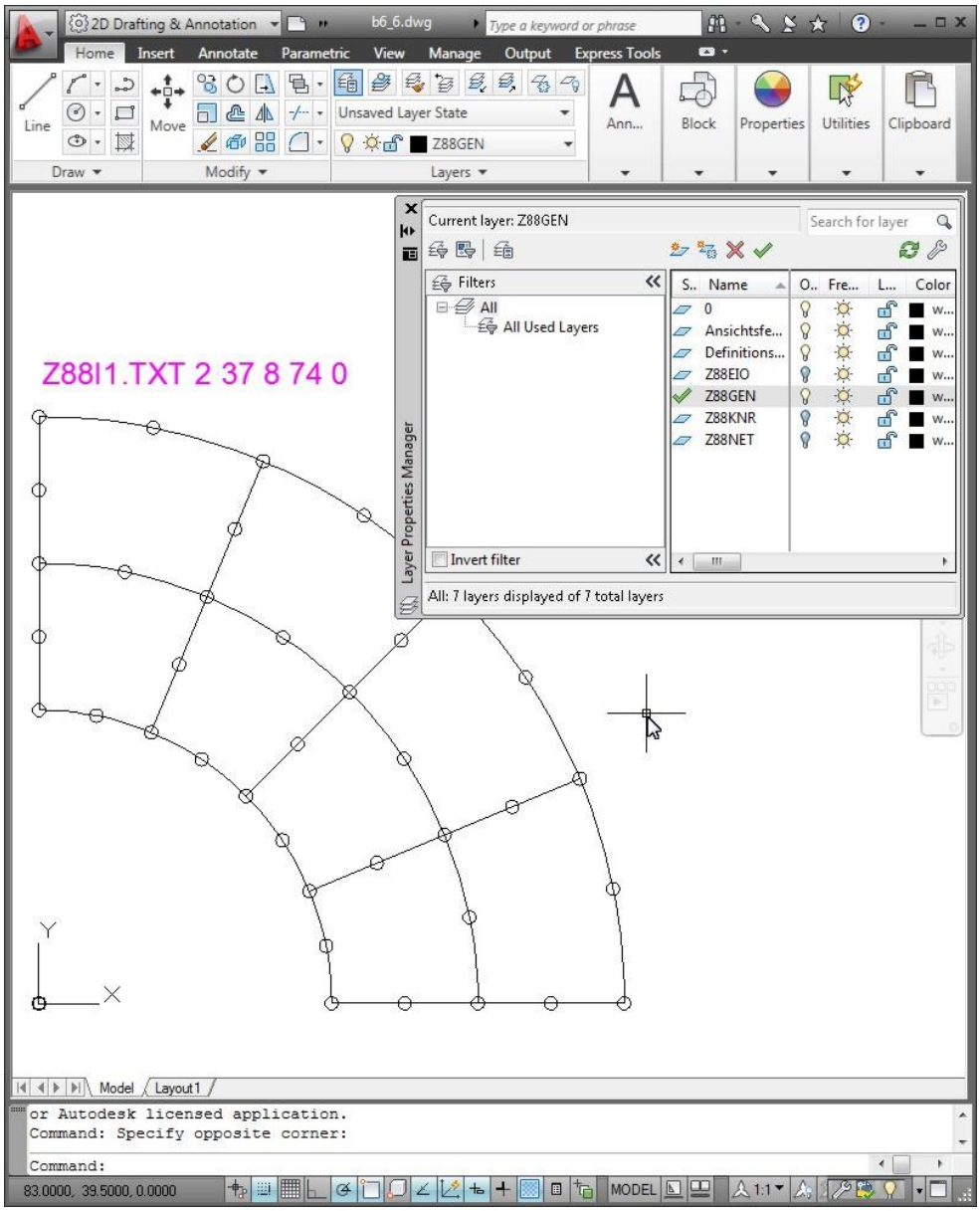
Start at the first element. For Z88 the first element is the element with which you start now, that means the one which you have chosen for your first element (*FE 1*). Select the node you want to be the first node of this element and draw a line to the node which shall be the second node of this element. From there, draw a line to the third node of this element. Connect all required nodes with lines and draw at last a line to the starting point, the first node, and then quit the LINE function. Thus, we might draw this line: P1-P2-P3-P7-P11-P10-P9-P6-P1, quit LINE. However, these lines would do fine, too: P9-P6-P1-P2-P3-P7-P11-P10-P9 or P3-P7-P11-P10-P9-P6-P1-P2-P3 or P11-P10-P9-P6-P1-P2-P3-P7-P11.

Then do the same with the second element. Remember: **You determine with this order which of the elements will be the real second element now**. In the previous 4th step you have only defined what kind of element the second element is. You determine here **how** the element is defined topologically. Thus, we might draw this line: P3-P4-P5-P8-P13-P12-P11-P7-P3, quit LINE. Let the other elements follow.
This procedure sounds strange and complicated but be assured that it will work much more easily and quickly than one can describe it: For these 8 elements you will finish work in less than two minutes.



6th step: Define the layer **Z88GEN** and switch it active. Write with the TEXT function into any place of your drawing the **general information,** i.e. the first input group of the general structure data Z88I1.TXT:
Z88I1.TXT
Dimension of the structure
Number of nodes
Number of finite elements
Number of degrees of freedom DOF
Coordinate flag (0 or 1)

Thus, here: Z88I1.TXT 2 37 8 74 0



On this stage you could leave AutoCAD by storing your drawing as a DXF file. You could import this DXF file by DXF import with Z88X while choosing the option *"... to Z88I1.TXT"*. Thus, Z88X will generate a Z88 input file Z88I1.TXT. This is what you did until now. Now you may enter the boundary conditions and surface loads into Z88I2.TXT and Z88I5.TXT. But for this example we'll proceed as follows:

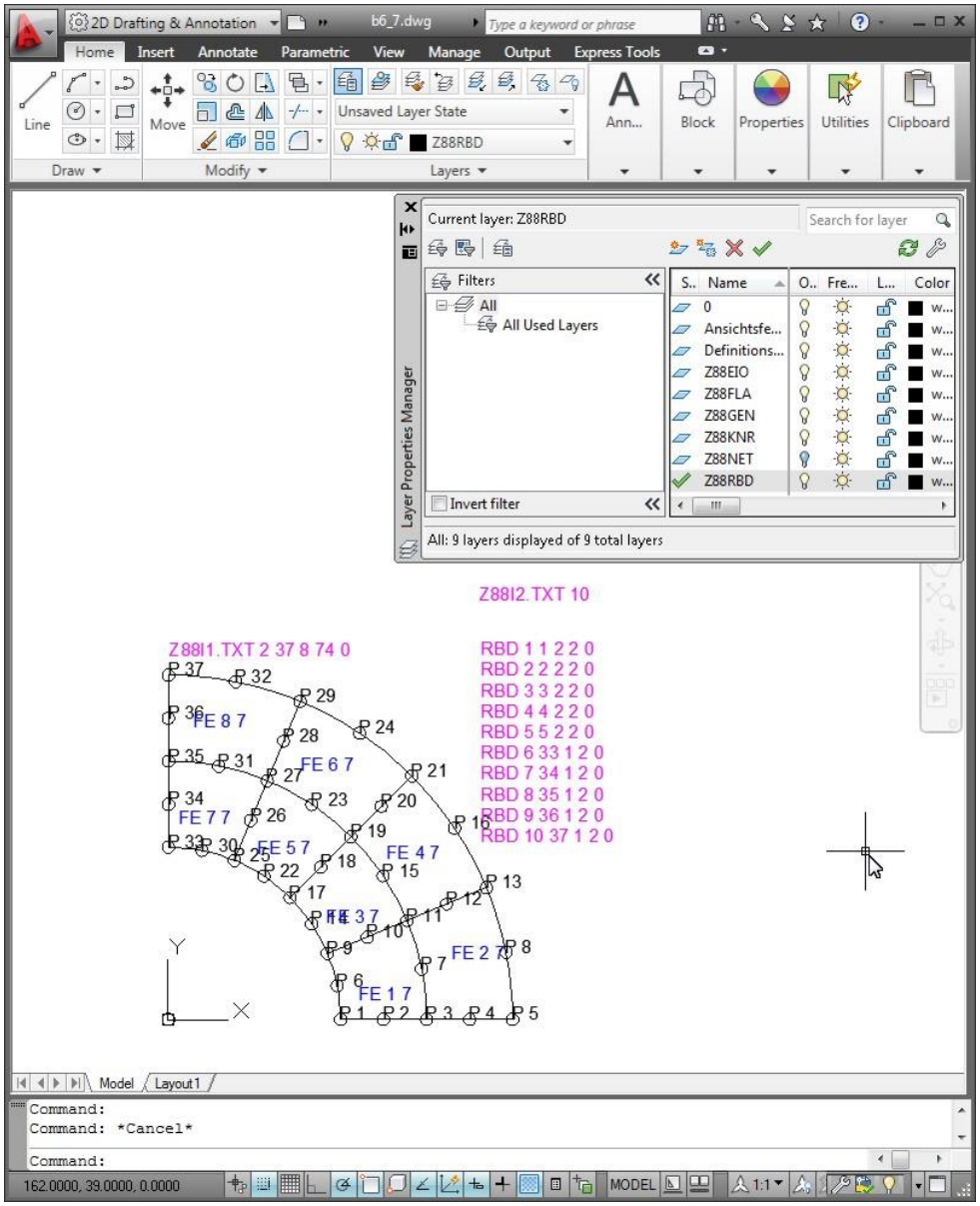
7th step: Define the Layer **Z88RBD** and activate it. Write with the TEXT function into a free space (well into any place of your drawing) the **number of the boundary conditions**, i.e. the

first input group of the boundary condition file Z88I2.TXT:

Z88I2.TXT Number of boundary conditions

In this investigation we will define fixed supports for nodes 1 ~ 5 in Y direction and fixed supports for nodes 33 ~ 37 in X direction resulting in 10 boundary conditions. Now we may apply the **boundary conditions**, i.e. the second input group of boundary conditions file Z88I2.TXT:

RBD
Number of the boundary condition
nodal number
Degree of freedom
Header flag force/displacement (1 or 2)
Value



8th step: if surface and pressure loads are defined: create the layer **Z88FLA** and activate it. Write with the TEXT function into any place of your drawing the **number of surface and**

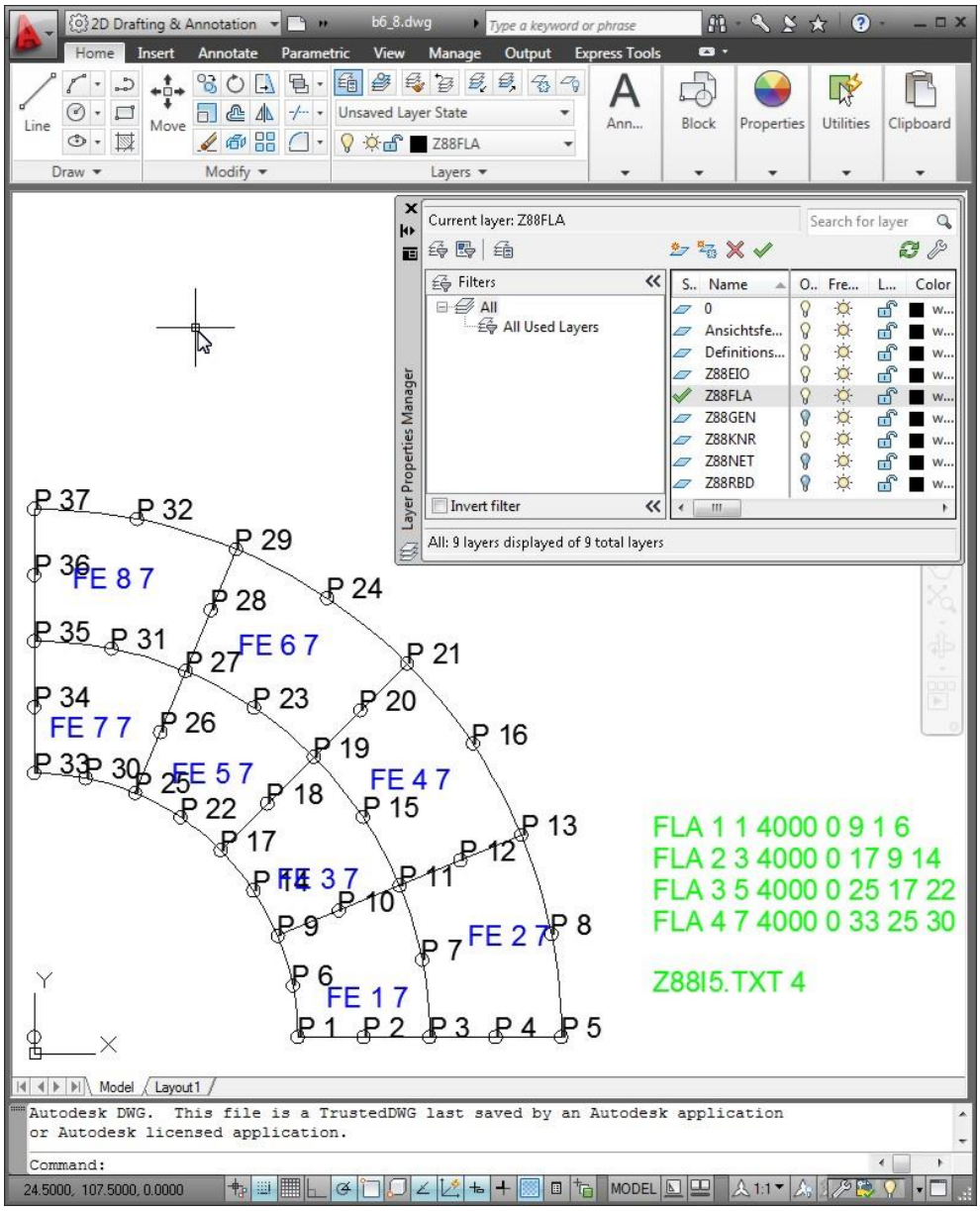
pressure loads i.e. the first input group of the surface and pressure loads file Z88I5.TXT

Z88I5.TXT number of surface and pressure loads
Thus: Z88I5.TXT 4

Now you may enter the **Surface and pressure loads** i.e. the second input group of the surface and pressure loads file Z88I5.TXT

FLA number of the surface and pressure load

<u>The following entries will work fine for Plain stress element No.7:</u>
Element number with surface load
Pressure, positive if pointing towards the edge
Tangential shear, positive in local r-direction
3 nodes of the loaded edge



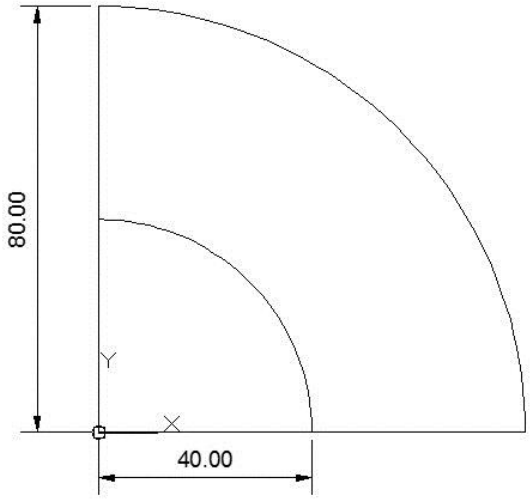
9th step: Store your model or drawing in the DXF file format. Choose AutoCAD R12 DXF format, if in doubt, but AutoCAD 2011 DXF works, too. For precision of decimal positions take the default value which the CAD program suggests. Then you may import this file by DXF import with Z88X while choosing the option *"... to Z88I*.TXT"*. Thus, Z88X will generate the Z88 input files Z88I1.TXT (general structure data), Z88I2.TXT (boundary conditions), and Z88I5.TXT (surface and pressure loads file).

2.4.4 EXAMPLE 2 FOR Z88X: SUPER ELEMENTS STRUCTURE

This example is very similar to the first one but now we will generate a super structure. This super structure will be loaded by DXF import with Z88X and then meshed by the mapped mesher Z88N resulting in a finite elements structure.

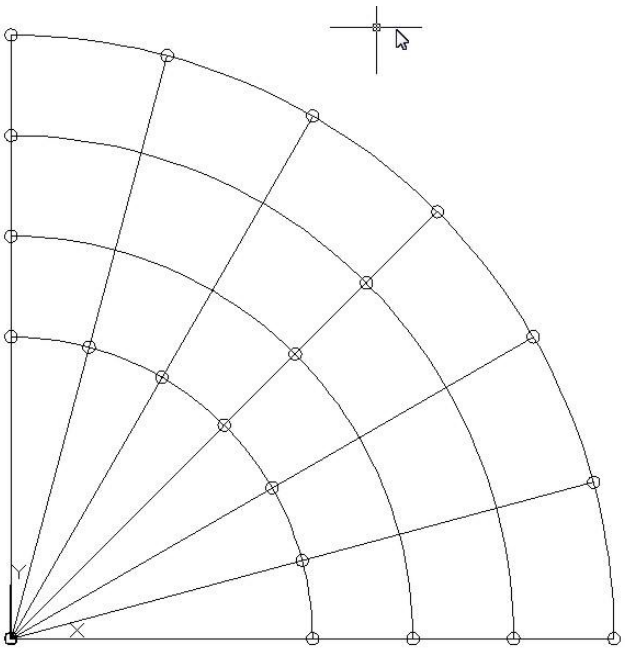
Consider a pipe under internal pressure of 1,000 bar (=100 N/mm^2). Inside diameter of the pipe is 80 mm, outside diameter of the pipe is 160 mm. The length is 40 mm. If one chooses the supports cleverly, a quarter of the pipe is enough to reflect the problem.

1st step: Design your component in the CAD system as usual.

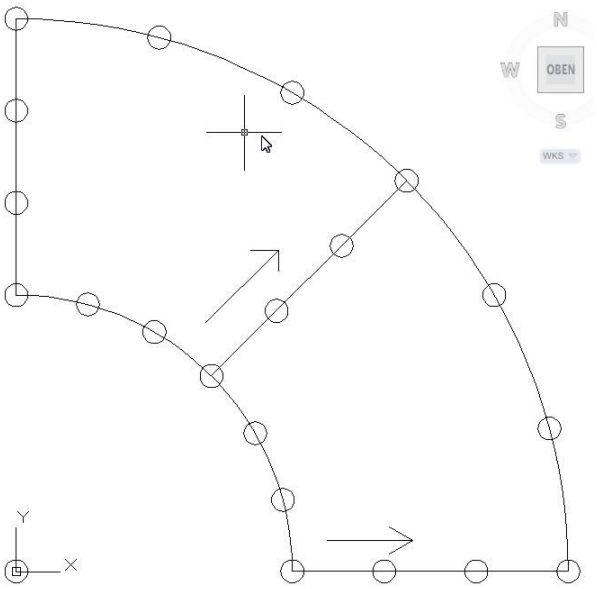


2nd step: We'll only use 2 super elements No. 11 with 12 nodes each – and this will do for a nice 90° arc because of the cubic interpolation functions of element No. 11. Subdivide the super structure into elements by lines, insert **all** points which are not yet existing (for example intersection points or end-points of lines are usable). Any order and layer. However, it is recommended not to use the Z88-layers like Z88NET, Z88GEN, Z88PKT, Z88KNR, Z88EIO, Z88FLA and Z88RBD. Better define any new layer for this or use already available layers from step 1.

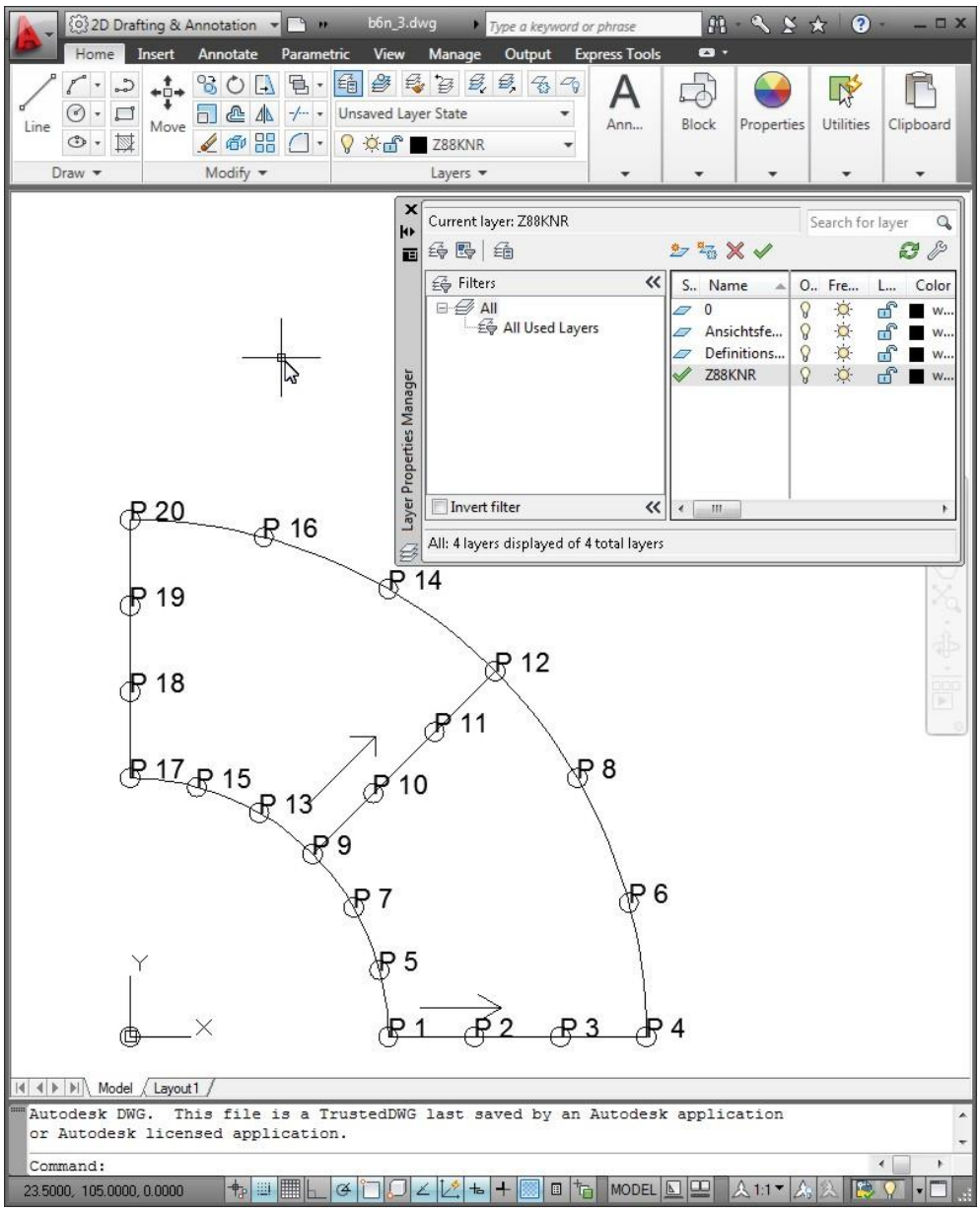
Take care to set nice looking points. Use the AutoCAD command DDPTYPE:



Now you may delete any auxiliary lines, arcs etc. to see the true super elements structure. When working with super elements it is always a good idea to insert arrows to mark the local x-axis for more easy operation later. Thus, you'll have the starting point for the multi-line, too.

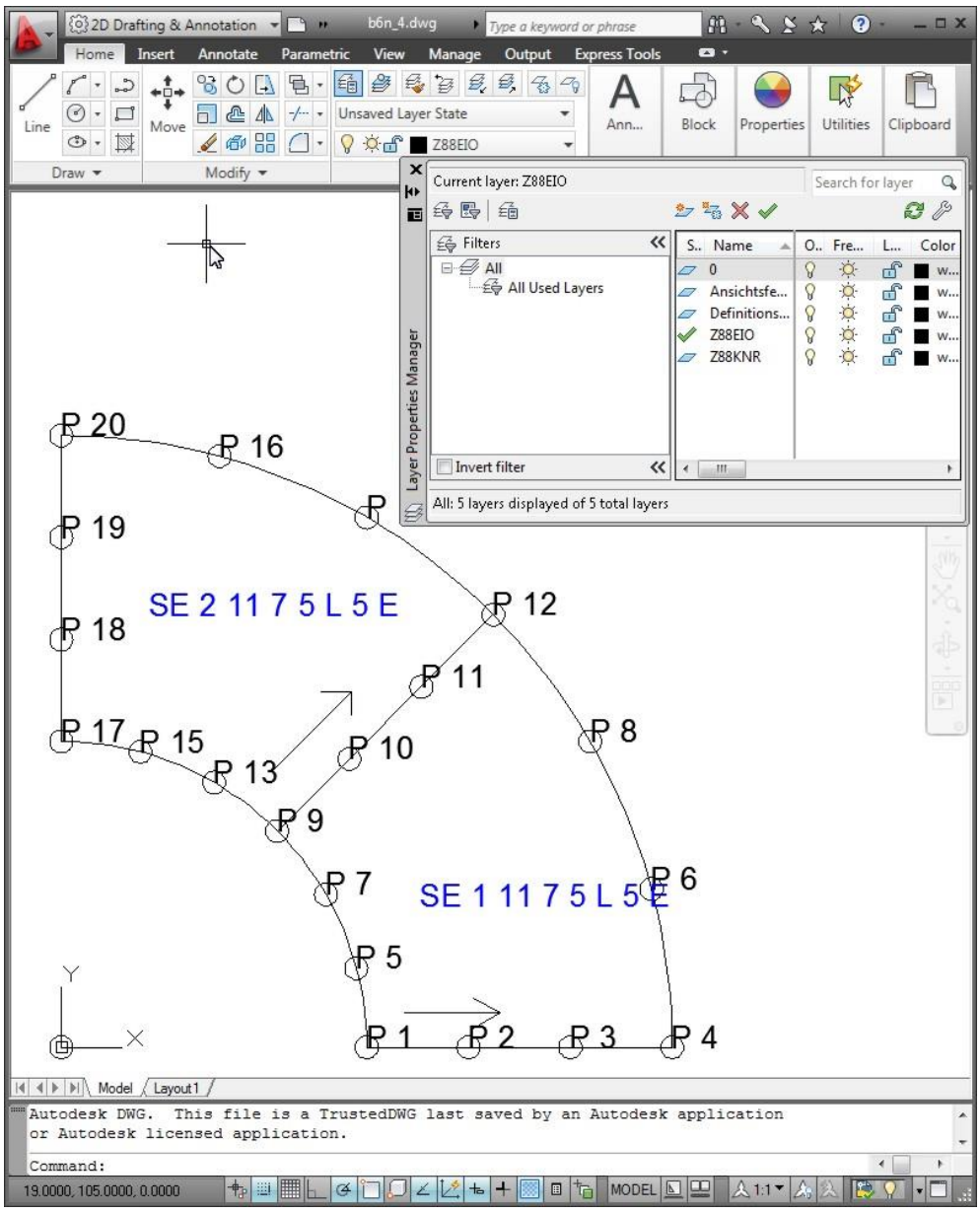


3rd step: Define the Z88-Layer Z88KNR and make it the active layer. Catch or trap every super node, which were already defined in the 1st step by your construction or have been completed in the 2nd step, and number them. Write to every node **P blank node-number** e.g. *P 33*, with the TEXT function of the CAD program. Be very careful to snap exactly the node and attach the number exactly to the node's location. Take your time! With the snap modes of AutoCAD (intersection point, end-point, point etc.) this works very well. Choose any order of the work sequence as you like.



4th step: Define the Layer **Z88EIO** and make it the active layer. Write the super element information with the TEXT function anywhere (of course, it looks nicer with the element info's placed in middle of the respective finite element or super element). The order of the work sequence is up to you. The following information has to be written:
SE
Element number
Super-element type
Type of the finite elements to be produced by meshing
Subdivision in local x direction
Type of subdivision in local x direction
Subdivision in local y direction
Type of subdivision in local y direction

Suppose to mesh the first super element of type No.11 into finite elements of type No.7. Subdivide in local x direction 5 times ascending geometrically and subdivide in local y direction 5 times equidistantly. Thus: SE 1 11 7 5 L 5 E
It might be a good idea to use another colour for the objects of layer Z88EIO – here, blue. However, you don't need to.



5th step: Define the Layer **Z88NET** and make it the active layer. You need concentration for this step, because a firm and rigid work sequence must now be kept because of the topological information. One of the most important information, the coincidence, is defined in this step that means which super elements are defined or outlined by which nodes. Choose a proper colour which differs well from the colours used till now and remove all superfluous information by switching off unused layers. Select the **LINE** command and select the proper snap options e.g. points, intersection points and, if necessary, end-points.

Start at the first element. For Z88 the first element is the element with which you start now, that means the one which you have chosen for your first super element (*SE 1*). Select the node you want to be the first node of this element and draw a line to the node which shall be the second node of this element. From there, draw a line to the third node of this element. Connect all required nodes with lines and draw at last a line to the starting point, the first node, and then quit the LINE function.

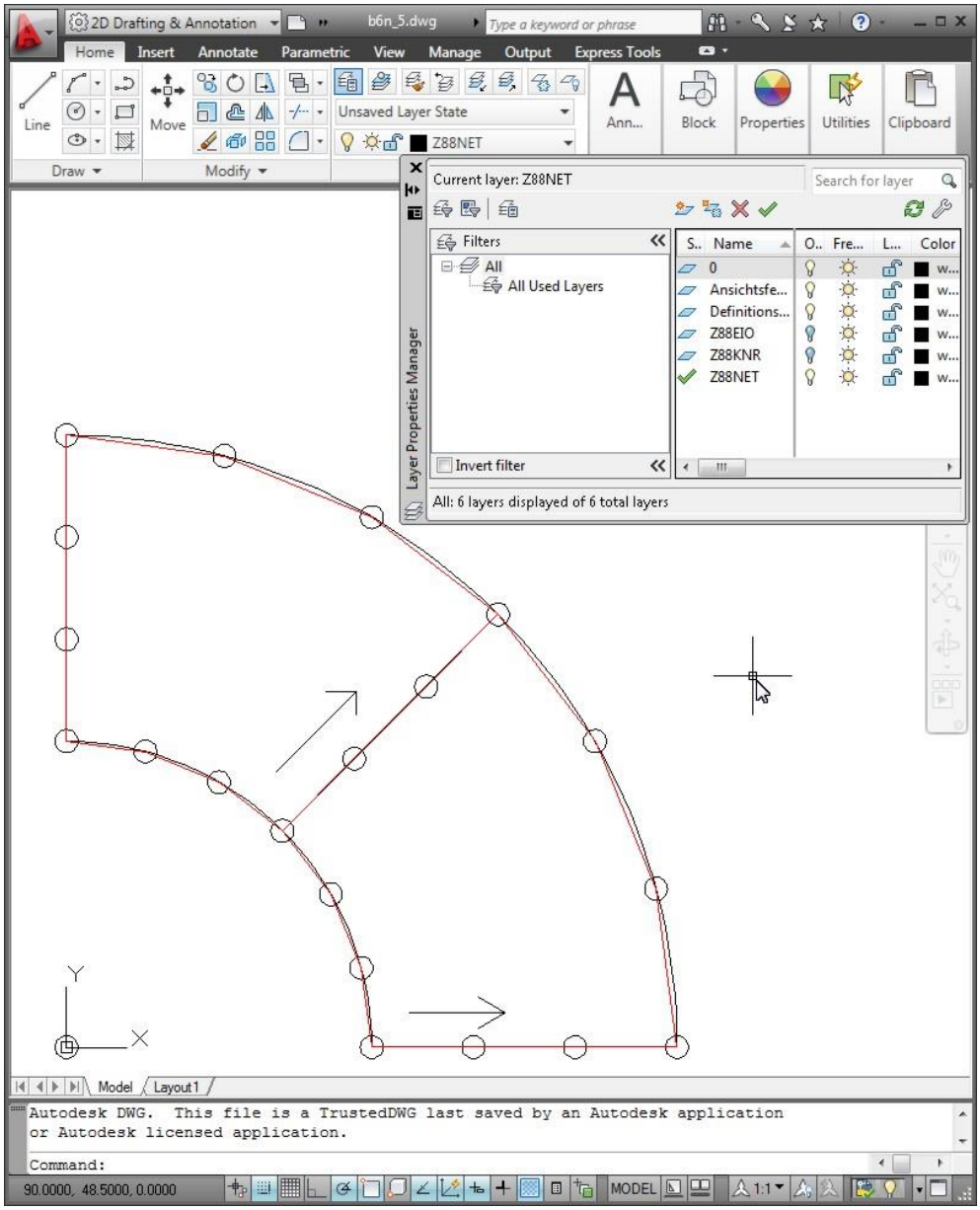
Thus, we might draw this line: P1-P2-P3-P4-P6-P8-P12-P11-P10-P9-P7-P5-P1. By the two corner nodes P1 and P4 the local x-axis is defined and this we've already marked by an arrow.

This auxiliary arrow has no meaning for Z88X – it was only a hint for us. This fits fine with our definition SE 1 11 7 5 L 5 E.

What would have happened if we would have drawn this line: P4-P6-P8-P12-P11-P10-P9-P7-P5-P1-P2-P3-P4? Basically, nothing. You are only to change the super element's definition to SE 1 11 7 5 E 5 l (← small letter L). And here's why: By drawing the line P4-P6-P8… you did define the local x-axis by the nodes P4 and P12 and, thus, the local y-axis from node P4 to node P1.

Then do the same with the second element. Remember: **You determine with this order which of the elements will be the real second element now**. In the previous 4th step you have only defined what kind of element the second element is. You determine here **how** the element is defined topologically. Thus, we might draw this line: P9-P10-P11-P12-P14-P16-P20-P19-P18-P17-P15-P13-P9, quit LINE.

This procedure takes less than half a minute.

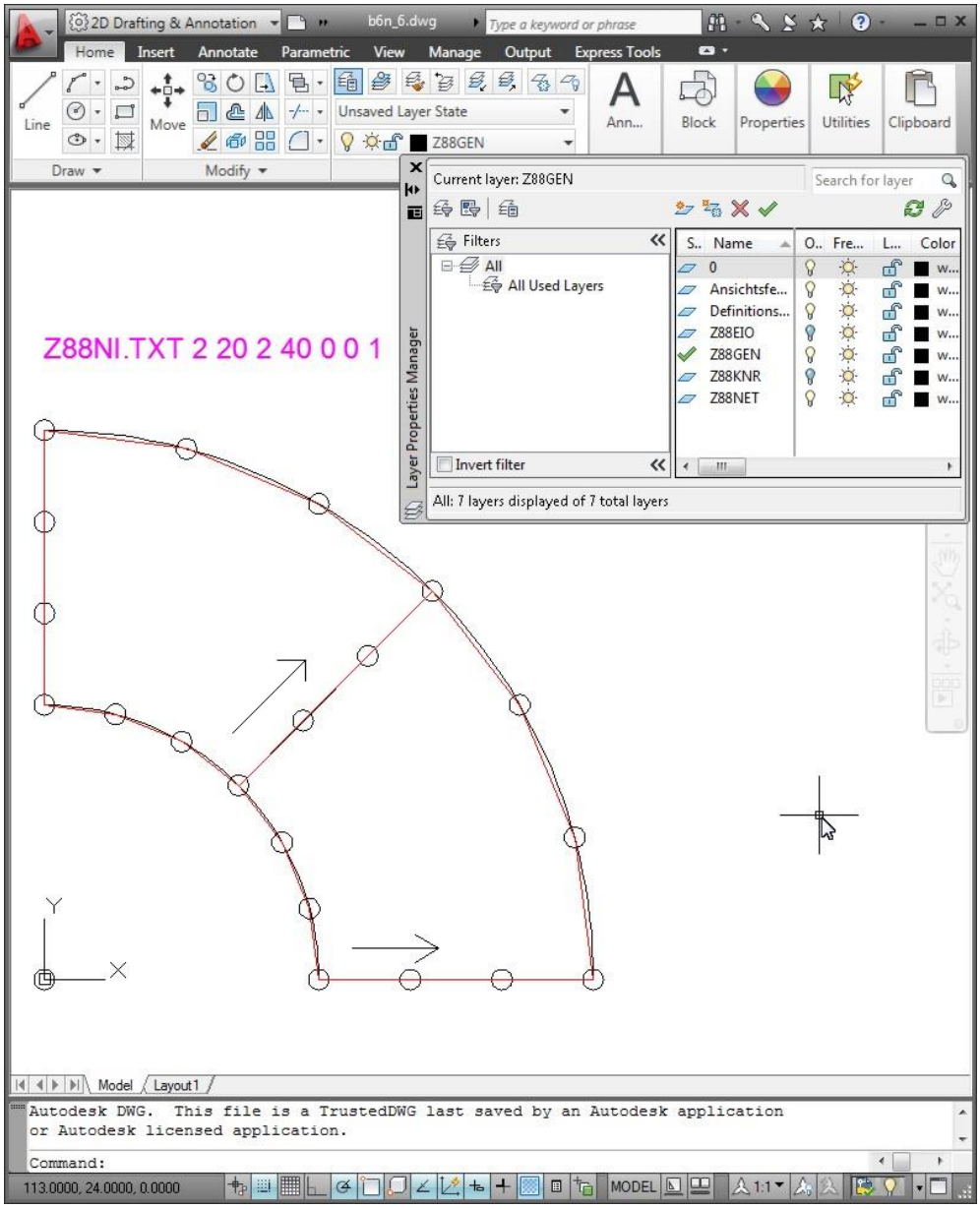


6th step: Define the layer **Z88GEN** and switch it active. Write with the TEXT function into any place of your drawing the **general information,** i.e. the first input group of the general

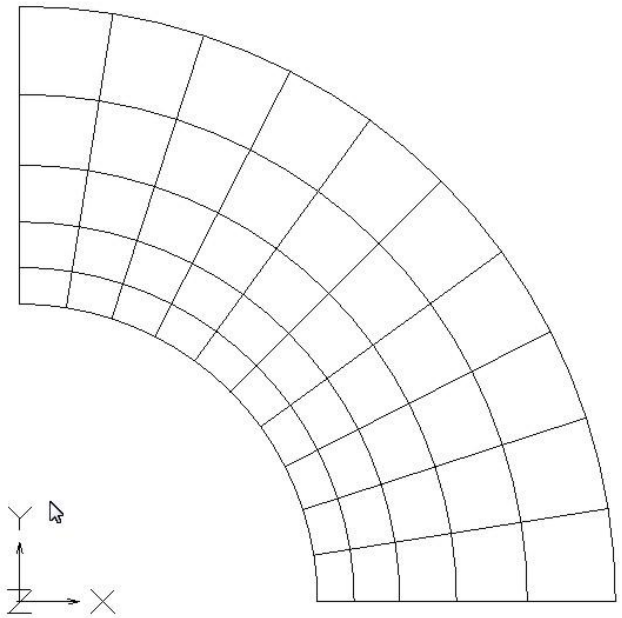
structure data Z88NI.TXT:

Z88NI.TXT
Dimension of the super structure
Number of nodes
Number of super elements
Number of degrees of freedom DOF
Coordinate flag for super elements (0 or 1)
Trap radius header flag (mostly 0)
Coordinate flag for finite elements (0 or 1)

However, here: Z88NI.TXT 2 20 2 40 0 0 1. Thus, the resulting FE structure will be written by the mapped mesher Z88N in polar coordinates.



7th step: Store this drawing as a DXF file. We'll import it by DXF Import with Z88X with the option *„…to Z88NI.TXT"*. Thus, Z88X interprets the DXF file as a super structure. Now launch the mapped mesher Z88N resulting in this FE structure:



Now you may add boundary conditions, materials, integration orders and element thickness.

2.5 THE 3D CONVERTERS Z88G AND Z88ASY.PL

Sometimes 3D CAD programs include so-called automeshers which devide a CAD model into finite elements. This generated mesh can be stored in some output format to fit the needs of the various FEA programs. Typical output formats are the COSMOS, the ANSYS and the NASTRAN format for the *COSMOS, ANSYS* or the *NASTRAN* FEA program.

Z88G for NASTRAN and COSMOS is developed and tested for *CREO* by Parametric Technology, USA. CREO must include the option *Pro/MECHANICA*. Then you may activate *FEM* in the CREO program after designing your 3D model , define a coordinate system (which must be in harmony with Z88!) and add forces and boundary conditions to single points. Create these single points with *Feature > Datum > Point*. For plates the direct entry of the pressure load is allowed. When using *Wildfire 2* and later versions, do not forget to define an analysis. Otherwise, no boundary conditions are filed! Modify the mesh control values, if necessary. Create the mesh with *Make Model* and choose the element type e.g. *Tet Mesh* or *Shell Mesh*. Store the mesh with *Output Model*, choose *NASTRAN* or *COSMOS/M* and *linear* or *parabolic*. Enter *z88g.nas* for NASTRAN files or *z88g.cos* for COSMOS files for the output file name.

Then lauch the converter **Z88G**. The converter produces the Z88 input files Z88I1.TXT, Z88I2.TXT and Z88I5.TXT automatically. Enter the material groups in Z88MAT.TXT along with the associated material data files and enter the element parameters like the thickness in Z88ELP.TXT. The material data in the NASTRAN or COSMOS files are not read by Z88G because they are often incorrect filed! Store the integration orders in Z88INT.TXT. Now the data set is totally compatible to Z88Aurora V2.

Plot Z88I1.TXT with the plot program Z88O. If you find a 3D model totally flat: You've defined a coordinate system CS0 in CREO which does not fit Z88's needs. Simply define a new correct coordinate system in CREO and define it as datum when outputting the model.

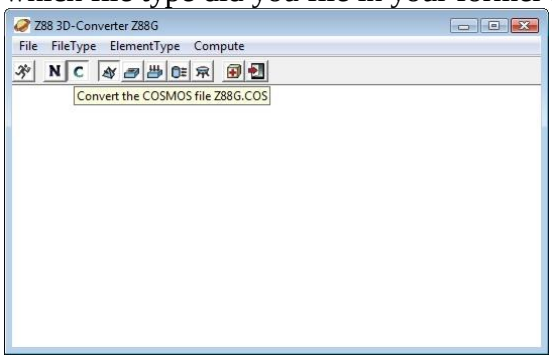
Keep in mind that those exchange file formats and their CREO output are subject to change every some months. Visit www.z88.de or www.z88.org for updated versions of Z88G.

You may create the following Z88 element types with Z88G:

- Tetrahedron No.16 (*Tetrahedron, parabolic* in CREO)
- Tetrahedron No.17 (*Tetrahedron, linear* in CREO)
- Plane stress No.14 (*Shell, triangle, parabolic* in CREO)
- Plane stress No.7 (*Shell,quadrangle, parabolic* in CREO)
- Plate No.18 (*Shell, triangle, parabolic* in CREO)
- Plate No.20 (*Shell,quadrangle, parabolic* in CREO)
- Torus No.15 (*Shell, triangle, parabolic* in CREO)
- Torus No.8 (*Shell,quadrangle, parabolic* in CREO)
- Shells No. 23 (*Shell, triangle, parabolic* in CREO)
- Shells No. 24 (*Shell,quadrangle, parabolic* in CREO)

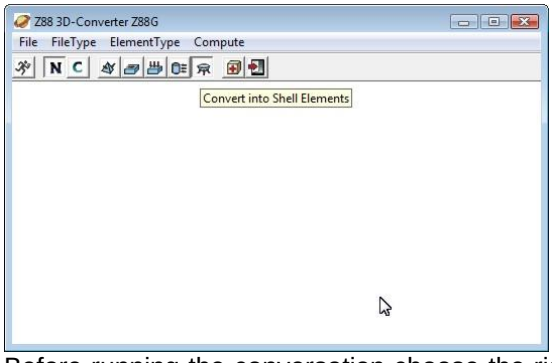
Please keep in mind that Z88G is capable to deal directly with pressure loads from CREO only with NASTRAN files. In this case, the file for surface and pressure loads Z88I5.TXT is generated. This is not possible for COSMOS files: Here you are to enter pressure loads via nodal forces.

How to proceed?
First step: Choose NASTRAN or COSMOS file format: If you choose NASTRAN the file Z88G.NAS is loaded, in case of COSMOS the file Z88G.COS is loaded. You must know which file type did you file in your former Pro/E session.



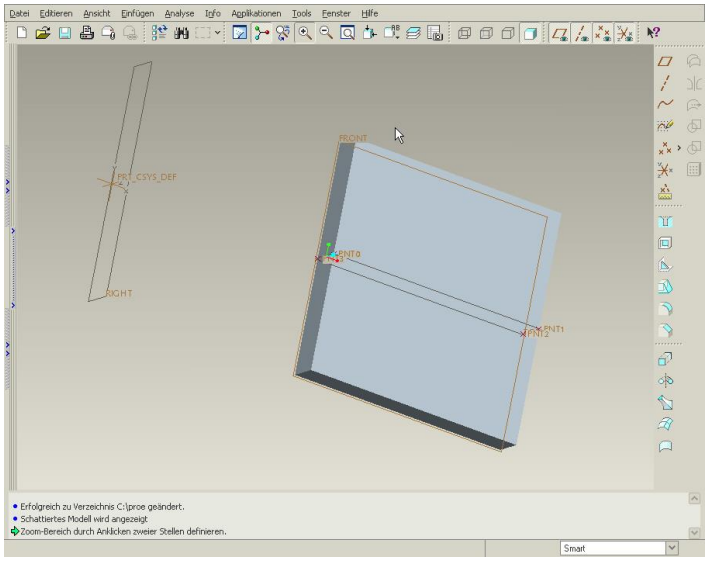
Choose file type before start. The UNIX version of Z88G operates in console mode.

Next step: CREO makes no distinction between plane stress elements, torus elements, shells and plate elements, so, it's up to you to feed Z88G with the right information; choose the proper element type (the type you prepared in your former Pro/E session) in Z88G before starting the conversation run:



Before running the conversation choose the right type of elements; works similar for the UNIX version of Z88G in console mode.

The generation of volumes is easy but the generation of plane stress elements, plates and torus elements is tricky: Firstly, build a volume with (small) thickness in Pro/E. Set reference points, especially for axisymmetric elements. Launch CREO and *idealize* the volume into shells: *Model* > *Idealizations* > *Shells* > *Midsurfaces*. This eliminates the depth. When working with axisymmetric elements keep in mind that you are working in cylinder coordinates: Your coordinate system coincidates with the axis of rotation and the "volume" lies on the corresponding radiuses:



(Here you see the generation of torus elements in CREO. Proceed similar for plane stress and plate elements)

Please keep in mind: These FEA output data formats, especially the NASTRAN format, are really monthly modified.

Thus, I programmed the ANSYS converter in *Perl*, which can be easily modified by you if the ANSYS PREP7 data format is (again) modified. The use of **Z88ASY.PL** is similar to Z88G. The input file is *always* Z88ASY.ANS. Launch Z88SAY.PL and specify the parameter for the element type to be stored, e.g. shells in example 5.11: *perl z88asy.pl –shell*

Z88ASY.PL can create these Z88 elements:

- Tetrahedron No.16 (*Tetrahedron, parabolic* in CREO) -tetra
- Tetrahedron No.17 (*Tetrahedron, linear* in CREO) -tetra
- Plane stress No.14 (*Shell, triangle, parabolic* in CREO) -schei
- Plane stress No.7 (*Shell,quadrangle, parabolic* in CREO) -schei
- Plate No.18 (*Shell, triangle, parabolic* in CREO) -plate
- Plate No.20 (*Shell,quadrangle, parabolic* in CREO) -plate
- Torus No.15 (*Shell, triangle, parabolic* in CREO) -torus
- Torus No.8 (*Shell,quadrangle, parabolic* in CREO) -torus
- Shells No. 23 (*Shell, triangle, parabolic* in CREO) -shell
- Shells No. 24 (*Shell,quadrangle, parabolic* in CREO) -shell

Install *Perl* from perl.org, for Windows I recommend *Strawberry Perl*.

Anyway: Z88G and Z88ASY.PL look quite harmless, but proper operated Z88G and Z88ASY.PL are mighty tools which allow you to file very large FEA structures to Z88. Consult Chp. 2.7.2. for further details.

2.6 THE CUTHILL-McKEE PROGRAM Z88H

The choice of the nodal numbers is extremely important for the compilation of the stiffness matrix and bad nodal numbering may result in huge memory needs which are not really necessary.

However, Z88H may reduce the memory needs for the direct Cholesky Solver Z88R *–choly* greatly. The sparse matrix iteration solver Z88R *–siccg* or *–sorcg* may also gain some advantages from a Z88H run, but the iteration solver is a-priori very stable regarding node numbering because of storing the non-zero elements only.
Basically, it it always good to achieve a small difference of nodal numbers for each finite element. This results in nodal numbers of similar size for an element. However, this is not always possible: consider a circular structur starting with nodal numbering at 0° with increasing numbers clockwise. When reaching 360°, elements with large differences of nodal numbers will occur.
Sometimes 3D CAD programs include so-called automeshers which devide a CAD model into finite elements. This generated mesh can be stored in some output format to fit the needs of the various FEA programs. But many of these automeshers generate meshes with very large nodal differences. This is true for CREO's CREO: If you choose *Tet Mesh parabolic*, CREO in a first operation generates linear tetrahedrons, i.e. with 4 rather than 10 nodes per element, with straight element edges. Then midnodes are put on the element edges resulting in parabolic elements with 10 nodes. These midnodes have relatively large nodal numbers because the corner nodes were numbered in the first step. Thus, every finite element features relatively small corner node numbers and relatively large mid node numbers resulting in large differences of nodal numbering. When choosing *Shell, triangle, parabolic*, the same situation occurs. This means that meshes built with CREO will always have bad nodal numbering.
For large meshes one needs to re-number the nodes to get finite elements with small differences of nodal numbers. Several proper procedures do exist in literature for this task. However, the so-called *Cuthill-McKee* procedure is a good compromise. One modification of it is the *reverse Cuthill- McKee algorithm*. For more information, consult *Schwarz, H.R.: Die Methode der finiten Elemente.* The C program Z88H is based on a FORTRAN77 program of Prof. Schwarz and is specially adapted to Z88. The core algorithm of H.R. Schwarz decides internally wether to use the normal *Cuthill-McKee procedure* or the *reverse Cuthill-McKee algorithm.*
The Cuthill-McKee program Z88H was originally designed for finite element meshes generated by 3D converter Z88G. However, Z88H can deal with all Z88 meshes. Z88H reads the Z88 input files Z88I1.TXT (general structure informations) and Z88I2.TXT (boundary conditions) and Z88I5.TXT (surface and pressure loads), files backups Z88I1.OLD, Z88I2.OLD and Z88I5.OLD and computes the modified input files Z88I1.TXT and Z88I2.TXT and Z88I5.TXT.
Own research studies showed that sometimes a second run of Z88H may improve again the numbering of a first run of Z88H. A third run seems to make things worse. In contrast, Z88H may sometimes compute a worse nodal numbering then the original mesh. You should have some experiments because the *Cuthill-McKee algorithm* may not always improve a given mesh.

And here's how you proceed:

1) Generate a finite elements mesh, i.e. the Z88 input files Z88I1.TXT and Z88I2.TXT and Z88I5.TXT. This can be done by:

- hand
- Z88 mesh generator Z88N (Z88I1.TXT only, then edit Z88I2.TXT and Z88I5.TXT by hand)
- a DXF file and Z88X
- a COSMOS or NASTRAN file and Z88G

2) Adjust Z88.DYN if necessary: MAXKOI is very important (Number of nodes per element × total number of elements) and MAXK, MAXE and MAXNFG.

3) Launch Z88R with test option and choose your type of solver, i.e.

Windows: Z88R > Mode > Test Mode, Compute > Run
UNIX: z88f –t

Fix the value for GS, i.e. the number of storage entries in the stiffness matrix (multiplying this values by 8 gives the memory need in bytes).

4) Launch Z88H.

5) Repeat step 3, i.e. run Z88R with the test option and check wether GS got smaller. This will be mostly the case if your mesh was generated by Z88G using a COSMOS or NASTRAN file. Otherwise, restore Z88I1.TXT, Z88I2.TXT and Z88I5.TXT from the backup files Z88I1.OLD, Z88I2.OLD and Z88I5.OLD.

6) Enter the value of GS into Z88.DYN in the line MAXGS and lauch Z88R with the compute mode and your choice of solver (the same as in Test mode!), e.g.

Windows: Z88R > Mode > Compute Mode, Compute > Run
UNIX: z88r -c

Remark:
Z88H features a section in the memory header file Z88.DYN:

CUTKEE START
MAXGRA 200 (maximum degree of nodes)
MAXNDL 1000 (steps of the algorithm)
CUTKEE END

Increase these entries for very large structures.

2.7 SEVERAL SUPPORT PROGRAMS

2.7.1 THE FILECHECKER Z88VRY

The file checker Z88VRY investigates input data sets for Z88 V14, V15 and for Z88Aurora V2, V3 and V4. Z88VRY was written in *Perl* to have an universal program for all operating systems. Perl is always installed under LINUX and most MacOS versions. For Windows you may load Perl from www.perl.org. You may install either Strawberry-Perl or ActiveState-Perl.

This is a one-click-installation without any problems and does no harm to your system. Then launch the file checker in a Windows-„command prompt“ or an UNIX terminal as follows:

```
perl z88vry.pl –english –os
```

This will check the Z88 files Z88I1.TXT, Z88I2.TXT, Z88I5.TXT, Z88MAN.TXT, Z88MAT.TXT, Z88ELP.TXT and Z88INT.TXT or Z88NI.TXT. If entering the second argument to `–aurora`, then only Z88I1.TXT, Z88I2.TXT and Z88I5.TXT are investigated.

After the start of Z88VRY you have the choice:

- check of input without boundary conditions
- check of input with boundary conditions
- check of the mapped mesher file Z88NI.TXT

Although Z88VRY recognizes many conceivable faulty possibilities and is internally quite tricky, situations like with compilers may occur where faults are not detected or seem to be recognized on other passages. Z88VRY stops when detecting the first error because otherwise resulting sequence errors are usually generated from this. Therefore, a recognized error must be fixed right now.

An error-free input file recognized from Z88VRY can nevertheless lead to subtle faults at the later program run. However, the probability is low to some extent. This statement refers to formal errors: Z88VRY neither recognizes inconsistent structures, nor wrong or too few boundary conditions !

Note:
Always check FE calculations with analytical rough calculations, results of experiments, plausibility considerations and other checks without exception !

2.7.2 THE ANSYS CONVERTER Z88ASY

This Perl script may convert ANSYS input files using PREP7 format into Z88 input data sets. This is true for these Z88 types:

- Tetrahedron No.16 (*Tetrahedron, parabolic* in CREO) -tetra
- Tetrahedron No.17 (*Tetrahedron, linear* in CREO) -tetra
- Plane stress No.14 (*Shell, triangle, parabolic* in CREO) -schei
- Plane stress No.7 (*Shell,quadrangle, parabolic* in CREO) -schei
- Plate No.18 (*Shell, triangle, parabolic* in CREO) -plate
- Plate No.20 (*Shell,quadrangle, parabolic* in CREO) -plate
- Torus No.15 (*Shell, triangle, parabolic* in CREO) -torus
- Torus No.8 (*Shell,quadrangle, parabolic* in CREO) -torus
- Shells No. 23 (*Shell, triangle, parabolic* in CREO) -shell
- Shells No. 24 (*Shell,quadrangle, parabolic* in CREO) -shell

Please note, that Z88ASY awaits an ANSYS file with the fixed name Z88ASY.ANS; rename your ANSYS file if necessary. Launch Z88ASY as follows:

```
perl z88asy.pl -tetra|-schei|-plate|-torus|-shell
```

Z88ASY.PL operates in German language only (because Z88ASY is a small add-on which I wrote just for fun), but this should present no problem: –tetra, –plate, –torus (=axisymmetric elements) and –shell are clear, and –schei means plane stress elements.

Z88ASY was developed for co-operation with CREO, thus, the features of chapter 2.5 are also true:

CREO makes no distinction between plane stress elements, torus elements, shells and plate elements, so, it's up to you to feed Z88ASY with the right information; choose the proper element type (the type you prepared in your former Pro/E session) in Z88ASY before starting the conversation run.

The converter produces the Z88 input files Z88I1.TXT, Z88I2.TXT and Z88I5.TXT automatically. Enter the material groups in Z88MAT.TXT along with the associated material data files and enter the element parameters like the thickness in Z88ELP.TXT. The material data in the ANSYS files are not read by Z88ASY. Store the integration orders in Z88INT.TXT. Now the data set is totally compatible to Z88Aurora V3 & V4.

Plot Z88I1.TXT with the plot program Z88O. If you find a 3D model totally flat: You've defined a coordinate system CS0 in CREO which does not fit Z88's needs. Simply define a new correct coordinate system in CREO and define it as datum when outputting the model. Visit www.z88.de or www.z88.org for updated versions of Z88ASY.

2.7.3 CONVERTING FILE FORMATS

Z88 input data sets may be used either for Windows or UNIX (this means LINUX and MacOS). The examples are filed in Windows format because most people work with Windows. The UNIX versions of Z88 do read these Windows data sets without any problems and do the computing right, anyway, but when *looking with an editor* some strange effects may occur: UNIX data sets are shown by a Windows editor as one single and very long line. However, Windows data sets are shown by an UNIX editor quite jagged or with added ^**M**'s. Both effects won't please most users.

How comes? Quite easy: Windows (and DOS in former times) terminates the end of lines by the two ASCII characters 13 and 10, i.e. CR and LF. UNIX, however, terminates the end of lines only by the single ASCII character 10, i.e. LF. You may convert these data format by appropriate programs: LINUX features the two converters *dos2unix* and *unix2dos*, which exist for Windows, too; "google" the Internet.

To spare you time of searching i've written the following convertes in Perl especially for Z88, which will convert the .TXT, .DXF and .DYN files for the different operating systems:

`perl w88d2u.pl` for Windows: convert Windows files into UNIX files
`perl u88d2u.pl` for UNIX: convert Windows files into UNIX files
`perl w88u2d.pl` for Windows: convert UNIX files into Windows files
`perl u88u2d.pl` for UNIX: convert UNIX files into Windows files

Usually, Perl programs should work both under Windows and UNIX, but due to the fact that the Windows and the UNIX file systems are very different, I've written two versions each. You may regard that the UNIX scripts are much more *perlish* and much faster than the

Windows versions – but the conversions works, and that counts. However, the Windows converters work correct under UNIX but not vice versa.

You may forget this CRLF/LF trouble with a „clever“ editor like *gedit* which is the default editor for the Gnome desktop of LINUX. Nethertheless, you may download *gedit* for Mac and Windows from the Internet: Such proper editors do present the files always in a correct human-readable form, regardless of Windows or UNIX format.

3 EDITING INPUT FILES

3.1 GENERAL INFORMATION

Z88 works with the following files:

(1) Input Files:

- *Z88I1.TXT (general structure data, coordinates, coincidence, material informations)*
- *Z88I2.TXT (boundary conditions, loads, constraints)*
- *Z88I5.TXT (surface and pressure loads)*
- *Z88MAN.TXT (solver parameters)*
- *Z88MAT.TXT (material groups)*
- *(number).TXT (associated material data)*
- *Z88ELP.TXT (element parameters)*
- *Z88INT.TXT (integration orders)*
- *Z88NI.TXT (input file for the mesh generator)*

Produce these input files with your CAD program and the CAD converter Z88X or the 3D converter Z88G or with an editor (e.g. *Notepad* of Windows, *Emacs*, *Joe* at UNIX) or word processing program (e.g. *Word* at Windows). If using a word processor systems keep in mind to edit pure ASCII texts without any hidden control characters ... every word processing program has such an option. Why not using your own editor (if you do not want or cannot work with a CAD program)?
Because you may work with the editor/word processor you are familiar with and used to.

(2) Output Files:

- *Z88O0.TXT (processed input data for documentation)*
- *Z88O1.TXT (processed boundary conditions for documentation)*
- *Z88O2.TXT (calculated displacements)*
- *Z88O3.TXT (calculated stresses)*
- *Z88O4.TXT (calculated nodal forces)*

The files Z88O5.TXT and Z88O8.TXT are not regular Z88 output files, containing the coordinates of the stress points and the reduced stresses for use for the plot program Z88O internally. They are pure ASCII files, so that advanced users may use them for own routines, if necessary.

Why work with files? Is that not old-fashioned and does "interactive" working not do a better job? No - Z88 is designed as an open, transparent system according to the UNIX philosophy: Several, compact modules communicate via files together.

- **A maximum of memory is useable** for the FE data, because always only relatively small, compact programs are loaded into memory.
- Z88 is very flexible and adaptable through its open structure. **Any kind of preprocessing and postprocessing is possible without restrictions.** You can generate the input files by small, self-written preprograms (such a preprogram is the mesh generator Z88N) or leave the job of processing the output data to other programs: You can quite easily load Z88 output files into EXCEL and analyse there.
- Every FEA program can, and so does Z88, produce a huge amount of data junk from time to time. You are very often interested only in very specific results, e.g. of special nodes. The output files are simple ASCII files. You can edit and shorten them as you like and print only the **really interesting results**.

- Very often input files are produced **much faster** than by any interactive queries: Many input lines are similar to prior lines: Use the block operations of your editor for copying !

Compatibility:
Z88 V14 files are totally compatible to Z88Aurora V2 data sets but not to former Z88 versions.

Rules for entering values:
There is no need for special rules or field divisions, only the usual C rules apply:
- *All values are to be separated by at least one blank*
- *Integer numbers may contain any point or exponents*
- *For floating point numbers no points need to be provided*
- *Numerical values which are 0 (zero), have to be entered explicitly.*

Integer numbers

Right	1	345	55555	0
Wrong	1.	345.	55555E+0	no entry

Floating point numbers (Z88 uses internally double precision floating point numbers *[Double]*)

Right	1.	345	5.5555E+10	0
Wrong	1,	345,	O (letter O)	no entry

Z88 input files may have comments in every line if all corresponding data has been filled out before. Separate the last data and the comment at least by one blank. Lines in Z88 input files can include 250 bytes (really needed are noticeably less than 80). Blank lines and pure comment lines are not permitted.
Examine when error messages or abnormal program stops of Z88:
- Are the files really pure text files, well in the ASCII format? Or have they been added unnoticed hidden control characters by your text processor?
- Is the last line of an input file terminated by at least one *RETURN* ?
- Is MAXKOI in Z88.DYN large enough? If in doubt enter 1000000 or higher for MAXKOI.
- Is your structure statically determined or in any way statically overdefined (allowed!)? Or is it statically indetermined, i. e. boundary conditions are missing which may cause serious trouble. Statically indetermined structures can appear easily for Beams No.2, Cams No.5 and Beams No.13 (take care of the rotation degrees of freedom).
- Is the coincidence list defined properly? Especially Hexahedrons No.10 are very sensitive to wrong numbering.
- Plot the initial structure with Z88O. If you won't see some pretty good stuff, then the rest can hardly be better!
- Always do a rough calculation! Are the calculated deflections extremely high? Then check the boundary conditions quite carefully!
- And for the UNIX operating system: Are the file permissions properly set ? For the .LOG files, too ? Do a *chmod 777* !
- Z88 input files for UNIX and Windows have the same structure. You may load without restriction Z88-UNIX files into Windows and vice versa. But did you do the proper conversion? Windows terminates lines by a CR/LF, but UNIX only by a LF! Many LINUX systems feature the converters *unix2dos* and *dos2unix*.

3.2 GENERAL STRUCTURE DATA Z88I1.TXT

In Z88I1.TXT the geometry data of the structure is entered.

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Double] = 8 bytes floating point number, alternatively with or without point

1st input group:
Enter general data into the first line, contains general structure data. Write all numbers into a line, separate at least by one blank respectively. All numbers here are of the type [Long].

1st number: Dimension of the structure (2 or 3) [Long]
2nd number: Number of nodes of the FEA structure [Long]
3rd number: Number of elements [Long]
4th number: Number of degrees of freedom [Long]
5th number: Coordinate flag KFLAG (0 or 1) [Long]. Attention: This position was in former Z88 versions reserved for the number of materials NEG.

Explanations:
KFLAG:
On input of 0 the coordinates are expected Cartesian coordinates while on input of 1 polar or cylindrical coordinates are expected. The latter are then converted into Cartesian coordinates and thereupon stored in this form in Z88O0.TXT.
Caution: The axisymmetric elements No.6, 8, 12 and 15 positively expect cylindrical coordinates, set KFLAG to 0 here!

2nd input group:
Starting with line 2, containing coordinates of nodes, one line per node, node numbers strictly ascending.

1st number: node number [Long]
2nd number: Number of the degrees of freedom for this node [Long]
3rd number: X-coordinate or, if KFLAG is 1, R- coordinate [Double]
4th number: Y-coordinate or, if KFLAG is 1, PHI-coordinate [Double]
5th number: Z-coordinate or, if KFLAG is 1, Z-coordinate [Double]

The Z coordinate can be dropped at 2-dimensional structures. Enter angles PHI in radian.

***Example 1:** The node no.156 has 2 degrees of freedom and the coordinates X = 45.3 and Y = 89.7 . > Thus: 156 2 45.3 89.7*

***Example 2:** The node no.68 is supposed to have 6 degrees of freedom (a Beam No.2 is attached) and cylindrical coordinates R = 100. , PHI = 0.7854 (corresponds to 45 °), Z = 56.87. > Thus: 68 6 100. 0.7854 56.87*

3rd input group:
Starting after last node, containing coincidence, i.e. the allocation of the element type and the corresponding nodes of every element. Enter two lines for every finite element. The element numbers, like the node numbers, must be entered strictly ascending.

1st line:
1st number: Element number [Long].
2nd number: Element type (1 to 25) [Long].

2nd line: Depending on element type
1st number: 1st node number for coincidence [Long]
2nd number: 2nd node number for coincidence [Long]
...
20th number: 20th node number for coincidence [Long]

Write all numbers into a line, separate at least by one blank respectively. All numbers here of the type [Long].

***Example:** An Isoparametric Serendipity Plane Stress Element No.7 has element number 23. The coincidence has the global nodes 14, 8, 17, 20, 38, 51, 55, 34 (locally these are the nodes 1-2-3-4-5-6-7-8) > Thus resulting in two lines:*
23 7
14 8 17 20 38 51 55 34

3.3 BOUNDARY CONDITIONS FILE Z88I2.TXT

In the file Z88I2.TXT the boundary conditions, displacements and forces affecting the model are entered. Surface loads are put into the file Z88I5.TXT.

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Double] = 8 bytes floating point number, alternatively with or without point

1st input group:
Number of boundary conditions/loads.

1st number: Number of boundary conditions/loads [Long]

2nd input group:
The boundary conditions and loads are defined. For every boundary condition and for every load one line, respectively.

1st number: node number with boundary condition: load or constraint [Long]
2nd number: Respective degree of freedom (1,2,3,4,5,6) [Long]
3rd number: Condition flag: 1 = force [Long] or 2 = displacement [Long]
4th number: Value of the load or displacement [Double]

***Example:** The node 1 shall be fixed at his 3 degrees of freedom, respectively. Node 3 features a load of -1,648 N in Y direction (i.e. DOF 2), the degrees of freedom 2 and 3 are supposed to be fixed for the node 5. This will result in 6 boundary conditions.*
> Thus:
6
1 1 2 0
1 2 2 0
1 3 2 0
3 2 1 -1648

5 2 2 0
5 3 2 0

It is a good idea to define surface and pressure loads in the file Z88I5.TXT.

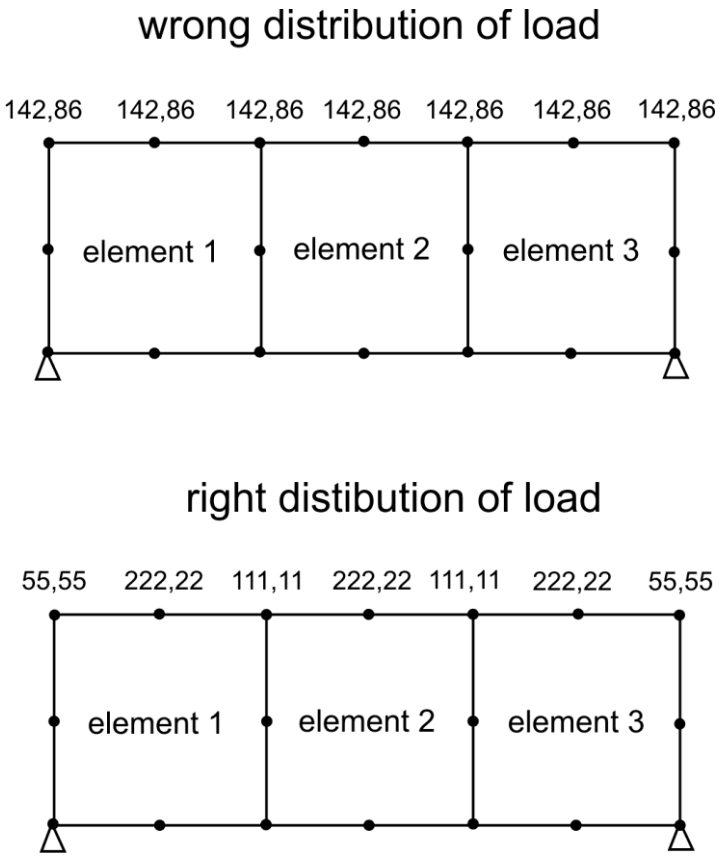
Only forces and constraints should entered here into Z88I2.TXT.

Of course, it is possible, too, to convert surface loads into concentrated forces "manually" and to enter these forces into Z88I2.TXT (which is the classical way but somewhat cumbersome).

For the elements with linear shape function, e.g. Hexahedrons No.1 and Torus No.6, edge loads and surface loads are distributed to the elements simply and straight-forward onto the respective nodes.

However, for elements with higher shape functions, i.e. square (Plane Stress No.3, No.7, Torus No.8, Hexahedron No.10 etc.) or cubic (Plane Stress No.11 and Torus No.12) edge and surface loads have to be put onto the elements according to certain rules which are not always physically obvious but mathematically absolutely correct. Amazingly, some load components can have negative values. Though these facts are not obvious, nevertheless they lead to correct results, which is not the case for intuitive distribution of loads to the respective nodes.

An example may clarify the facts:



An FE structure consists of three plane stress elements No.7 with the load of 1,000 N distributed on the upper edge in Y direction, see figure 2:

Incorrect: 1,000N/7=142.86 N per node. Not correct for elements with square shape function.

Correct: 2 × 1/6 + 2 × (1/6+1/6) + 3 × 2/3 = 18/6 = 3, corresponds to 1,000 N
"1/6 points" = 1,000/18×1 = 55.55
"2/6 points" = 1,000/18×2 = 111.11
"2/3 points" = 1,000/18×4 = 222.22
Control: 2×55.55 + 2×111.11 +3×222.22 = 1,000 N, o.k.

Here's why:

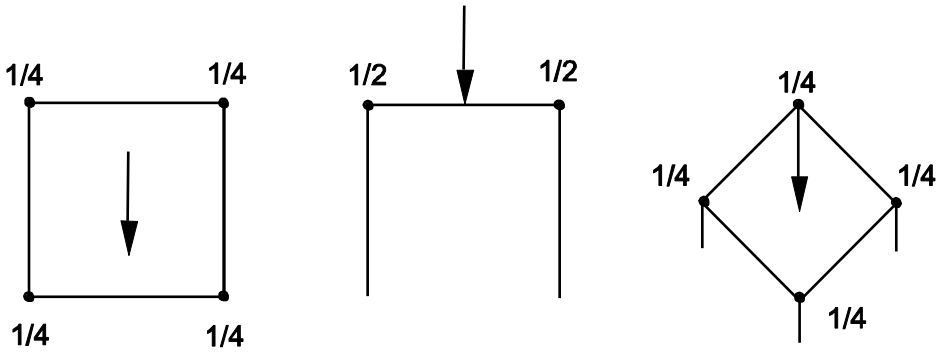


Figure 1: Elements with <u>linear</u> shape functions, e.g. Hexahedron No.1

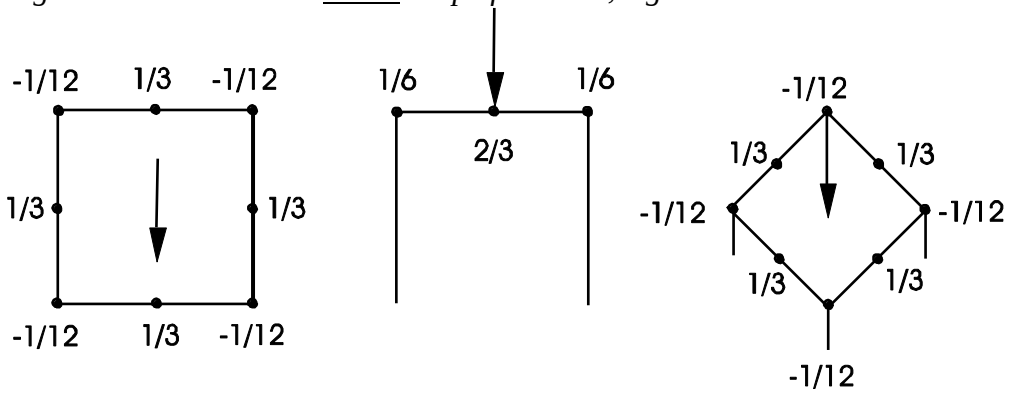


Figure 2: Elements with <u>quadratic</u> shape functions,
e.g. plane stress element No.3 and 7, Torus No.8, Hexahedron No.10

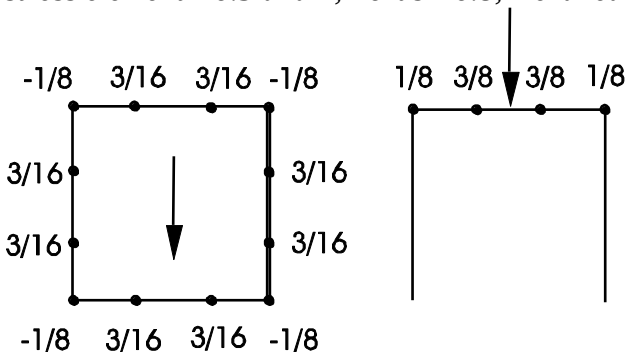


Figure 3: Elements with <u>cubic</u> shape functions,
e.g. plane stress element No.11, torus No.12, plate No.19

3.4 SURFACE AND PRESSURE LOADS FILE Z88I5.TXT

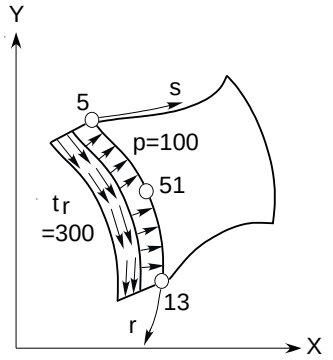
This file must always exist. If you do not have any surface and pressure loads, enter a 0 (zero) into the first line, add a *RETURN* and skip the second input group.
Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Double] = 8 bytes floating point number, alternatively with or without point

1st input group:
1st number: Number of surface and pressure loads [Long]

2nd input group:
Surface and pressure loads – one line per load. Of course, an element may have more than one load applied. The following entries depend from the element type with surface and pressure load to avoid unnecessary data entries.
As for the local directions: Define the local r and s directions by the nodes and their sequence. These local directions for the surface loads may differ from the local r and s coordinate system of the finite element. The numbering has to conform to the element numbering, see chap. 5.

Plain stress element No.7 and 14 and Torus elements No.8 and 15:
Element number with surface load [Long]
Pressure, positive if pointing towards the edge [Double]
Tangential shear, positive in local r-direction [Double]
3 nodes of the loaded edge [3 × Double]

Example: The plain stress element 97 features surface load. The load should be applied onto the edge defined by the corner nodes 5 and 13 and by the mid node 51. One surface load is applied normally to the edge with 100 N/mm and the other surface load is applied tangentially and positive in local r direction with 300 N/mm (defined by the two corner nodes).
Thus:
> 97 100. 300. 5 13 51



Plane stress element with surface loads

Hexahedron No.1:
Element number with surface and pressure load [Long]
Pressure, positive if pointing towards the surface [Double]
Tangential shear, positive in local r direction [Double]
Tangential shear, positive in local s direction [Double]
4 nodes of the loaded surface [4 × Long]

Example: The hexahedron 356 features surface loads. The load should be applied onto the surface defined by the corner nodes 51, 34, 99 and 12 .The first surface load is pressure with 100 N/mm. The second surface load is applied tangentially and positive in local r direction with 200 N/mm. The third surface load is applied tangentially and positive in local s direction with 300 N/mm. Thus
> 356 100. 200. 300. 51 34 99 12

Hexahedron No.10:

Element number with surface and pressure load [Long]
Pressure, positive if pointing towards the surface [Double]
Tangential shear, positive in local r direction [Double]
Tangential shear, positive in local s direction [Double]
8 nodes of the loaded surface [8 × Double]

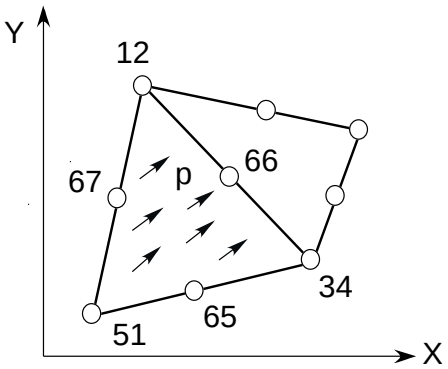
Example: The hexahedron 456 features surface loads. The load should be applied onto the surface defined by the corner nodes 51, 34, 99 and 12 and the mid nodes 102, 151, 166 and 191. The first surface load is pressure with 100 N/mm. The second surface load is applied tangentially and positive in local r direction with 200 N/mm. The third surface load is applied tangentially and positive in local s direction with 300 N/mm. Thus
> 456 100. 200. 300. 51 34 99 12 102 151 166 191

Tetrahedron No.17:
Element number with pressure load [Long]
Pressure, positive if pointing towards the surface [Double]
3 nodes of the loaded surface [3 × Double]

Example: The tetrahedron 356 features surface loads. The load should be applied onto the surface defined by the corner nodes 51, 34 and 12.The surface load is pressure with 100 N/mm pointing towards the surface, i.e. positive. Thus:
> 356 100. 51 34 12

Tetrahedron No.16:
Element number with pressure load [Long]
Pressure, positive if pointing towards the surface [Double]
6 nodes of the loaded surface [6 × Double]

Example: The tetrahedron 888 features surface loads. The load should be applied onto the surface defined by the corner nodes 51, 34 and 12 and the mid nodes 65, 66 and 67.The surface load is pressure with 100 N/mm pointing towards the surface, i.e. positive. Thus:
> 888 100. 51 34 12 65 66 67

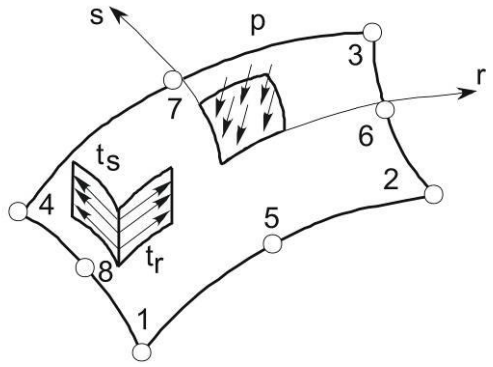


Tetraeder with pressure load on one element side

Plate elements No.18, 19 and 20:
Element number with pressure load [Long]
Pressure, positive if pointing towards the surface [Double]

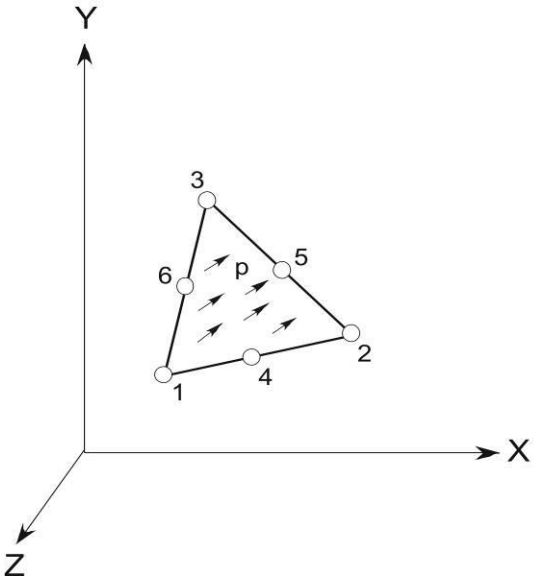
Shell No.21:
> Element number
> Pressure, positive if pointing towards the surface

> Tangential shear in local r direction
> Tangential shear in local s direction
> 4 corner nodes and 4 mid nodes of the loaded surface. Mathematically positive in top view.
The local r direction is defined by the nodes 1-2, the local s direction is defined by the nodes 1-4. The local nodes 1 to 8 for the surface load may differ from the local nodes 1 to 8 used for the coincidence.



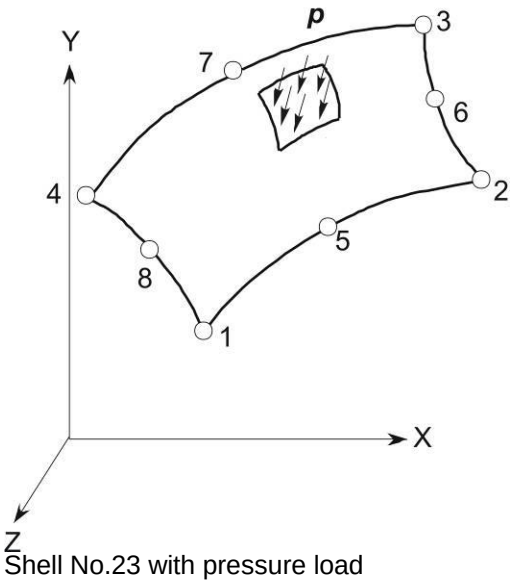
Shell No.21 with pressure load

Shell No.22:
> Element number
> Pressure, positive if pointing towards the surface
> 3 corner nodes and 3 mid nodes of the loaded surface. Mathematically positive in top view.



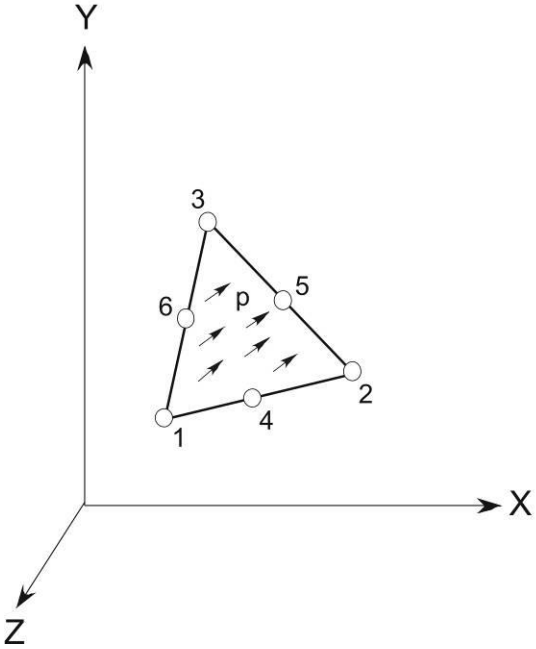
Shell No.22 with pressure load

Shell No.23:
> Element number
> Pressure, positive if pointing towards the surface
> 4 corner nodes and 4 mid nodes of the loaded surface. Mathematically positive in top view.



Shell No.23 with pressure load

Shell No.24:
> Element number
> Pressure, positive if pointing towards the surface
> 3 corner nodes and 3 mid nodes of the loaded surface. Mathematically positive in top view.



Shell No.24 with pressure load

3.5 MATERIAL DEFINITIONS FILE Z88MAT.TXT

Because of the extension by a material database the material definitions data in Z88 Aurora are stored in a separate file. The file merely consists of an input group in one line, a *.TXT file which contains the material data is accessed from this file.

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Character] = a sequence of characters

1st input group:
1st number: Number of materials [Long]

2nd input group: one line for each material
1st number: Material starts with element no. inclusively[Long]
2nd number: Material ends with element no. inclusively[Long]
*3rd entry: Name of the material parameters file *.TXT [Character]*

Example:
In a structure elements 1 ~ 8 are made of steel, elements 9 ~ 12 are made of light alloy and elements 13 ~ 15 are made of steel. Thus:
3
1 8 51.txt (contains data for steel)
9 12 52.txt (contains data for light alloy)
13 15 51.txt (contains data for steel)

3.6 MATERIAL DAT FILES *.TXT

Features Young's Modulus and Poisons's Ratio for a material. The name of the file is arbitrary but should contain the extension .TXT and should be linked to the appropriate entry in Z88MAT.TXT.

Mind the following formats:
[Double] = 8 bytes floating point number, alternatively with or without point

1st input group, one line:
1. number: Young's Modulus [Double]
2. number: Poisons's Ratio [Double]

Example:
In a structure elements 1 ~ 8 are made of steel, elements 9 ~ 12 are made of light alloy and elements 13 ~ 15 are made of steel. Thus:

file 51.txt contains : 206000. 0.3
file 52.txt contains : 73000. 0.33

3.7 ELEMENT PARAMETERS FILE Z88ELP.TXT

Contains the plate, shell and beam parameters as follows:

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Double] = 8 bytes floating point number, alternatively with or without point

1st input group:
1st number: Number of groups of element parameters [Long]

2nd input group: one line for each group
1st number: Element starts with [Long]

2nd number: Element ends with [Long]
3rd number: QPARA (i.e. cross section area, thickness etc.) [Double]

and in addition for beams 2,13 and 25:
4th number: Second moment of inertia yy (bending around yy axis) I_{yy} [Double]
5th number: Max. distance from neutral axis yy e_{yy} [Double]
6th number: Second moment of inertia zz (bending around zz axis) I_{zz} [Double]
7th number: Max. distance from neutral axis zz e_{zz} [Double]
8th number: Second moment of area (torsion) I_T [Double]
9th number: Second modulus (torsion) W_T [Double]
Beam No.25 only in addition:
10th number Flag for choosing the bend theory: Bernoulli (0) or Timoshenko (1) [Long]
11th number X-coordinate of the control point [Double]
12th number Y- coordinate of the control point [Double]
13th number Z- coordinate of the control point [Double]
14thnumber shear ratio (shear correction factor) [Double],
for example in case of rectangular cross section= 5/6 = 0,8333

Example 1:
A structure features plates with different thickness. Plate elements 1 ~ 40 may have a thickness of 10 mm and the plate elements 41 ~ 80 may have a thickness of 20 mm. Thus:
2
1 40 10.
41 80 20.
Example 2:
A framework may have trusses no.4 (elements 1 ~ 4) and beams no.2 (elements 5 ~ 9). The trusses are supposed to have a cross section area of 200 mm^2 and the beams are supposed to have the following data: cross section area = 100 mm^2, I_{yy} = 833 mm^4, e_{yy} = 5 mm, I_{zz} = 833 mm^4, e_{zz} = 5, I_T = 1406 mm^4 , W_T = 208 mm^3.
2
1 4 200.
5 9 100. 833. 5. 833. 5. 1406. 208.

3.8 INTEGRATION ORDERS FILE Z88INT.TXT

Features the integration orders for the calculation of displacements and the calculation of stresses, respectively.

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number

1st input group:
1st number: Number of element groups [Long]

2nd input group: one line for each group
1st number: Element starts with [Long]
2nd number: Element ends with [Long]
3rd number: INTORD = integration order for displacements [Long]
4th number: INTOS = integration order for stresses [Long]

Possible entries for INTOS:
0 = Calculation of stresses into the corner nodes, reduced stress calculation not possible.

For isoparametric elements No.1, 7, 8, 10, 11, 12, 19, 20, 23:
1, 2, 3 or 4 (i.e. N×N) = Calculation of stresses into the Gauss points. Reduced stress calculation is possible. A good value is 3 (= 3×3 Gauss points). For element type No.1 and No.20 a value of 2 could be fine. For type No.19 a value of 4 (= 4×4 Gauss points) is recommended.

For isoparametric elements No.14, 15, 18, 24:
3, 7 or 13 (i.e. N) = Calculation of stresses into the Gauss points. Reduced stress calculation is possible. A good value is 7 (= 7 Gauss points). For type No.18 a value of 3, i.e. 3 Gauss points could be fine.

For isoparametric elements No.16, 17:
1, 4 or 5 (i.e. N) = Calculation of stresses into the Gauss points. Reduced stress calculation is possible. A good value for element type 16 is 5 (= 5 Gauss points). For element type No.17 a value of 1 could be fine.

INTOS has no meaning for element types No.2, 3, 4, 5, 6, 9, and 13. You may enter 1.

Example 1:
An axisymmetric structure featuring 30 axisymmetric elements no.8 may use 3×3 Gauss points for the displacement calculation but may use 4×4 Gauss points for the stress calculation. Thus:
1
1 30 3 4

Example 2:
A spatial structure may consist of Hexahedrons no.10 (elements 1 ~ 512) and a few trusses no.4 (elements 513 ~ 520) used as elastic supports. The displacement calculation may use 3×3 Gauss points for the displacement calculation but may use 2×2 Gauss points for the stress calculation for the hexahedrons, respectively. Thus:
2
1 512 3 2
513 520 1 1 (the order of integration has no meaning for the trusses)

3.9 MESH GENERATOR INPUT FILE Z88NI.TXT

The layout of Z88NI.TXT is very similar to the layout of Z88I1.TXT, the input file for the FE solver: Only the &-labelled data is required in addition.

Mind the following formats:
[Long] = 4 bytes or 8 bytes integer number
[Double] = 8 bytes floating point number, alternatively with or without point
[Character] = A letter

1st input group:

1st number: Dimension of the structure (2 or 3)

2nd number: Number of nodes of the super structure
3rd number: Number of super-elements
4th number: Number of degrees of freedom
5th number: Coordinate flag KFLAGSS for the super-elements (0 or 1)
& 6th number: Trap radius flag NIFLAG (0 or 1)
& 7th number: Coordinate flag KFLAG for the finite elements (0 or 1)

Write all numbers into a line, separate at least by one blank respectively. All numbers here of the type [Long].

Explanations:
KFLAGSS:
On input of 0 the coordinates are expected Cartesian while on input of 1 polar or cylindrical coordinates are expected. The latter are then converted into Cartesian coordinates and thereupon stored in this form in Z88I1.TXT if KFLAG (see below) is set to 0. Caution: The axisymmetric elements No.8 and 12 positively expect cylindrical coordinates, set KFLAGSS to 0 here!

Example: *Super-structure 2-dimensional with 37 nodes, 7 super elements, 74 degrees of freedom. Cylindrical coordinates (= 1), trap radius default value (= 0), Coordinate flag KFLAG for the finite elements 1= output into Z88I1.TXT in cylindrical coordinates. Thus:*
2 37 7 74 1 0 1

NIFLAG:
In order to identify already defined nodes the mesh generator needs a trap radius. The defaults are 0.01 for for EPSX, EPSY and EPSZ if NIFLAG is 0. These values can be modified at extremely small or large structures. To initiate this change, set NIFLAG to 1. The new trap radiuses of EPSX, EPSY and EPSZ are then defined in Z88NI.TXT as the 6th input group.

Example: *Super-structure 2-dimensional with 37 nodes, 7 super elements, 74 degrees of freedom. Cylindrical coordinates (= 1), trap radius default value (= 0), Coordinate flag KFLAG for the finite elements 1= output into Z88I1.TXT in cylindrical coordinates. Thus:*
2 37 7 74 1 0 1

KFLAG:
Internally, Z88N works with natural or Cartesian coordinates. Sometimes, though, you might want to store the output of Z88N as polar or cylindrical coordinates into the output file Z88I1.TXT. With this flag (=1) the output takes place in polar or cylindrical coordinates. This is independent from the flag KFLAGSS for the input file Z88NI.TXT.

Example: *Super-structure 2-dimensional with 37 nodes, 7 super elements, 74 degrees of freedom. Cylindrical coordinates (= 1), trap radius default value (= 0), Coordinate flag KFLAG for the finite elements 1= output into Z88I1.TXT in cylindrical coordinates. Thus:*
2 37 7 74 1 0 1

2nd input group:
Starting in line 2, contains coordinates of nodes, one line per node, node numbers strictly ascending.

1st number: Node number [Long]
2nd number: Number of the degrees of freedom for this node [Long]

3rd number: X-coordinate or, if KFLAG is 1, R- coordinate [Double]
4th number: Y-coordinate or, if KFLAG is 1, PHI-coordinate [Double]
5th number: Z-coordinate or, if KFLAG is 1, Z-coordinate [Double]

The Z coordinate may be skipped for 2-dimensional structures.

Example: *The node no.8 has 3 degrees of freedom and the coordinates X = 112.45, Y = 0. , Z = 56.75. Thus: 8 3 112.45 0. 56.75*

3rd input group:
Starting after last node, contains coincidence, i.e. the allocation of the element type and the corresponding nodes of every element. Edit two lines for every super element. The element numbers, like the node numbers, must be entered strictly ascending.

1st line:
1st number: Element number [Long].
2nd number: Super-element type (1,7,8,10,11,12,20,21) [Long].

2nd line: Depending on element type
1st number: 1st node number for coincidence [Long]
2nd number: 2nd node number for coincidence [Long]
.....
20th number: 20th node number for coincidence [Long]

Write all numbers into a line, separate at least by one blank respectively. All numbers here of the type [Long].

This are the mesh generator-suitable elements:
Element No.1: Isoparametric Hexahedrons 8 nodes
Element No.7: Isoparametric Serendipity Plane Stress Element 8 nodes
Element No.8: Isoparametric Serendipity Torus 8 nodes
Element No.10: Isoparametric Serendipity Hexahedron 20 nodes
Element No.11: Isoparametric Serendipity Plane Stress Element 12 nodes
Element No.12: Isoparametric Serendipity Torus 12 nodes
Element No.20: Isoparametric Serendipity Plate 8 nodes
Element No.21: Isoparametric Serendipity Shell 16 nodes

Example: *An Isoparametric Serendipity Plane Stress Element No.7 has element number 23. The coincidence has the global nodes 14, 8, 17, 20, 38, 51, 55, 34 (locally these are the nodes 1-2-3-4-5-6-7-8, see chapter 4.7). Thus resulting in two lines:*
23 7
14 8 17 20 38 51 55 34

& 4th input group:
Starting after last coincidence line contains the descriptive details for the mesh generation process. 2 lines for every super element.
1st line:
1st number: Super element no. [Long]
2nd number: Finite element type (types 1, 7, 8, 10, 19, 20, 21) to be generated [Long]

2nd line:

1st number: Number of finite elements in local x direction [Long]
2nd number: Type of subdivision of CMODE x [Character]
3rd number: Number of finite elements in local y direction [Long]
4th number: Type of the subdivision CMODE y [Character]
5th number: Number of finite elements in local z direction [Long]
6th number: Type of the subdivision of CMODE z [Character]

The two values for Z are skipped at 2-dimensional structures.

Explanations: **CMODE** can accept the following values:
- "E": Subdivision equidistant, "e" is also permitted
- "L": Subdivision increasing geometrically in local coordinate direction
- "l": Subdivision decreasing geometrically in local coordinate direction

The local x-, y and z axes are defined as follows:
- Local x axis points in direction of local nodes 1 and 2
- Local y axis points in direction of local nodes 1 and 4
- Local z axis points in direction of local nodes 1 and 5

See following sketch below.

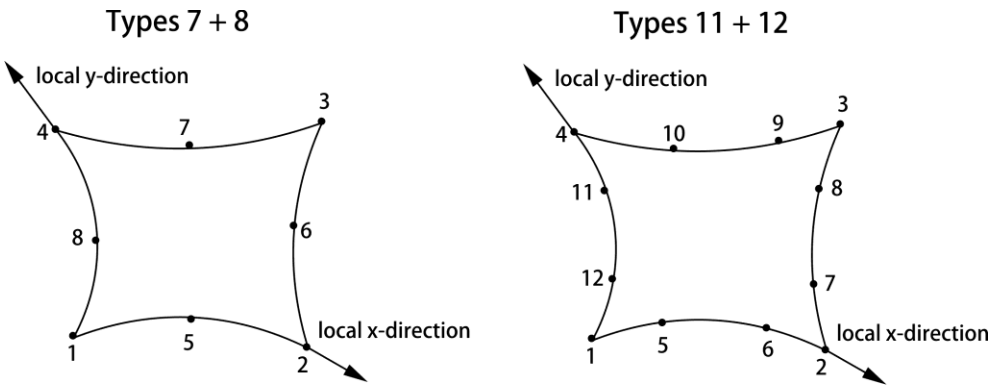
Example: Subdivide an Isoparametric Serendipity Plane Stress Element with 12 nodes (Element No.11) into finite elements of type Isoparametric Serendipity Plane Stress Element with 8 nodes (Element No.7). Subdivide in local x direction three times equidistantly and subdivide 5 times increasing geometrically in local y direction. The super element is supposed to have the number 31. Thus resulting in two lines:
31 11
7 3 E 5 L (e or E for equidistant are equivalent)

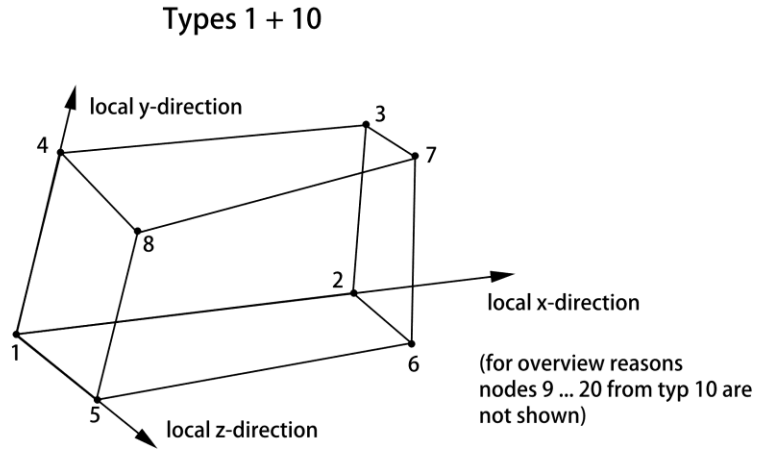
& 5th input group, optionally after the end of input group 4:
Input group 6 is required if NIFLAG was set to 1, i. e. the trap radiuses is supposed to be modified. 1 line:

1st number: Trap radius in global X direction EPSX [Double]
2nd number: Trap radius in global Y direction EPSY [Double]
3rd number: Trap radius in global Z direction EPSZ [Double]

Skip the Z detail for 2-dimensionalen structures.

Example: The trap radiuses shall be set to 0.0000003 for X, Y and Z respectively.
> Thus : *0.0000003 0.0000003 0.0000003*
This is effective only if NIFLAG was set to 1 in the first input group!





3.10 SOLVER PARAMETERS FILE Z88MAN.TXT

The solver parameters file Z88MAN.TXT is divided into three parts: the global part, the linear solver part and the stress part. The following figure shows a typical Z88MAN.TXT.

```
DYNAMIC START

GLOBAL START
      IBFLAG        0
      IPFLAG        0
      IHFLAG        0
      SIMCASE       1
GLOBAL END

SOLVER START
      MAXIT         10000
      EPS           1e-007
      RALPHA        0.0001
      ROMEGA        1.1
SOLVER END

STRESS START
      KDFLAG        0
      ISFLAG        1
STRESS END

DYNAMIC END
```

Explanations to the separate specifications:

GLOBAL:

IBFLAG:
If Beams No.2 or Beams No.13 or Beams No.25 appear in the structure, then set beam flag IBFLAG to 1, otherwise it must be 0.

IPFLAG:
If Plates No.18, No.19 or No.20 appear in the structure, then set plate flag IPFLAG to 1, otherwise it must be 0.

Caution: This Z88 release allows only beams or plates in a structure, not both in the same structure, because the DOF of the beams and the plates are not compatible!

IHFLAG:
The shell flag is 1 if shells no. 23 or 24 are used.

SIMCASE is 1

SOLVER:

MAXIT is the first termination criterion. When reaching this number of iterations the iteration solvers SICCG and analogously SORCG are terminated in any case. The values of the solution vector reached up to this point are printed, however.

EPS This value is compared to a norm of the residual vector. When this value is reached for the iteration solvers SICCG and SORCG, the solution reached should have a good precision. This is the second termination criterion. Enter a relatively small value, e.g. 0.00001 or 0.0000001. Note that there is no absolute truth in this field! No matter which norm of the residual vector is compared against this limit - you can never be sure that all elements of the solution vector are precise. The choice of EPS influences the iteration count and, thus, the computing speed enormously. Remember this when comparing Z88 Aurora to the big, commercial solvers (you do not know which termination criterions are internally used anyway): The limit you can adjust there may have absolutely nothing to do with EPS of Z88. However, extensive tests proved that the deflections of different nodes compared quite well to those from the commercial solvers if EPS was between 0.00001 and 0.0000001 with similar computing time. Please note: When computing large FEA structures with different solvers, you will never know which solver delivers the best result anyway!

RALPHA is *the convergence acceleration parameter* α. With this parameter for the SIC pre-conditioner you choose the shift factor α for the iteration solver SICCG (from 0 to 1, good values may vary from 0.0001 to 0.1). 0.0001 is a good initial value.

ROMEGA is *the convergence acceleration parameter* ω. With this parameter for the SOR pre-conditioner you choose the relaxation factor ω for the iteration solver SORCG (from 0 to 2, good values may vary from 0.8 to 1.2). Which value to choose for ω? Good question! Try ω with 1, which will never lead to totally bad results, and then try other values for further runs with this structure.

Example 1:

You want to use the Iterations Sparsematrix Solver and stop after 5000 iterations, the limit is 0.0000001 and the convergence acceleration parameter ω for SOR is 0.9, since you want to use the SORCG-Solver ("SORCG:sparse, iterativ"). Thus:

MAXIT	*5000*
EPS	*0.0000001*
RALPHA	*Standard value without significance*
ROMEGA	*0.9*

Example 2:

You want to use the Iteration Sparse Matrix Solver and you want to stop positively after 10000 iterations, the limit shall be 10^{-9} and the convergence acceleration factor α for SIC shall be 0.001 because you want to use the SICCG-Solver ("SICCG:sparse, iterative"). Thus:

MAXIT	*10000*
EPS	*1e-9*
RALPHA	*0.001*
ROMEGA	*Standard value without significance*

Example 3:

You want to use the Cholesky solver. Thus:

The control values MAXIT, EPS, RALPHA, ROMEGA and ICORE can be arbitrary and are without significance.

STRESS:

KDFLAG: *For the plane stress elements No.3, 7, 11 and 14 [Long]*

0 = standard stress calculation
1 = additional calculation of the radial and tangential stresses

ISFLAG: *Choice of the reduced stress hypothesis [Long]*
0 = no calculation of the reduced stresses
1 = *von Mises* stresses
2 = principal or *Rankine* stresses
3 = *Tresca* stresses

Example 1: *A structure featuring plane stress elements no.7 may calculate in addition radial and tangential stresses, thus KDFLAG = 1. The reduced stresses calculation may use the v.Mises criterion: ISFLAG = 1. Thus:*

KDFLAG	*1*
ISFLAG	*1*

Example2: *A structure featuring plane stress elements no.7 may calculate only default stresses, thus KDFLAG = 0. No reduced stresses calculation: ISFLAG =0. Thus:*

KDFLAG	*0*
ISFLAG	*0*

3.11 COMPARISON OF THE Z88 FILE FORMATS

The file formats of the four Z88 versions: Z88 Aurora V2, Z88V14.0, Z88 Aurora V1 and Z88 V13.0A are quite similar but especially for Z88 Aurora V2,V3 and V4 the data is distributed to more files than in former versions for better interaction with the GUI. This data structure applies for Z88V15, too.

	Z88 Aurora V2,V3,V4 and Z88V14/15	***Z88 Aurora V1***	***Z88 V13.0A***
strukture data	*Z88I1.TXT*	*Z88I1.TXT*	*Z88I1.TXT*
material groups	*Z88MAT.TXT*	*Z88MAT.TXT*	*Z88I1.TXT*
material data	**.TXT*	**.CSV*	
element parameters	*Z88ELP.TXT*	*Z88ELP.TXT*	*Z88I1.TXT*
integration orders for deflection calculation.	*Z88INT.TXT*	*Z88MAT.TXT*	*Z88I1.TXT*
integration orders for stresses calculation	*Z88INT.TXT*	*Z88MAN.TXT*	*Z88I3.TXT*
solver parameter	*Z88MAN.TXT*	*Z88MAN.TXT*	*Z88I4.TXT*
constraints[1] **)*	*Z88I2.TXT*	*Z88I2.TXT*	*Z88I2.TXT*
surface loads[1] **)*	*Z88I5.TXT*	*Z88I5.TXT*	*Z88I5.TXT*
number of materials NEG	*Z88MAT.TXT*	*Z88MAN.TXT*	*Z88I1.TXT*
coordinate flag KFLAG	*Z88I1.TXT*	*Z88I1.TXT*	*Z88I1.TXT*
beam flag IBFLAG	*Z88MAN.TXT*	*Z88I1.TXT*	*Z88I1.TXT*
plate flag IPFLAG	*Z88MAN.TXT*	*Z88I1.TXT*	*Z88I1.TXT*
surface loads flag IQFLAG	*n/a*	*Z88MAN.TXT*	*Z88I1.TXT*
shell flag IHFLAG	*Z88MAN.TXT*	*Z88I1.TXT*	*Z88I1.TXT*
radial/tangential stresses flag: KDFLAG	*Z88MAN.TXT*	*Z88MAN.TXT (here: KSFLAG)*	*Z88I3.TXT (here: KFLAG)*
reduced stresses flag: ISFLAG	*Z88MAN.TXT*	*Z88MAN.TXT*	*Z88I3.TXT*

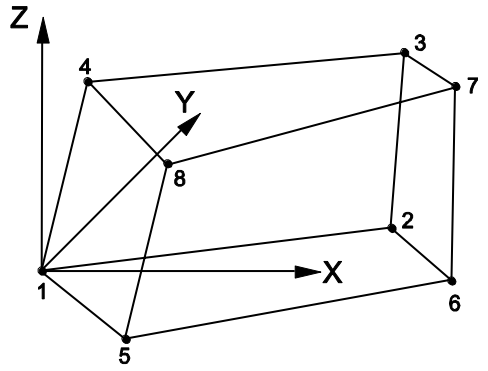
[1]**) formats are totally identical for all four Z88 versions*

4 DESCRIPTION OF THE FINITE ELEMENTS

4.1 HEXAHEDRON NO.1 WITH 8 NODES

The hexahedron element calculates deflections and stresses in space using linear shape functions. It is a transformed element; therefore it may be wedge-shaped or may have another oblique-angled form. The transformation is isoparametric. The integration is carried out numerically in all three axes according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 2 is mostly sufficient. Hexahedron No.1 is also well usable as a thick plate element, if the plate's thickness is not too small against the other dimensions.

Hexahedrons No.1 can be generated by the mesh generator Z88N from super elements Hexahedrons No.10 and Hexahedrons No.1.



Input:

CAD (see chapter 2.4.2):
Upper plane: 1 - 2 - 3 - 4 - 1, quit LINE function
Lower plane: 5 - 6 -7 - 8 - 5, quit LINE function
1 - 5, quit LINE function
2 - 6, quit LINE function
3 - 7, quit LINE function
4 - 8, quit LINE function

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 1
> 8 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any other value, has no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation: 2 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

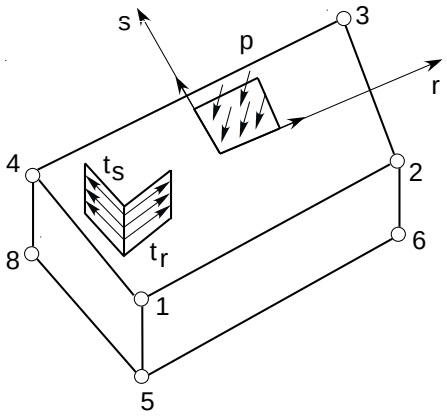
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no influence

> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.1 – otherwise, enter a 0 into the first line:

> *Element number with surface and pressure load*
> *Pressure, positive if pointing towards the surface*
> *Tangential shear, positive in local r direction*
> *Tangential shear, positive in local s direction*
> *4 corner nodes of the loaded surface. Mathematically positive in top view.*

The local r direction is defined by the nodes 1-2, the local s direction is defined by the nodes 1-4. The local nodes 1, 2, 3 , 4 may differ from the local nodes 1, 2, 3, 4 used for the coincidence.



Results:

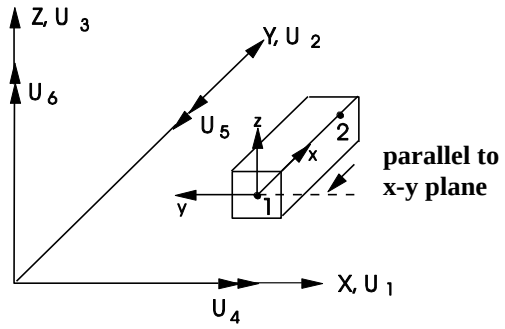
Displacements in X, Y and Z

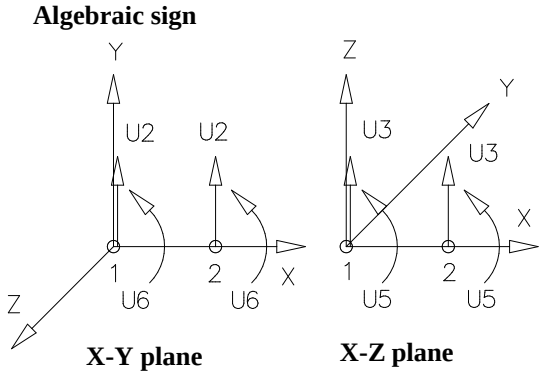
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional von Mises or principal or Tresca stresses.

Nodal forces in X, Y and Z for each element and each node.

4.2 BEAM NO.2 WITH 2 NODES IN SPACE

Beam element with any symmetric profile (no slanting bend) with the restriction that the local y-y axis must be parallel to the global X-Y coordinate system. The profile values are provided in Z88ELP.TXT. Thus, you can use any symmetric profile in contrast to other FEA programs which incorporate a variety of different special beam and profile subroutines without matching all symmetric profiles as necessary. The element matches exactly Bernoulli's bend theory and Hooke's law. It uses no approximate solution as for the continuum elements.





Input:

CAD (see 2.4.2): *Line from node 1 to node 2*

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 6 degrees of freedom in a node (Attention: DOF5 (not right hand rule), see below)
> Element type is 2
> 2 nodes per element

Z88ELP.TXT
> Cross-sectional area QPARA
> Second moment of inertia I_{yy} (bending around y-y axis)
> Max. distance e_{yy} from neutral axis y-y
> Second moment of inertia I_{zz} (bending around z-z axis)
> Max. distance e_{zz} from neutral axis z-z
> Second moment of area (torsion) I_T
> Second modulus (torsion) W_T

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

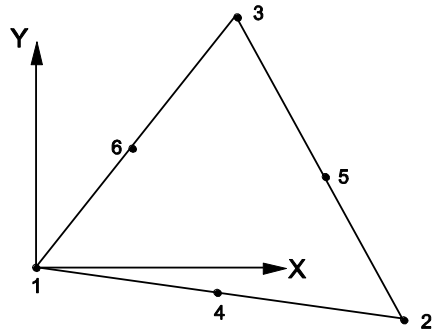
Z88MAN.TXT
> Set beam flag IBFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

Results:
Displacements in X, Y and Z and rotations around X, Y and Z. Attention DOF5 (not right hand rule), see below
Stresses: SIGXX, TAUXX: Direct stress, shear stress, SIGZZ1, SIGZZ2: Bending stress around z-z for node 1 and node 2, SIGYY1 SIGYY2: Bending stress around y-y for node 1 and node 2
Nodal forces in X, Y and Z and nodal moments around X, Y and Z for each element and each node.

4.3 PLANE STRESS TRIANGLE NO.3 WITH 6 NODES

This is a simple, triangular plane stress element with complete quadratic shape functions. This element is obsolete and kept in Z88 only for studies. Elements No. 7, 11 or 14 are much better. Pay attention to edge loads, cf. chapter 3.3. No entries into the surface and pressure loads file Z88I5.TXT!

.



Input:

CAD (see chapter 2.4.2): *1-4-2-5-3-6-1*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 2 degrees of freedom for each node
> Element type is 3
> 6 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

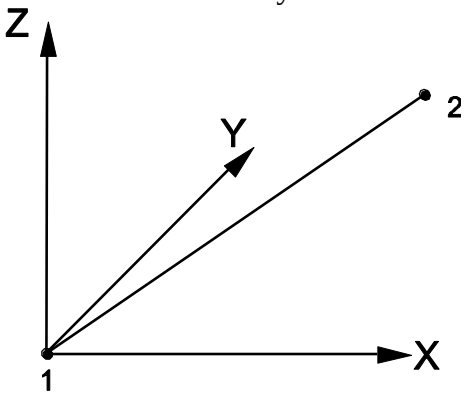
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG = 0: Calculation of SIGXX, SIGYY and TAUXY
> Radial/Tangential stress flag KDFLAG = 1: Additional calculation of SIGRR, SIGTT and TAURT
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the center of gravity
2 = principal or Rankine stresses in the center of gravity
3 = Tresca stresses in the center of gravity

Results:

Displacements into X and Y
Stresses: The stresses are calculated in the element's centre of gravity. The coordinates of the centre of gravity are thus printed. For KDFLAG = 1 the radial stresses SIGRR, the tangential stresses SIGTT and the accompanying shear stresses SIGRT are computed additionally (makes only sense if a rotational-symmetric structure is available). For easier orientation the respective radiuses and angles of the centre of gravity are printed. Optional von Mises stresses in the center of gravity.
Nodal forces in X and Y for each element and each node.

4.4 TRUSS NO.4 IN SPACE

The truss element No.4 can take any location in space. It is part of the simplest elements in Z88 and is calculated extremely fast. The truss elements match Hooke's law exactly. Hint: Trusses No. 4 are very suitable for modelling spring supports or oblique-angled supports.



Input:

CAD (see chapter 2.4.2): *Line from node 1 to node 2*

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 4
> 2 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the cross-sectional area of the truss

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

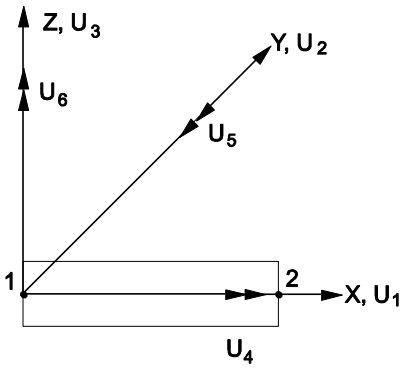
Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

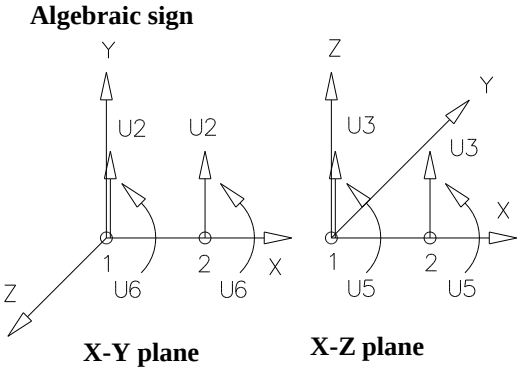
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

Results:
Displacements in X, Y and Z
Stresses: Normal stresses
Nodal forces in X, Y and Z for each element and each node.

4.5 SHAFT ELEMENT NO.5 WITH 2 NODES

The shaft element is a simplification of the general beam element No.2: It has always a circular cross-cut. The element lies concentrically to the X axis, consequently, local and global coordinates have the same direction. Thus, inputs and calculations are simplified strongly. Like with the beam element, the results are exact according to Bernoulli's bend theory and Hooke's law, and not approximate solutions like with the continuum elements.





X-Y plane **X-Z plane**

Input:

CAD (see 2.4.2): *Line from node 1 to node 2*

Z88I1.TXT
> Set KFLAG to 0 for Cartesian coordinates
> 6 degrees of freedom in a node (Attention DOF5 (not right hand rule), see below)
> Element type is 5
> 2 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the diameter of the shaft

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

Results:

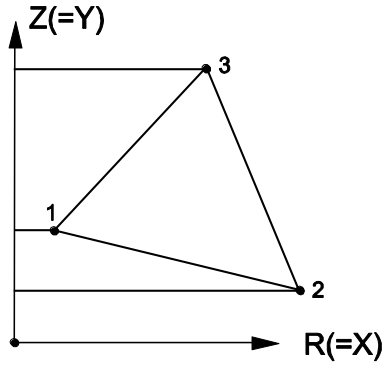
Displacements in X, Y and Z and rotations around X, Y and Z. Attention DOF5 (not right hand rule), see below

Stresses: SIGXX, TAUXX: Normal stress, shear stress, SIGXY1, SIGXY2: Bending stress in X-Y plane for node 1 and node 2, SIGXZ1 SIGXZ2: Bending stress in X-Z plane for node 1 and node 2

Nodal forces in X, Y and Z and **nodal moments** around X, Y and Z for each element and each node.

4.6 TORUS NO.6 WITH 3 NODES

This element is implemented only for historical reasons and possible data exchange to other FEA systems. Much better: Torus No.8 or Torus No.12 or No.15. No entries into the surface and pressure loads file Z88I5.TXT!



This is a simple, triangular torus element with linear shape functions for axisymmetric structures. The displacement results for this very simple element are quite useable, but the stress calculation results are inaccurate. The stresses are calculated in the corner nodes internally and then distributed as average value in the centre of gravity. However, the use of the torus elements No.8 or No.12 or No.15 is highly recommended especially for accurate stress calculations.

Input:

CAD (see 2.4.2): *1-2-3-1*

Z88I1.TXT
> In principle cylindrical coordinates are expected: KFLAG must be 0!
R coordinate (= X), always positive
Z coordinate (= Y), always positive
> 2 degrees of freedom for each node, DOF R and Z (= X and Y)).
> Element type is 6
> 3 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any value, no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no influence
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the center of gravity
2 = principal or Rankine stresses in the center of gravity
3 = Tresca stresses in the center of gravity

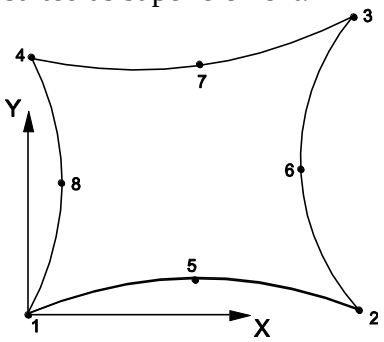
Results:

Displacements in R and Z (= X and Y)
Stresses: The stress are internally computed in the corner nodes, but plotted in the centre of gravity.
It is: SIGRR = stress in R direction = radial stress (= X direction), SIGZZ = stress in Z direction (= Y direction), TAURZ = shear stress in RZ plane (= XY plane), SIGTE = stress in peripherical direction = tangential stress.
Optional von Mises stresses.
Nodal forces for each element and each node.

4.7 PLANE STRESS ELEMENT NO.7 WITH 8 NODES

This is a curvilinear Serendipity plane stress element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Consequently, the integration order can be selected in Z88INT. The order 3 is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT. You may combine this element with elements no.3 (not recommended) or elements no.14 (good).

Plane Stress Elements No.7 can be generated by the mesh generator Z88N from super elements Plane Stress Elements No.7 or No.11. Thus, the Plane Stress Element No.7 is well suited as super element.



Input:

CAD (see 2.4.2): *1-5-2-6-3-7-4-8-1*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 2 degrees of freedom for each node
> Element type is 7
> 8 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

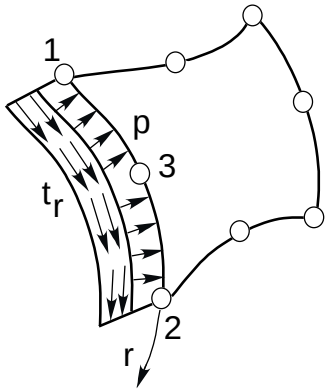
Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG = 0: Calculation of SIGXX, SIGYY and TAUXY
> Radial/Tangential stress flag KDFLAG = 1: Additional calculation of SIGRR, SIGTT and TAURT
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.7 – otherwise, enter a 0 into the first line:

> Element number with edge load
> Pressure, positive if pointing towards the edge
> Tangential shear, positive in local r direction
> 2 corner nodes and one mid node of the loaded surface. Mathematically positive in top view.

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3 may differ from the local nodes 1, 2, 3 used for the coincidence.



Results:

Displacements in X and Y.

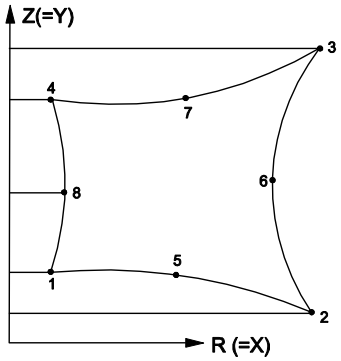
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. For KDFLAG = 1 the radial stresses SIGRR, the tangential stresses SIGTT and the accompanying shear stresses SIGRT are computed additionally (makes only sense if a rotational-symmetric structure is available). For easier orientation the respective radiuses and angles of the nodes/points are printed. Optional von Mises or principal or Tresca stresses

Nodal forces in X and Y for each element and each node.

4.8 TORUS NO.8 WITH 8 NODES

This is a curvilinear Serendipity torus element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT. The order 3 is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT. You may combine this element with elements no.15.

Torus elements No.8 can be generated by the mesh generator Z88N from the super elements torus elements No.8 or No.12. Thus, Torus No.8 is well suited as super element.



Input:

CAD (see 2.4.2): *1-5-2-6-3-7-4-8-1*

Z88I1.TXT
> In principle cylindrical coordinates are expected: KFLAG must be 0!
R coordinate (= X), always positive
Z coordinate (= Y), always positive
> 2 degrees of freedom for each node, DOF R and Z (= X and Y).
> Element type is 8
> 8 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any value, no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

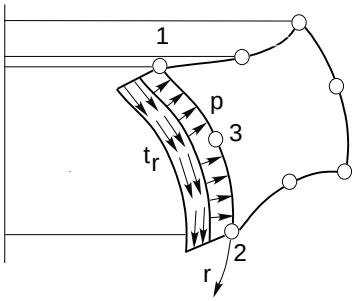
Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG, any, has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0 !)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0 !)
3 = Tresca stresses in the Gauss points (INTOS not 0 !)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.8 – otherwise, enter a 0 into the first line:

> Element number with surface and pressure load
> Pressure, positive if pointing towards the edge
> Tangential shear, positive in local r direction
> 2 corner nodes and one mid node of the loaded surface. Mathematically positive in plain view.

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3 may differ from the local nodes 1, 2, 3 used for the coincidence.



Results:

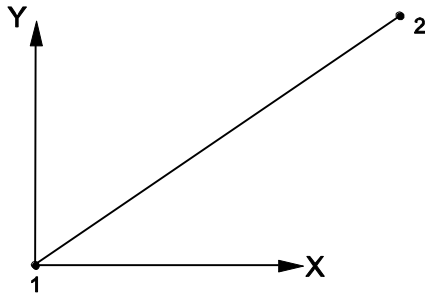
Displacements in R and Z (= X and Y).

Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. It is: SIGRR = stress in R direction = radial stress (= X direction), SIGZZ = stress in Z direction (= Y direction), TAURZ = shear stress in RZ plane (= XY plane), SIGTE = stress in peripherical direction = tangential stress. Optional von Mises, principal or Tresca stresses.

Nodal forces in R (= X) and Z (= Y) for each element and each node.

4.9 TRUSS NO.9 IN PLANE

The truss element No.9 can take any location in the X-Y plane. It is the simplest element in Z88 and is calculated extremely fast. The truss elements match Hooke's law exactly. Hint: Trusses No. 9 are very suitable for modelling spring supports or oblique-angled supports.



Input:

CAD (see 2.4.2): *Line from node 1 to node 2*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 2 degrees of freedom for each node
> Element type is 9
> 2 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the cross-sectional area of the truss

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

Results:

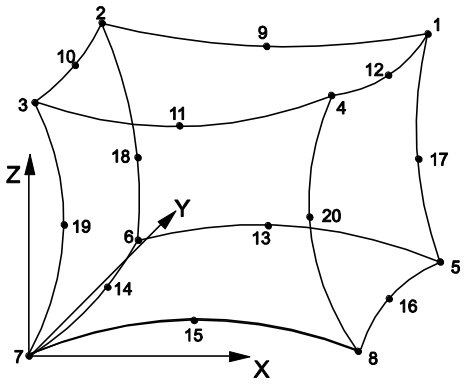
Displacements in X and Y
Stresses: Normal stresses
Nodal forces in X and Y for each element and each node.

4.10 HEXAHEDRON NO.10 WITH 20 NODES

This is a curvilinear Serendipity volume element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in all axes according to Gauss- Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 3 is good. The quality of the displacement and stress calculations are far better than the results of the hexahedron element No.1.

Hexahedron No.1 also applies well for thick plate elements, if the plate's thickness is not too small compared to the other dimensions. Or use shell elements No.21 and No.22.

The element causes heavy computing load and needs a large amount of memory because the element stiffness matrix has the order 60×60.



The nodal numbering of the element No.10 must be done carefully and must exactly match the sketch below. Pay attention to the location of the axis system! The possible error message „Jacobi determinant zero or negative " is a hint for incorrect node numbering.
Pay attention to surface and pressure loads when using forces, cf. chapter 3.3. It is easier to enter these loads via the surface and pressure loads file Z88I5.TXT.

Hexahedron No.10 can be generated by the mesh generator Z88N from super elements Hexahedron No.10. Thus, the Hexahedron No.10 is well suited as super element. Hexahedron No.10 can also generate 8-node Hexahedrons No.1.

Input:

CAD (see 2.4.2):
Upper plane: 1 - 9 - 2 - 10 - 3 - 11 - 4 -12 - 1, quit LINE function
Lower plane: 5 - 13 - 6 - 14 - 7 - 15 - 8 - 16 - 5, quit LINE function
1 - 17 - 5, quit LINE function
2 - 18 - 6, quit LINE function
3 - 19 - 7, quit LINE function
4 - 20 - 8, quit LINE function

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 10
> 20 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any other value, has no influence

Z88INT.TXT
> *Integration order INTORD for displacement calculation: 3 is usually good.*
> *Integration order INTOS for stress calculation:*
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

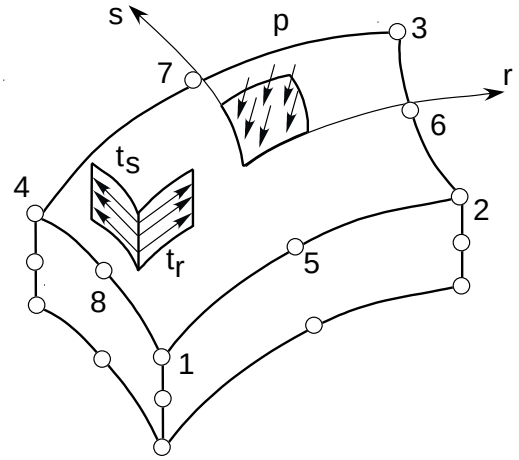
Z88MAT.TXT
> *Define materials, ref. chapter. 3.5 and 3.6.*

Z88MAN.TXT
> *Radial/Tangential stress flag KDFLAG* has no influence
> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.10 – otherwise, enter a 0 into the first line:

> *Element number with surface and pressure load*
> *Pressure, positive if pointing towards the surface*
> *Tangential shear, positive in local r direction*
> *Tangential shear, positive in local s direction*
> *4 corner nodes and 4 mid nodes of the loaded surface. Mathematically positive in top view.*

The local r direction is defined by the nodes 1-2; the local s direction is defined by the nodes 1-4. The local nodes 1, 2, 3, 4 may differ from the local nodes 1, 2, 3, 4 used for the coincidence.



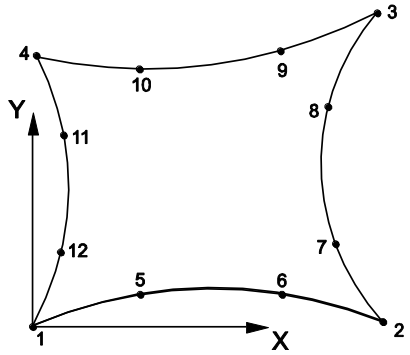
Results:

Displacements in X, Y and Z
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional von Mises or principal or Tresca stresses.
Nodal forces in X, Y and Z for each element and each node.

4.11 PLANE STRESS ELEMENT NO.11 WITH 12 NODES

This is a curvilinear Serendipity plane stress element with cubic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 3 is mostly the best choice. This element calculates both displacements and stresses with outstanding precision. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT.

Plane Stress Elements No.7 can be generated by the mesh generator Z88N from super elements Plane Stress Elements No.11. Thus, the Plane Stress Element No.11 is well suited as super element. However, Plane Stress Elements No.11 cannot be generated by the mesh generator Z88N from super elements Plane Stress Elements No.11.



Input:

CAD (see 2.4.2): *1-5-6-2-7-8-3-9-10-4-11-12-1*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 2 degrees of freedom for each node
> Element type is 11
> 12 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

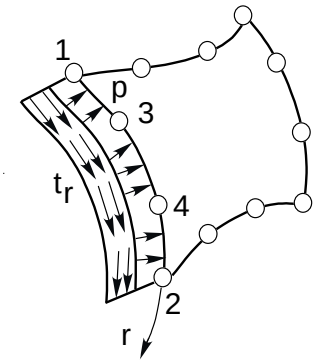
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG = 0: Calculation of SIGXX, SIGYY and TAUXY
> Radial/Tangential stress flag KDFLAG = 1: Additional calculation of SIGRR, SIGTT and TAURT
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)

3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.11 – otherwise, enter a 0 into the first line:

> Element number with surface and pressure load
> Pressure, positive if pointing towards the edge
> Tangential shear, positive in local r direction
> 2 corner nodes and 2 mid nodes of the loaded surface. Mathematically positive in top view.

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3, 4 may differ from the local nodes 1, 2, 3, 4 used for the coincidence.



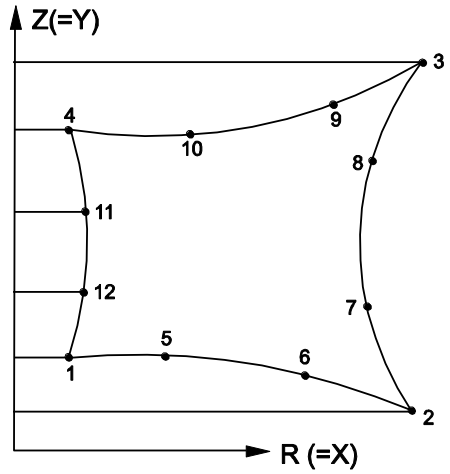
Results:

Displacements in X and Y.
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. For KDFLAG = 1 the radial stresses SIGRR, the tangential stresses SIGTT and the accompanying shear stresses SIGRT are computed additionally (makes only sense if a rotational-symmetric structure is available). For easier orientation the respective radiuses and angles of the nodes/points are printed. Optional von Mises or principal or Tresca stresses
Nodal forces in X and Y for each element and each node.

4.12 TORUS NO.12 WITH 12 NODES

This is a curvilinear Serendipity torus element with cubic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 3 is mostly sufficient. This element calculates both displacements and stresses with outstanding precision. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT.

Torus elements No.8 can be generated by the mesh generator Z88N from super elements torus elements No.12. Thus, the torus element No.12 is well suited as super element. However, torus elements No.12 cannot be generated by the mesh generator Z88N from super elements torus elements No.12.



Input:

CAD (see 2.4.2): *1-5-6-2-7-8-3-9-10-4-11-12-1*

Z88I1.TXT
> In principle cylindrical coordinates are expected: KFLAG must be 0!
R coordinate (= X), always positive
Z coordinate (= Y), always positive
> 2 degrees of freedom for each node, DOF R and Z (= X and Y).
> Element type is 12
> 12 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any value, no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

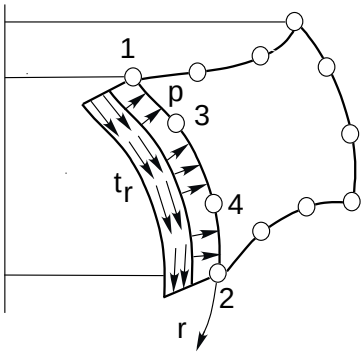
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG, any, has no meaning
> Reduced stress flag ISFLAG:

0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0 !)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0 !)
3 = Tresca stresses in the Gauss points (INTOS not 0 !)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.12 – otherwise, enter a 0 into the first line:

> Element number with surface and pressure load
> Pressure, positive if pointing towards the edge
> Tangential shear, positive in local r direction
> 2 corner nodes and 2 mid nodes of the loaded surface. Mathematically positive in top view.

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3, 4 may differ from the local nodes 1, 2, 3, 4 used for the coincidence.

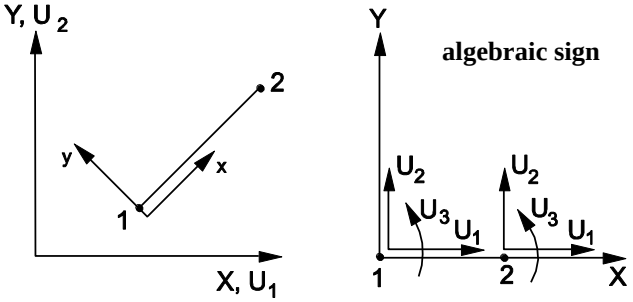


Results:

Displacements in R and Z (= X and Y).
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. It is: SIGRR = stress in R direction = radial stress (= X direction), SIGZZ = stress in Z direction (= Y direction), TAURZ = shear stress in RZ plane (= XY plane), SIGTE = stress in peripherical direction = tangential stress. Optional von Mises or principal or Tresca stresses.
Nodal forces in R (= X) and Z (= Y) for each element and each node.

4.13 BEAM NO.13 IN PLANE

Beam element with any symmetric profile. The profile values are provided in Z88ELP.TXT. Thus, you can use any symmetric profile in contrast to other FEA programs which incorporate a variety of different special beam and profile subroutines without matching all symmetric profiles as necessary. The element matches exactly Bernoulli's bend theory and Hooke's law. It uses no approximate solution compared to the continuum elements.



Input:

CAD (see 2.4.2): *Line from node 1 to node 2*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 3 degrees of freedom in a node
> Element type is 13
> 2 nodes per element

Z88ELP.TXT
> Cross-sectional area QPARA
> insert 0 for second moment of inertia I_{yy} (bending around y-y axis)
> insert 0 for max. distance e_{yy} from neutral axis y-y
> Second moment of inertia I_{zz} (bending around z-z axis)
> Max. distance e_{zz} from neutral axis z-z
> insert 0 for second moment of area (torsion) I_T
> insert 0 for second modulus (torsion) W_T

Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

Z88MAN.TXT
> Set beam flag IBFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

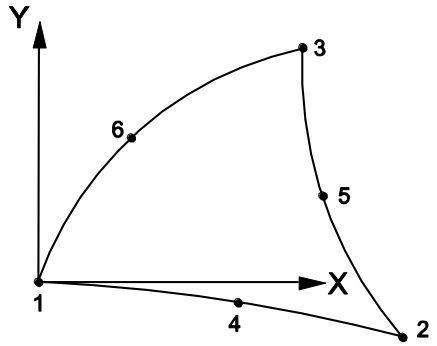
Results:

Displacements in X and Y and **rotations** around Z.
Stresses: SIGXX, TAUXX: Normal stress, shear stress, SIGZZ1, SIGZZ2: Bending stress around z-z for node 1 and node 2
Nodal forces in X and Y and **nodal moments** around Z for each element and each node.

4.14 PLANE STRESS ELEMENT NO.14 WITH 6 NODES

This is a curvilinear Serendipity plane stress element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically according to Gauss-Legendre. Consequently, the integration order can be selected in Z88INT.TXT. The order 7 (= 7 Gauss points) is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT.

This element type is implemented for use with automeshers. Thus, a mesh generation with Z88N is not possible. Use plane stress elements No.7 for Z88N.
Use plane stress element No.7 whenever possible. It is substantially more precise than this isoparametric triangle.



Input:

CAD (see 2.4.2): *1-4-2-5-3-6-1*

Z88I1.TXT
> KFLAG for Cartesian (0) or polar coordinates (1)
> 2 degrees of freedom for each node
> Element type is 14
> 6 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation. 7 is usually good. Possible is: 3 for 3 Gauss points, 7 for 7 Gauss points and 13 for 13 Gauss points. For easy combination with plane stress elements No.7, function ISOD88 of Z88 uses internally these values:
integration order 1 or 2: 3 Gauss points
integration order 4: 7 Gauss points
Example: Z88INT.TXT uses an entry of 2 for INTORD: Thus, plane stress elements No.7 use 2×2 = 4 Gauss points and plane stress elements No.14 use 3 Gauss points for integration.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,7,13 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

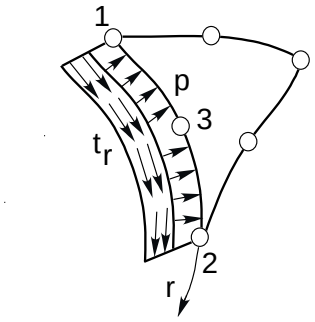
Z88MAN.TXT

> *Radial/Tangential stress flag KDFLAG* = 0: Calculation of SIGXX, SIGYY and TAUXY
> *Radial/Tangential stress flag KDFLAG* = 1: Additional calculation of SIGRR, SIGTT and TAURT
> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.14 – otherwise, enter a 0 into the first line:

> *Element number with surface and pressure load*
> *Pressure, positive if pointing towards the edge*
> *Tangential shear, positive in local r direction*
> *2 corner nodes and one mid node of the loaded surface. Mathematically positive in top view.*

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3 may differ from the local nodes 1, 2, 3 used for the coincidence.



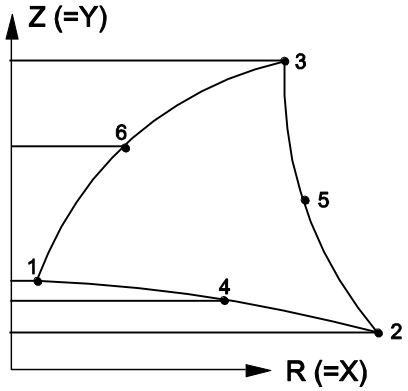
Results:

Displacements in X and Y.
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. For KFLAG = 1 the radial stresses SIGRR, the tangential stresses SIGTT and the accompanying shear stresses SIGRT are computed additionally (makes only sense if a rotational-symmetric structure is available). For easier orientation the respective radiuses and angles of the nodes/points are printed. Optional von Mises or principal or Tresca stresses.
Nodal forces in X and Y for each element and each node.

4.15 TORUS NO.15 WITH 6 NODES

This is a curvilinear Serendipity torus element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 7 is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). Pay attention to edge loads when using forces, cf. chapter 3.3. It is easier to enter edge loads via the surface and pressure loads file Z88I5.TXT.

This element type is implemented for use with automeshers. Thus, a mesh generation with Z88N is not possible. Use torus elements No.8 for Z88N.
Use torus element No.8 whenever possible. It is substantially more precise than this isoparametric triangle.



Input:

CAD (see 2.4.2): *1-4-2-5-3-6-1*

Z88I1.TXT
> In principle cylindrical coordinates are expected: KFLAG must be 0!
R coordinate (= X), always positive
Z coordinate (= Y), always positive
> 2 degrees of freedom for each node, DOF R and Z (= X and Y).
> Element type is 15
> 6 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any value, no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation. 7 is usually good. Possible is: 3 for 3 Gauss points, 7 for 7 Gauss points and 13 for 13 Gauss points. For easy combination with torus elements No.8, function ISOD88 of Z88 uses internally these values:
integration order 1 or 2: 3 Gauss points
integration order 4: 7 Gauss points
Example: Z88INT.TXT uses an entry of 2 for INTORD: Thus, torus elements No.8 use 2×2 = 4 Gauss points and torus elements No.15 use 3 Gauss points for integration.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,7,13 = Calculation of stresses in the Gauss points

Z88MAT.TXT

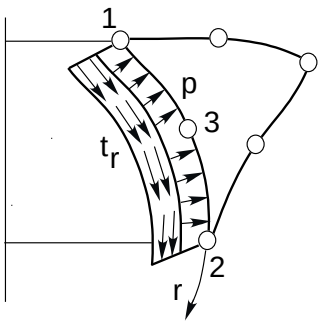
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces edge loads are applied onto element no.15 – otherwise, enter a 0 into the first line:

> Element number with surface and pressure load
> Pressure, positive if pointing towards the edge
> Tangential shear, positive in local r direction
> 2 corner nodes and one mid node of the loaded surface. Mathematically positive in top view.

The local r direction is defined by the nodes 1-2. The local nodes 1, 2, 3 may differ from the local nodes 1, 2, 3 used for the coincidence.



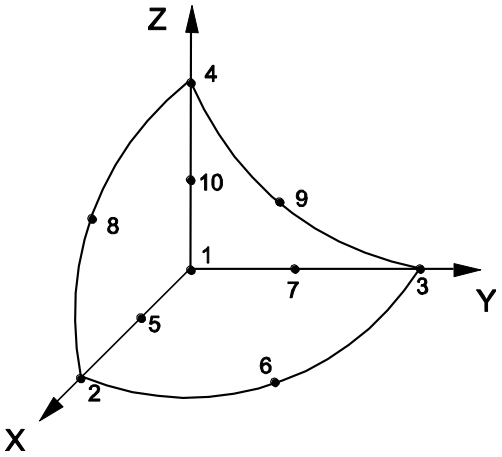
Results:
Displacements in R and Z (= X and Y).
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. It is: SIGRR = stress in R direction = radial stress (= X direction), SIGZZ = stress in Z direction (= Y direction), TAURZ = shear stress in RZ plane (= XY plane), SIGTE = stress in peripherical direction = tangential stress. Optional von Mises or principal or Tresca stresses.
Nodal forces in R (= X) and Z (= Y) for each element and each node.

4.16 TETRAHEDRON NO.16 WITH 10 NODES

This is a curvilinear Serendipity volume element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically according to Gauss-Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 4 is good. The quality of the displacement and stress calculations are far better than the results of the tetrahedron element No.17 but less precise than hexahedron No.10.

This element type is implemented for use with automeshers. For further information see chapter 2.5.

Tetrahedron No.16 also applies well for thick plate elements, if the plate's thickness is not too small compared to the other dimensions. Pay attention to pressure loads when using forces, cf. chapter 3.3. It is easier to enter pressure loads via the surface and pressure loads file Z88I5.TXT.



The nodal numbering of the element No.16 must be done carefully and must exactly match the sketch below. Pay attention to the location of the axis system! The possible error message *„Jacobi determinant zero or negative "* is a hint for incorrect node numbering.

Tetrahedron No.16 cannot be generated by the mapped mesh generator Z88N. **Caution:** The automeshers of CAD systems very often produce very bad nodal numbering resulting in an useless large amount of memory needs of Z88R's Cholesky solver. Thus, you may renumber especially the nodes or use one of the sparse matrix solvers i.e. SICCG, SORCG.

Input:

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 16
> 10 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any other value, has no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation. 4 is usually good. Allowed are 1 for 1 Gauss point, 4 for 4 Gauss points and 5 for 5 Gauss points
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,4,5 = Calculation of stresses in the Gauss points

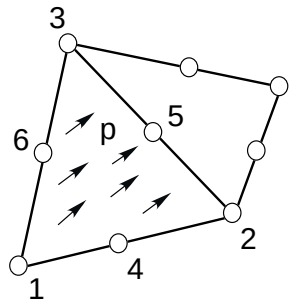
Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces pressure loads are applied onto element no.16 – otherwise, enter a 0 into the first line:

> Element number with pressure load
> Pressure, positive if pointing towards the edge
> 3 corner nodes and 3 mid nodes of the loaded surface. Mathematically positive in plain view.

The local nodes 1 to 6 may differ from the local nodes 1 to 6 used for the coincidence.



Results:
Displacements in X, Y and Z
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional von Mises or principal or Tresca stresses.
Nodal forces in X, Y and Z for each element and each node.

4.17 TETRAHEDRON NO.17 WITH 4 NODES

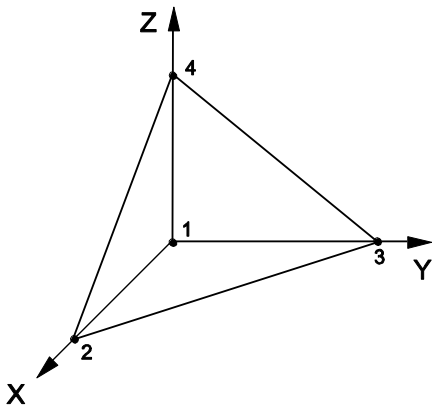
This is a volume element with linear shape functions. The transformation is isoparametric. The integration is carried out numerically according to Gauss- Legendre. Thus, the integration order can be selected in Z88INT.TXT. The order 1 is good.

This element type is implemented for use with automeshers. For further information see chapter 2.5.

Tetrahedron No.17 also applies well for thick plate elements, if the plate's thickness is not too small compared to the other dimensions.

Basically, this element calculates deflections and stresses very badly i.e. inaccurately. One needs very fine meshes to obtain useful results. Its one and only reason is the data exchange with 3D CAD systems. Use tetrahedrons No.16, hexahedrons No.1 and (best choice) hexahedrons No.10.

Tetrahedron No.17 cannot be generated by the mapped mesh generator Z88N.



Input:

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 17
> 4 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is 0 or any other value, has no influence

Z88INT.TXT
> Integration order INTORD for displacement calculation. 1 is usually good. Allowed are 1 for 1 Gauss point, 4 for 4 Gauss points and 5 for 5 Gauss points
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,4,5 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

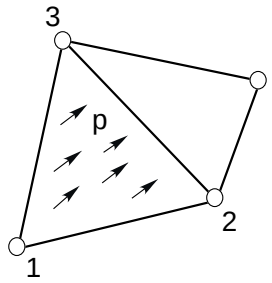
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:

0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces pressure loads are applied onto element no.17 – otherwise, enter a 0 into the first line:

> Element number with pressure load
> Pressure, positive if pointing towards the edge
> 3 corner nodes of the loaded surface. Mathematically positive in plain view.

The local nodes 1 to 3 may differ from the local nodes 1 to 3 used for the coincidence.



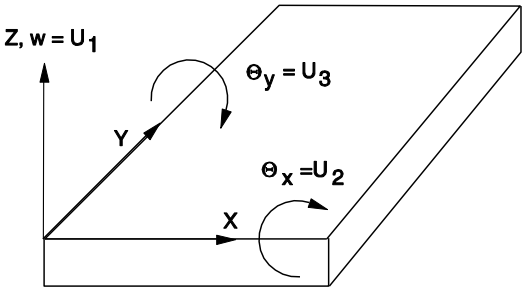
Results:

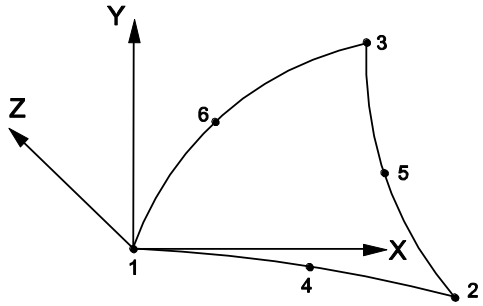
Displacements in X, Y and Z
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional von Mises or principal or Tresca stresses.
Nodal forces in X, Y and Z for each element and each node.

4.18 PLATE NO.18 WITH 6 NODES

This is a curvilinear Serendipity *Reissner-Mindlin* plate element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Consequently, the integration order can be selected in Z88INT.TXT. The order 3 (= 3 points) is mostly sufficient (reduced integration). This element calculates both displacements and stresses quite good. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). For this element you need to set the plate flag IPFLAG to 1. Attention: In contrary to the usual rules of the classic mechanics Z88 defines θ_x the rotation around the X-axis and θ_y the rotation around the Y-axis.

This element type is implemented for use with automeshers. Thus, a mesh generation with Z88N is not possible, because this will make no sense. Use plates No.20 for the mapped mesher Z88N. Because plates No.20 compute both the deflections and the stresses more exactly than the curvilinear triangle plates No.18, you should prefer always plates No.20.





Input:

CAD: *1-4-2-5-3-6-1*, ref. Chap. 2.7.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> set plate flag IPFLAG to 1 (or 2, if you want to reduce the shear influence)
> 3 degrees of freedom for each node (w, θ_x, θ_y)
> Element type is 18
> 6 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation. 3 is usually good. Possible is: 3 for 3 Gauss points, 7 for 7 Gauss points and 13 for 13 Gauss points. For easy combination with plate elements No.20, function SPLA88 of Z88 uses internally these values:
integration order 1 or 2: 3 Gauss points
integration order 4: 7 Gauss points
Example: Z88INT.TXT uses an entry of 2 for INTORD: Thus, plate element No.20 use 2×2 = 4 Gauss points and

plate element No.18 use 3 Gauss points for integration.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,7,13 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> set plate flag IPFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces pressure loads are applied onto element no.18 – otherwise, enter a 0 into the first line:

> Element number with pressure load
> Pressure, positive if pointing towards the surface

Results:

Displacements in Z (i.e. w) and rotations θ_x around X-axis and θ_y around the Y-axis.

Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. The following results will be presented:

- plate bending moments M_{xx} and M_{yy} (unit: force × length / length)
- plate torsion moments $M_{xy} = M_{yx}$ (unit: force × length / length)
- the shear forces Q_{yz} and Q_{zx} (unit: force / length)
- the true stresses resulting from plate bending moments and plate torsion moments

Optional *von Mises* or principal or Tresca stresses.
Nodal forces in X and Y for each element and each node.

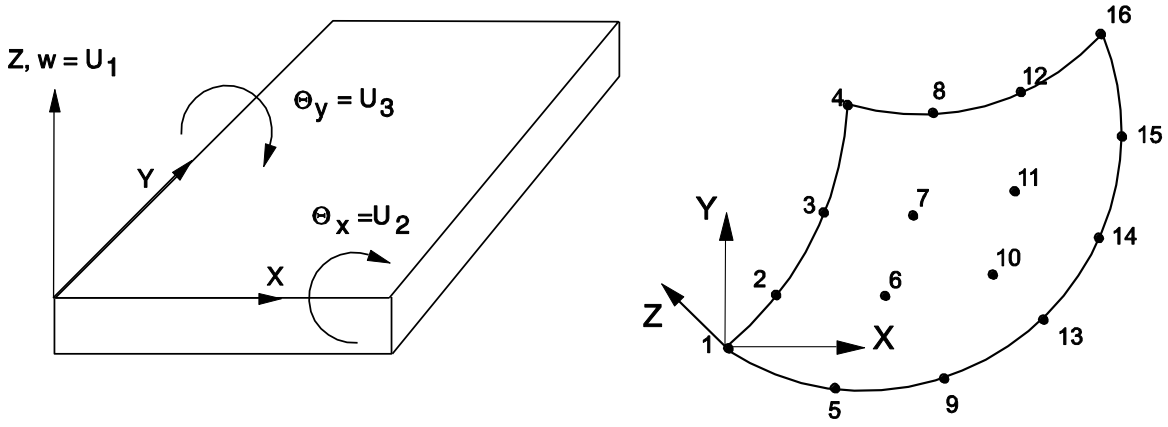
4.19 PLATE NO.19 WITH 16 NODES

This is a curvilinear Lagrange-*Reissner-Mindlin* plate element with cubic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Consequently, the integration order can be selected in Z88INT.TXT. The order 4 (= 4×4 points) is very good. This element calculates both displacements and stresses very precisely. The input amount is heavy; you should use the mesher Z88N.

The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). For this element you need to set the plate flag IPFLAG to 1. Attention: In contrary to the usual rules of the classic mechanics Z88 defines θ_x the rotation around the X-axis and θ_y the rotation around the Y-axis.

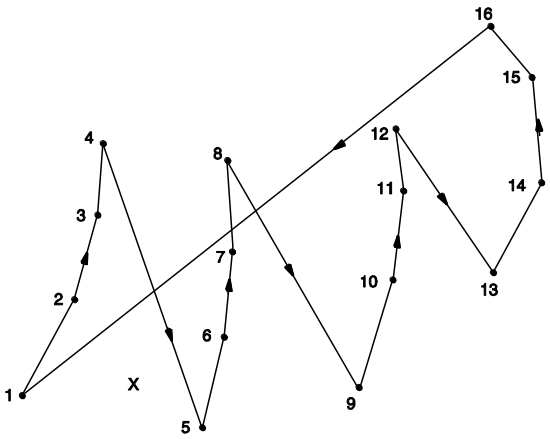
Mesh generation with Z88N: Use plates No.20 for super elements, resulting in finite elements of type 19 (plates No.20 may generated by AutoCAD or CREO, ref. the chapters of Z88X and Z88G). A bit tricky, but works quite fine.
For example, some lines from a mesh generator input file Z88NI.TXT:

```
.....
5    20          super element 5 of type 20
20   25   27   22   24   26   28   21
.....
5    19          generate from super element 5 (which is of type 20 is, see above) finite elements of type 19
3E   3E      .. and subdivide them three times equidistant in X-direction and three times equidistant in Y- direction
```



Input:

CAD: *1-2-3-4-5-6-7-8-9-10-11-12-13-14-15-16-1* , ref. chap. 2.7.2. Usually, you will not work in this way. It's much easier to build within a CAD program a super elements mesh with 8-node plates No.20. Export this mesh as a DXF file and use Z88X to produce a mesh generator input file Z88NI.TXT. Run the mapped mesher Z88N and generate a finite elements mesh with plates No.19. Then you may supply the boundary conditions.



Z88I1.TXT

> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> set plate flag IPFLAG to 1 (or 2, if you want to reduce the shear influence)
> 3 degrees of freedom for each node (w, θ_x,θ_y)
> Element type is 19
> 16 nodes per element

Z88ELP.TXT

> Cross-section parameter QPARA is the element thickness

Z88INT.TXT

> Integration order INTORD for displacement calculation. 4 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT

> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT

> set plate flag IPFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT

This file is only used (see 3.4) if in addition to nodal forces pressure loads are applied onto element no.19 – otherwise, enter a 0 into the first line:

> Element number with pressure load
> Pressure, positive if pointing towards the edge

Results:

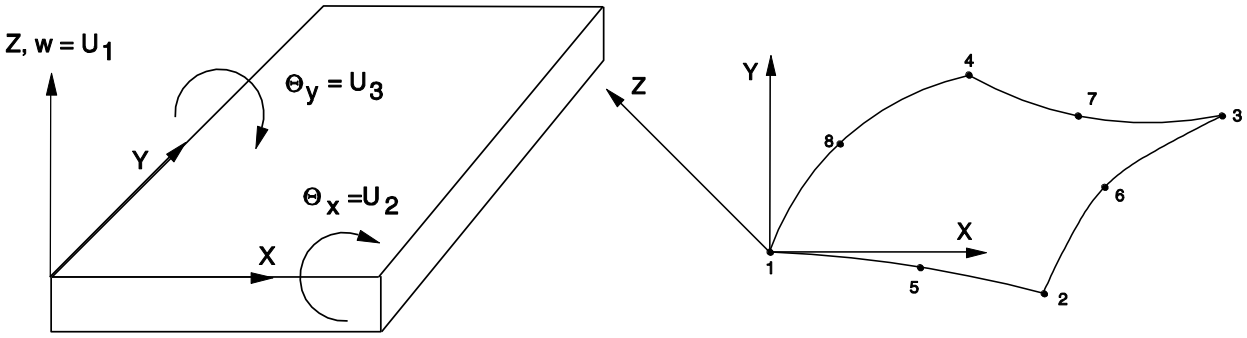
Displacements in Z (i.e. w) and rotations θ_x around X-axis and θ_y around the Y-axis.
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. The following results will be presented:

- plate bending moments M_{xx} and M_{yy} (unit: force × length / length)
- plate torsion moments $M_{xy} = M_{yx}$ (unit: force × length / length)
- the shear forces Q_{yz} and Q_{zx} (unit: force / length)
- the true stresses resulting from plate bending moments and plate torsion moments

Optional *von Mises* or principal or Tresca stresses.
Nodal forces in X and Y for each element and each node.

4.20 PLATE NO.20 WITH 8 NODES

This is a curvilinear Serendipity *Reissner-Mindlin* plate element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in both axes according to Gauss-Legendre. Consequently, the integration order can be selected in Z88INT.TXT. The order 2 (= 2×2 points) is mostly sufficient (reduced integration). This element calculates both displacements and stresses quite good. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). For this element you need to set the plate flag IPFLAG to 1. Attention: In contrary to the usual rules of the classic mechanics Z88 defines θ_x the rotation around the X-axis and θ_y the rotation around the Y-axis.
This element type is implemented for use with automeshers. In addition, a mesh generation with Z88N is possible. Super elements of type 20 can generate finite elements of type 20, and plates of type 19 with 16 nodes, too.



Input:

CAD: *1-5-2-6-3-7-4-8-1,* ref. chap. 2.7.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> set plate flag IPFLAG to 1 (or 2, if you want to reduce the shear influence)
> 3 degrees of freedom for each node (w, θ_x,θ_y)
> Element type is 20
> 8 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation. 2 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> set plate flag IPFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG:
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)

2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces pressure loads are applied onto element no.19 – otherwise, enter a 0 into the first line:

> Element number with pressure load
> Pressure, positive if pointing towards the edge

Results:

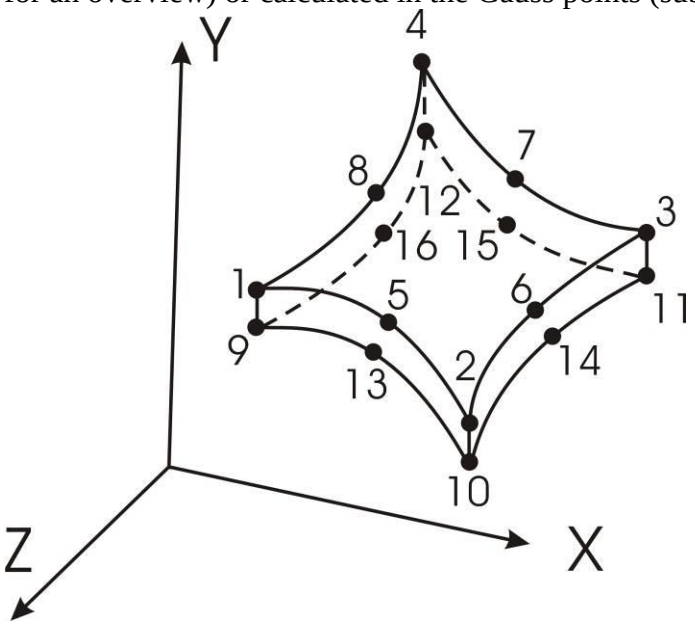
Displacements in Z (i.e. w) and rotations θ_x around X-axis and θ_y around the Y-axis.
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. The following results will be presented:

- plate bending moments M_{xx} and M_{yy} (unit: force × length / length)
- plate torsion moments $M_{xy} = M_{yx}$ (unit: force × length / length)
- the shear forces Q_{yz} and Q_{zx} (unit: force / length)
- the true stresses resulting from plate bending moments and plate torsion moments

Optional *von Mises* or principal or Tresca stresses.
Nodal forces in X and Y for each element and each node.

4.21 SHELL NO.21 WITH 16 NODES

This is a curvilinear Serendipity volume shell element. The transformation is isoparametric. The integration is carried out numerically in all axes according to Gauss-Legendre. The element can be arbitrarily curved; it is actually a hexahedron with square shape functions on the surface and linear shape functions in the thickness direction. The integration order can be selected in Z88INT.TXT. The order 3 (i.e. 3×3 Gauss Points) is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly).



The three degrees of freedom are the global displacements in X, Y and Z. However, there are no rotational degrees of freedom, because Type 21 is in fact a volume element. The element can be generated by the mapped mesher Z88N: Type 21 → Type 21.

Input:

CAD: upper plane: 1-5-2-6-3-7-4-8-1; lower plane: 9-13-10-14-11-15-12-16-9;
lines: 1-9; 2-10; 3-11; 4-12, see chapter 2.4.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 21
> 16 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is insignificant

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
1,2,3,4 = Calculation of stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

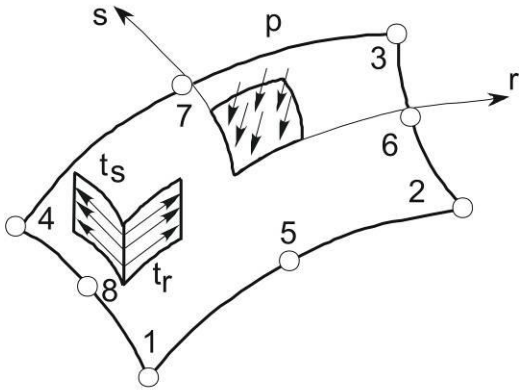
Z88MAN.TXT
> Radial/Tangential stress flag KDFLAG has no influence

> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.21 – otherwise, enter a 0 into the first line:

> *Element number*
> *Pressure, positive if pointing towards the surface*
> *Tangential shear, positive in local r direction*
> *Tangential shear, positive in local s direction*
> *4 corner nodes and 4 mid nodes of the loaded surface. Mathematically positive in top view.*

The local r direction is defined by the nodes 1-2, the local s direction is defined by the nodes 1-4. The local nodes 1 to 8 for the surface load may differ from the local nodes 1 to 8 used for the coincidence.

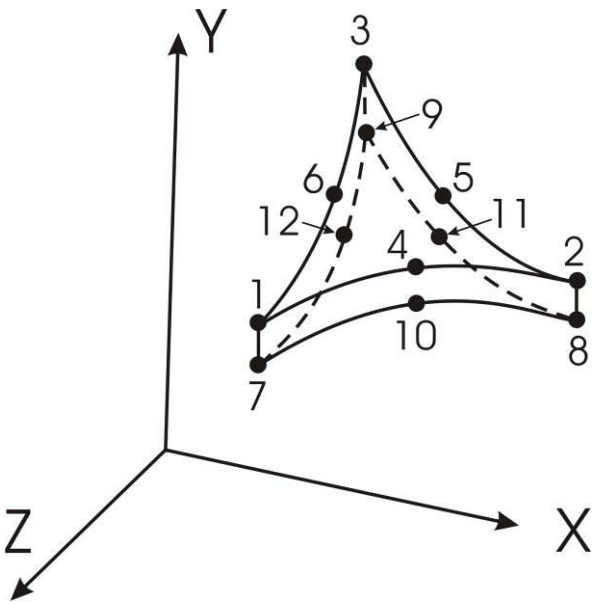


Results:

Displacements in X, Y and Z
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional *von Mises* or principal or Tresca stresses.
Nodal forces in X, Y and Z for each element and each node

4.22 SHELL NO.22 WITH 12 NODES

This is a curvilinear Serendipity volume shell element. The transformation is isoparametric. The integration is carried out numerically in all axes according to Gauss-Legendre. The element can be arbitrarily curved; it is actually a kind of pie segment with square shape functions on the surface and linear shape functions in the thickness direction. The integration order can be selected in Z88INT.TXT. The order 3 (i.e. 3×3 Gauss Points) is mostly sufficient. This element calculates both displacements and stresses very exactly. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly).



The three degrees of freedom are the global displacements in X, Y and Z. However, there are no rotational degrees of freedom, because Type 22 is in fact a volume element.

Input:

CAD: upper plane: 1-4-2-5-3-6-1; lower plane: 7-10-8-11-9-12-7;
lines: 1-7; 2-8; 3-9; see chapter 2.4.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 3 degrees of freedom for each node
> Element type is 22
> 12 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is insignificant

Z88INT.TXT
> Integration order INTORD for displacement calculation: 3, 7, and 13 are possible. 7 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of stresses in the corner nodes
3,7,13 = Calculation of stresses in the Gauss points

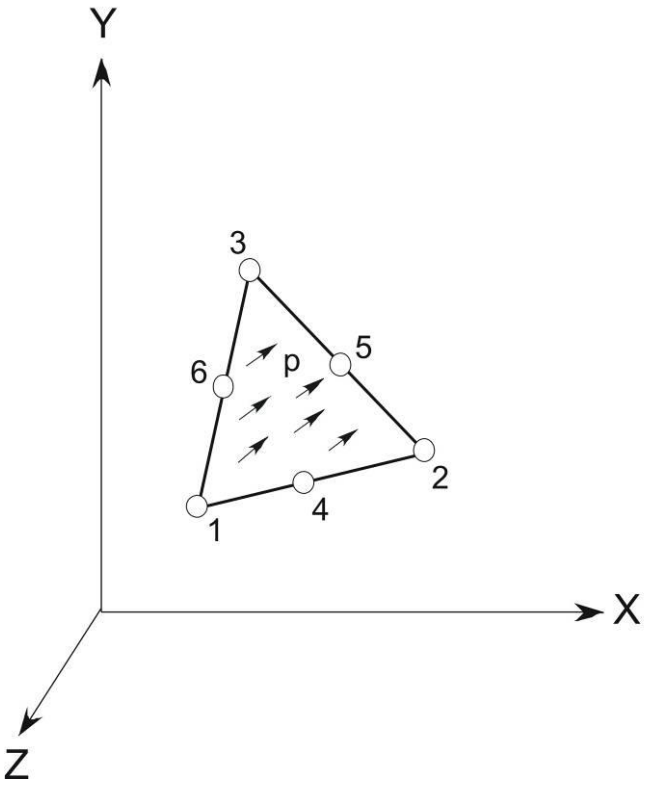
Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT

> *Radial/Tangential stress flag KDFLAG* has no influence
> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.22 – otherwise, enter a 0 into the first line:

> *Element number*
> *Pressure, positive if pointing towards the surface*
> *3 corner nodes and 3 mid nodes of the loaded surface. Mathematically positive in top view.*

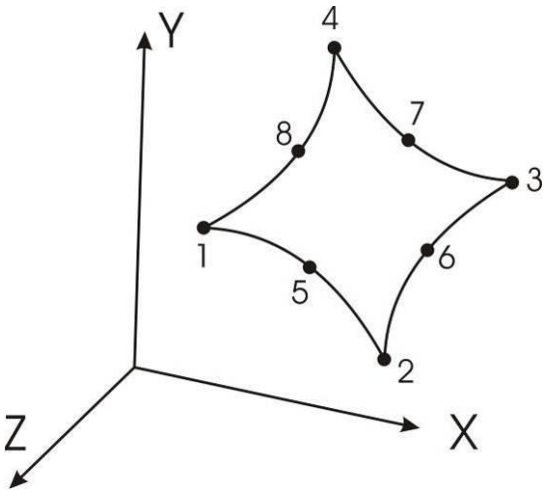


Results:

Displacements in X, Y and Z
Stresses: SIGXX, SIGYY, SIGZZ, TAUXY, TAUYZ, TAUZX, respectively for corner nodes or Gauss points. Optional *von Mises* or principal or Tresca stresses.
Nodal forces in X, Y and Z for each element and each node.

4.23 SHELL NO.23 WITH 8 NODES

This is a curvilinear Serendipity shell element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in all axes according to Gauss-Legendre. All nodes have to be on a common surface which may be placed arbitrarily in a space – which is very useful for the data exchange with 3D CAD systems. The integration order can be selected in Z88INT.TXT. The order 3 (i.e. 3×3 Gauss Points) is mostly sufficient. This element calculates both displacements and stresses quite good. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). For this element, the shell flag IHFLAG should be set to 1 in Z88MAN.TXT. In case of thin shells, set IHFLAG to 2 or 3. In case of *very* thin shells set it to 4.



The first three degrees of freedom are the global displacements in X, Y and Z. The degrees of freedom 4 and 5 are the *global* torsions on the respective node (thus, quite useless); degree of freedom 6 is a pseudo-DOF without practical significance. Only the global displacements in X, Y and Z are practically useful and of interest for mechanical engineers.

Input:

CAD: *1-5-2-6-3-7-4-8-1* , see chapter 2.4.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 6 degrees of freedom for each node – but only DOF 1~3 are of interest
> Element type is 23
> 8 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

Z88INT.TXT
> Integration order INTORD for displacement calculation. 3 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of the stresses in the corner nodes
1,2,3,4 = Calculation of the stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

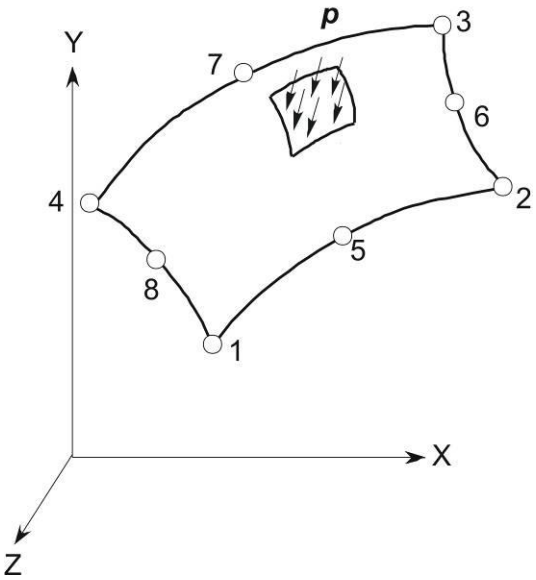
Z88MAN.TXT

> *Set shell flag IHFLAG to 1, or to 2 or 3 in case of thin shells, and to 4 in case of very thin shells*
> *Radial/Tangential stress flag KDFLAG* has no influence
> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.23 – otherwise, enter a 0 into the first line:

> *Element number*
> *Pressure, positive if pointing towards the surface*
> *4 corner nodes and 4 mid nodes of the loaded surface. Mathematically positive in top view.*

The local r direction is defined by the nodes 1-2, the local s direction is defined by the nodes 1-4. The local nodes 1 to 8 for the surface load may differ from the local nodes 1 to 8 used for the coincidence.

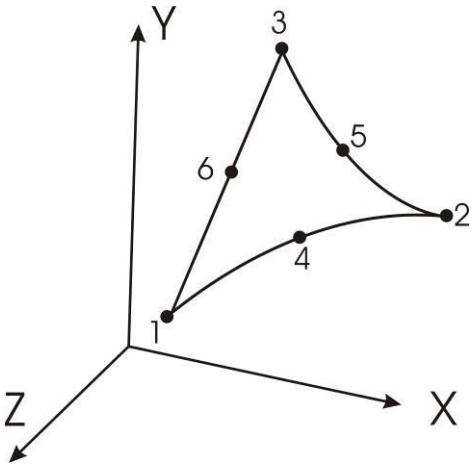


Results:

Displacements in X, Y and Z and global **Rotations** around X- and Y-axis (θ_x u. θ_y)
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. The stresses SIGXX, SIGYY and TAUXY as well as optionally *von Mises* or principal or Tresca stresses are output.
Nodal forces first for each element, then for each node.

4.24 SHELL NO.24 WITH 6 NODES

This is a curvilinear Serendipity shell element with quadratic shape functions. The transformation is isoparametric. The integration is carried out numerically in all axes according to Gauss-Legendre. All nodes have to be on a common surface which may be placed arbitrarily in a space – which is very useful for the data exchange with 3D CAD systems. The integration order can be selected in Z88INT.TXT. The order 7 (i.e. 7 Gauss Points) is mostly sufficient. This element calculates both displacements and stresses quite good. The integration order can be chosen again for the stress calculation. The stresses are calculated in the corner nodes (good for an overview) or calculated in the Gauss points (substantially more exactly). For this element, the shell flag IHFLAG should be set to 1 in Z88MAN.TXT. In case of thin shells, set IHFLAG to 2 or 3. In case of *very* thin shells set it to 4.



The first three degrees of freedom are the global displacements in X, Y and Z. The degrees of freedom 4 and 5 are the *global* torsions on the respective node (thus, quite useless); degree of freedom 6 is a pseudo-DOF without practical significance. Only the global displacements in X, Y and Z are practically useful and of interest for mechanical engineers.

Input:

CAD: *1-4-2-5-3-6-1*, see chapter 2.4.2

Z88I1.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 6 degrees of freedom for each node – but only DOF 1~3 are of interest
> Element type is 24
> 6 nodes per element

Z88ELP.TXT
> Cross-section parameter QPARA is the element thickness

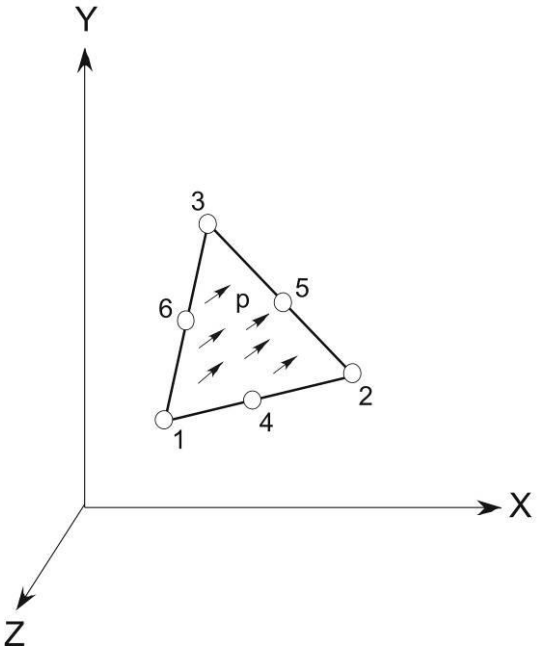
Z88INT.TXT
> Integration order INTORD for displacement calculation. 3, 7, and 13 are possible. 7 is usually good.
> Integration order INTOS for stress calculation:
0 = Calculation of the stresses in the corner nodes
3,7,13 = Calculation of the stresses in the Gauss points

Z88MAT.TXT
> Define materials, ref. chapter. 3.5 and 3.6.

Z88MAN.TXT
> *Set shell flag IHFLAG to 1, or to 2 or 3 in case of thin shells, and to 4 in case of very thin shells*
> *Radial/Tangential stress flag KDFLAG* has no influence
> *Reduced stress flag ISFLAG:*
0 = no calculation of reduced stresses
1 = von Mises stresses in the Gauss points (INTOS not 0!)
2 = principal or Rankine stresses in the Gauss points (INTOS not 0!)
3 = Tresca stresses in the Gauss points (INTOS not 0!)

Z88I5.TXT
This file is only used (see 3.4) if in addition to nodal forces surface and pressure loads are applied onto element no.24 – otherwise, enter a 0 into the first line:

> *Element number*
> *Pressure, positive if pointing towards the surface*
> *3 corner nodes and 3 mid nodes of the loaded surface. Mathematically positive in top view.*

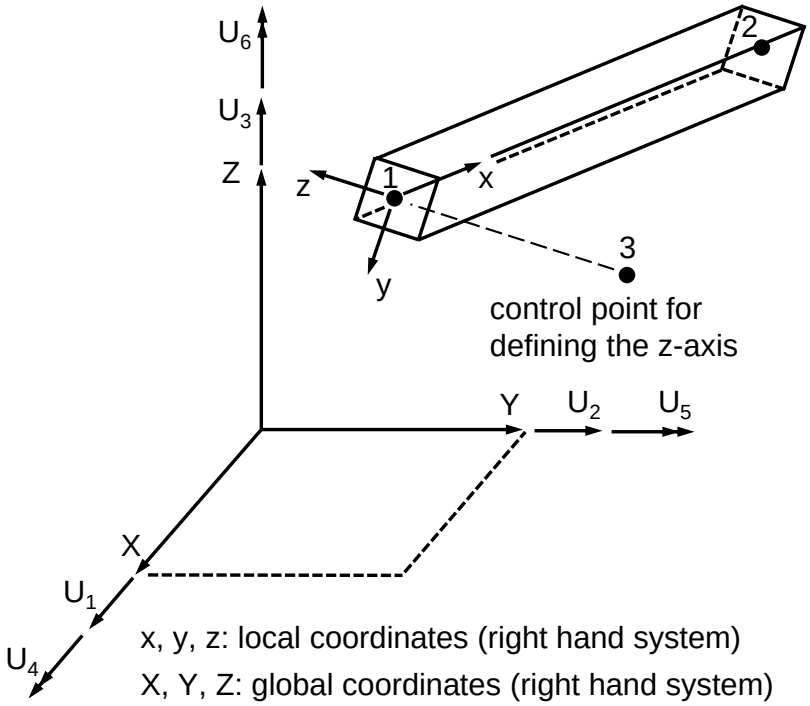


Results:

Displacements in X, Y and Z and global **Rotations** around X- and Y-axis (θ_x u. θ_y)
Stresses: The stresses are calculated in the corner nodes or Gauss points and printed along with their locations. The stresses SIGXX, SIGYY and TAUXY as well as optionally *von Mises* or principal or Tresca stresses are output.
Nodal forces first for each element, then for each node.

4.25 BEAM NO. 25 WITH 2 NODES IN SPACE

Beam element with any symmetric profile (no slanting bend). The cross section of this element is in contrary to element No.2 capable to take arbitrary orientations. The orientation is defined by an additional control point / control node (signed by "3" in the figure below). The control point do not has to be perpendicular to the axis 1-2 in the figure. But it is not allowed that the control point lies on the axis 1-2. The axis which lies in the plane 1-2-3 and perpendicular to 1-2 becomes the local z-axis. The local x-axis directs from 1 to 2 and the local y-axis is calculated by the cross product.
The profile values are provided in the GUI. They are related to the local coordinate system. The beam element No.25 can calculate on the basis of the theory of Bernoulli or the theory of Timoshenko. If the theory of Timoshenko is chosen, the shear ratio (shear correction factor) has to be defined by the user.
The element matches exactly Bernoulli's / Timoshenko's bend theory and Hooke's law. It uses no approximate solution as for the continuum elements.



Input:

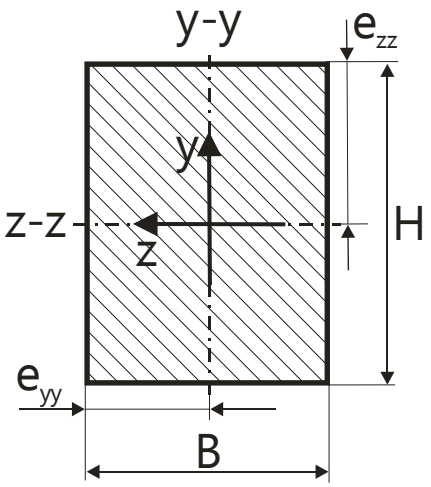
CAD (see chapter 2.4.2):
Line from node 1 to node 2

Z88STRUCTURE.TXT
> KFLAG for Cartesian (0) or cylindrical coordinates (1)
> 6 degrees of freedom in a node (Attention: DoF5 (not right hand rule), see below)
> Element type is 25
> 2 nodes per element

Z88ELP.TXT
> Cross-sectional area QPARA
> Second moment of inertia I_{yy} (bending around y-y axis) IYY
> Max. distance e_{yy} from neutral axis y-y EYY

> Second moment of inertia I_{zz} (bending around z-z axis) IZZ
> Max. distance e_{zz} from neutral axis z-z EZZ
> Second moment of area (torsion) I_T IT
> Second modulus (torsion) W_T WT
> Flag for choosing the bend theory: Bernoulli (0) or Timoshenko (1) IFBETI
> X-coordinate of the control point XCP
> Y- coordinate of the control point YCP
> Z- coordinate of the control point ZCP
> shear ratio (shear correction factor) RKAP, for example in case of rectangular cross section= 5/6 = 0,8333

The following figure is found in Z88Aurora at the register card „element geometry“. It describes the definition of the max. distances from the neutral axes and the axes definition required for the second moments of inertia. Here, in addition to the original figure, the local axes are inserted. The second moment of inertia I_{yy} for example belongs to the case that rotation about the y-axis is considered.



Z88INT.TXT
> Integration order INTORD for displacement calculation: any order, has no influence
> Integration order INTOS for stress calculation: any order, has no influence

Z88MAT.TXT
> Define materials, ref. chapter 3.5 and 3.6.

Z88MAN.TXT
> Set beam flag IBFLAG to 1
> Radial/Tangential stress flag KDFLAG has no meaning
> Reduced stress flag ISFLAG has no meaning

Displacements in X, Y and Z and rotations around X, Y and Z.
Stresses: SIGXX, TAUXX: Direct stress, shear stress, SIGZZ1, SIGZZ2: Bending stress around z-z for node 1 and node 2, SIGYY1 SIGYY2: Bending stress around y-y for node 1 and node 2
Nodal forces in X, Y and Z and nodal moments around X, Y and Z for each element and each node.

5 EXAMPLES

5.0 OVERVIEW

You will find several examples in this chapter along with their respective input files B*.* on the Z88 book CD or the Internet distribution. The examples 4, 6 and 7 can be calculated analytically by hand. Look for further examples in our book:

Rieg, F.; Hackenschmidt, R., Alber-Laukant, B.: Finite Element Analysis for Engineers. Carl Hanser Verlag: München Wien: 2014.
ISBN 978-1-56990-487-9, www.hanserpublications.com

Work with the examples which resemble your own applications. Also look at the protocol files *.LOG produced by the Z88 modules. Plot the various examples. Vary the input files, especially the mesh generator-input files for the examples 1, 5 and 7. Doing so gives you a smart feeling for the how-to of Z88 very quick. If examples won't run, first check for memory problems. Are there any other programs in the computer's memory, especially those fat and greedy memory eaters like office packages? All examples were tested on various computer equipment and operating systems, and many examples do run even on old-fashioned computers. Nevertheless, Z88 is running very large structures on modern PCs without any problems, see example 5.10. The largest structure computed with Z88 up to now featured 12 Mio. DOF and was run on a 64 Bit PC with 64 Bit Windows Server 2003 and with 64 Bit LINUX, too. If necessary, adjust Z88.DYN. Investigate the *.LOG files: It is shown here if Z88 modules run out of memory. UNIX: Check file and directory permissions. After you have investigated the ready-to-run examples, try to draw the examples in your CAD program. Export to DXF files and convert them into Z88 files. If the CAD converter does not convert your DXF files properly, then redo the steps 3 and 5 of chapter 2.4.2. Did you "snap" the points cleanly ? If nothing works try another CAD program. If you've got a 3D CAD program with an integrated automesher you may export FE meshes to COSMOS or NASTRAN files and read these files into Z88 with Z88G. Or run the Perl script Z88ASY with ANSYS-PREP7 files. Check the amount of needed memory and the quality of the nodal numbering by running Z88R in test mode. Renumber with the Cuthill McKee program Z88H, if necessary. Or, even better, use the sparse matrix solver Z88R –siccg or –sorcg.

Example 1: Fork wrench. Plane stress problem with Serendipity Plane Stress No.7 and mesh generator use. Learning objectives: CAD and mesh generator use at curvilinear plane structures, displaying stresses in the plot program. This example is fixed on the Z88 distribution ready to run as the first introduction example with Z88X.DXF and Z88I2.TXT.

Example 2: Crane truss. Modelled with Trusses No.4. Learning objectives: Use of the different views and rotation possibilities in space within the plot program.

Example 3: Transmission cam. Cam with different diameters, forces and moments in different planes with cam elements No.5, statically over-defined. Learning objectives: Use of the cam elements, especially for the boundary conditions at finite elements with 6 degrees of freedom per node, use of the different views in the plot program.

Example 4: Beam in plane, repeatedly statically over-defined. On both sides firmly fixed Beam No.13. Learning objectives: Use of Beams No.13, choice of the boundary conditions and the interpretation of the results.

Example 5: Disk segment in cake form. General spatial problem with Hexahedrons No.10 (20 nodes) as super elements and mesh generation of Hexahedrons No.1 (8 nodes). Learning objectives: Use of the mesh generator at curvilinear spatial elements, showing stresses, different views and spatial rotation possibilities in the plot program. After running this example successfully it is a nice idea to make the mesh generator generating Hexahedrons No.10 instead of Hexahedrons No.1, what is just a breeze. But you must define new nodes for the boundary conditions.

Example 6: Pipe under inner pressure of 1,000 bar. Axially symmetric problem, solved as plane stress problem with Plane Stress Elements No.7. Learning objectives: Clever use of symmetry qualities of a structure and choice of the proper boundary conditions and **surface loads**, showing stresses in the plot program.

Example 7: Press fit. Axially symmetric problem with Tori No.8 and use of mesh generator. Learning objectives: Work with torus elements, use of the mesh generator with mesh compression, stress display in the plot program.

Example 8: Crankshaft. Space structure with Tetrahedrons No.16. Learning objectives: Starting with a NASTRAN file from CREO, we will use the 3D converter Z88G, the Cuthill-McKee program Z88H and both the solvers, i.e. the direct Cholesky solver Z88R -choly and the sparse matrix solver Z88R -siccg. This is an example for a larger FEA structure imported from a CAD system.

Example 9: Rectangular plate with 16 nodes Lagrange plate elements No.19. Learning objectives: Starting with an AutoCAD drawing for a super structure with plates No.20, we'll export the DXF file to the CAD converter Z88X. Running the mesh generator Z88N will generate a mesh of plates No.19. The system will be solved by the sparse matrix iteration solver.

Example 10: Piston of a diesel engine with Tetrahedrons No.16. Learning objectives: Starting with a NASTRAN file from CREO, we will use the 3D converter Z88G and the sparse matrix iteration solver Z88R -siccg. This is an example for a FEA structure imported from a CAD system using the surface and pressure loads file Z88I5.TXT.

Example 11: Rectangular tube. A tube is drilled and computed by shells no.24. Interesting is the interpretation of the results. Learning objectives: FEA with shells.

Notes: The input and output files are printed sometimes shortened to avoid useless pages. Only the essential is shown. You can start every example at any time. Remember that 0 (zero) never is real zero but is represented as an approximation to the floating point numbers in a computer. Input values entered in Z88I1.TXT as 0 can appear in output files like Z88O0.TXT as very small numbers which is caused by formatting of the operating system's runtime libraries. This is normal. Of course, this is also true for real calculated results, for example displacements in Z88O2.TXT, stresses in Z88O3.TXT and nodal forces in Z88O4.TXT. Such results have always to be seen in relation to other results: Is, for example, in Z88O2.TXT the biggest calculated displacement 0.1 mm, then consider another displacement, let's say 1.234E-006 mm, as de-facto zero.

5.1 FORK WRENCH WITH PLANE STRESS ELE. NO.7

Copy the example files from directory B1 into your Z88 working directory (this has been already carried out on the Z88 CDs or Internet packages for your immediate start):

Z88X.DXF	CAD input file
Z88I2.TXT	boundary conditions
Z88I5.TXT	surface loads (with a 0 in the first line)
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
51.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

Simply proceed with the following steps to get familiar with Z88:

CAD:

As for this first example, you should only look at the CAD super structure without producing it. This comes with later examples. Import Z88X.DXF into your CAD program and view it. Usually you would draw or model the super structure in your CAD system. Do not change anything and leave your CAD program without saving, converting etc. If you do not have any suitable CAD system, then drop this step.

Z88:

Z88X, conversion from Z88X.DXF to Z88NI.TXT.

Windows: Press button *Z88X* in the Z88 commander, Button *DXF → Z88NI, Run Button.* Quit the Z88X message box.

LINUX/UNIX: In the Z88 commander under *CAD converters* press button *DXF → Z88NI.*

Z88O, looking at the super structure.

Windows: In the Z88 commander press button *Z88O.* If you press now the *Run button*, don't worry about the error message because Z88O wants to load the file Z88I1.TXT as a default which does not exist at the moment. However, you want to load now Z88NI.TXT: Proceed as follows: *Define structure file button > Z88NI.TXT*, *Run button.* Then switch to *Wireframe* by the appropriate button and show the nodal numbers and the element numbers by *Labels > All*. Zoom in with the *Prior* key. Close Z88O.

LINUX/UNIX: In the Z88 commander press button *Z88O.* If you press now the *Run button*, don't worry about the error message because Z88O wants to load the file Z88I1.TXT as a default which does not exist at the moment. However, you want to load now Z88NI.TXT: Proceed as follows: *File button > Z88NI.TXT*, *Run button.* Then switch to *Wireframe* by the appropriate button and show the nodal numbers and the element numbers by *Labels > All*. Zoom in with the *Prior* key. Close Z88O.

Z88N, mesh generator, reads Z88NI.TXT and produces Z88I1.TXT.

Windows: In the Z88 commander button *Z88N, Run button.* Quit the Z88N message box. **Hint:** You should always close the unneeded Z88 modules by quitting the message box to have a maximum of memory.

LINUX/UNIX: In the Z88 commander press button *Z88N.*

Z88O, looking at the finite elements structure. Proceed as follows:

Windows: In the Z88 commander press button *Z88O, Run Button.*

LINUX/UNIX: In the Z88 commander press button *Z88O*, *Run Button.*

Z88R, calculates displacements, stresses and nodal forces. Proceed as follows:

Windows: In the Z88 commander button *Z88R, Cholesky button*, *Run button*

LINUX/UNIX: In the Z88 commander radio button *Computation*, button *Cholesky*.

Z88O, looking at the deflected finite elements structure. Proceed as follows:

Windows: In the Z88 commander press button *Z88O, Run Button, Wireframe Button, Deflected Button.* As a default, the deflections are multiplied by 100. This is too large for this example. Thus: *Factors > Deflections >* enter for FUX and FUY 10 each. You may also look at the reduced stresses because Z88R was run before. Try the buttons *Reduced stresses in corner nodes*, *Reduced stresses mean values per element* and *Reduced stresses in Gauss points* (this feature for undeflected structures only).

LINUX/UNIX: In the Z88 commander press button *Z88O, Run Button, Wireframe Button, Deflected Button.* As a default, the deflections are multiplied by 100. This is too large for this example. Thus: *Factors > Deflections >* enter for FUX and FUY 10 each. You may also look at the reduced stresses because Z88R was run before. Try the buttons *Stresses Corner Nodes*, *Stresses per Element* and *Stresses Gauss Points* (this feature for undeflected structures only).

Your task:
A fork wrench should be loaded with the screw's tightness torque. A couple of forces are applied in the wrench's mouth according to the torque and the fixed points are assumed to be at the locations where the mechanic's hand grips the wrench. In fact, these clever boundary conditions are doing the same task as (in reality!) the fixed points in the mouth and the forces applied to the grip, but are much easier to handle.

The fork wrench should be modelled by 7 super elements Plane Stress No.7. The mesh generator should produce 66 finite elements from the super elements. The element thickness is 10 mm each. Mesh generation: Local and global axes are not the same direction in this example: Local x direction at super element 1 defines by the local nodes 1 and 2 which correspond to the global nodes 1 and 3. The local y direction of SE 1 is determined by local nodes 1 and 4 which correspond to the global nodes 1 and 7. Further take into account: Super elements which have a joint side must have an absolutely identical subdivision at this side. Thus, SE 1 and SE 2 share the line 3-4-5: The subdivisions in y direction must be exactly the same. Here 3 subdivisions, respectively.

Now calculate this example as indicated above. After that, one can experiment: Subdivide the SE 7 in Z88NI.TXT as a meaningful variation as follows:

```
7  7                ("Super element 7 is of type 7, i.e. Plane Stress Element No.7")
6  L  3  E ( "Subdivide SE 7 into finite elements Plane Stress No.7 and subdivide into x
              direction 6 times geometrically ascending and in y direction 3 times equidistant")
```

Of course, the SE 1 to SE 5 as well could each be condensed in direction of the screw:

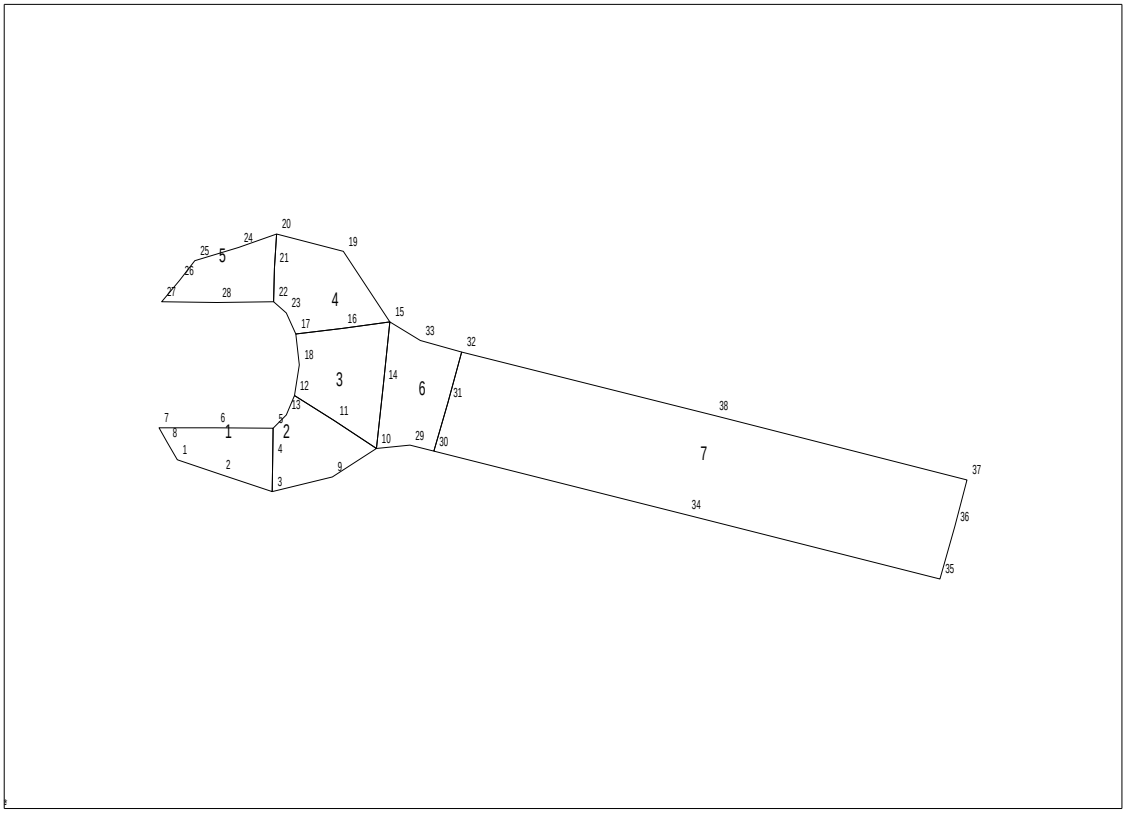
```
1  7
3  L  3  E
2  7
3  L  3  E
.... continue ....
```

Note: As it is obvious for the input files, you can add comments after all required data are

entered in every line. Separate the last date from the comment by at least one blank. You can do this just the same in your own files. A maximum of altogether 250 characters per line is permitted.

5.1.1 Input

This example works with a super structure, i.e. a very rough FE mesh. The mesh generator should generate a FE structure from the super structure. Thus, the first task is to design the mesh generator input file Z88NI.TXT. Chapter 2.4 outlines the procedure if working with CAD. If you work without a CAD system, you design the file Z88NI.TXT by editor or word processing program. The super structure shall look as follows:



With CAD program:
Follow the description of chapter 2.4. Do not forget to write the super element information on the layer Z88EIO by TEXT function. Thus
SE 1 7 7 3 E 3 E *(1st SE, SE type7, FE type7, subdiv. x 3 times equid., y 3 times equid.)*
SE 2 7 7 3 E 3 E *(2nd SE, SE type7, FE type7, subdiv. x 3 times equid., y 3 times equid.)*
SE 3 7 7 3 E 3 E
SE 4 7 7 3 E 3 E
SE 5 7 7 3 E 3 E
SE 6 7 7 1 E 3 E
SE 7 7 7 6 E 3 E

...and write the general information and material information onto the layer Z88GEN :

Z88NI.TXT 2 38 7 76 0 0 *(2-DIM,38 nodes,7SE,76 DOF, flags 0)*

Export the drawing as DXF file with the name Z88X.DXF and start the CAD converter Z88X with the option "from Z88X.DXF to Z88NI.TXT" (DXF → NI). Z88X will produce the mesh

generator input file Z88NI.TXT. You should have a look at it with Z88O.

With editor:

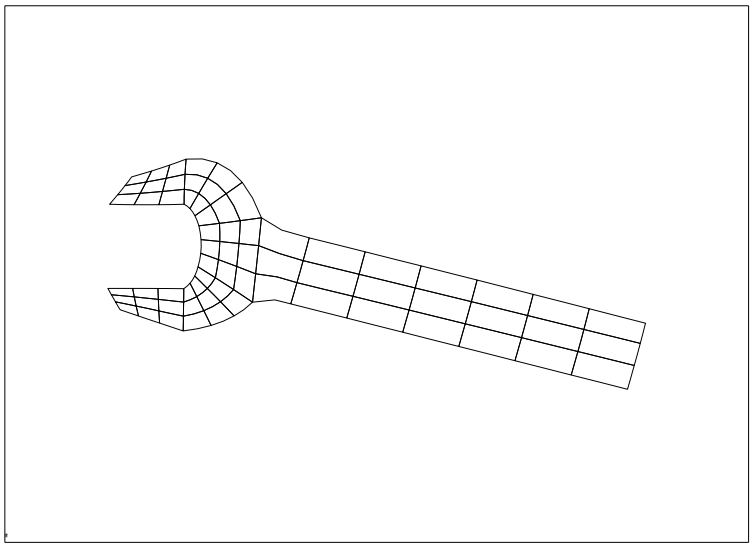
Write the mesh generator input file Z88NI.TXT (cf. chapter 3.9) with an editor:

```
2   38   7   76   0   0          (2-DIM,38 nodes,7SE,76 DOF, flags 0)
1   2   22.040   32.175          (Node 1, 2 DOF, X and Y coordinates)
2   2   31.913   28.798          (Node 2, 2 DOF, X and Y coordinates)
3   2   43.781   24.826
4   2   43.880   32.373
5   2   43.980   39.424
 .....                           (Coordinates for nodes 6... 36 not represented)
37 2   202.847 27.507
38 2   144.905 42.403
1   7                           (SE 1 of the type Plane Stress No.7)
1   3   5   7   2   4   6   8   (Coincidence for 1st SE)
2   7                           (SE 2 of the type Plane Stress No. 7)
3 10  12  5   9  11 13  4       (Coincidence for 2nd SE)
.....                           (Coincidence for elements 3 .. 6 dropped here)
7   7
30 35 37 32 34 36 38 31
1  7                        (Subdivide 1st SE into FE  type 7 and
3  E  3  E                 subdivide into x 3 times equidistant + into y 3 times equidistant)
2  7                        (Subdivide 2nd SE into FE  type 7 and
3  E  3  E                 subdivide into x 3 times equidistant + into y 3 times equidistant)
3  7
3  E  3  E
4  7
3  E  3  E
5  7
3  E  3  E
6  7
1  E  3  E
7  7
6  E  3  E
```

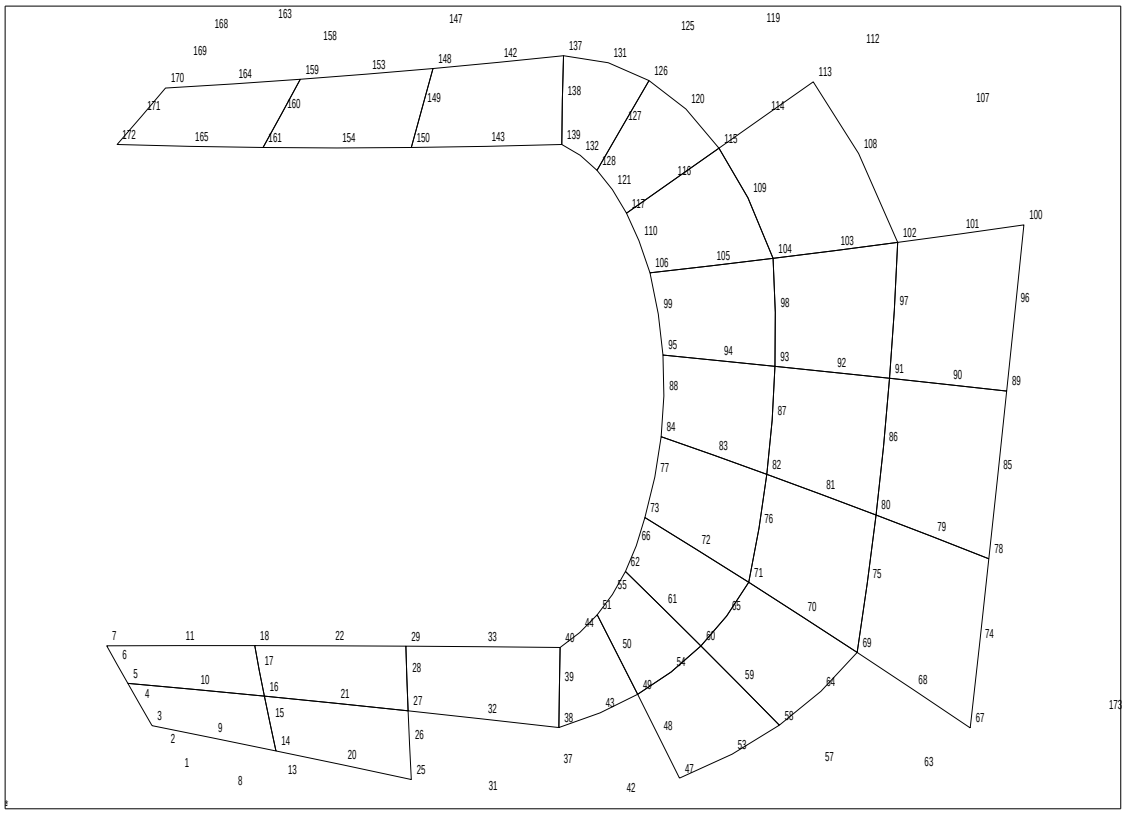
With CAD program and editor:

Start the mesh generator Z88N for producing the final Z88 structure file Z88I1.TXT. Look at it either

- in the CAD program (from Z88I1.TXT to Z88X.DXF) after conversion with Z88X or
- with the Z88 plot program Z88O for defining the boundary conditions:



Enlarge the wrench's mouth by zooming for defining the two nodes which will get the load representing the torque (to simplify matters it is assumed, that the screw gets only selectively a couple of forces as torque at the corners and that the screw itself and not the wrench revolves):



We find the nodes 11 and 143. The pictures printed here were produced directly by Z88O.

In the same way both the nodes for fixing the wrench are determined and the boundary conditions are entered:

with an Editor:
Design the boundary condition file Z88I2.TXT by editing:

16	*(16 Boundary conditions altogether)*
11 2 1 -7143	*(1st BC: Node 11, DOF 2, Force -7,143 N assumed)*

```
143  2  1  7143          (2nd BC: Node 143, DOF 2, Force 7,143 N assumed)
216  1  2  0             (3rd BC: Node 216, DOF 1, Displacement 0 (= fixed) assumed)
216  2  2  0
220  1  2  0
220  2  2  0
227  1  2  0
227  2  2  0
231  1  2  0
231  2  2  0
238  1  2  0
238  2  2  0
242  1  2  0
242  2  2  0
249  1  2  0
249  2  2  0
```

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

```
1                 (one material group in total)
1 66 51.txt       (range from ele.1 ~ ele.66 and reads 51.txt, see 3.5)
```

51.TXT:

```
206000 0.3        (Young's modulus 206000, Poisson's ratio 0.3, see 3.6)
```

Z88ELP.TXT:

```
1                       (one set of element parameters in total)
1 66 10 0 0 0 0 0 0     (range from ele.1 ~ Ele.66, thickness 10, other entries not interesting,
                         see 3.7)
```

Z88INT.TXT:

```
1                 one set of integration orders in total)
1  66  3   3      (range from ele.1 ~ ele.66, INTORD=3, INTOS=3, see 3.8)
```

Z88MAN.TXT: Only these entries are of interest, see 3.10:

```
IBFLAG   0    (no beams in the structure)
IPFLAG   0    (no plates in the structure)
IHFLAG   0    (no shells in the structure)
KDFLAG   0    (no calculation of radial- and tangential stresses)
ISFLAG   1    (reduced stresses: von Mises)
```

This data is distributed to several files for best working of our very advanced pre- and postprocessor Z88Aurora V2 - for Z88 V14 this is a bit oversized but was realized for best compatibility, however.

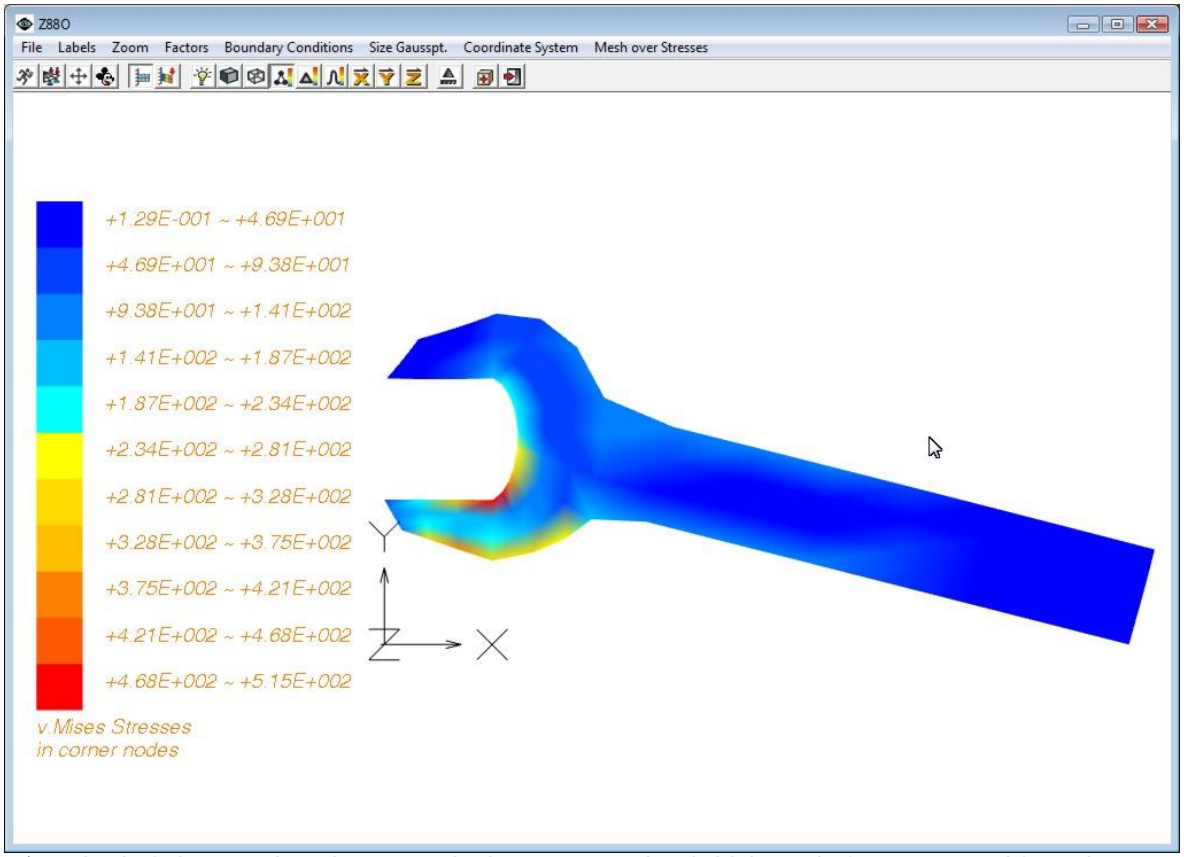
Now launch the Cholesky solver Z88R -choly. You will see during the run of Z88R, that 14.848 memory places are needed in the total stiffness matrix. NKOI, i.e. memory places in the coincidence vector KOI, is printed as 540. This matches Z88.DYN. Where does the

number 540 come from? 66 finite elements of the type Plane Stress No.7 with 8 nodes each, makes 66×8 = 528. The number 540 results because Z88R always calculates 20 nodes for security reasons for the last finite element. Thus, NKOI becomes here: 65×8 + 20 = 540.

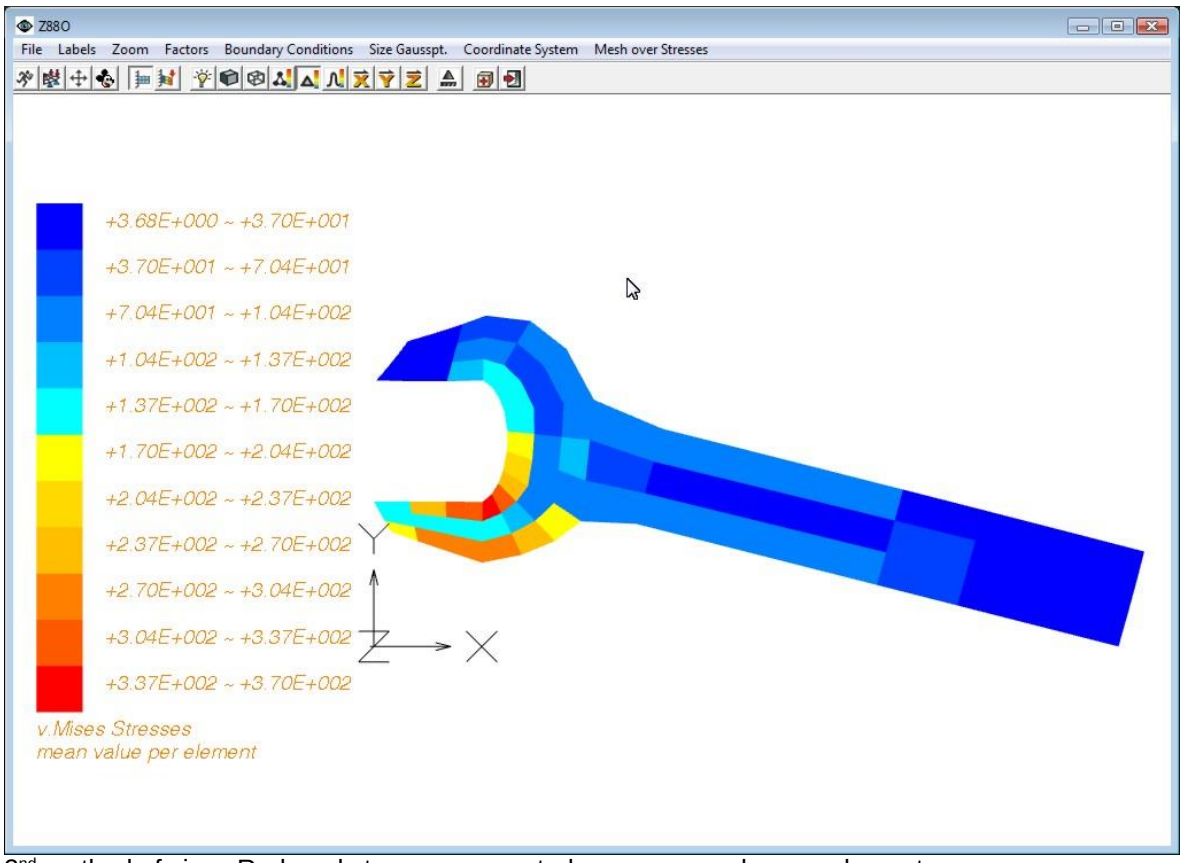
5.1.2 Results

The Cholesky solver Z88R provides the following output files:
Z88O0.TXT stores the processed structure data. It is mainly intended for documentation purposes, but also shows if your input file Z88NI.TXT for the mesh generator did what you meant it to do.
Z88O1.TXT stores the processed boundary conditions: For documentation purposes. And: Was your boundary conditions input in Z88I2.TXT correctly interpreted?
Z88O2.TXT, the displacements, the main task and solution of the FEA problem.
Z88O3.TXT, the calculated stresses. The results in Z88O3.TXT depend on the parameters in Z88MAN.TXT.
Z88O4.TXT, the computed nodal forces.

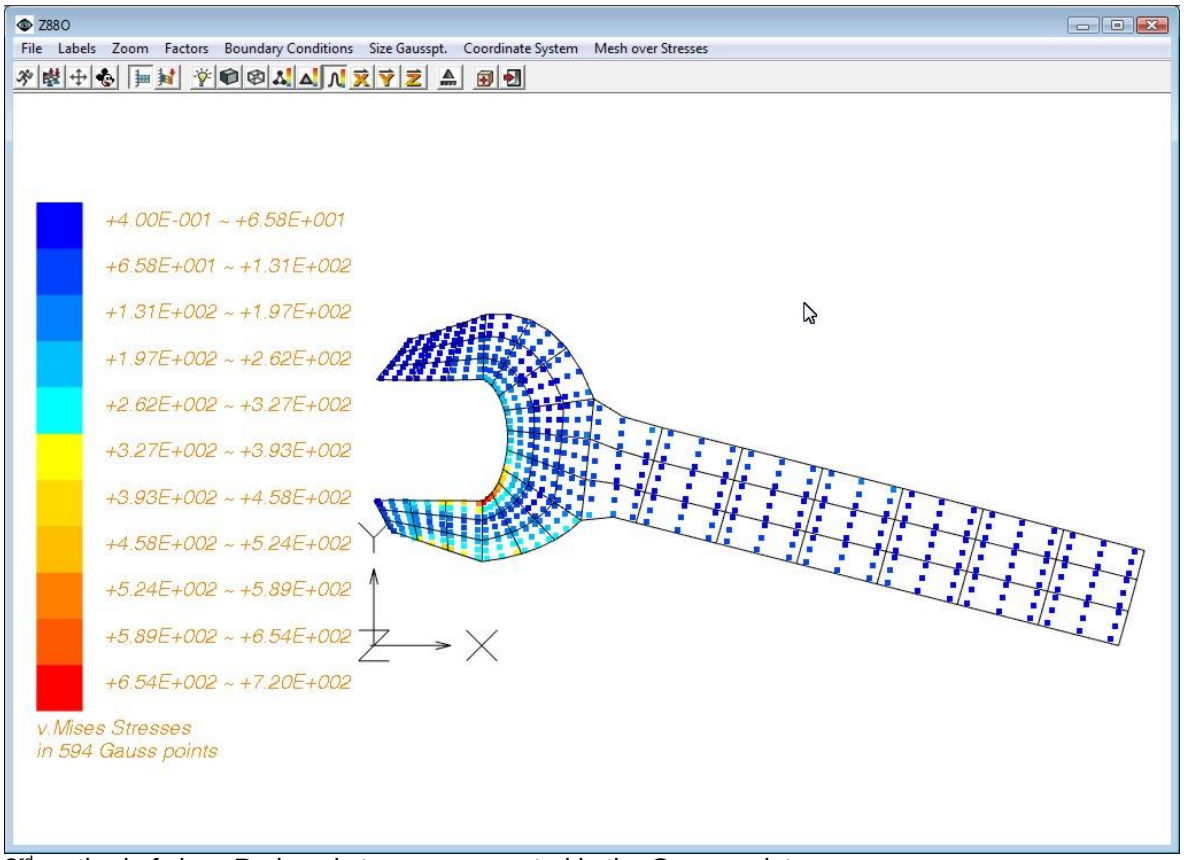
The OpenGL plot program **Z88O** can use three methods of view for reduced stresses: the average reduced stresses per node, average reduced stresses per element and the reduced stresses computed in the Gauss points. These three methods can give very different results depending on stress peaks. Usually the stresses computed in the Gauss points give the highest and most exact values depending on the kind of structure and boundary conditions. Otherwise, if you get nearly the same values for all three methods of view, then your kind of structure and the boundary conditions are very equable.



1st method of view: Reduced stresses in the corner nodes (which are in fact computed from the Gauss points around a node).



2nd method of view: Reduced stresses computed as a mean value per element.



3rd method of view: Reduced stresses computed in the Gauss points.

5.2 CRANE TRUSS WITH TRUSSES NO.4

Copy the example files from directory B2 into your Z88 working directory:

Z88X.DXF	CAD input file
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
52.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

CAD:
In this example you should only look at the CAD FE structure without producing it. This comes with later examples. Import Z88X.DXF into your CAD program and view it. Usually you would draw or model the structure in your CAD system. Do not change anything and leave your CAD program without saving, converting etc. If you do not have any suitable CAD system, then drop this step.

Z88:
Z88X, conversion from Z88X.DXF to Z88I1.TXT, Z88I2.TXT and Z88I3.TXT.
Windows: In the Z88 commander launch Z88X, press Button *DXF → Z88I** (default), *Run Button*.
LINUX/UNIX: In the Z88 commander press button *DXF → Z88I** under *CAD converters.*

Z88O, look at finite element structure. Proceed as follows:
Windows: In the Z88 commander launch Z88O, *Run Button*. Use the Wireframe Mode. Rotate the structure with the keys *F2~F7*, reset with *F8*. Pan with the arrow keys and *Home* and *End*, zoom in and out with *Prior* and *Next*. Then press the *Autoscale Button* (3rd button from left), to reset all transformations. Switch on *Mouse* (4th button from left). Now you may pan by the left mouse key pressed, zoom by the middle mouse key pressed and rotate by the right mouse key pressed. You may also label the nodes or elements: *Labels* etc.
LINUX/UNIX: In the Z88 commander launch Z88O, *Run Button*. Use the Wireframe Mode. Rotate the structure with the keys *F2~F7*, reset with *F8*. Pan with the arrow keys and *Home* and *End*, zoom in and out with *Prior* and *Next*. Then press the *Autoscale Button* (6th button from top), to reset all transformations. Switch on *Mouse* (7th button from top). Now you may pan by the left mouse key pressed, zoom by the middle mouse key pressed and rotate by the right mouse key pressed. You may also label the nodes or elements: *Labels* etc.

Z88R, calculates displacements, stresses and nodal forces. Proceed as follows:

Windows: In the Z88 commander button *Z88R, Cholesky button*, *Run button*

LINUX/UNIX: In the Z88 commander radio button *Computation*, Button *Cholesky*.

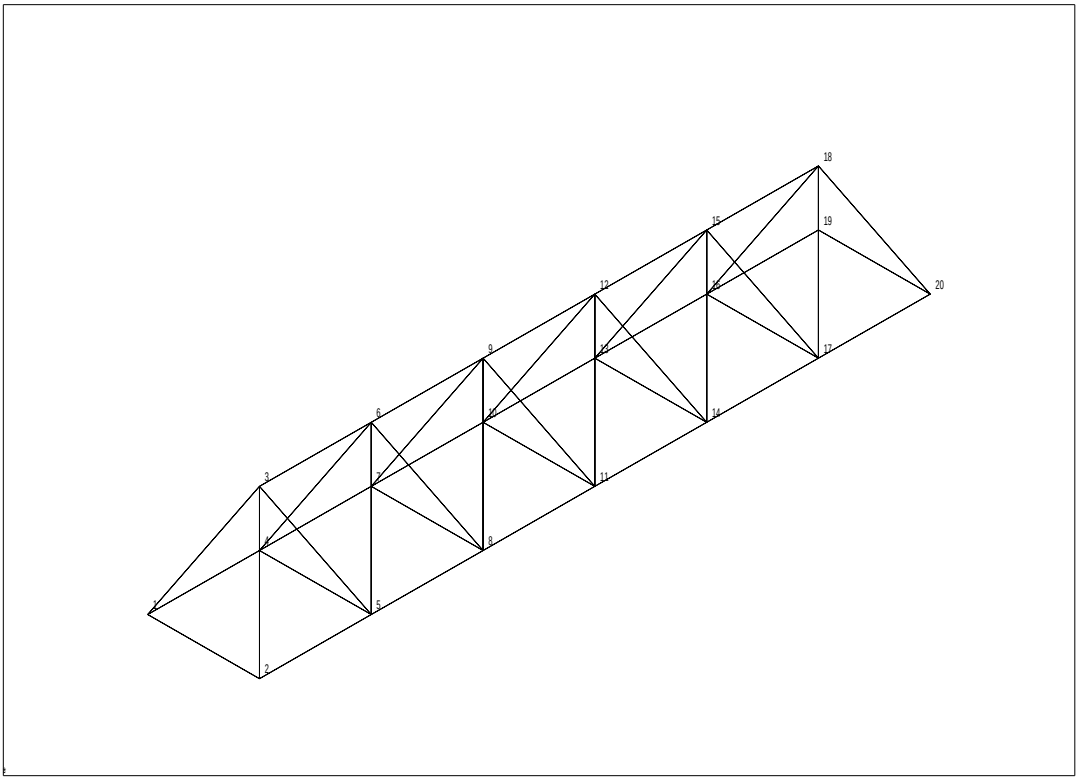
Z88O, looking at the deflected structure. Proceed as follows:
Windows, LINUX/UNIX: look at the deflected finite element structure. The deflections are magnified per default by the factor 100 which is correct for this example. If you'll press the three displacement buttons (X, Y and Z) you'll notice that the nodal displacements are plotted with different colours. Compare this to the values in the displacement file Z88O2.TXT.

If you'll enter into the solver parameter file Z88MAN.TXT: *KSFLAG 0* and *ISFLAG 1* and in addition into the integration orders file Z88INT.TXT *1 54 0 0* , you may run Z88R again. Now Z88O will present the tensile stresses as "reduced stresses" by switching to *Reduced stresses mean value per Element* (Windows) or *Stresses per Element* (UNIX).

The example is simple and straight. Experiment with the 3D features of the plot program Z88O.

A crane truss consists of 54 trusses, 20 nodes and forms a spatial framework. The nodes 1, 2 and 19, 20 are fixed, the nodes 7 and 8 are loaded per -30,000 N in Z direction. The total length is 12 m . The inputs in the sample file are in mm but inputs in meters are just as possible if the other entries like Young's modulus and cross-sectional area also refer to meters (or yards or inches). The Young's modulus is 200,000 N/mm^2, Poisson's ratio 0.3, the cross-sectional area 500 mm^2 each.

This example is taken from the (very good) book SCHWARZ, H.R.: FORTRAN Programme zur Methode der Finiten Elemente. Teubner Verlag, Stuttgart, Germany 1984.



5.2.1 Input

With CAD program:
Proceed after the description chapter 2.4.2. Do not forget to write on the layer Z88EIO the element descriptions by TEXT function:

FE 1 4 *(1st finite element type 4)*
FE 2 4 *(2nd finite element type 4)*
.....(Information not shown for elements 3 to 53)
FE 54 4 *(54th finite element type 4)*

Write on the layer Z88GEN the general information and material information, like

```
Z88I1.TXT  3   20  54   60  0        (3-D,20 nodes,54 ele,60 DOF, KFLAG 0 )
```

Since Trusses No.4 are structure elements (and thus cannot be subdivided like finite elements), the mesh generator cannot be used. You can immediately write the boundary conditions with the TEXT function on the layer Z88RBD: The structure should be fixed to the node 1, 2 and 19, 20. A load of 30,000 N each is applied to the nodes 7 and 8. The load should be applied downward, therefore -30,000 N.

```
Z88I2.TXT   10          (10 boundary conditions altogether)
RBD   1    1   2   2   0   (1st   BC: Node 1, DOF 2, Displacement 0 (=fixed in Y direction)
RBD   2    1   3   2   0   (2nd BC: Node 1, DOF 3, Displacement 0 (=fixed in Z direction)
RBD   3    2   1   2   0   (3rd BC: Node 2, DOF 1, Displacement 0 (=fixed in X direction)
RBD   4    2   3   2   0   (4th BC: Node 2, DOF 3, Displacement 0 (=fixed in Z direction)
RBD   5    7   3   1   -30000    (5th BC: Node 7, DOF 3, load -30,000)
RBD   6    8   3   1   -30000
RBD   7   19   1   2   0
RBD   8   19   3   2   0
RBD   9   20   2   2   0
RBD  10   20   3   2   0
```

Export the drawing as DXF file with the name Z88X.DXF and then launch the CAD converter Z88X with the option "from Z88X.DXF to Z88I*.TXT" (DXF → I*). The CAD converter will produce the input files Z88I1.TXT, Z88I2.TXT, Z88I5.TXT.

With an editor:
Enter the structure data into Z88I1.TXT by editor (cf. section 3.2):

```
3  20  54  60  0                  (3-dim,20 nodes,54 elements,60 DOF, KFLAG 0)
 1   3     0      2000     0      (1st node, 3 DOF, X, Y and Z coordinate)
 2   3     0         0     0      (2nd node, 3 DOF, X, Y und Z coordinate)
 3   3  1000      1000  2000
 4   3  2000      2000     0
 5   3  2000         0     0
.....                             (nodes 6 ..18 dropped here)
19   3  12000     2000     0
20   3  12000        0     0
 1   4                            (1st element, type Truss No.4)
 1   2                            (coincidence 1st element)
 2   4                            (2nd element, type Truss No.4)
 4   5                            (coincidence 2nd element)
 3   4
 7   8
.....                             (elements 4 ..53 dropped here)
54   4
17  19
```

The structure should be fixed to the node 1, 2 and 19, 20. A load of 30,000 N each is applied to the nodes 7 and 8. The load should be applied downward, therefore -30,000 N. Ref. to 3.3:

```
10                  (10 boundary conditions)
 1  2  2  0        (Node 1, DOF 2, Displacement 0 (=fixed in Y direction)
 1  3  2  0        (Node 1, DOF 3, Displacement 0 (=fixed in Z direction)
 2  1  2  0        (Node 2, DOF 1, Displacement 0 (=fixed in X direction)
 2  3  2  0        (Node 2, DOF 3, Displacement 0 (=fixed in Z direction)
 7  3  1  -30000   (Node 7, DOF 3, load -30,000)
 8  3  1  -30000
19  1  2  0
19  3  2  0
20  2  2  0
20  3  2  0
```

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

```
1                   (one material group in total)
1 54 52.txt         (range from ele.1 ~ ele.54 and reads 52.txt, see 3.5)
```

52.TXT:

```
200000 0.3          (Young's modulus 200000, Poisson's ratio 0.3, see 3.6)
```

Z88ELP.TXT:

```
1                       (one set of element parameters in total)
1 54 500 0 0 0 0 0 0    (range from ele.1 ~ Ele.54, cross-section area 500, other entries not
                         interesting, see 3.7)
```

Z88INT.TXT:

```
1                   one set of integration orders in total)
1  54  0   0        (range from ele.1 ~ ele.54, INTORD=0, INTOS=0, see 3.8)
```

Z88MAN.TXT: Only these entries are of interest, see 3.10:

```
IBFLAG    0     (no beams in the structure)
IPFLAG    0     (no plates in the structure)
IHFLAG    0     (no shells in the structure)
KDFLAG    0     (no calculation of radial- and tangential stresses)
ISFLAG    0     (no reduced stresses)
```

CAD and editor:

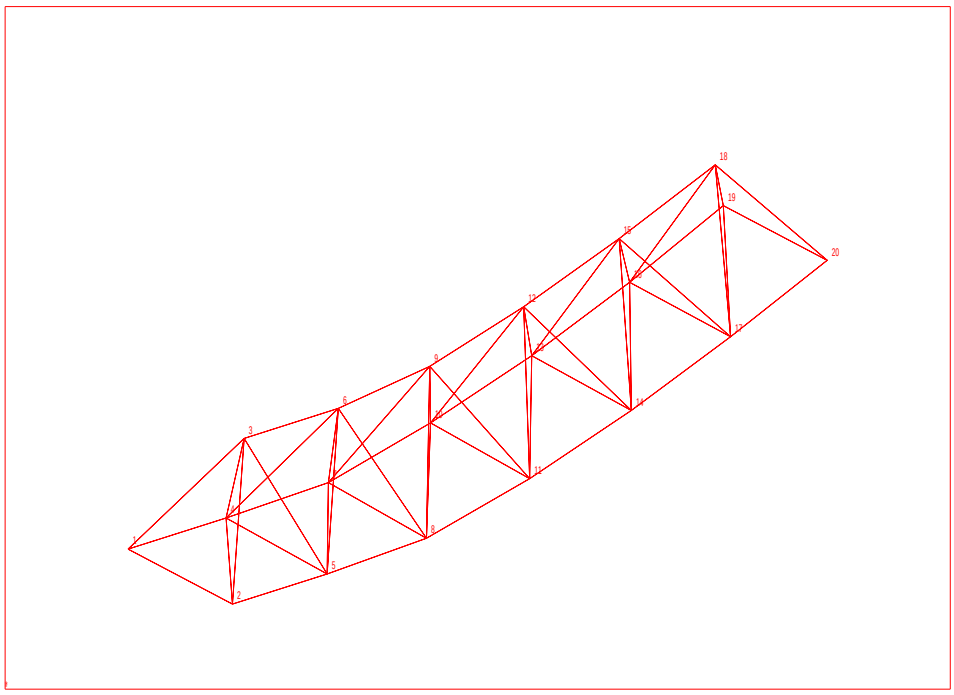
Because now the structure data Z88I1.TXT, the boundary conditions Z88I2.TXT, the surface loads file Z88I5.TXT (with a 0 in the first line) and the parameter files do exist, you can launch Z88R –choly. However, you may work with Z88R –siccg or Z88R –sorcg, too, but this very small framework is best suited for the Cholesky solver.

5.2.2 Results

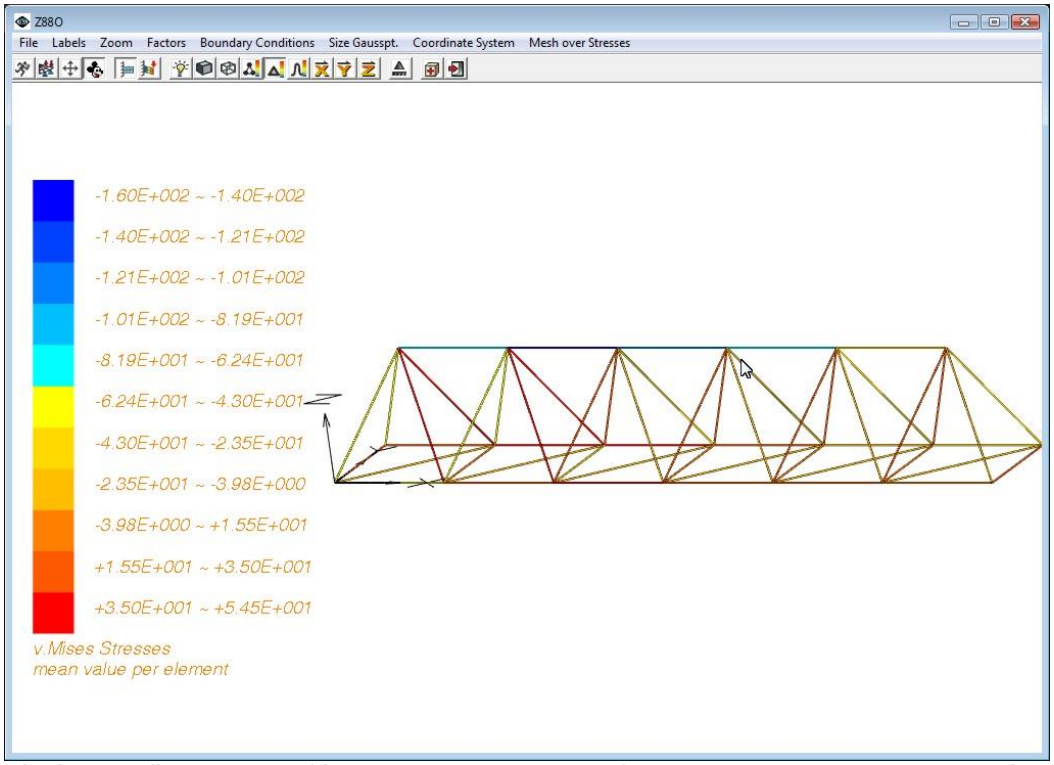
The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not

depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces.

The following picture of the plot program shows the deflected structure for FUX, FUY and FUZ = 100 each (magnifications of the deflections):



Reduced stresses are not provided in the plot program Z88O for Trusses No.4. But Z88O does it because tensile stresses of trusses are equivalent to *von Mises* stresses. Why don't you try it? You only have to outwit Z88O by entering ISFLAG 1 into Z88MAN.TXT. Re-run Z88R. Then launch Z88O and switch to *Reduced stresses mean values per element.* You should switch off *Mesh over stresses*.



Plotting tensile stresses with Z88O. Enter ISFLAG 1 into Z88MAN.TXT, run Z88R again.

5.3 TRANSMISSION CAM WITH CAM ELEMENTS NO.5

Copy the example files from directory B3 into your Z88 working directory:

Z88I1.TXT	structure data
Z88I2.TXT	boundary conditions
Z88I5.TXT	surface loads (with a 0 in der first line)
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
51.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

CAD:
Makes no sense for this extremely simple structure. However, for own experiments you may run Z88X with the switch „Z88I* to DXF“, thus, generating a DXF file from the input files Z88I1.TXT, Z88I2.TXT and Z88I5.TXT. Now you may read this DXF file into AutoCAD.

Z88:
Z88X, conversion from Z88X.DXF to Z88I1.TXT, Z88I2.TXT and Z88I5.TXT.
Windows: In the Z88 commander launch Z88X, press Button *DXF → Z88I** (default), *Run Button*.
LINUX/UNIX: In the Z88 commander press button *DXF → Z88I** under *CAD converters.*

Z88O, look at finite element structure. Proceed as follows:
Windows: In the Z88 commander launch Z88O, *Run Button*. Use the Wireframe Mode. Switch on *Mouse* (4th button from left). You may also label the nodes and elements: *Labels > Label All.*
LINUX/UNIX: In the Z88 commander launch Z88O, *Run Button*. Use the Wireframe Mode. Switch on *Mouse* (7th button from top). You may also label the nodes and elements: *Labels > Label All.*

Z88R, calculates displacements, stresses and nodal forces. Proceed as follows:

Windows: In the Z88 commander button *Z88R, Cholesky button*, *Run button*

LINUX/UNIX: In the Z88 commander radio button *Computation*, Button *Cholesky*.

Z88O, look at the deflected finite element structure. Proceed as follows:
Windows, LINUX/UNIX: Choose *Deflected*. The deflections are magnified per default by the factor 100 which is not enough for this example. Enter 1,000 each for *FUX, FUY* and *FUZ* in *Menu > Factors > Deflections*.

Basically, the calculation and displaying of reduced stresses is not provided in Z88 for cams No.5, because newer literal sources state correctly that reduced stresses for cams and other machinery parts under dynamic loads do not only depend on the normal and direct stresses (which are computed by Z88), but also on stress concentration factors (impossible to calculate in Z88 and other FEA systems with beam or cam elements; however, plane stress elements like No.7 would do this job, of course) and other factors.

Task: A transmission cam is designed as follows:

- Cam section, D= 30 mm, L = 30 mm , fixed bearing at the left end
- Gear wheel 1, reference circle D = 45 mm, L = 20 mm
- Cam section, D = 35 mm, L = 60 mm, moveable bearing in the middle
- Gear wheel 2, reference circle D = 60 mm, L = 15 mm
- Cam section, D = 40 mm, L = 60 mm, moveable bearing at the right end

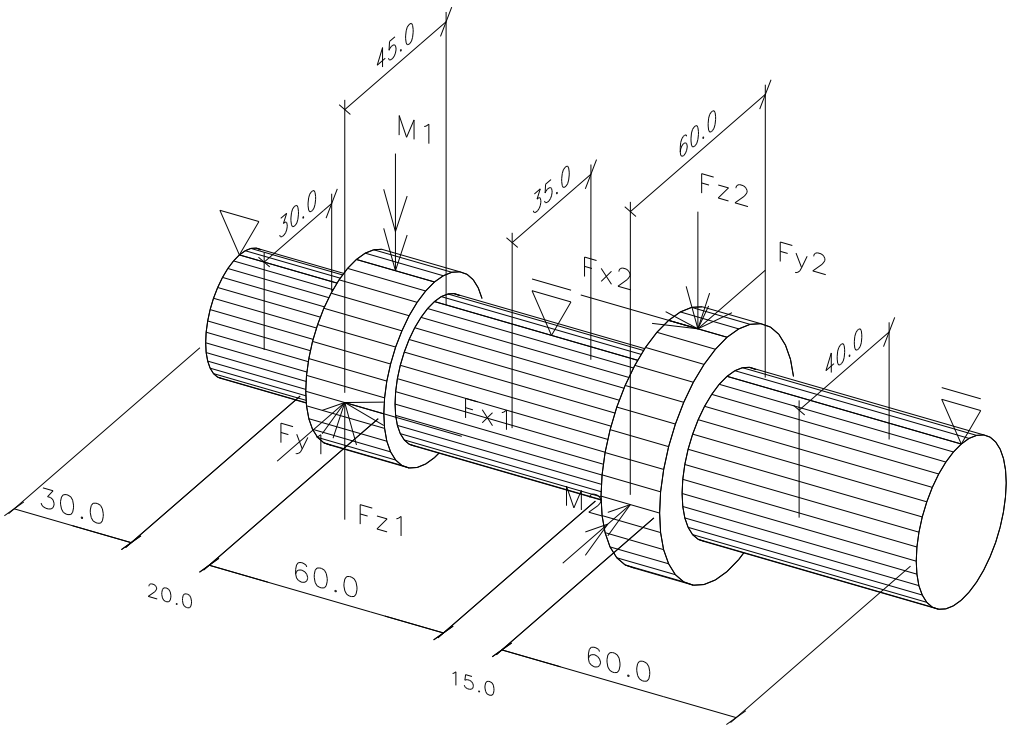
For the loads we picture the cam with the following coordinate system: If we look onto the cam as the main view, then the origin should be at the left end in the middle of the cam. X runs along the cam, Z runs to the upper direction, Y runs in the rear.

Gear wheel 1 gets the following loads in the (physical) point X1 = 40, Y1 = -22.5, Z1 = 0: Fx1 = -10,801 N, Fy1 = 6,809 N, Fz1 = 18,708 N. Fx1 results in a bending moment M1 around the Z axis of -243,023 Nmm.

Gear wheel 2 gets the following loads in the (physical) point X2 = 117.5, Y2 = 0, Z2 = 30: Fx2 = 8,101 N, Fy2 = -14,031 N, Fz2 = -5,107 N. Fx2 results in a bending moment M2 around the Y axis of -243,030 Nmm.

This results in loads in XY and XZ plane. The "physical" points do not exist in the FE calculation, of course, because a cam element is formed analytically only of two points along an axis. The Y and Z coordinates are always 0.

The cam is subdivided into eight cam elements No.5 = 9 nodes. The bearings are assumed in the nodes 1, 5 and 9. Very important: Node 1 is fixed in addition in the degree of freedom 4 (the torsion degree of freedom) in order to compute the torsion angle between the two gears. Otherwise, the structure is statically under-defined !



5.3.1 Input

This example can almost be entered easier by editor into a file than with CAD. The CAD use has real advantages for the examples 1, 2, 5 and 6.

With an editor:

Enter the structure data into Z88I1.TXT by editor (cf. section 3.2):

```
3  9   8  54   3    0          (3D, 9 Node, 8 Ele, 54 DOF, KFLAG 0)
 1  6    0      0   0          (Node 1, 6 DOF, X-, Y- und Z-Koordinate)
 2  6   30      0   0          (Node 2, 6 DOF, X-, Y- und Z-Koordinate)
 3  6   40      0   0
 4  6   50      0   0
 5  6   80      0   0
 6  6  110      0   0
 7  6  117.5    0   0
 8  6  125      0   0
 9  6  185      0   0
1   5                          (Element 1, cam No.5)
1   2                          (Coincidence Ele 1)
2   5                          (Element 2, type 5)
2   3                          (coincidence Ele 2)
..... (Elemente 3 to 7 dropped here)
8   5
8   9
```

The boundary conditions Z88I2.TXT:

```
18                             (18 Boundary conditions)
 1   1   2       0             (Node 1, DOF 1 (=X) fixed)
 1   2   2       0             (Node 1, DOF 2 (=Y) fixed)
 1   3   2       0             (Node 1, DOF 3 (=Z) fixed)
 1   4   2       0             (Node 1, DOF 4 (=torsion) fixed)
 3   1   1    -10801           (Node 3, DOF 1 (=X), load -10,801 N)
 3   2   1     +6809           (Node 3, DOF 2 (=Y), load 6,809 N)
 3   3   1    +18708           (Node 3, DOF 3 (=Z), load 18,708 N)
 3   4   1   -420930           (Node 3, DOF 4 (torsion) -420,930 Nmm)
 3   6   1   -243023           (Node 3, DOF 6 (bend. moment around Z),-243,023Nmm)
 5   2   2       0
 5   3   2       0
 7   1   1     +8101
 7   2   1    -14031
 7   3   1     -5107
 7   4   1  +420930
 7   5   1   -243030
 9   2   2       0
 9   3   2       0
```

The parameter file Z88MAN.TXT and the integration orders file Z88INT.TXT can have any content rgarding the stresses (cf. sections 3.10 and 3.8), because Gauss points, radial and tangential stresses as well as calculation of the von Mises stresses has no significance for Cam Elements No.5.

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

1	*(one material group in total)*
1 8 51.txt	*(range from ele.1 ~ ele.8 and reads 51.txt, see 3.5)*

51.TXT:

206000 0.3	*(Young's modulus 206000, Poisson's ratio 0.3, see 3.6)*

Z88ELP.TXT:

3	*(3 sets of element parameters)*
1 3 30 0 0 0 0 0 0	*(1.set from ele.1 ~ ele.3, diameter 30, vgl. 3.7)*
4 7 35 0 0 0 0 0 0	*(2.set from ele.4 ~ ele.7, diameter 35, vgl. 3.7)*
8 8 40 0 0 0 0 0 0	*(3.set from ele.8 ~ ele.8, diameter 40, vgl. 3.7)*

Z88INT.TXT:

1	*one set of integration orders in total)*
1 8 0 0	*(range from ele.1 ~ ele.8, INTORD=0, INTOS=0, see 3.8)*

Z88MAN.TXT: Only these entries are of interest, see 3.10:

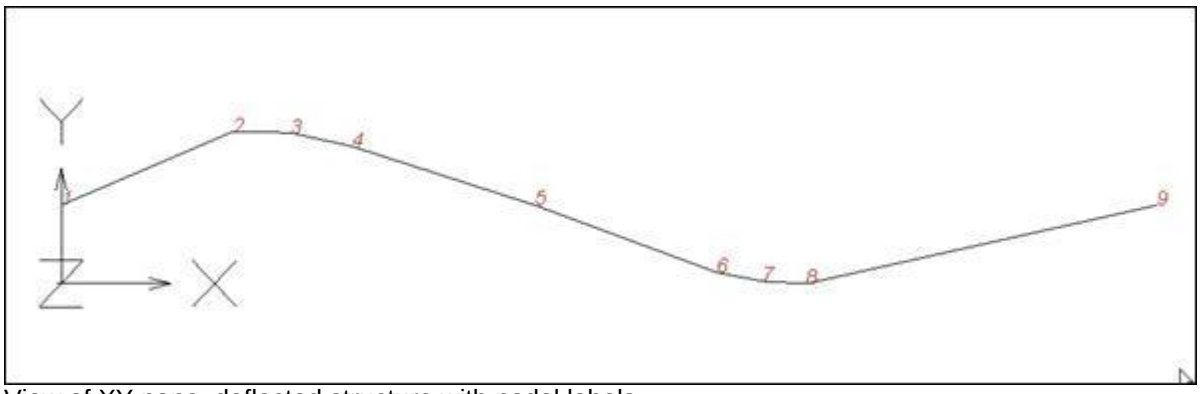
IBFLAG	0	*(no beams in the structure)*
IPFLAG	0	*(no plates in the structure)*
IHFLAG	0	*(no shells in the structure)*
KDFLAG	0	*(no calculation of radial- and tangential stresses)*
ISFLAG	0	*(no reduced stresses)*

CAD and editor:
Because now the structure data Z88I1.TXT, the boundary conditions Z88I2.TXT, the surface loads file Z88I5.TXT (with a 0 in the first line) and the parameter files do exist, you can launch Z88R –choly.

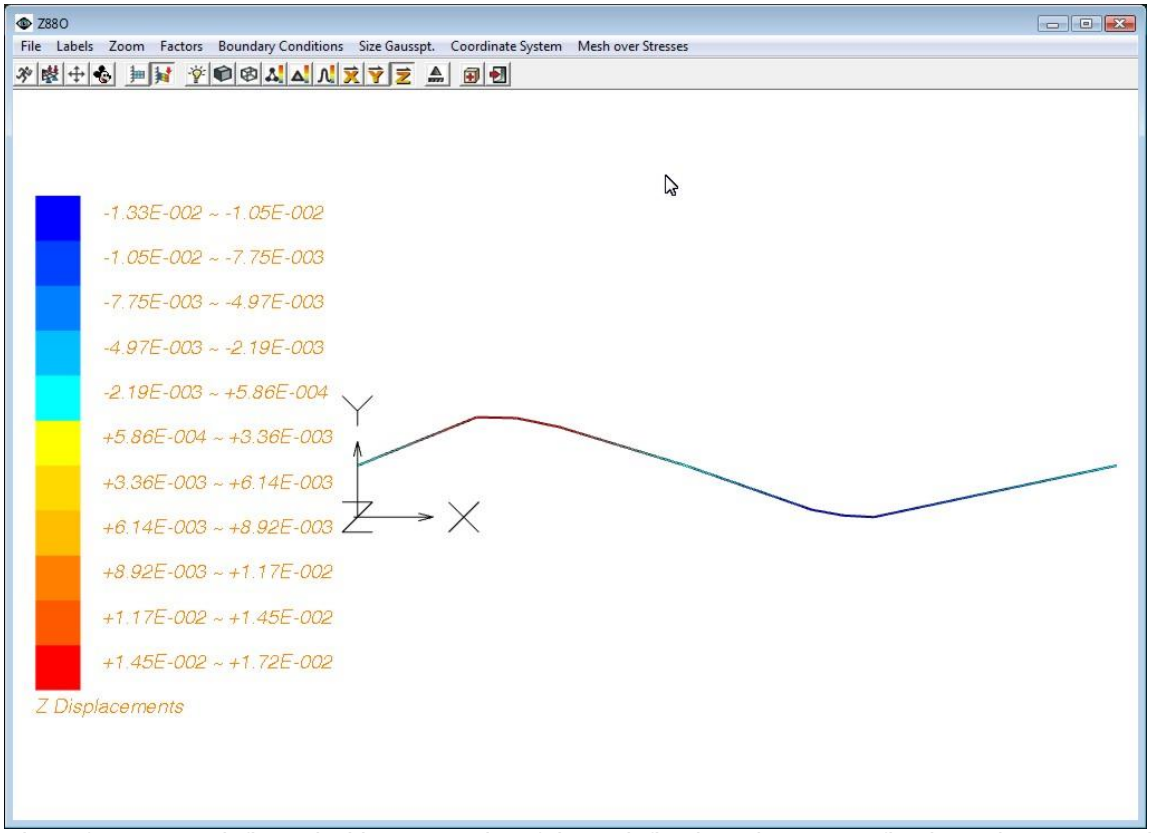
5.3.2 Results

The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces. Keep in mind, that the "forces" of the DOF 4, 5 and 6 are really moments, because the DOF 4, 5 and 6 are rotations.

The following pictures of the plot program show the deflected structure for FUX, FUY and FUZ = 1,000 each (magnifications of the deflections):



View of XY pane, deflected structure with nodal labels



View of XZ pane, deflected with coarse plot of the Z deflections (*Button Deflections Z*). Compare this to the exact values in Z88O2.TXT.

5.4 BEAM in PLANE WITH BEAMS NO.13

Copy the example files from directory B4 into your Z88 working directory:

Z88X.DXF	CAD input file
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
52.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

Z88: (in reduced form, more detailed instructions cf. examples 5.1, 5.2 and 5.3)
Z88O, looking at structure, structure file Z88I1.TXT
Z88R calculates deflections, stresses and nodal forces
Z88O, plot FE structure, now also deflected (FUX, FUY, FUZ per 10.)

This example deals with a beam, fixed on both sides, and loaded with 1,648 N in the middle in downward direction. This mechanical problem is covered in every mechanical and civil engineering handbook. Geometry: Length ℓ= 1,000 mm, cross-cut 50 x 10 mm. Thus: A = 500 mm^2, I_{zz} = 4,167 mm^4, e_{zz} = 5 mm.

The deflection curve has inflection points, we therefore take 4 beams No.13. Nodes 1 and 5 will be fixed and node 3 is loaded.

You would calculate analytically:

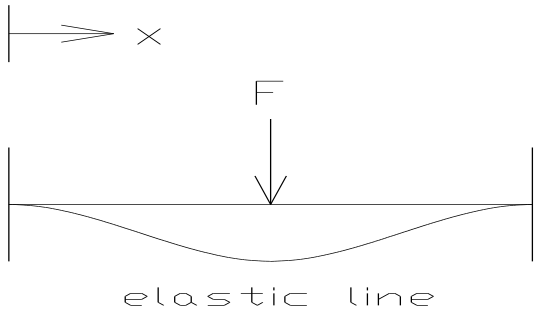
f in the middle: $f = \frac{F\ell^3}{192\,EI} = 10\,\text{mm}$

f in the inflection points: $f_w = \frac{f}{2} = 5\,\text{mm}$

The bending moments on the left, middle, on the right: $M_b = \frac{F\ell}{8} = 206{,}000\,\text{Nmm}$

The slope angle in the inflection points: $\psi = \text{atan}\left(\frac{3f}{\ell}\right) = 0.029991\,\text{rad}$

When interpreting the results of Z88O2.TXT (deflections) and Z88O4.TXT (nodal forces and moments) refer to the sign definition of chapter 4.13. Especially Z88O4.TXT, node 3: The force F(2) = force in Y direction is the sum of the forces of elements 2 and 3, due to extrinsic force. The force F(3) = bending moment is not a summary of elements 2 and 3, because it is an intrinsic moment, not an extrinsic load! Also the signs of the load F(3) at node 1 and F(3) at node 5 are correct, refer to chapter 4.13. Keep in mind that the classical mechanical science sometimes uses different conventions.



5.4.1 Input:

This example shows that a FEA basically needs nodes in all locations where you want to get results. As the beam is fixed left and right, the maximum of displacements appears in the middle for x = ℓ/2, but the bending curve features two inflection points for x = ℓ/4 and x = 3ℓ/4. To calculate results for this locations, the structure must be subdivided with nodes in x = 0, x = ℓ/4, x = ℓ/2 and x = 3ℓ/4.

Only the file input is shown here because CAD use is useless here.

Z88I1.TXT so becomes:

```
2  5  4 15  0    (2-D,5 nodes,4 ele,5 DOF,KFLAG 0)
1  3     0  0    (1.node, 3 DOF, X and Y coordinate)
2  3   250  0
3  3   500  0
4  3   750  0
5  3  1000  0
1 13            (1. element, type beam in plane No.13)
1  2            (coincidence for 1. element)
2 13
2  3
3 13
3  4
4 13
4  5
```

The node 1 is fixed in all degrees of freedom at the boundary conditions. It is important to fix especially the DOF 1 = displacement in X direction so that the structure cannot move. Node 5 is fixed in DOF 2 = displacement in Y direction and DOF 3 = rotation around Z axis. You could also fix DOF 1 for node 5, if you wish. But in reality one of the bearings or supports will allow for thermal expansion. This was taken into account in Z88I2.TXT.

Here is Z88I2.TXT:

```
6                    (6 Boundary conditions)
 1  1  2    0        (Node 1, DOF 1 gets a displacment of 0 = DOF 1 fixed)
 1  2  2    0        (Node 1, DOF 2 fixed)
 1  3  2    0        (Node 1, DOF 3 fixed (restraining moment)
 3  2  1 -1648       (Node 3, DOF 2 gets load of -1,648 N)
 5  2  2    0
 5  3  2    0
```

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

```
1                (one material group in total)
1 4 51.txt       (range from ele.1 ~ ele.4 and reads 51.txt, see 3.5)
```

51.TXT:

```
206000 0.3       (Young's modulus 206000, Poisson's ratio 0.3, see 3.6)
```

Z88ELP.TXT:

```
1                        (1 set of element parameters)
1 4 500 0 0 4167 5 0 0   (ele 1 ~ 4, QPARA, Ixx=0, exx=0, Izz, ezz, It=0, Wt=0)
```

Z88INT.TXT:

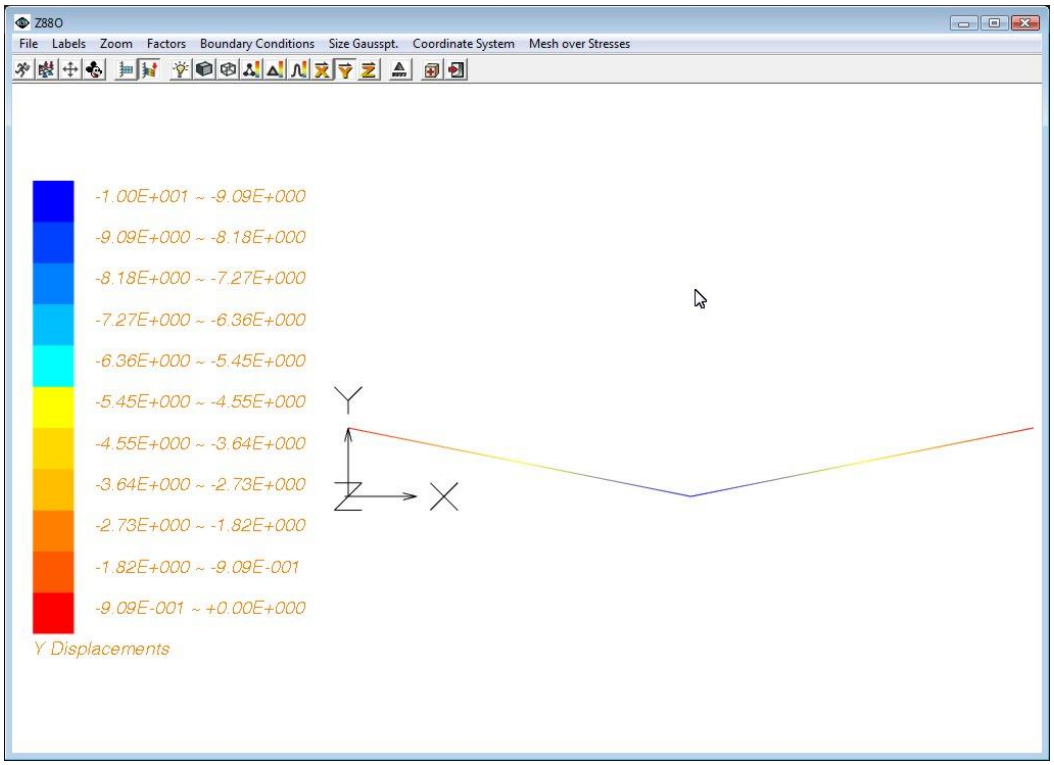
```
1                one set of integration orders in total)
```

1 4 0 0 *(range from ele.1 ~ ele.4, INTORD=0, INTOS=0, see 3.8)*

Z88MAN.TXT: Only these entries are of interest, see 3.10:
IBFLAG 1 *(beams in the structure)*
IPFLAG 0 *(no plates in the structure)*
IHFLAG 0 *(no shells in the structure)*
KDFLAG 0 *(no calculation of radial- and tangential stresses)*
ISFLAG 0 *(no reduced stresses)*

5.4.2 Results

The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces.
The following picture of the plot program shows the deflected structure for FUX, FUY and FUZ = 10 each (magnifications of the deflections).
Attention to the results of the nodal force calculation: Node 3: The force F(2) = force in Y direction is the sum of the forces of elements 2 and 3, due to extrinsic force. The force F(3) = bending moment is not a summary of elements 2 and 3, because it is an intrinsic moment, not an extrinsic load! Also the signs of the load F(3) at node 1 and F(3) at node 5 are correct, refer to chapter 4.13. Keep in mind that the classical mechanical science sometimes uses different conventions.
Additional remark: Such simple examples are well suitable to become aware of the sign definitions. Experiment with this example and calculate other bend cases from good handbooks. Frameworks with Beams No.2 are calculated accordingly. However, a real spatial structure then must be available: At least one Z coordinate must not equal 0.

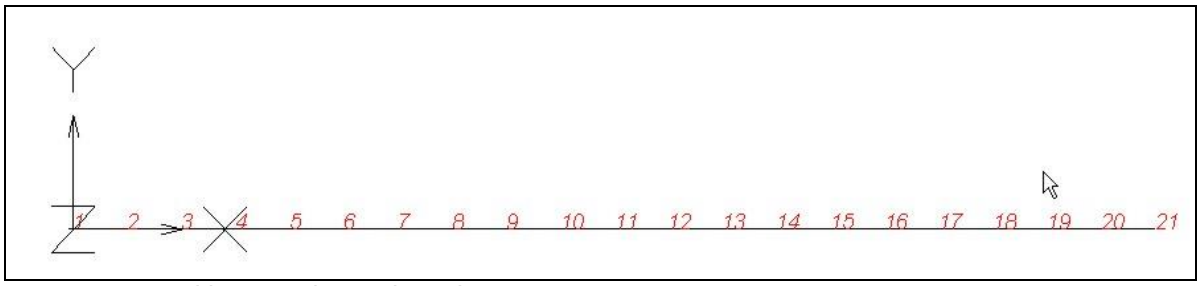


View of the deflected structure

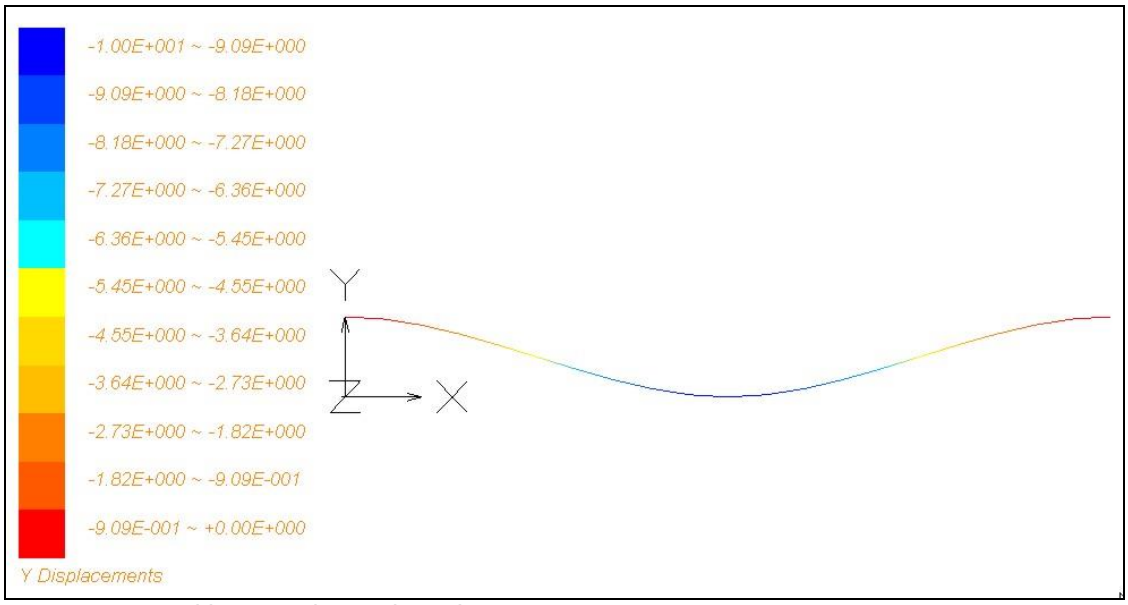
Take into account: The plot program Z88O connects the nodes with straight lines, although the deflection curve represents a cubic parable in the case of a Beam No.13 or No.2. This means: Z88O shows the deformations correctly for the node, but straight lines are between the nodes. Therefore, no deflection curve is shown. If you want to plot a real nice deflection curve with Z88O, then use basically more nodes, e.g. 15 to 20 nodes for this example (the cubic bending curve is then featured by a couple of straight lines). Just do it: Erlarge thy file Z88I1.TXT to 21 nodes and 20 elements und modify the boundary conditions file as follows:

```
 6
 1    1    2   0.
 1    2    2   0.
 1    3    2   0.
11    2    1 -1648.
21    2    2  0.
21    3    2  0.
```

Of course, this was prepared for you, see the directory B4_20ELE.



New structure with 21 nodes and 20 elements



New structure with 21 nodes and 20 elements

As you see we've got a quite nice line of deflection. And we may also plot the values of the deflections. Factors for Deflection FUX, FUY and FUZ 10 each.

Keep in mind: Place nodes into your structure where you want to get results!

5.5 PLATE SEGMENT WITH HEXAHEDRONS NO.1

Copy the example files from directory B5 into your Z88 working directory:

Z88X.DXF	CAD input file
Z88I2.TXT	boundary conditions
Z88I5.TXT	surface loads (with a 0 in the first line)
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
51.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

CAD:
Import Z88X.DXF into your CAD program and look at it. Usually you would have designed this example in a CAD system and then exported it as Z88X.DXF.

Z88: (in reduced form, more detailed instructions cf. examples 5.1, 5.2 and 5.3)
Z88X, conversion, "from Z88X.DXF to Z88NI.TXT"
Z88O, looking at super structure, super structure file Z88NI.TXT
Z88N, computes the finite element mesh
Z88O, looking at finite element structure, structure file Z88I1.TXT, undeflected
Z88X, conversion, "from Z88I*.TXT to Z88X.DXF"

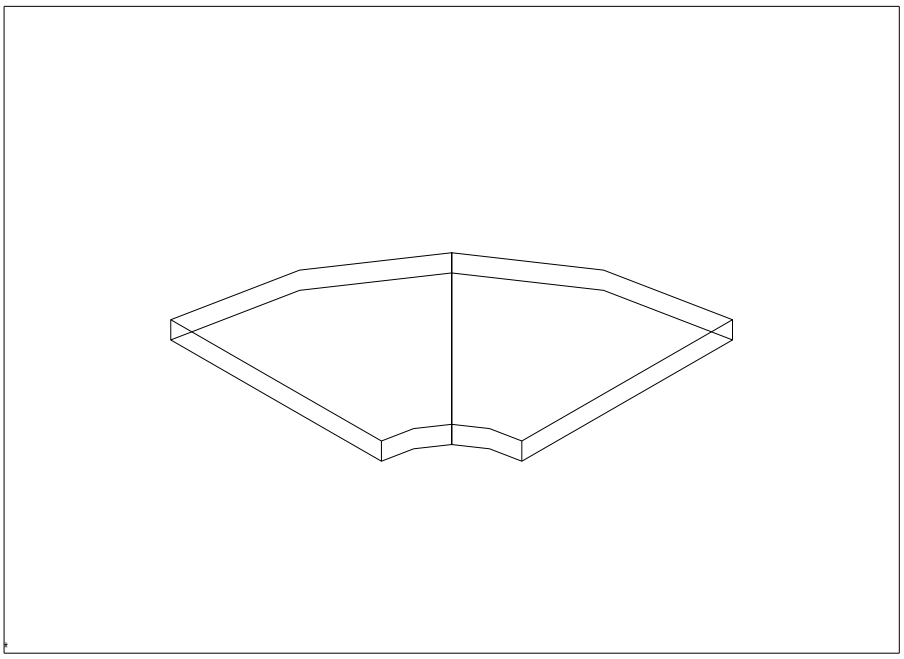
CAD:
Import Z88X.DXF into your CAD program and look at it. Usually you would have now added the boundary conditions and header parameters for Z88I3.TXT and then exported as Z88X.DXF.

Z88: (in reduced form, more detailed instructions cf. examples 5.1, 5.2 and 5.3)
Z88X, conversion, "from Z88X.DXF to Z88I*.TXT"
Z88R calculates deflections, stresses and nodal forces
Z88O plots FE structure, now deflected (FUX, FUY, FUZ per 10.), show v. Mises stresses

We deal with a 90 degrees disk segment which looks like a piece of tart. It is fixed at the outer edge and is loaded with 7,000 N at the inner edge. For such structures data entry is best by cylindrical coordinates. To fix the geometry two super elements Hexahedrons No.10 will do fine. These two SE are now to be subdivided into 48 Hexahedrons No.1 for the FE mesh.

This example is very suitable for experiments with the mesh generator . . if you do this, you have to define new boundary conditions, if necessary: With the help of your CAD program or the Z88 plot program.

Concerning the stress indication take into account that the stresses are plotted in the Gauss points. Gauss points lie within of a finite element, never directly on the surface. One gets stresses on the surface by extrapolation, e.g. bending stresses by use of the geometric analogy.



Super structure,consisting of two Hexahedrons No.10 with 20 nodes each

5.5.1 Input

With CAD program:
Use the description in chapter 2.4.2. Do not forget to write the super element information on the layer Z88EIO by TEXT function. Thus

SE 1 1 8 L 3 e 1 e *(1st super element, finite element type 1, subdivide into x 8 times increasing, into y 3 times equid., no subdivision into z)*
SE 2 1 8 L 3 e 1 e (*2nd super element, finite element type 1, subdivide into x 8 times increasing, into y 3 times equid., no subdivision into z)*
Write the general information and material information on the layer Z88GEN:

Z88NI.TXT 3 32 2 96 0 0 0 *(3-Dim, 32 nodes, 2 SE, 96 DOF, flags 0)*

Export the drawing as DXF file with the name Z88X.DXF and start the CAD converter Z88X with the option "from Z88X.DXF to Z88NI.TXT" (DXF → NI). Z88X will produce the mesh generator input file Z88NI.TXT. (You should have a look at it with Z88O).

With editor:
Write the mesh generator input file Z88NI.TXT (cf. chapter 3.9) with an editor:

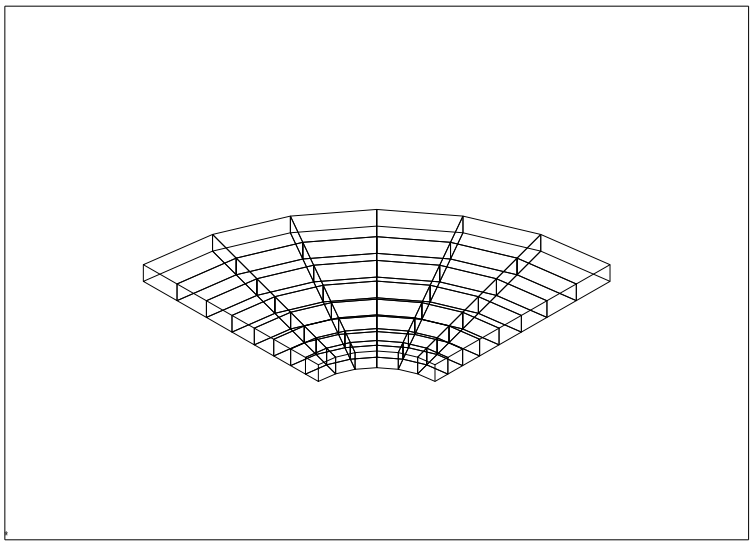
```
 3  32  2  96  0  0  0    (3-Dim, 32 nodes, 2 SE, 96 DOF, flags 0 )
 1  3  20  0  5           (1st node, 3 DOF, R-, Phi and Z coordinate)
 2  3  80  0  5           (2nd node, 3 DOF, R-, Phi and Z coordinate)
 3  3  80  45  5
.....                     (nodes 4..  30 not represented)
31  3  80  90  2.5
32  3  20  90  2.5
1  10                                                  (Super ele 1, type Hexah. No.10)
1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20   (coincidence for SE 1)
```

```
2  10                                                    (Super ele 2, type Hexah. No.10)
4 3 21 22 8 7 23 24 11 25 26 27 15 28 29 30 20 19 31 32  (coincidence for SE 2)
1  1                          (Subdivide SE1 into Hexahedrons No.1 and subdivide into
8  L  3  E  1  E              x 8 times increasing, into y 3 times equid., no subdivision into z)
2  1                          (Subdivide SE2 into Hexahedrons No.1 and subdivide into
8  L  3  E  1  E              x 8 times increasing, into y 3 times equid., no subdivision into z)
```

CAD and editor:

Start the mesh generator Z88N to produce the final Z88 structure file Z88I1.TXT. Look at it either

- in the CAD program (from Z88I1.TXT to Z88X.DXF) after conversion with Z88X or
- with the Z88 plot program Z88O for defining the boundary conditions:



View of the FE mesh Z88I1.TXT produced by the mesh generator

Now determine in the plot program or CAD system the nodes which are to be fixed or to be loaded and enter the boundary conditions:

In the CAD program:

Switch to the layer Z88RBD and write with the TEXT function into any free place:

```
Z88I2.TXT   49                  (49 boundary conditions altogether)
RBD   1     1   3   1   -1000   (1st BC: Node 1, DOF 3 (=Z), a load of 1,000 N downward)
RBD   2     3   3   1   -1000
RBD   3     5   3   1   -1000
RBD   4     7   3   1   -1000
RBD   5    65   1   2   0       (5th BC: Node 65, DOF 1 fixed)
RBD   6    65   2   2   0       (6th BC: Node 65, DOF 2 fixed)
RBD   7    65   3   2   0       (7th BC: Node 65, DOF 3 fixed)
.....(the nodes 66,67,68,69,70,71,72 are fixed in all 3 degrees of freedom, like node 65)
RBD  29   73   3   1   -1000
RBD  30   75   3   1   -1000
RBD  31   77   3   1   -1000
.... (the nodes 121,122,123,124,125 are fixed in all 3 degrees of freedom, like node 126)
RBD  47  126   1   2   0
RBD  48  126   2   2   0
RBD  49  126   3   2   0
```

With editor:
Design the boundary conditions file Z88I2.TXT by editing:

```
 49                  (49 boundary conditions altogether)
  1  3  1  -1000     (Node 1, DOF 3 (=Z), a load of 1,000 N downward)
  3  3  1  -1000
  5  3  1  -1000
  7  3  1  -1000
 65  1  2  0         (Node 65, DOF 1 fixed)
 65  2  2  0         (Node 65, DOF 2 fixed)
 65  3  2  0         (Node 65, DOF 3 fixed)
.....(the nodes 66,67,68,69,70,71,72 are fixed in all 3 degrees of freedom, like node 65)
 73  3  1  -1000
 75  3  1  -1000
 77  3  1  -1000
.... (the nodes 121,122,123,124,125 are fixed in all 3 degrees of freedom, like node 126)
126  1  2  0
126  2  2  0
126  3  2  0
```

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:
1 *(one material group in total)*
1 48 51.txt *(range from ele.1 ~ ele.48 and reads 51.txt, see 3.5)*

51.TXT:
206000 0.3 *(Young's modulus 206000, Poisson's ratio 0.3, see 3.6)*

Z88ELP.TXT:
1 *(1 set of element parameters)*
1 48 0 0 0 0 0 0 0 *(ele 1 ~ 48, QPARA=0, I_{xx}=0, e_{xx}=0, I_{zz}=0, e_{zz}=0, I_t=0, W_t=0)*

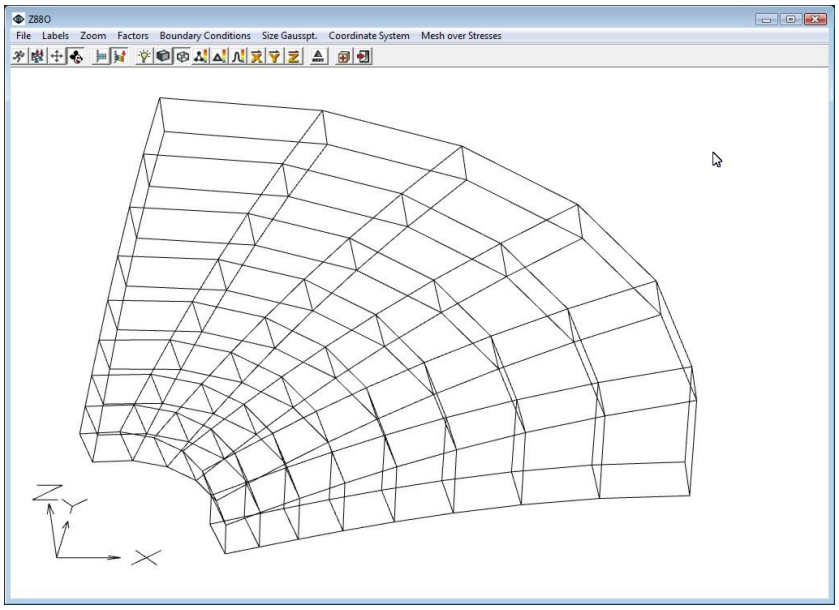
Z88INT.TXT:
1 *one set of integration orders in total)*
1 48 2 2 *(range from ele.1 ~ ele.48, INTORD=2, INTOS=2, see 3.8)*

Z88MAN.TXT: Only these entries are of interest, see 3.10:
IBFLAG 0 *(no beams in the structure)*
IPFLAG 0 *(no plates in the structure)*
IHFLAG 0 *(no shells in the structure)*
KDFLAG 0 *(no calculation of radial- and tangential stresses)*
ISFLAG 1 *(reduced stresses: von Mises)*

CAD and editor:
Now launch the Cholesky solver Z88R –choly. Z88I5.TXT features a 0 in the first line.

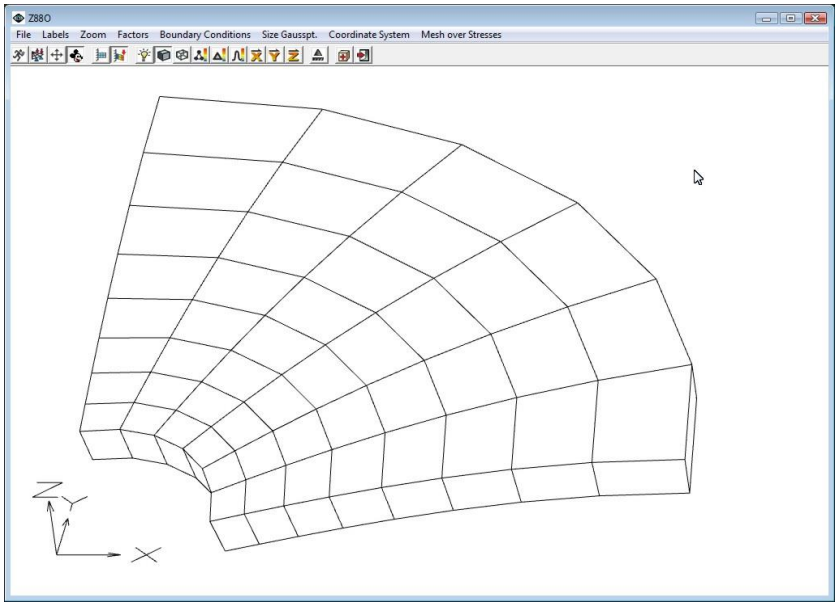
5.5.2 Results

The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces.
The following picture of the plot program shows the deflected structure for FUX, FUY and FUZ = 10 each (magnifications of the deflections):



View of the deflected structure, Wireframe Mode.

Hint: The super structure is very easy to design with e.g. AutoCAD. Draw the edges using arcs. The nodal points can easily be produced by the function > Draw > Point > Divide. When outlining the elements using the LINE function be sure to position the view in space exactly to match all nodes of a super element properly. This is a common source for a later malfunction of the CAD converter Z88X!



View of the deflected structure, Hiddenline Mode.

Hint: In reality you won't compute such a structure with hexahedrons with linear shape functions (Type No.1) but with hexahedrons with quadratic shape functions (Type No.10). See *Rieg, F.; Hackenschmidt, R., Alber-Laukant, B.: Finite Elemente Analyse für Ingenieure. 4. Auflage. München Wien. Carl Hanser: 2012 (in German language).*

5.6 PIPE UNDER INTERNAL PRESSURE, PLAIN STRESS ELEMENT NO.7

Copy the example files from directory B6 into your Z88 working directory:

Z88X.DXF	CAD input file
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
52.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

CAD:
Import Z88X.DXF into your CAD program and look at it. Usually you would have designed this example in a CAD system and then exported it as Z88X.DXF.

Z88: (in reduced form, more detailed instructions cf. examples 5.1, 5.2 and 5.3)
Z88X, conversion, "from Z88X.DXF to Z88I*.TXT"
Z88O, looking at structure, structure file Z88I1.TXT
Z88r calculates deflections, stresses & nodal forces
Z88O, plot FE structure, now also deflected (FUX, FUY, FUZ per 100.)

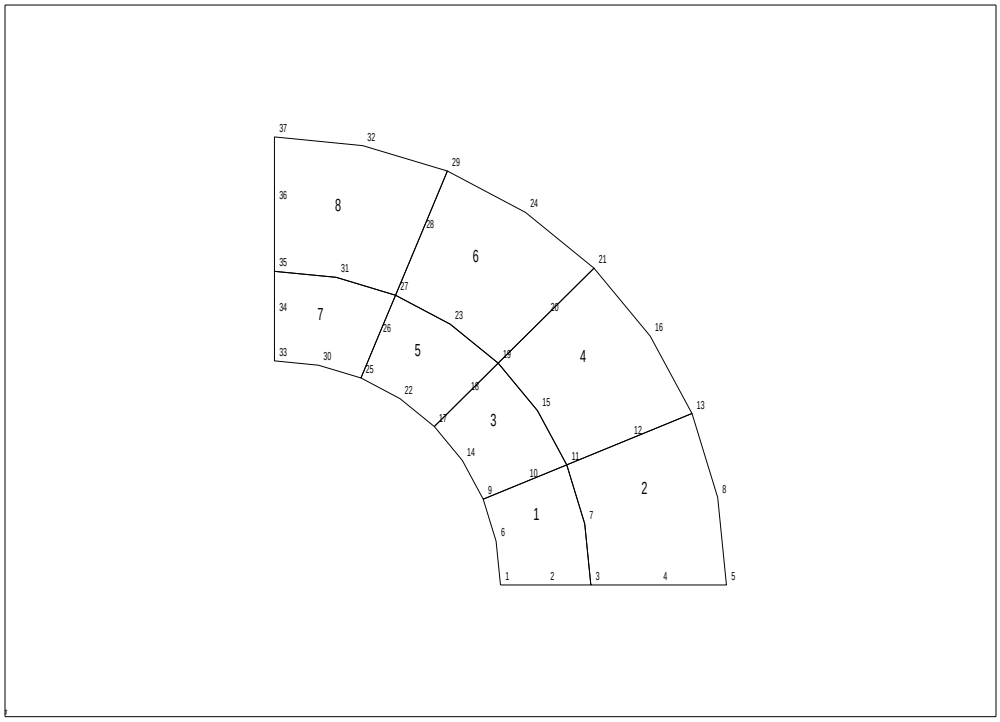
We deal with a pipe under internal pressure of 1,000 bar (=100 N/mm^2). Inside diameter of the pipe is 80 mm, outside diameter of the pipe is 160 mm. The length is 40 mm. If one chooses the supports cleverly, a quarter of the pipe is enough to reflect the problem.

Such structures are best suited for polar coordinates. The internal pressure of 1,000 bar corresponds to a force of 251,327 N which is loaded onto the inside quadrant. The 251,327 N have to be distributed onto the nodes 1,6,9,14,17,22,25,30 and 33 in accordance with the rules for boundary conditions (cf. chapter 3.3):
"1/6 points": 10,472 N
"2/3 points": 41,888 N
"2/6 points": 20,944 N
Control: 2×10,472+4×41,888+3×20,944 = 251,328 O.k.

These forces have an outwardly directed radial effect. Thus, they must be subdivided into X and Y components for boundary conditions. E.g. the node 6 as "2/3 point" is subdivided into X = 41,083 N and into Y = 8,172 N, because node 6 has an angle φ = 11.25 degrees.

When dealing with a rotationally symmetrical structure, the additional calculation of radial stresses and tangential stresses can be interesting: Set KDFLAG to 1 in Z88MAN.TXT. As stresses are calculated in the Gauss points, use linear extrapolations to get the stresses directly in the inside diameter and the outside diameter.

This problem is simple to check analytically. Consult appropriate machine element books for proper calculation formulas or see chapter 5.7.



Plot of the undeflected structure

5.6.1 Input

With CAD program:
Proceed after the description chapter 2.4.2. Do not forget to write on the layer Z88EIO the element descriptions by TEXT function:

FE 1 7 *(1st finite element type 7)*
FE 2 7 *(2nd finite element type 7)*
..... *(element 3 to 7 dropped here)*
FE 8 7 *(8th finite element type 7)*

Write the general information and material information on the layer Z88GEN, like

Z88I1.TXT 2 37 8 74 1 *(2D, 37 nodes, 8 ele, 74 DOF, polar coordinates: KFLAG=1)*

Write the boundary conditions with the TEXT function onto the layer Z88RBD. Here we have the case of edge loads for the boundary conditions. You should consult chapter 3.3. and take into account the explanation and sketches for load distributions.

Z88I2.TXT 26 *(26 boundary conditions)*
RBD 1 1 1 1 10472 *(1st BC: Node 1, DOF 1(= X), a load of 10,472 N)*
RBD 2 1 2 2 0 *(2nd BC: Node 1, DOF 2 (=Y), a displacement of 0 (=fixed))*
RBD 3 2 2 2 0
RBD 4 3 2 2 0
RBD 5 4 2 2 0
RBD 6 5 2 2 0
RBD 7 6 1 1 41083
RBD 8 6 2 1 8172

```
RBD   9   9 1   1   19350
RBD  10   9 2   1   8015
RBD  11  14 1   1   34829
RBD  12  14 2   1   23272
RBD  13  17 1   1   14810
RBD  14  17 2   1   14810
RBD  15  22 1   1   23272
RBD  16  22 2   1   34829
RBD  17  25 1   1   8015
RBD  18  25 2   1   19350
RBD  19  30 1   1   8172
RBD  20  30 2   1   41083
RBD  21  33 1   2   0
RBD  22  33 2   1   10472
RBD  23  34 1   2   0
RBD  24  35 1   2   0
RBD  25  36 1   2   0
RBD  26  37 1   2   0
```

Export the drawing as DXF file with the name Z88X.DXF, then start the CAD converter Z88X with the option "from Z88X.DXF to Z88I*.TXT" (DXF → I*). The CAD converter produces the three Z88 input files Z88I1.TXT, Z88I2.TXT, Z88I5.TXT.

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

```
1                 (one material group in total)
1 8 51.txt        (range from ele.1 ~ ele.8 and reads 51.txt, see 3.5)
```

51.TXT:

```
206000 0.3        (Young's modulus 206000, Poisson's ratio 0.3, see 3.6)
```

Z88ELP.TXT:

```
1                       (1 set of element parameters, see 3.7)
1 8 40 0 0 0 0 0 0      (ele 1 ~ 8, QPARA=40, Ixx=0, exx=0, Izz=0, ezz=0, It=0, Wt=0)
```

Z88INT.TXT:

```
1                 one set of integration orders in total)
1  8  3   3       (range from ele.1 ~ ele.8, INTORD=3, INTOS=3, see 3.8)
```

Z88MAN.TXT: Only these entries are of interest, see 3.10:

```
IBFLAG    0     (no beams in the structure)
IPFLAG    0     (no plates in the structure)
IHFLAG    0     (no shells in the structure)
KDFLAG    1     (additional calculation of radial- and tangential stresses)
ISFLAG    1     (reduced stresses: von Mises)
```

With editor:
Write the structure data file Z88I1.TXT (cf. chapter 3.2) with an editor:

```
2  37  8  74  1        ( 2D, 37 nodes, 8 elements, 74 DOF, Polar coor.:KFLAG=1)
 1  2  40  0           (1st node, 2 DOF, R and Phi coordinate)
 2  2  48  0           (2nd node, 2 DOF, R and Phi coordinate)
 3  2  56  0
 4  2  68  0
 5  2  80  0
 6  2  40  11.25
 7  2  56  11.25
 8  2  80  11.25
 9  2  40  22.5
.....                  (Nodes 10.. 35 dropped here )
36  2  68  90
37  2  80  90
 1  7                          (element 1, Plain Stress Element No.7)
 1  3  11  9  2  7  10  6      (coincidence 1st element)
 2  7
 3  5  13  11  4  8  12  7
.....                          (elements 3 .. 7 dropped here)
 8  7                          (element 8, Plain Stress Element No.7)
27  29  37  35  28  32  36  31 (coincidence 8th element)
```

Here we have the case of edge loads for the boundary conditions. Consult chapter 3.3. and take into account the explanation and sketches for load distributions. Here is Z88I2.TXT:

```
 26                 (26 boundary conditions)
  1  1  1  10472    (Node 1, DOF 1(= X), a load of 10,472 N)
  1  2  2  0        (Node 1, DOF 2 (=Y), a displacement of 0 (=fixed))
  2  2  2  0
  3  2  2  0
  4  2  2  0
  5  2  2  0
  6  1  1  41083
  6  2  1  8172
  9  1  1  19350
  9  2  1  8015
 14  1  1  34829
 14  2  1  23272
 17  1  1  14810
 17  2  1  14810
 22  1  1  23272
 22  2  1  34829
 25  1  1  8015
 25  2  1  19350
 30  1  1  8172
 30  2  1  41083
 33  1  2  0
 33  2  1  10472
 34  1  2  0
```

```
35  1   2   0
36  1   2   0
37  1   2   0
```

This example is very nice for experiments with the boundary conditions: Enter deflections rather than forces into X and Y, e.g. 0.01 mm in radial direction to the outside. At node 1 you can enter the 0.01 mm directly as X displacement and at node 33 you can enter directly the Y displacement of 0.01 mm, but for the other nodes the radial displacements of 0.01 mm must be subdivided into X and Y components respectively (via sine and cosine). Or enter mixed BC: A couple of nodes with displacements, the others with forces.. In practice nobody would do so for such a task, however, but Z88 can handle it.

A broad experimenting field also opens up with stress calculation: You have 5 possibilities for INTOS in Z88INT.TXT, two possibilities for KDFLAG in Z88MAN.TXT and four choices for ISFLAG in Z88MAN.TXT, cf. Chapters 3.8, 3.10 and 4.7. Thus, you can produce plenty of results:

Z88INT.TXT:

```
1                   (one set of integration orders)
1  8  3  3          (from ele.1 ~ ele.8, INTORD=3, INTOS=3, see 3.8)
```

Z88MAN.TXT: Here are only important, see 3.10:

```
KDFLAG  1   (additional calculation of radial- and tangential stresses)
ISFLAG  1   (reduced stresses: von Mises )
```

CAD and editor:

The structure data Z88I1.TXT, the boundary conditions Z88I2.TXT, the surface loads Z88I5.TXT (with a 0 in the first line) and the parameter files are ready to go. Now launch Z88R –choly (or the iteration solver, if you wish).

Boundary conditions by edge loads:

The data entry by single forces was somewhat cumbersome because of dividing the force of 251.327 N to several nodal points with respect to the actual angle position. It is much more easier to enter edge loads by the surface and pressure loads file Z88I5.TXT. The edge load is:

$$q = \frac{F}{\ell} = \frac{F}{r \times \varphi} = \frac{251327}{40 \times \pi/2} = 4000\, N/mm$$

This edge load acts onto the elements 1, 3, 5 and 7. The edge of element 1 is the edge defined by the corner nodes 9 and 1 and the middle node 6 etc. The edge load points normally to the edge, there are no tangential loads. Thus, the surface and pressure loads file Z88I5.TXT is:

```
4
1   4000.   0.    9   1   6
3   4000.   0.   17   9  14
5   4000.   0.   25  17  22
7   4000.   0.   33  25  30
```

The surface loads file is now read because the first entry is > 0.

Now edit the boundary conditions file Z88I2.TXT: Skip all forces:

```
10
 1   2   2   0.
 2   2   2   0.
 3   2   2   0.
 4   2   2   0.
 5   2   2   0.
33   1   2   0.
34   1   2   0.
35   1   2   0.
36   1   2   0.
37   1   2   0.
```

Please see the directory B6_Q on the CD-ROM or the Internet packages. Now compute deflections, stresses and nodal forces as usual with Z88R –choly.

5.6.2 Results:

The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces.

This example is very suitable to demonstrate all the possibilities of the stress calculation with Z88D and Plain Stress Elements No.7 (or Plain Stress Elements No.11). We recall:

Z88INT.TXT:
1
1 8 3 3 *(INTOS=1,2,3,4 see 3.8)*

Z88MAN.TXT: see 3.10:
KDFLAG 1 *(0 or 1: additional calculation of radial- and tangential stresses)*
ISFLAG 1 *(0,1,2,3 : no reduced stresses,v.Mises,principal s.,Tresca)*

Now experiment.. you have $5 \times 2 \times 4 = 40$ possibilities.

Now you should plot the boundary conditions. The problem here is that some nodes have more than one BC e.g. node 1 features a force in X direction and is fixed in Y direction, too:

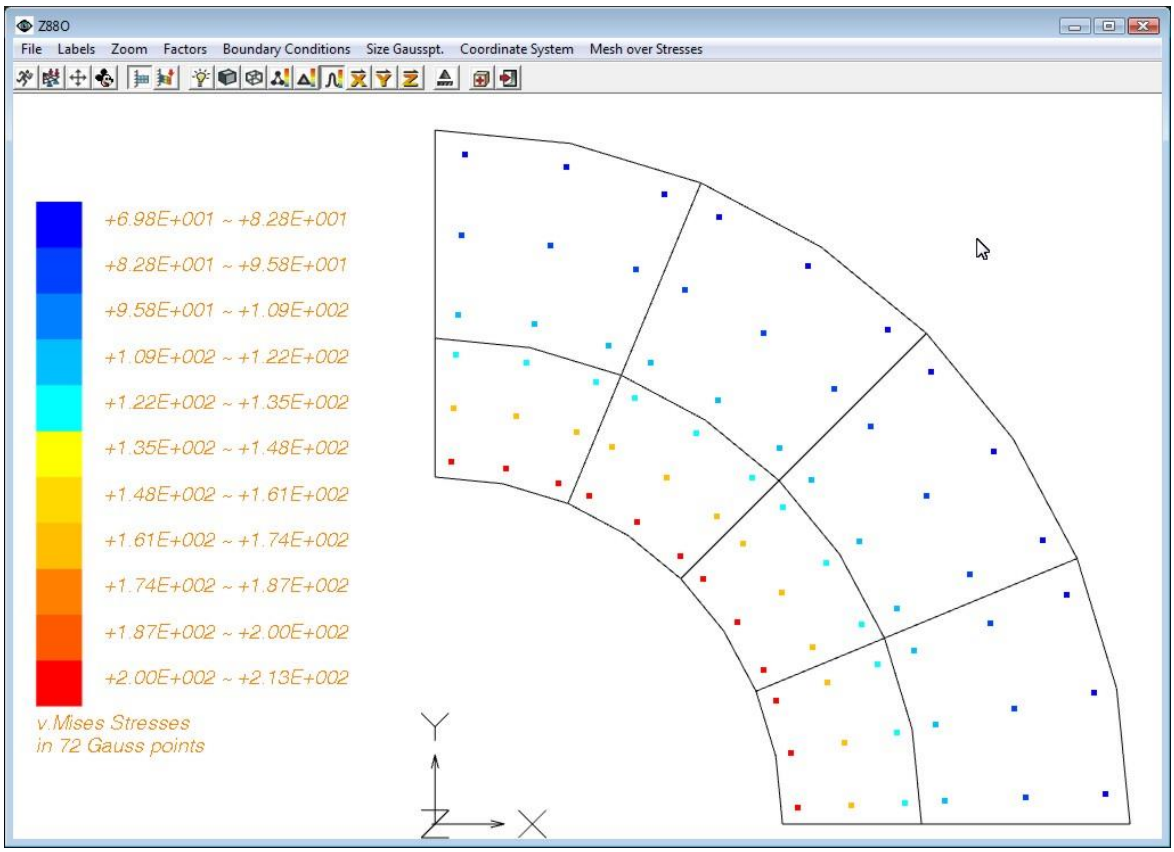
```
 1   1   1  +1.04720E+004
 1   2   2  +0.00000E+000
```

Thus, you select the BC you want to see.

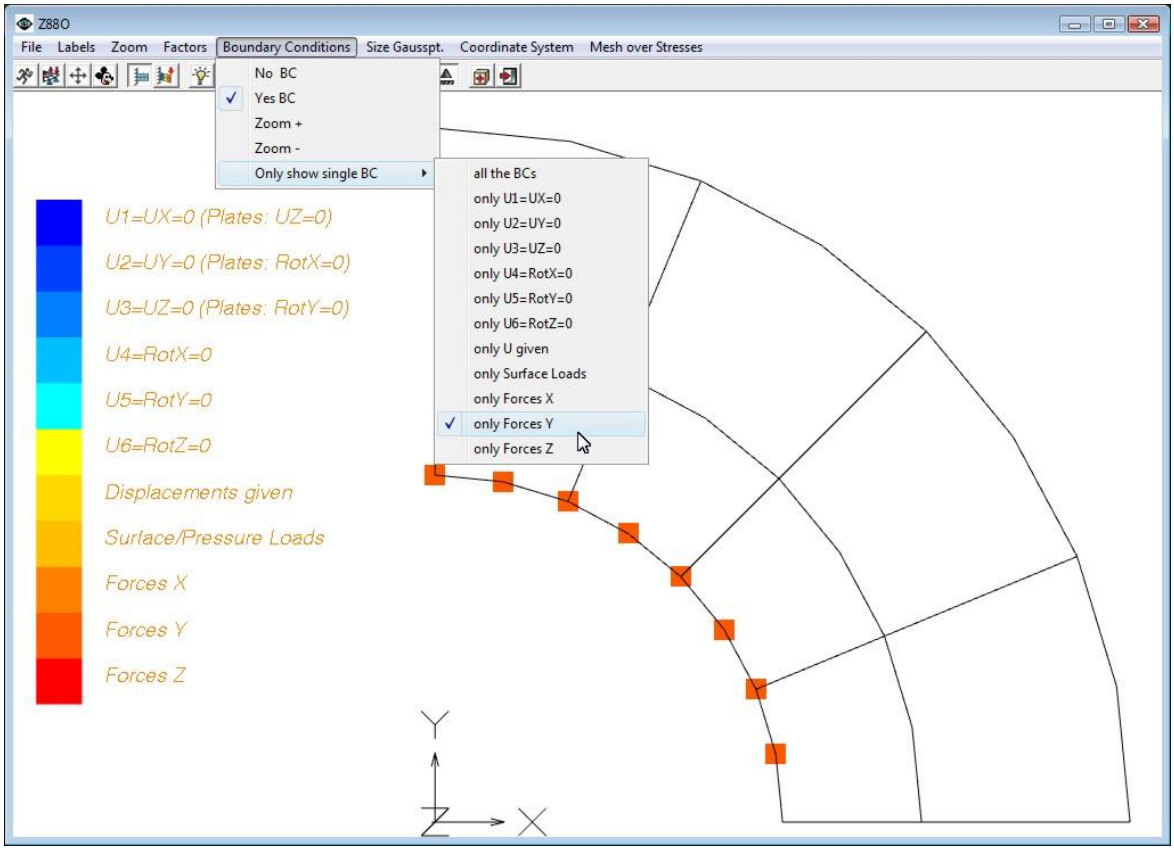
Suppose you would now choose a hardened steel. This means to compute the *principal stresses* not the *von Mises* stresses. Thus, the ISFLAG in Z88MAN.TXT would now read 2:

Z88MAN.TXT: Only important, see 3.10:
KDFLAG 1 *(additional calculation of radial- and tangential stresses)*
ISFLAG 2 *(reduced stresses: principal stresses)*

Then re-run Z88R.



Plot of the stresses in the Gauss points with Z88O



Example for the selective plot of BCs with Z88O

5.7 PIPE UNDER INTERNAL PRESSURE, TORUS NO.8

Copy the example files from directory B7 into your Z88 working directory:

Z88X.DXF	CAD input file
Z88I2.TXT	boundary conditions
Z88I5.TXT	surface loads (with a 0 in the first line)
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
51.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

CAD:
Import Z88X.DXF into your CAD program and view the super structure. You usually would have designed this example in a CAD system and then exported it as Z88X.DXF.

Z88:
Z88X, conversion "from Z88X.DXF to Z88NI.TXT"
Z88O, structure file Z88NI, look at the super structure
Z88N, mesh generator, produces Z88I1.TXT
Z88O, structure file Z88I1.TXT, undeflected FE structure
Z88X, conversion, "from Z88I* . TXT to Z88X.DXF"

CAD:
Import Z88X.DXF into your CAD program and look at it. You usually would have now added the boundary conditions and control information Z88I3.TXT into CAD and then exported it as Z88X.DXF.

Z88:
Z88X, conversion, "from Z88X.DXF to Z88I* . TXT"
Z88R calculates deflections, stresses & nodal forces
Z88O, plots FE structure, now also deflected and stresses display

We look at a pipe under internal pressure. Pipe inside diameter 80 mm, pipe outside diameter 160 mm, length 40 mm. For Torus elements the cross-section of the pipe is important.
The inside radius shall be expanded by 0.1 mm = r_d (press fit). Attach this displacements to the nodes from 1 to 11. To fix the structure in space, e.g. fix node 6 in Z direction.

One calculates analytically (assuming Young's modulus E= 206,000 N/mm^2 and Poisson's ratio υ= 0.3):

pressure: $$p = \frac{r_d E}{r_i} \cdot \frac{1}{\frac{1+q_a}{1-q_a} + \nu} = 262\ \text{N/mm}^2 = 2,620\ \text{bar} \quad with \quad q_a = \frac{r_i^2}{r_a^2} = 0.25$$

radial stresses: $$\sigma_{r_i} = -\,p = -\,262\ \text{N/mm}^2$$
$$\sigma_{r_a} = 0$$

tangential stresses: $\sigma_{t_i} = p \times \frac{1 + q_a}{1 - q_a} = 437 \text{ N/mm}^2$

$$\sigma_{t_a} = 2p \times \frac{q_a}{1 - q_a} = 175 \text{ N/mm}^2$$

von Mises stresses: $\sigma_{Vi} = \sqrt{\sigma_r^2 + \sigma_\theta^2 - \sigma_r \cdot \sigma_\theta} =$

$$\sqrt{(-262)^2 + 437^2 - (-262) \cdot 437} = 612 \text{ N/mm}^2$$

Because stresses are calculated in the Gauss points, use linear extrapolations to get the stresses directly in the inside diameter and the outside diameter.

The force: $F = p\,A = p\,2\,\pi\,r_i\,\ell = 2{,}633{,}911 \text{ N}$

This confirms the sum of the forces of the elements 1-5 for the nodes 1-11 in Z88O4.TXT.

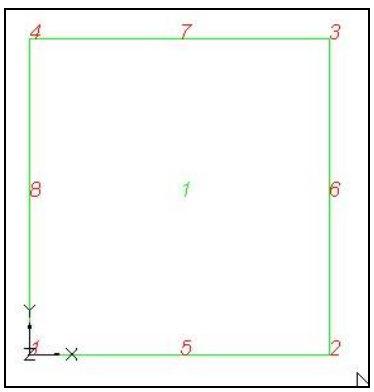
5.7.1 Input

General: The entries for the mesh generator contain merely a single Torus No.8 as super element. It is subdivided into 40 finite elements. A Torus No.12 also could, of course, be used as super element. Yet this is quite useless for this simple super structure, being designed of straight lines. Torus elements No.12 are more powerful than Torus elements No.8 if the super structure has many curvilinear edges because they feature cubic shape functions, but Torus No.8 uses only square parables. Thus, many curvilinear structures allow a better approach with few Torus elements No.12 due to the higher curve function.
Make sure that cylindrical coordinates are always expected for Torus No.6, No.8 and No.12, i.e. radius R (replaces X) and height coordinate Z (replaces Y). R and Z must feature always positive values ! KFLAG must be zero!

With CAD program:
Proceed after the description chapter 2.4.2. Do not forget to write on the layer Z88EIO the super element descriptions by TEXT function:
SE 1 8 8 L 5 e *(subdivide 8x into X geometrical ascending and 5x equidistant into Y)*

Write the general information and material information on the layer Z88GEN,
Z88NI.TXT 2 8 1 16 0 0 0 *(2D, 8 nodes, 1 SE, 16 DOF, all flags 0)*

Export the drawing as DXF file with the name Z88X.DXF and start the CAD converter Z88X with the option "from Z88X.DXF to Z88NI.TXT". Z88X will produce the mesh generator input file Z88NI.TXT. You should have a look at it with Z88O:



Super structure Z88NI.TXT

With editor:
Write the mesh generator input file Z88NI.TXT (cf. chapter 3.9) with an editor:

```
2  8  1  16  0  0  0        (2D, 8 nodes, 1 SE, 16 DOF, all flags 0)
1   2   40    0            (1st node,  2 DOF, R and Z coordinate)
2   2   80    0            (2nd node, 2 DOF, R and Z coordinate)
3   2   80   40
4   2   40   40
5   2   60    0
6   2   80   20
7   2   60   40
8   2   40   20
1   8                      (superelement 1, type Torus No.8)
1  2  3  4  5  6  7  8      (coincidence 1st SE)
1   8                      (subdivide SE1 into Torus elements No.8 and subdivide)
8   L   5   E              (8 times geometrical ascending into X and 5 times equidistant into Y)
```

CAD and editor:
Start the mesh generator Z88N to produce the final Z88 structure file Z88I1.TXT. Look at it either

- in the CAD program (from Z88I1.TXT to Z88X.DXF) after conversion with Z88X or
- with the Z88 plot program Z88O for defining the boundary conditions:

We force displacements of 0.1 mm upon the inside margin. Every node receives the same value as the load division in accordance with section 2.4 applies to forces only. Take care that the structure is fixed in space again. Therefore fix the degree of freedom 2 for the node 6. Any other nodes are possible, too.

With CAD program:
Switch to the layer Z88RBD and write with the TEXT function into any free place:

```
Z88I2.TXT   12          (12 boundary conditions)
RBD   1   1   1   2   0.1    (RB 1: node 1, at DOF 1, i.e into R, a displacement of 0.1 mm)
RBD   2   2   1   2   0.1
RBD   3   3   1   2   0.1
RBD   4   4   1   2   0.1
RBD   5   5   1   2   0.1
RBD   5   6   1   2   0.1
RBD   7   6   2   2   0      (BC 7: for fixing structure in space)
RBD   8   7   1   2   0.1
RBD   9   8   1   2   0.1
RBD  10   9   1   2   0.1
RBD  11  10   1   2   0.1
RBD  12  11   1   2   0.1
```

With editor:
Create the file of the boundary conditions Z88I2.TXT by editing:

```
12                  (12 boundary conditions)
 1   1   2   0.1    node 1, at DOF 1, i.e into R, a displacement of 0.1 mm)
 2   1   2   0.1
```

```
 3  1  2  0.1
 4  1  2  0.1
 5  1  2  0.1
 6  1  2  0.1
 6  2  2  0      (for fixing structure in space)
 7  1  2  0.1
 8  1  2  0.1
 9  1  2  0.1
10  1  2  0.1
11  1  2  0.1
```

In addition, you'll need these files: material groups Z88MAT.TXT, material data file 51.TXT, element parameters Z88ELP.IXT, integration orders Z88INT.TXT and the solver parameters Z88MAN.TXT. Create them by use of an editor (this has already been done for you in the example files):

Z88MAT.TXT:

```
1                (one material group in total)
1 40 51.txt      (range from ele.1 ~ ele.40 and reads 51.txt, see 3.5)
```

51.TXT:

```
206000 0.3       (Young's modulus 206000, Poisson's ratio 0.3, see 3.6)
```

Z88ELP.TXT:

```
1                        (1 set of element parameters, see 3.7)
1 40  0 0 0 0 0 0 0      (ele 1 ~ 40, QPARA=0, Ixx=0, exx=0, Izz=0, ezz=0, It=0, Wt=0)
```

Z88INT.TXT:

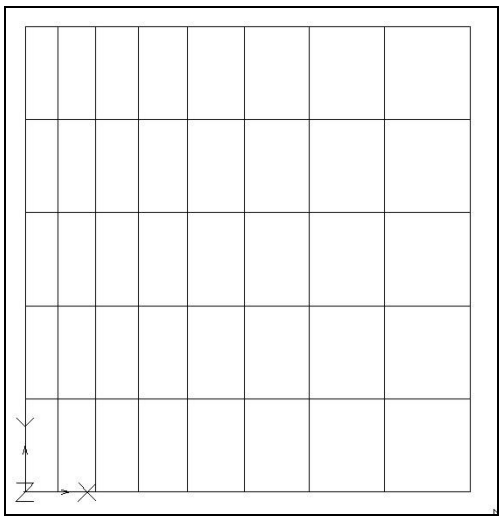
```
1                one set of integration orders in total)
1  40  3   3     (range from ele.1 ~ ele.40, INTORD=3, INTOS=3, see 3.8)
```

Z88MAN.TXT: Only these entries are of interest, see 3.10:

```
IBFLAG   0   (no beams in the structure)
IPFLAG   0   (no plates in the structure)
IHFLAG   0   (no shells in the structure)
KDFLAG   0   (no additional calculation of radial- and tangential stresses)
ISFLAG   1   (reduced stresses: von Mises)
```

KDFLAG always 0, because additional output of radial and tangential stresses is useless for torus elements. SIGRR (radial stresses) and SIGTE (tangential stresses) are calculated for torus elements anyway, cf. section 4.8.

Export the drawing as DXF file with the name Z88X.DXF, then start the CAD converter Z88X with the option "from Z88X.DXF to Z88I*.TXT". The CAD converter produces the three Z88 input files Z88I1.TXT, Z88I2.TXT, Z88I5.TXT.

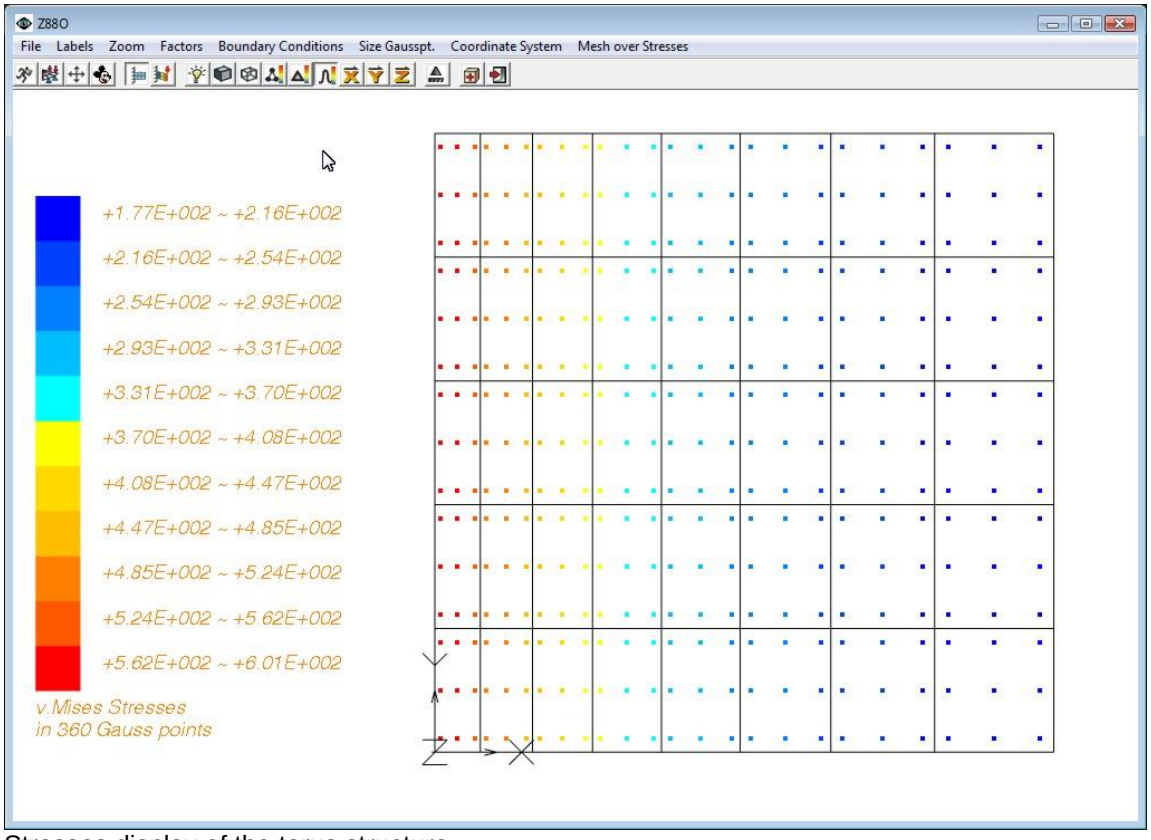


FE mesh Z88I1.TXT

Now launch the Cholesky solver Z88R –choly.

5.7.2 Results

The Cholesky solver Z88R provides the following output files: **Z88O0.TXT** stores the processed structure data. It is mainly intended for documentation purposes. **Z88O1.TXT** stores the processed boundary conditions: For documentation purposes. **Z88O2.TXT**, the displacements. **Z88O3.TXT**, the calculated stresses. The results in Z88O3.TXT do not depend on the parameters in Z88MAN.TXT. **Z88O4.TXT**, the computed nodal forces.



Stresses display of the torus structure

5.8 MOTORCYCLE CRANKSHAFT, TETRAHEDRON NO. 16

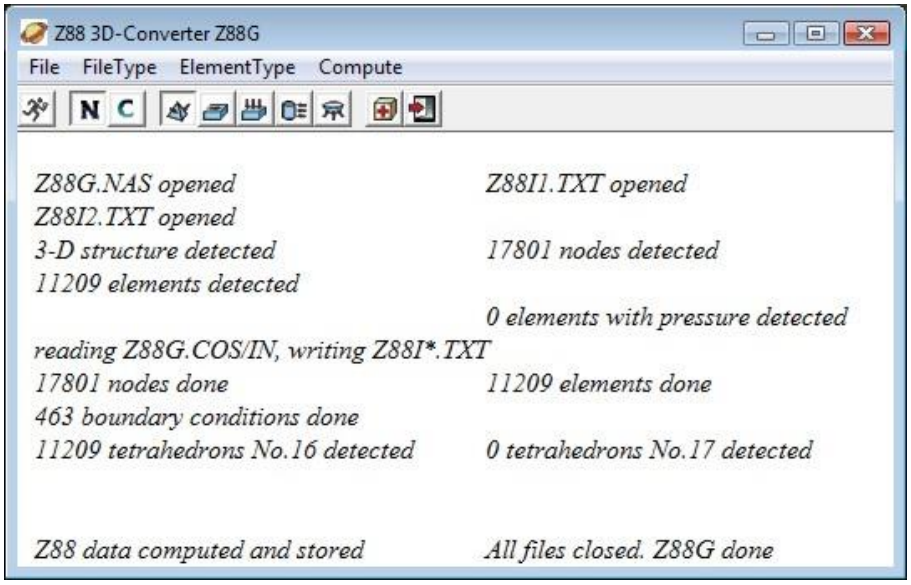
Copy the example files from directory B11 into your Z88 working directory:

Z88G.NAS	NASTRAN input file
Z88MAN.TXT	parameters for the solver
Z88MAT.TXT	material groups
51.TXT	material data file
Z88ELP.TXT	element parameters
Z88INT.TXT	integration orders

We want to compute a crankshaft for a monocylinder motorcycle engine and put a force of -5,000 N onto the piston. The meshing will do CREO.

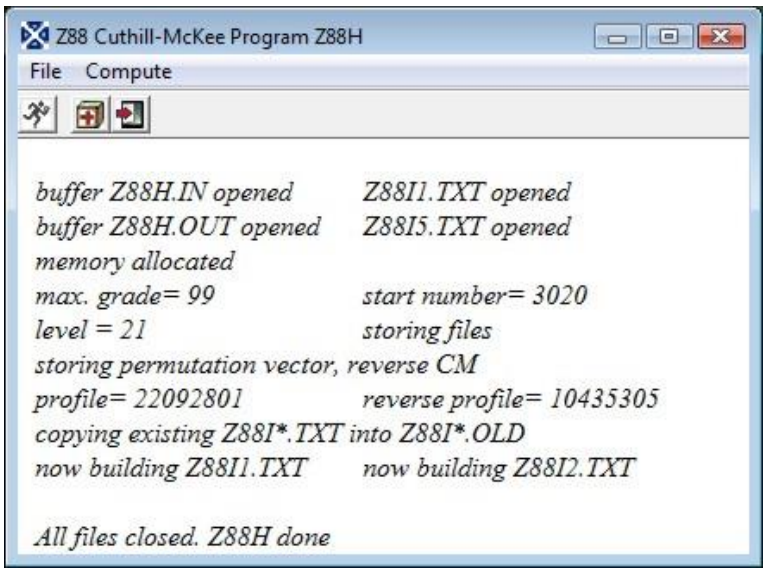
The boundary conditions are a bit tricky for this example: Put a reference (or datum) point to the centre of the face of the crankshaft. We'll need this point to fix the crankshaft in Z direction, i.e. lengthwise.

The ball bearings, which allow always some angular movement, and, thus, should be regarded as moment-free supports, are fastened to the larger shaft axes. The flange facings of the shaft axes are to be fixed in X and Y direction. Because whole surfaces are fixed, don't allow one ore more of these surfaces to be fixed in Z direction, too. This would result in blocking the angular movement - try it, if you won't believe it. A total force of -5,000 N will be put onto the peripheral surface of the crankshaft journal. The mesh is automatically generated by CREO featuring parabolic tetrahedrons. After storing the NASTRAN file, a Z88 session may start with **Z88G:**



Windows: 3D converter Z88G. Looks quite similar on UNIX machines.

and proceed with the Cuthill-McKee algorithm **Z88H**, because we'll expect a very bad node-numbering for the parabolic tetrahedrons.



Windows: Cuthill-McKee program Z88H. Looks quite similar on UNIX machines.

The first line of Z88I1.TXT tells you the following values:

- 17,801 nodes
- 11,209 elements
- 53,403 dof

Attention: For safety reasons, please add always 3 to each minimum value.
MAXKOI must have as a minimum 11209 elements × 10 nodes per element = 112090 + 3 = 112093.

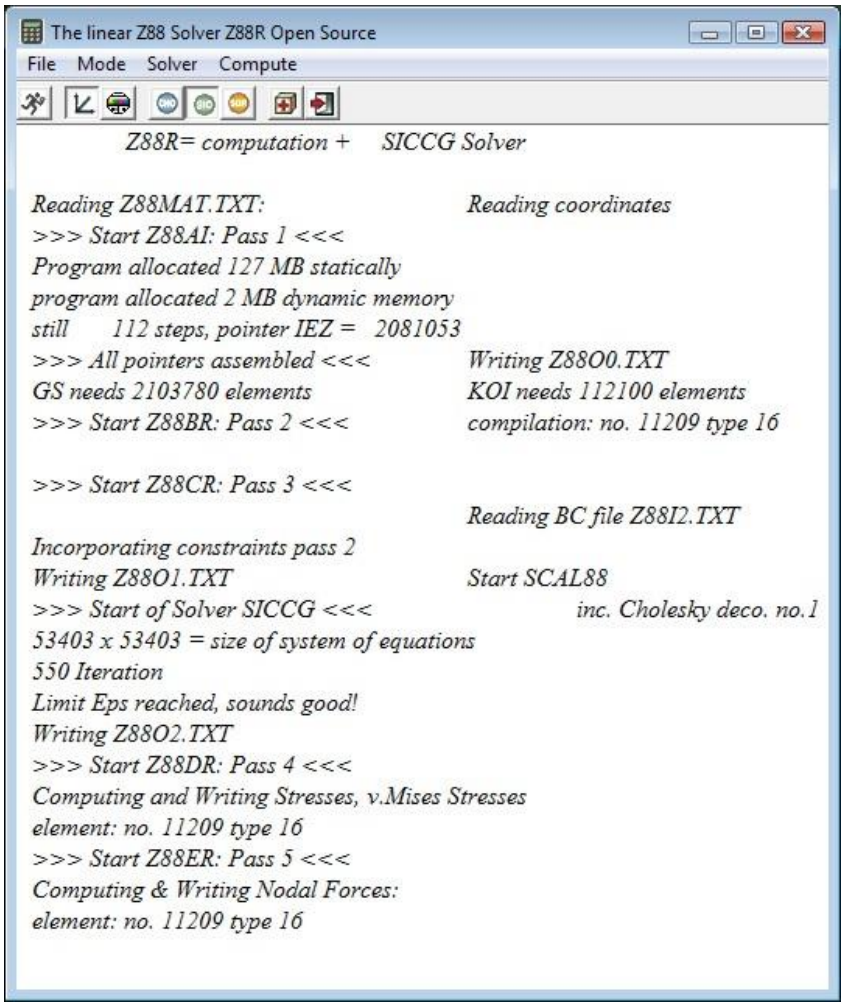
Thus, **Z88.DYN** should look as follows:
MAXGS get this entry by running Z88R in Test mode
MAXKOI at least 112090 + 3 = 112093
MAXK at least 17801 + 3 = 17804
MAXE at least 11209 + 3 = 11212
MAXNFG at least 53403 + 3 = 53406
MAXMAT at least 1 + 3 = 4
MAXPEL at least 1 + 3 = 4
MAXJNT at least 1 + 3 = 4

Proceed with a look at the structure with **Z88O** and run **Z88R** –choly in Testmode resulting in 48672507 × 8 Byte = 370 MByte for the stiffness matrix only. Adding the further vectors you'll need ~ 390 MByte of memory. However, this is absolutely no problem for modern PCs but you'll state that the computing time will be some minutes according to the huge part of zeros in the skyline *even after* a run of Z88H.

But there is help: Run Z88R in SICCG mode with these (quite rich) entries in Z88.DYN:

```
COMMON START
   MAXGS    2200000
   MAXKOI    200000
   MAXK       20000
   MAXE       20000
```

```
    MAXNFG      55000
    MAXMAT         32
    MAXPEL         32
    MAXJNT         32
    MAXPR        5000
    MAXRBD       4000
    MAXIEZ    2200000
    MAXGP     1000000
COMMON END
```

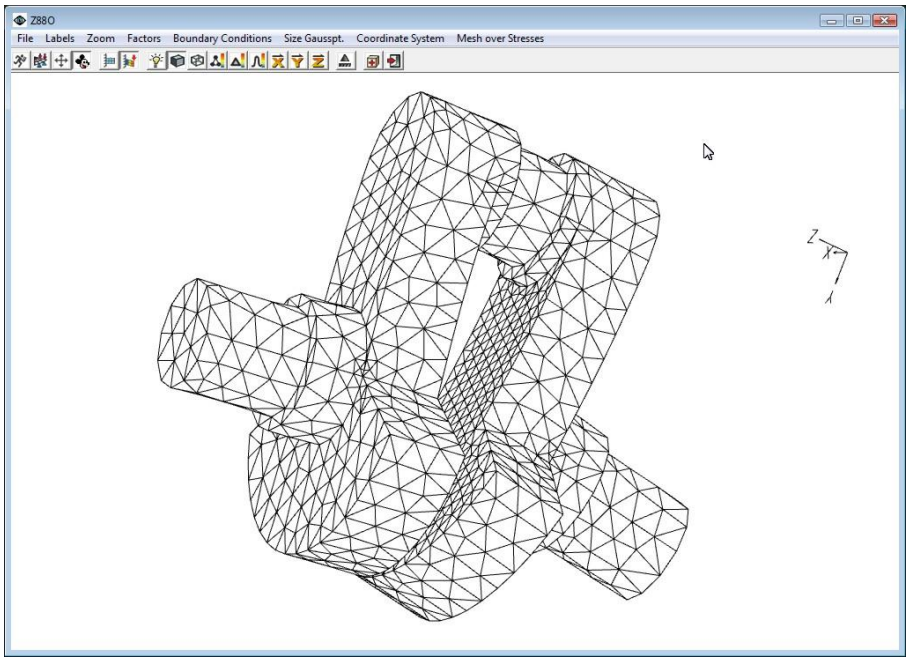


Windows: Computing deflections with Z88R -siccg. Looks quite similar on UNIX machines.

Here, the sparse matrix iteration solver is much more faster than the Cholesky solver and the iteration solver needs much fewer memory. The advantages of the iteration solver will increase with larger structures. But keep in mind that the computing times are difficult to compare: If you change *EPS* to, for example, 1E-5 or 1E-10, then Z88R iterates more or less resulting in shorter or longer computing timers.

You may also run the sparse matrix iteration solver Z88R –sorcg, then you'll need even less memory. However, the computing time may increase because one is unable to determine the best value for the relaxation parameter *ROMEGA* in advance resulting in shorter or longer computing times. For example: ROMEGA = 1.0 results in 706 iterations. This solver mode Z88R –sorcg is very good if you're running out of memory, otherwise, take Z88R –siccg.

See the deflected structure with **Z88O**. The angular deflection of the axes is quite amazing. Now you would read off the deflections of distinguished nodes, multiply with the appropriate lever arms and check with the bearing catalogue if your ball bearings will allow this angular movement without problems.



Windows: Plot programm Z88O, deflected structure.

5.9 RECTANGULAR PLATE, PLATE NO. 19

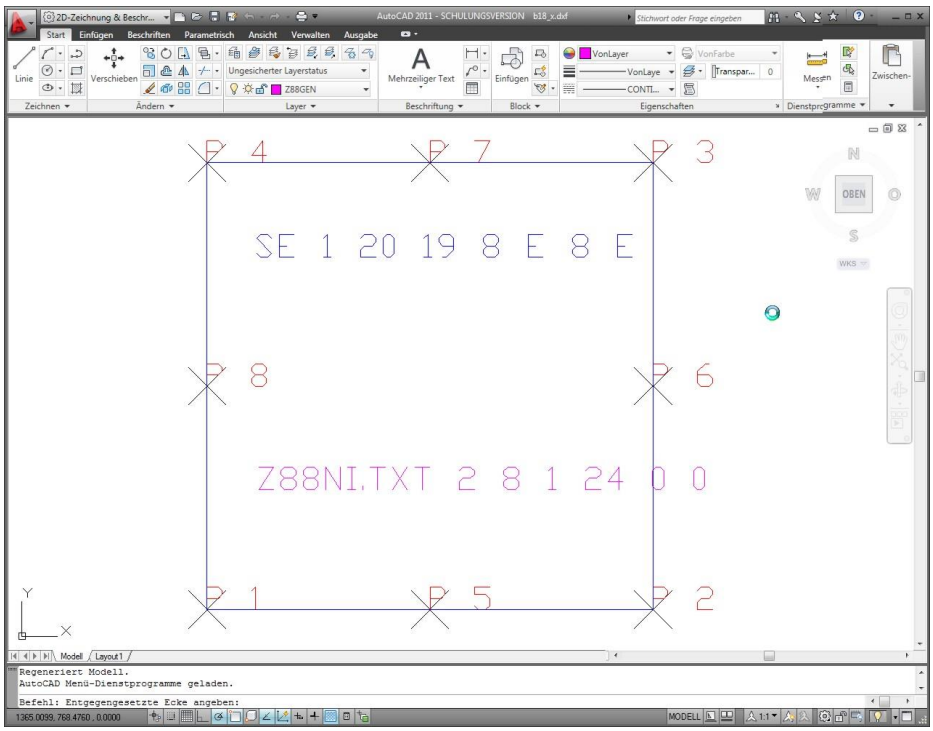
We want to compute a thick rectangular plate of steel. Data:

- Dimensions: 1,000 × 1,000 × 100 mm
- Surface load 46.42 N/mm^2
- Young's Modulus 206,000 N/mm^2
- Poisson's Ratio 0.3

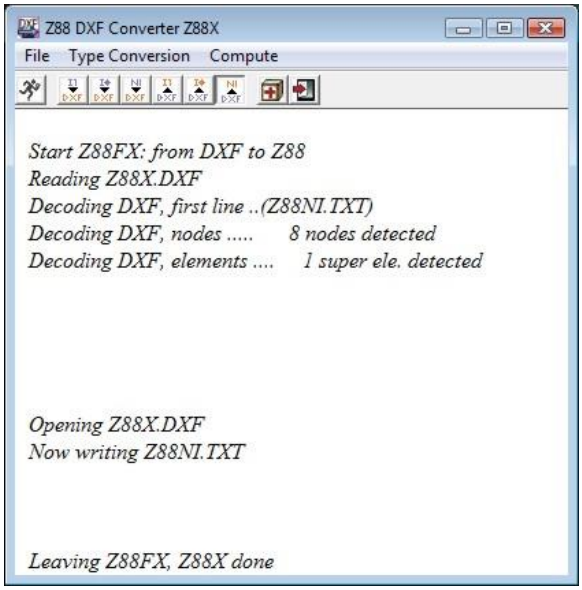
We will draw the plate super structure in AutoCAD. Draw one single super element plate type No.20, which will be subdivided by the mesher Z88N into 8 × 8 = 64 plates of type No.19, i.e. with 16 nodes each. Of course, for this example you could use an editor and generate the mesh generator input file by hand at the same pace.

You'll find the exact procedure plottet in chapter 2.4 - however, try it by yourself and export the drawing as Z88X.DXF into the Z88 directory. If it doesn't work at all (but it really does):

Copy the directory B18 into your Z88 working directory.

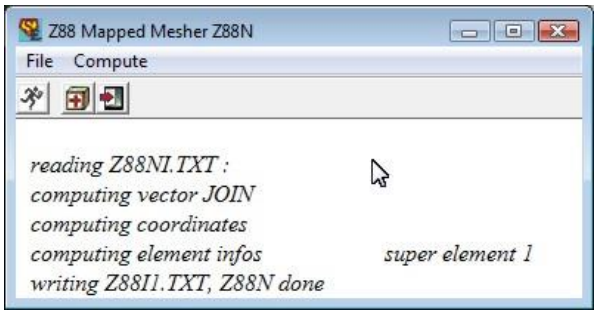


Windows: AutoCAD 2011 drawing the rectangular plate.



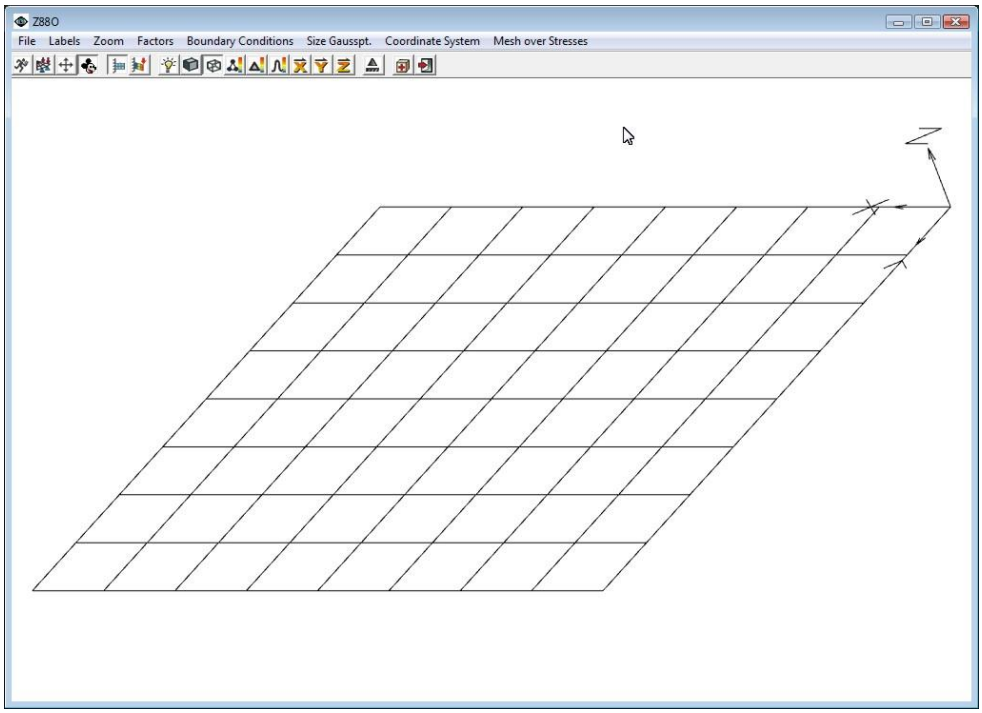
Windows: CAD converter Z88X. Looks very similar on UNIX machines.

Choose *from Z88X → Z88NI.TXT*. Then, launch the mesher Z88N:



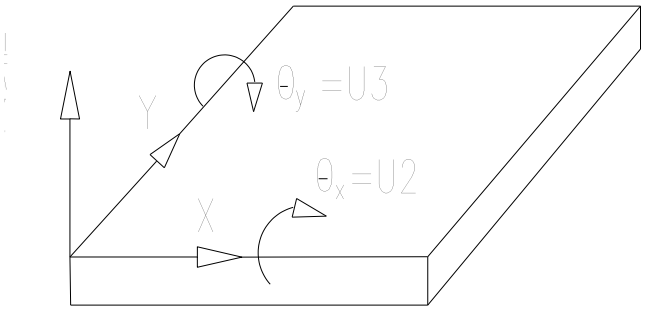
Windows: mesh generator Z88N. Looks very similar on UNIX machines.

Now you may look at the structure with **Z88O**:



Windows: Plot program Z88O, undeflected structure. Looks similar on UNIX computers.

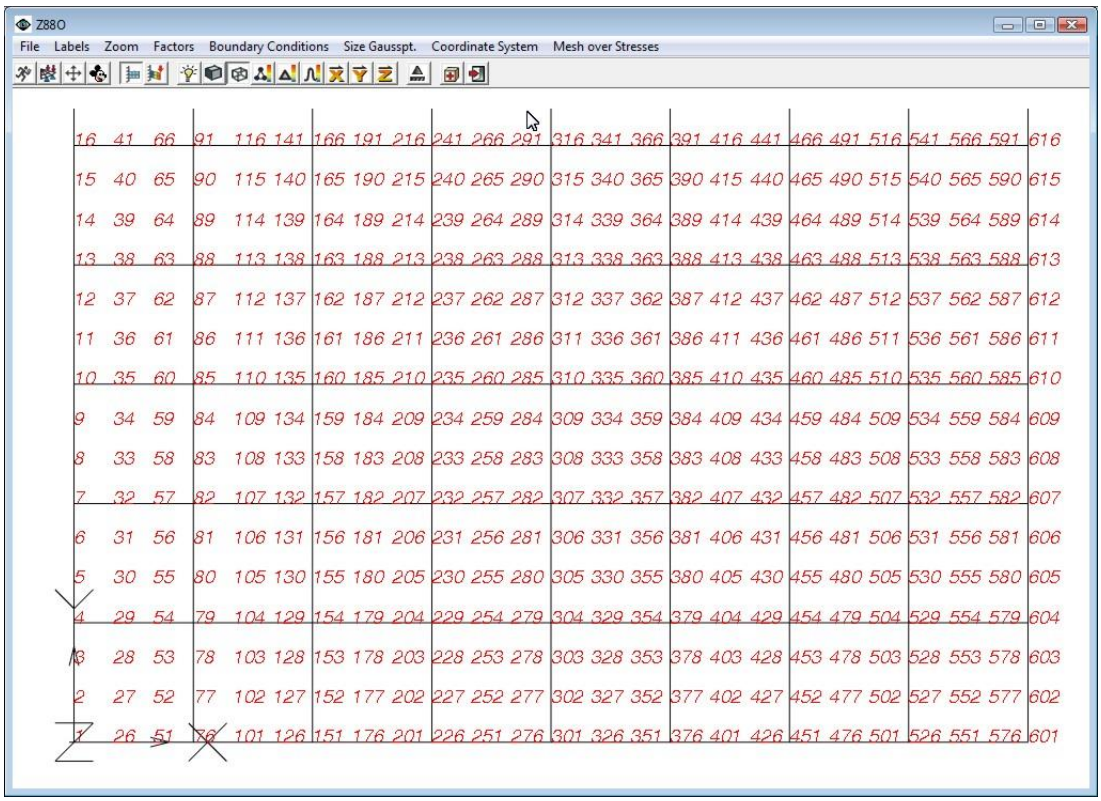
Now you've got some work: you must read off the node numbers for the boundary conditions in Z88O. We have to decide how to support the plate. We'll choose "cutting edges", i.e. the boundaries are supported by a "bezel" above and below. This allows angular movement crosswise to the bezels, but fixture in direction of the bezels.



If you want to support the boundary in front, i.e. running in X direction, with cutting edges, then you must fix the degree of freedom 1 (the Z direction) and the degree of freedom 3 (the rotation around the Y axis).

We've got 625 nodes in total. Which to support? Good question! In order to save some work (seldom a good idea) we'll try to fix only the corner nodes of the elements, which lay on the boundaries. This nodes are

- left boundary: 1, 4, 7, 10, 13, 16, 19, 22, 25
- lower boundary: 1, 76, 151, 226, 301, 376, 451, 526, 601
- upper boundary: 25, 100, 175, 250, 325, 400, 475, 550, 625
- right boundary: 601, 604, 607, 610, 613, 616, 619, 622, 625



Windows: read off the the nodes with Z88O. Looks similar on UNIX machines.

See the beginning and the end of the boundary conditions file Z88I2.TXT (if you are too lazy to do the work of entering the boundary conditions: *B18_2ROU.TXT*) :

```
68
1     1   2   0.
1     2   2   0.
1     3   2   0.
4     1   2   0.
4     2   2   0.
....
622   1   2   0.
622   2   2   0.
625   1   2   0.
625   2   2   0.
625   3   2   0.
```

We may now launch one of the solvers. Because the structure is really tiny, the Cholesky solver is the right choice. The displacement file Z88O2.TXT gives us the information for node 313, which lies exactly in the middle of the plate:

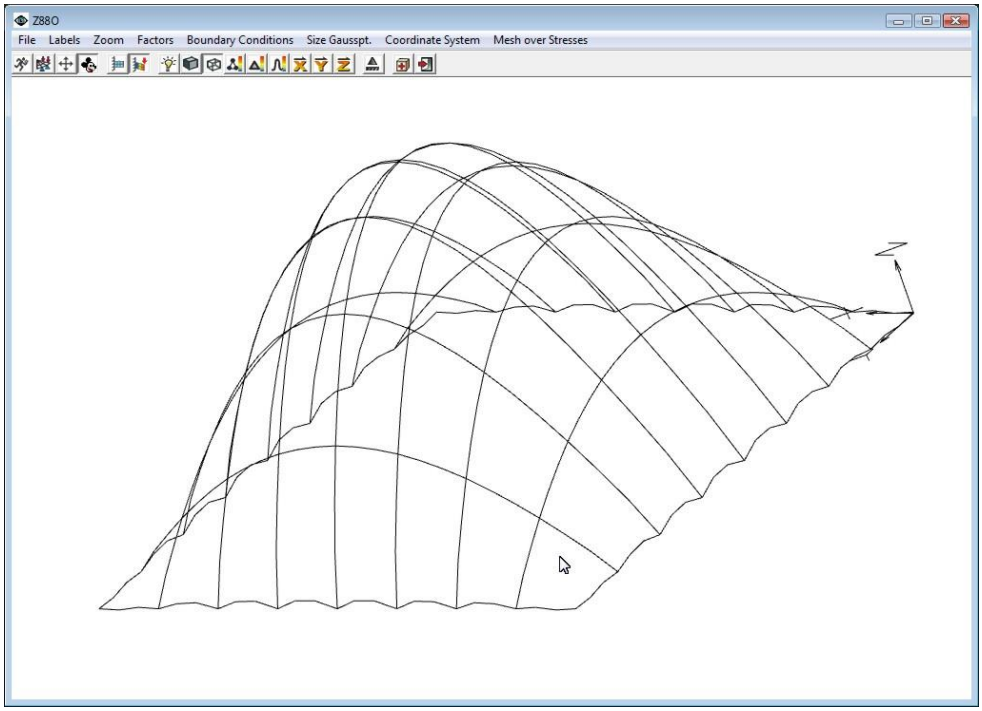
```
    313    +1.1236511E+001    -2.1751298E-008    +2.1751298E-008
```

The deflection U2 (i.e. the rotation around the X axis) and U3 (i.e. the rotation around the Y axis) are zero, looks good. The deflection U1, i.e. w, is 11.24 mm. "Analytically" (this is also only an approximation for thin plates, ref. to the classical mechanics literature) one computes:

$$f = \frac{0.71\, p\, b^4}{E\, h^3} = \frac{0.71 \cdot 46.42 \cdot 500^4}{206{,}000 \cdot 100^3} = 10 \text{ mm}$$

This results in a variety of $\frac{10 - 11.24}{10} \cdot 100 = -12\,\%$.

Here's why. Firstly, the analytical formulae in the literature are thin plates of the Kirchhoff type neglecting the shear forces, secondly, this formulae were won with series expansion and thirdly, we could truely put some more work into a better formulation of the boundary conditions. Here's how our plot looks with a magnification factor of 50:



See how the boundaries raise between the corner nodes? Guess we must swallow the bitter pill and support all the nodes laying on boundaries (copy file *B18_2.TXT* to Z88I2.TXT). This results in:

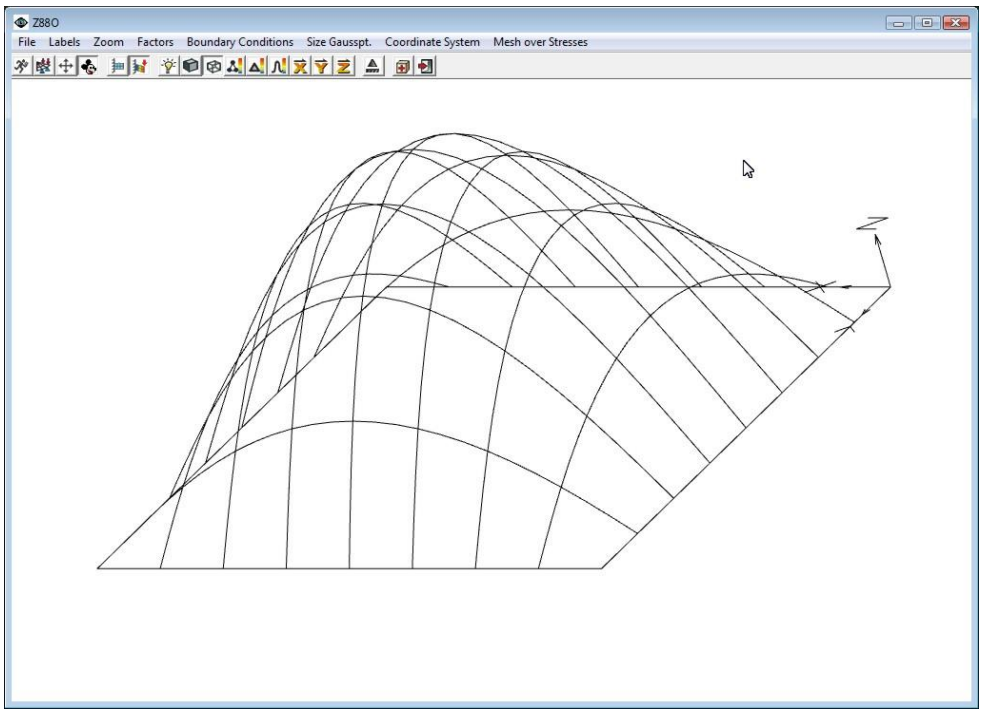
w at node 313: 10,5 mm, variety to the analytical calculation about 5% (the analytical calculation supplies thin plates and is not very exact here. This thin plates should feature a thickness of about 1/50, 1/100 or fewer of the main dimensions!)

We may calculate the stresses "analytically":

$$\sigma_x = \sigma_y = \frac{1.15\, p\, b^2}{h^2} = \frac{1{,}15 \cdot 46.42 \cdot 500^2}{100^2} = 1335\ \text{N/mm}^2$$

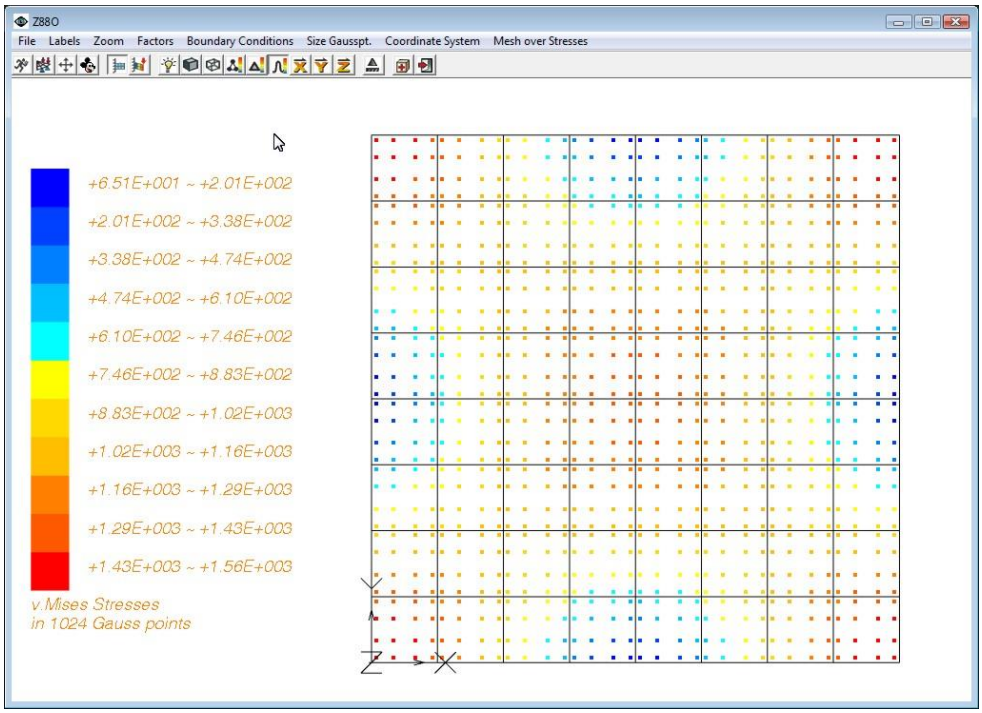
For computing the stresses in the corner nodes, set INTOS to 0 in Z88INT.TXT and KDFLAG and ISFLAG to 0 each in Z88MAN.TXT.

After running Z88R you may read off the stresses of node 313 from the elemente 28, 29, 36 or 37; it is the node with XX= 600 and YY= 600: $\sigma_x = \sigma_y = 1334\ \text{N/mm}^2$.



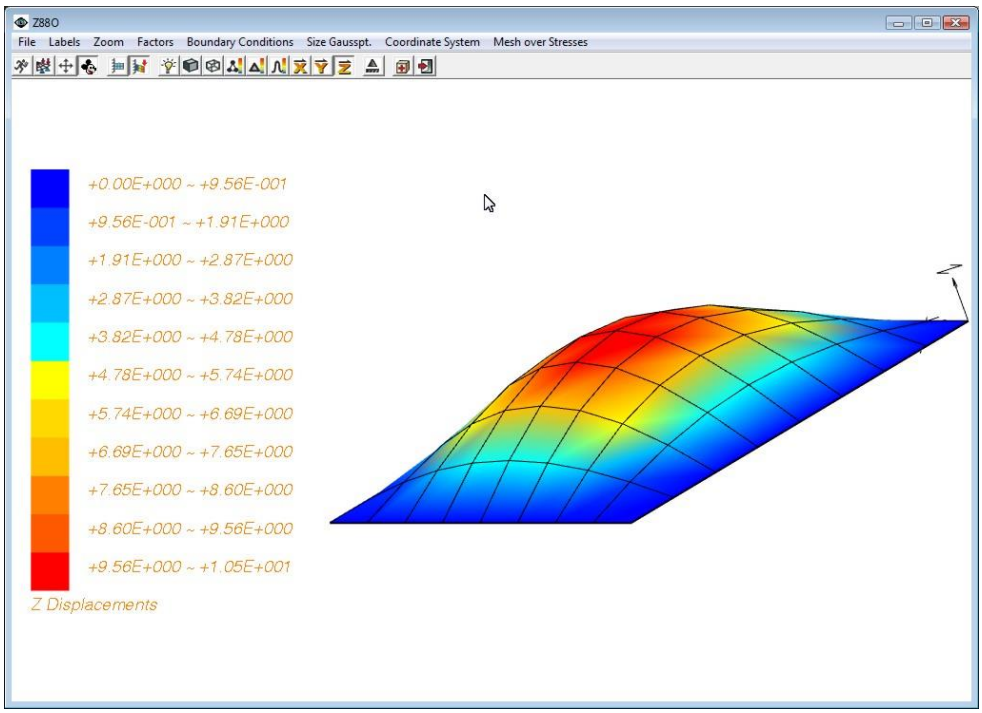
Now the boundaries are supported properly.

Finally, we'll compute the stresses in the Gauss points and, thus, adjust Z88INT.TXT and Z88MAN.TXT as follows: INTOS 4 and KDFLAG 0 and ISFLAG 1. After a Z88R run we may look at the *von Mises* stresses:



Windows: Plot of the *von Mises* stresses in the 4 x 4 Gauss points. Z88O.

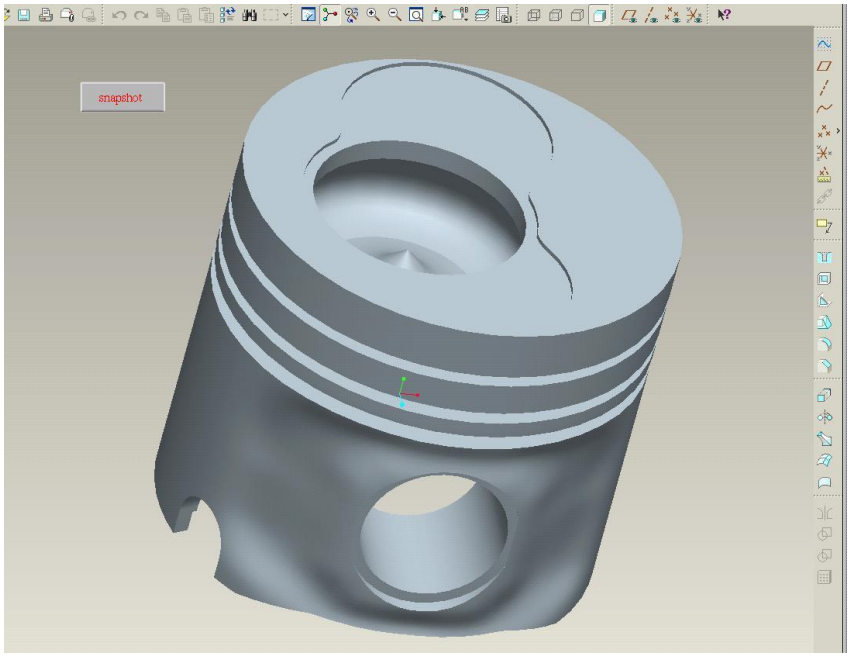
Now you've got a small impression of plate calculation. Consult the devil (and Daniel Webster) when computing deflections and stresses for plates! I recommend parabolic tetrahedrons or hexahedrons in contrary for (thick) plate calculations, that means more input expense but the results are always save and free of suspicious interpretation constraints.



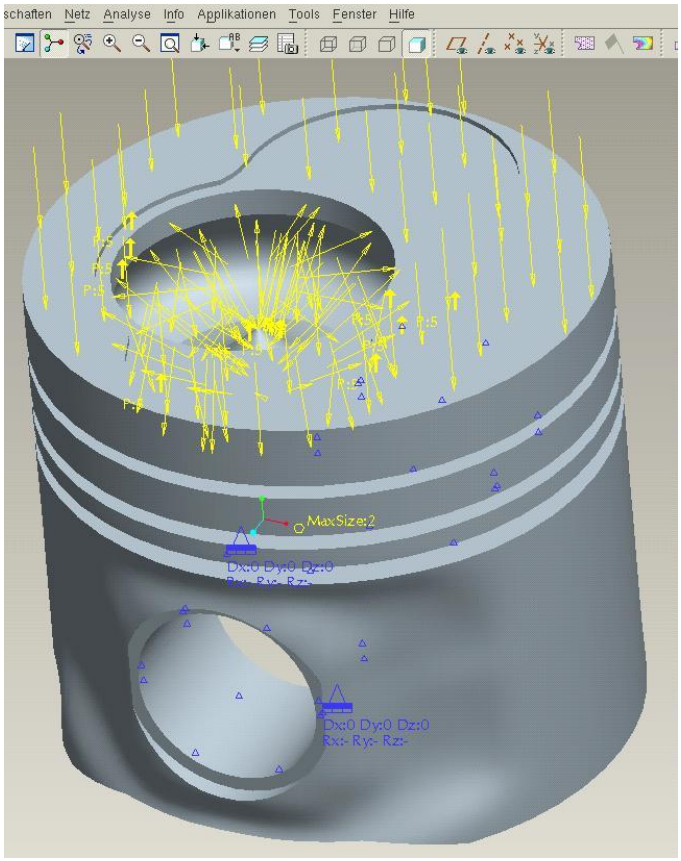
Windows: Plot of the Z displacements. Z88O. Looks similar on UNIX machines.

5.10 DIESEL ENGINE PISTON, TETRAHEDRONS NO.16 & 17

This example compares linear shape functions tetrahedrons with 4 nodes and square shape functions tetrahedrons with 10 nodes. However, the pressure load is applied by the surface and pressure loads file Z88I5.TXT. Both the NASTRAN files were compiled with CREO Wildfire 2:

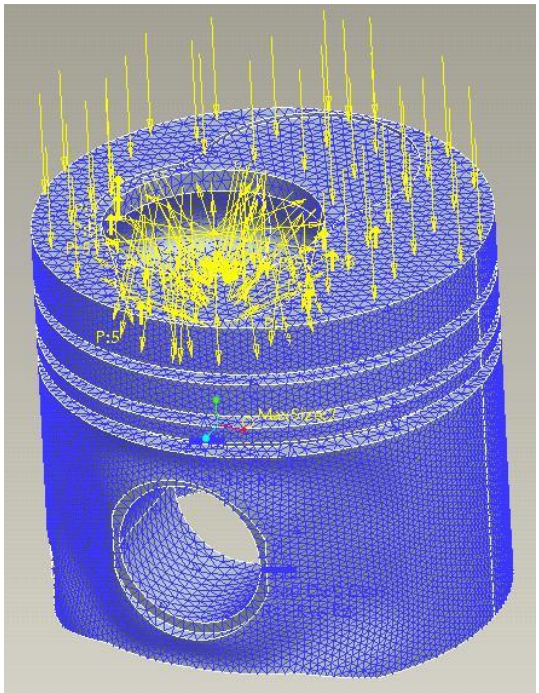


Diesel engine piston of an AUDI engine (simplyfied), modelled by Dipl.-Ing. Jens-Uwe Goering.



Diesel engine piston with pressure load of 50 bar, max. mesh size 2mm.

The piston was modelled similar to the pistons of modern AUDI diesel engines. The pressure load of 50 bar = 5 N/mm^2 and the light alloy material with E = 73,000 N/mm^2 und ν = 0.33 were chosen with arbitrariness. Of course, in reality higher pressures and other kinds of light alloy are used – but this is not important for our test runs here. We compiled a fine-meshed structure by allowing a max. mesh size of only 2 mm in CREO.


The compiled mesh resulting in ~ 280,000 tetrahedrons.

Here we go with linear shape functions tetrahedrons. For your convenience a directory B21_LIN is prepared and Z88.DYN should look as follows:

```
COMMON START
  MAXGS    3600000
  MAXKOI   1120000
  MAXK       58000
  MAXE      280000
  MAXNFG    172000
  MAXMAT        32
  MAXPEL        32
  MAXJNT        32
  MAXPR      50000
  MAXRBD      4000
  MAXIEZ   3600000
  MAXGP    1200000
COMMON END
```

The surface and pressure loads file Z88I5.TXT looks as follows (please check with the chapters 3.4 and 4.17):

```
4430   Z88I5.TXT,via Z88G V14 NASTRAN
  265 +5.00000E+000   731   728   732
  292 +5.00000E+000   344   345   847
  525 +5.00000E+000 16105 16106 15009
  640 +5.00000E+000 15582 15584 15583
  658 +5.00000E+000 15582 15548 15547
  701 +5.00000E+000   812   817   815
  .........
```

The sparse matrix solver Z88R -siccg needs 89 MB if you'll choose the Cholesky preconditioning with an $\alpha = 0.0001$. Then, the solver does 202 iterations and will finish the job on a modern PC running Windows within one minute.

Z88 computes: $\sigma_{vonMises} = 35.1$ N/mm2 $y_{max} = -0.0121$ mm

Now we'll run the job with square shape functions tetrahedrons resulting in this Z88.DYN:

```
COMMON START
  MAXGS   51000000
  MAXKOI   2800000
  MAXK      416000
  MAXE      280000
  MAXNFG   1250000
  MAXMAT        32
  MAXPEL        32
  MAXJNT        32
  MAXPR      50000
  MAXRBD     12000
  MAXIEZ  51000000
  MAXGP    1500000
COMMON END
```

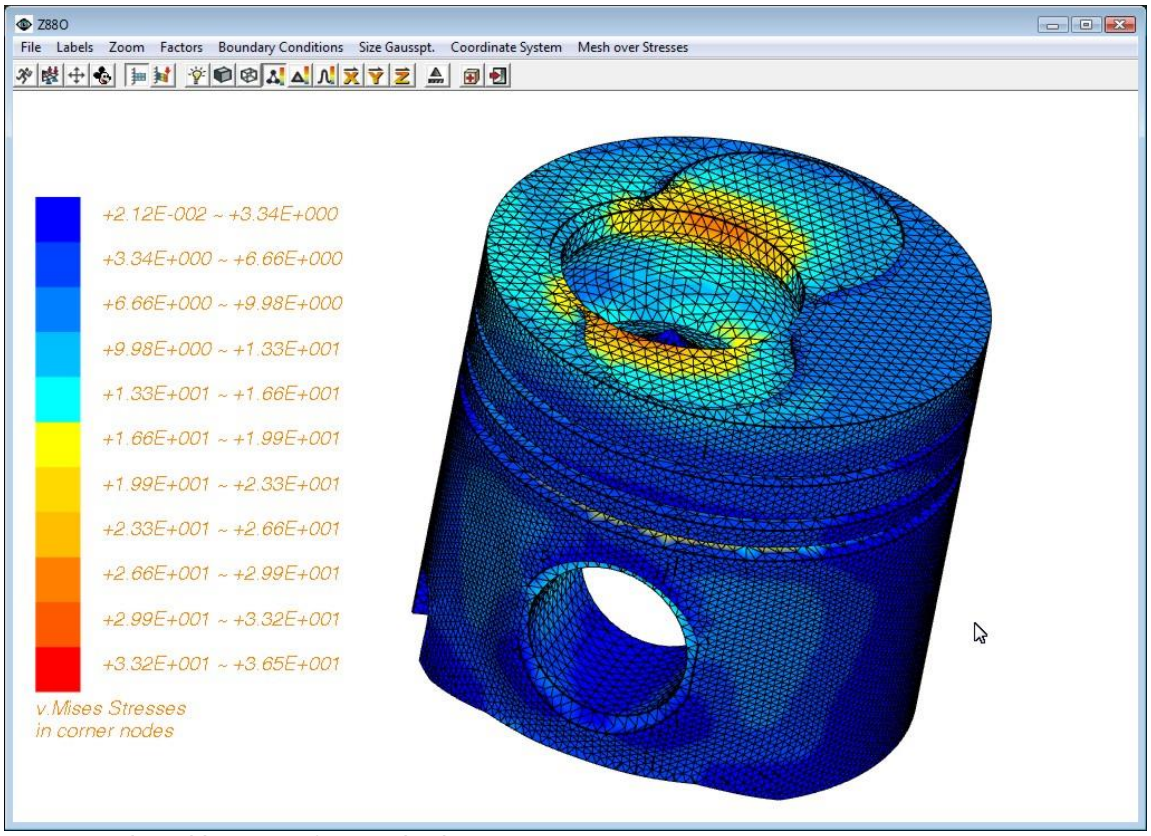
Use the directory B21_PARA.

The surface and pressure loads file Z88I5.TXT looks as follows (please check with the chapters 3.4 and 4.16):

```
4430   Z88I5.TXT,via Z88G V14 NASTRAN
    5 +5.00000E+000   394   734   610 59815 61330 59813
  128 +5.00000E+000 16135 16138 16136 167350 167355 167348
  292 +5.00000E+000 15401 15400 15399 162081 162074 162075
  369 +5.00000E+000 15319 15302 15317 161397 161396 161503
  379 +5.00000E+000   828   833   831 63009 63029 63008
  682 +5.00000E+000 15582 15548 15547 163056 163041 163044
  .........
```

The sparse matrix solver Z88R -siccg needs 1,070 MB if you'll choose the Cholesky preconditioning with an $\alpha = 0.0001$ (you may reduce this amount by ~1/3 if you'll choose the SOR preconditioning with an $\omega = 1.2$). Then the solver does 668 iterations and finishes the run on a PC with an AMD Athlon 64 X2 3800+ and 4 GByte memory running Windows in 45 min.

Z88 computes: $\sigma_{vonMises} = 36.5$ N/mm2 $y_{max} = -0.0128$ mm



Stresses plotted by Z88O for tetrahedrons No.16.

As you see the results differ only minimally and the big time and memory expense for the square shape functions tetrahedrons No.16 was completely useless. But just this is the art of finite elements computing – to choose the best suitable element types!

5.11 RECTANGULAR TUBE AND SHELLS NO.24

Consider a rectangular tube 300 × 270 × 1000, which is drilled at one end 0.12°. Of course, this example can be computed with hexahedrons or tetrahedrons, but because the thickness is small compared to the other dimensions shell elements may be good choice. We apply on every edge a load of 100,000 N; the material is steel. One computes analytically:

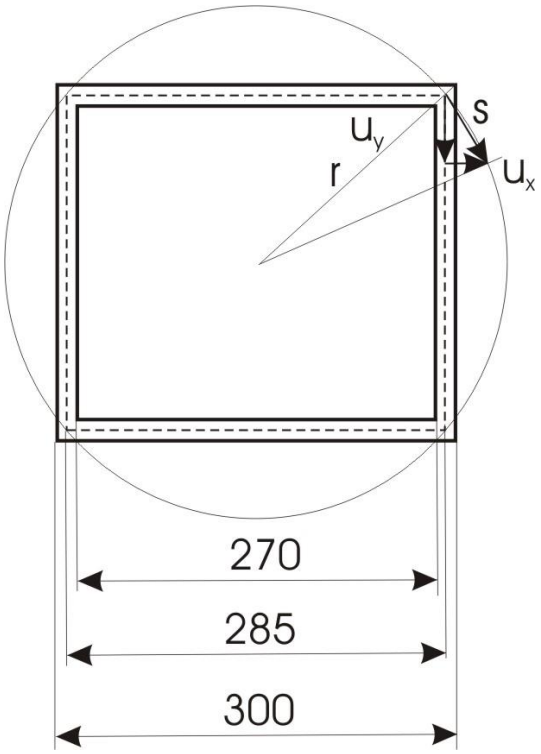
$$\varphi = \frac{T \cdot \ell}{G \cdot I_T}$$

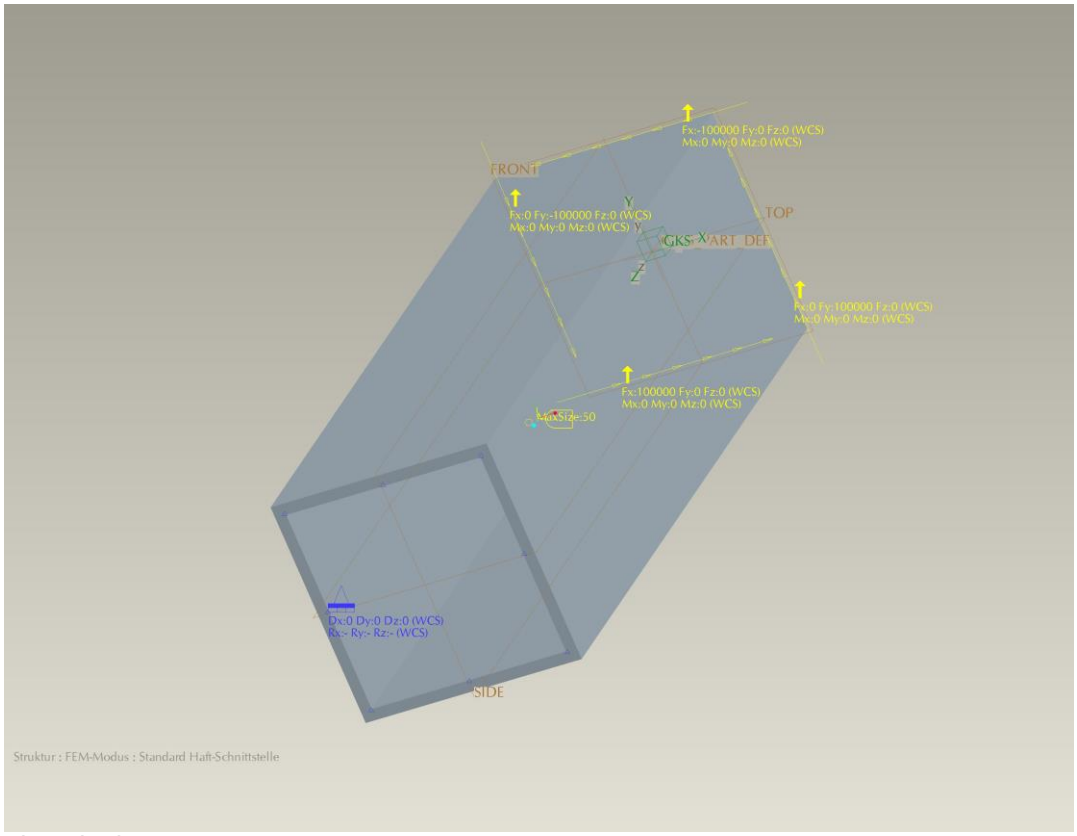
$$I_T = \frac{4(bh)^2}{2\left(\frac{b}{t_1} + \frac{h}{t_2}\right)} = \frac{4(285 \cdot 285)^2}{2\left(\frac{285}{15} + \frac{285}{15}\right)} = 3.47 \cdot 10^8$$

$$T = 4 \cdot F \cdot r = 4 \cdot 1 \cdot 10^5 \cdot \frac{285}{2} = 5.7 \cdot 10^7$$

$$G = \frac{E}{2(1+\nu)} = \frac{206000}{2(1+0.3)} = 7.9 \cdot 10^4$$

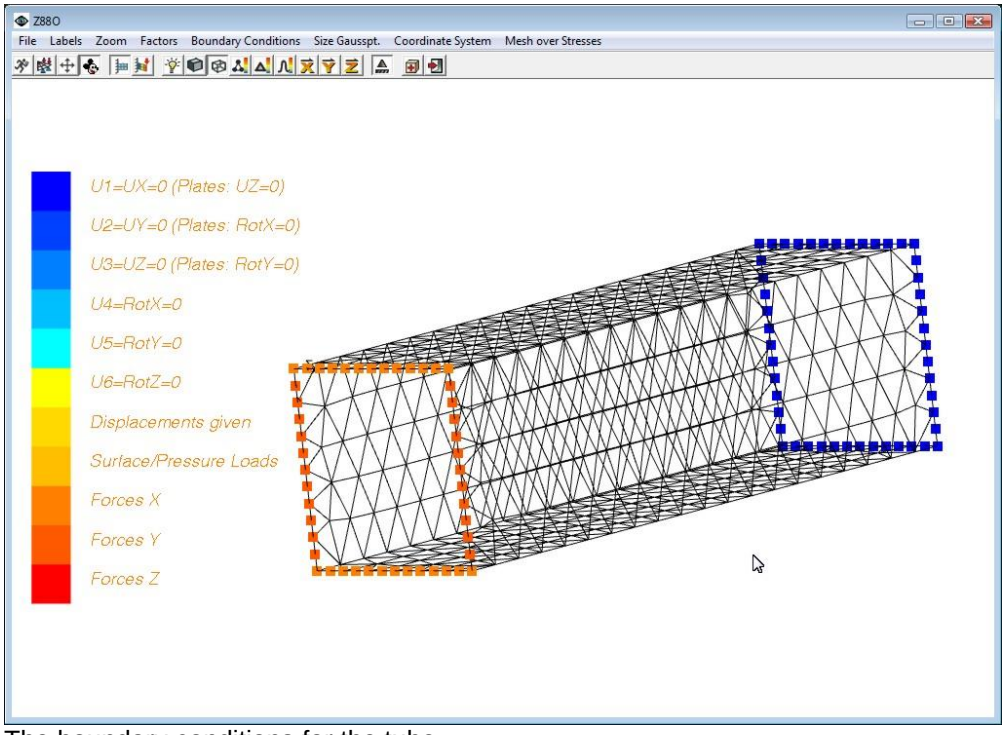
$$\varphi = \frac{5.7 \cdot 10^7 \cdot 1000}{7.9 \cdot 10^4 \cdot 3.47 \cdot 10^8} = 0.0021 rad \approx 0.12°$$





The tube in CREO

After converting the NASTRAN file (see directory B24) with Z88G you may show the boundary conditions in Z88O (Attention: switch to *Wireframe*):



The boundary conditions for the tube

The nodes 1 and 2 are corner nodes; one reads from Z88O2.TXT: $U_X = U_Y = 0.294$ mm. Control (see sketch to the beginning of this example):

$$\varphi = \frac{s}{r} = \frac{\sqrt{U_X^2 + U_Y^2}}{r} = \frac{\sqrt{0.294^2 + 0.294^2}}{0.5 \cdot 285 \cdot \sqrt{2}} = 0.021 \approx 0.12° \text{ , very good.}$$

The stresses are computed to:

One computes analytically according to Szabó, I.: Höhere Technische Mechanik, p. 306 to 309:

The St.Vénant part: $\tau_{St} = 2.45\, N / mm^2$

The Bredt part: $\tau_B = 23.31 N / mm^2$

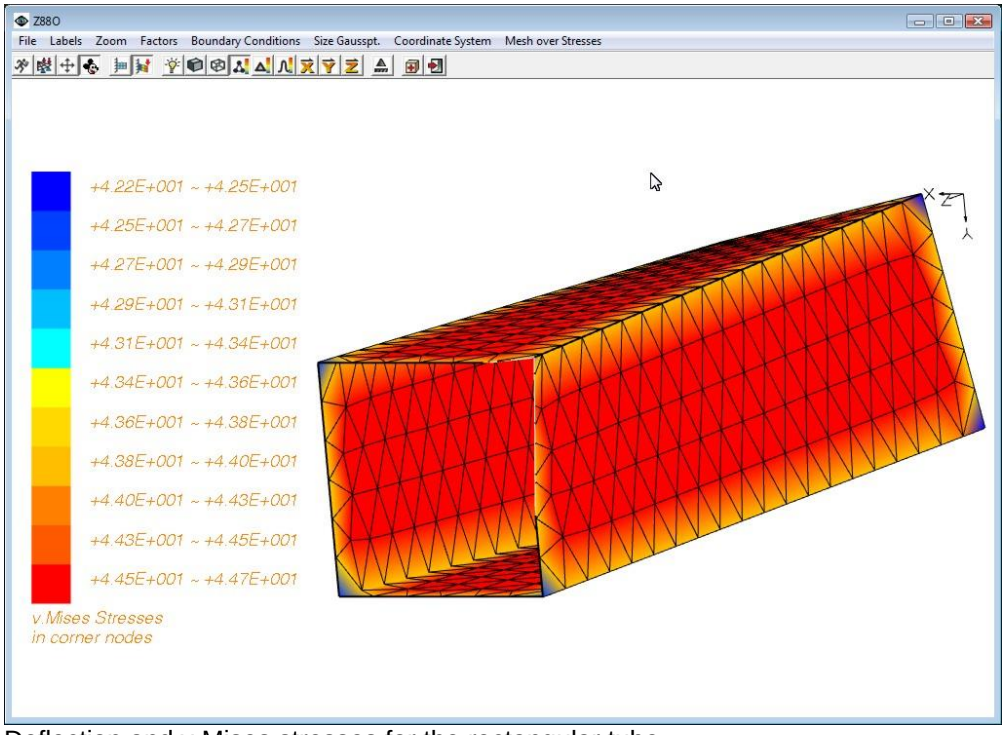
$\tau_T = \tau_B + \tau_{St} = 23.31 + 2.45 = 25.7\, N / mm^2$

This is the *pure stress of torsion*. Now we'll compute the reduced stresses according to *v.Mises*:

Von Mises: $\sigma_V = \sqrt{3 \cdot \tau_T^2} = \sqrt{3} \cdot 25.7 = 44.5\, N / mm^2$

Z88O shows ~ 45 N/mm^2, this sounds really good.

Keep in mind to set IHFLAG to 1 in Z88MAN.TXT for this example.



Deflection and v.Mises stresses for the rectangular tube

Keep in mind that finite elements calculations with shell elements are even worse than plate calculations and the interpretation of the results is often rather tricky: there is up to now no shell element or shell theory which is sufficient for every shell problem.