



**MEPLA**

Software for Structural Glass Design

# Brief Introduction Version 5.0

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## 1 Geometry

- The panel form can be freely defined without delimitation. The corner points are to be entered in mathematically positive order (against the clockwise direction).
- The edges of the panel can be defined by the indication of a rotation center as well in form of arcs. For a complete description of a round edge the direction of rotation is needed. Thus it must be specified whether the curved border turns positively (against the clockwise direction) or negatively around the rotation center.
- The element mesh will be generated automatically by a “free”-meshing algorithm so that any geometry can be build. The edges thereby are not allowed to cross each other.
- As additional input the size (side length) of the elements which shall be produced is needed.
- The accuracy of a finite element calculation depends on the mesh quality and quantity. The side length of the elements is preset to 80 mm, which is usually sufficient for normal panes sizes.

## 2 Layer

### 2.1 Order of layers

- Currently the German standards do not allow a bonding effect of the PVB interlayers (except for insulating glass units). Therefore laminated glass panes must here be calculated in one of the two following methods:
  - o Usage of a very small modulus of elasticity for the bonding material e.g.  $E = 0.03 \text{ N/mm}^2$ . Then the glass panels are slightly connected and can more or even slide of each other. (This is the default setting for long time loading)
  - o Or the loads are partitioned according the specific stiffness of the regarded pane. For example: A laminated glass pane 10/0.76/10 mm is loaded by a face load of  $0.75 \text{ kN/m}^2$ . Then one pane can be calculated with a thickness of 10 mm, which will receive a half of the loading ( $0.375 \text{ kN/m}^2$ ).
- For countries where the bonding effect can be considered, it's possible to calculate laminated glass panels by any shear effect of any layout.
- The total number of layers must be odd, as two glass panels always must encapsulate the intermediate bonding layer.
- The numbering of the panes takes place from the bottom to the top (in positive z-direction), so as if they are laid on.

### 2.2 Insulated glass units

- Is more than one glass package selected (short denoted as: package), the system will be considered as insulted glass unit.

- Then the items for the description of the intermediate gap will open. Here must be defined
  - o the filling gas (air, argon,...),
  - o the gap size
  - o and possible temperature changes for the gas.
- For calculations of insulating glass units the external (outside) pressure must be given. As all calculations are done in the units „N/mm<sup>2</sup>“also the outside pressure must be defined in this unit.
  - o Conversion: 1 bar = 0.1 N/mm<sup>2</sup>, so that a usual air pressure of 1.010 bar must be keyed in with 0.1010 N/mm<sup>2</sup>.
- In addition a difference of height between the production and installation of the insulating glass unit may be specified by  $\Delta H$  [m].
- Further information will be found under climate loads.

### 3 Supports

#### 3.1 Springs

- Spring supports as unique acting springs, which may be set at any desired position in the plate for each of the 3 directions x, y and z and the 2 rotations rigidities  $C_{\varphi}$  and  $C_{\theta}$ .
- The unit for the spring rigidities is N/mm and Nmm/rad.
- When a stiffness of 0 N/mm is set, no spring stiffness will act in this direction.
- Automatically there are 3 springs suggested. In the first corner point of the system in x- and y direction and in the second point only in y- direction. These very weak springs (default value of 1.0 N/mm) are not designed to carry any loads, only to prevent the system for uncontrolled in-plane moving and rotating.

#### 3.2 Edge supports

- From the table of support conditions the appropriate bearing design can be chosen. These bearings will also be used for all other edges of higher packages at same position - if some has been defined.
- The standard simple support for glass pane edges is type 0.
- For improvement of symmetry conditions sometimes type 2 or/and 3 will be used. Using this kind of supports the system can maximally be halved or quartered to save computation time. In such a case, the loads must comply to this symmetry condition and must be reduced in same way.

#### 3.3 Glass point fixings

- Ten different kinds of glass fixings are available:
  - o type 1: Countersunk fixing
  - o type 2: Disk fixing
  - o type 3: Circular edge clamp support
  - o type 4: Angular edge clamp support
  - o type 5: Circular downholder
  - o type 6: Angular downholder

- type 7: Adhesive plate fixing (without borehole)
  - type 8: Countersunk fixing within the first pane only
  - type 9: Countersunk fixing within the first package of an DGU
  - type 10: Disk fixing within the first package of DGU
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- The glass fixings may be set at any desired position in the glass plate. But, an angular clamp support cannot be set however into a corner position. If clamp supports are set into the proximity of a corner, then here only straight borders are possible and no round edges.
  - The border of the glass fixings type 1, 2, 7, 8, 9 and 10 may not lie nearer than approx. 25 mm to the edges of the plate.
  - The glass holders of kind 3 to 6 (clamp supports) have a supporting effect over the separating rubber pad.
  - The clamp fixings of kind 5 and 6 can't be used to support the pane in plane direction. They only work as downholders. Tangential to the glass edge all kind of clamp supports cannot transfer forces to the glass. A binding of these clamping fixings using rods must be regarded very conscientiously in order not to produce a kinematic system.
  - A glass point fixing must be defined first over its reference. Thus also different kinds in a plate can be used.
  - The pre-definitions are fictitious standard fixings with frequently occurring dimensions, preset of us.
  - New custom fixings can be permanently stored in the data base under "settings/glass point fixings", so that they can always be reused.
  - The finite element mesh is produced automatically. It can occur however that an error message appears. Then the mesh could not be generated correctly and the element size must be changed slightly up and down (+10 / -10mm).
  - It is to note on an evenly distributed finite element mesh around the point fixing, in order to obtain optimum results.
  - The spring rigidities describe the rigidity of the sub-construction at the place of the fixings base point or also its design. When the rotational degrees of freedom  $C_\varphi$  and  $C_\theta$  are set to zero, a ball shaped head will be described, which can freely rotate.
  - Alternatively the glass fixing can be connected using a sterical orientated rod. This rod has hinges at his both ends, where it will be fixed at the wall and the glass fixings base point.
  - The distance  $Z_h$  describes the position of the place, where the fixing design ends and the springs are acting. E.g. if this point is lying 15 mm under the bottom face of the plate, then this distance must be indicated with -15mm (negatively), as its position is located against the direction of the positive z-axis.
  - The rotation behaviour of the clamp fixings (type 3 to 6) (all others always can freely rotate around the z-axis) can be set to "rigid" (standard) or "free". For rigid settings also torsion loads can be transferred by the glass fixing around the z-axis.
  - Clamp supports of type 3 to 6 are automatically set to "free", if a rod has been set as connection.
  - The downholders of type 5 and 6 act only from top (from negative z-direction) onto the given glass package. They can therefore also be used as suction protection for other bearings to prevent the pane from lifting in the event of a suction load.

- At all point fixings as well forces or moments can be separately applied.

### 3.4 Spacer

- The spacer allows the input of an insulating glass pane with free edges (i.e. an unsupported pane edge) or elastically supported edges.
- The corresponding edge to be fitted with a spacer must be selected.
- If an E-modulus of 100 N/mm<sup>2</sup> (shear modulus 0.0 N/mm<sup>2</sup>) is used for a width of 5 mm, an almost constant distance is assumed (standard setting). This setting describes the overall behaviour of aluminium profile, silicone bonding and the butyl.
- If the behaviour is to be depicted even more realistically, a non-linear behaviour can be selected, so that the window edge can open elastically - but when the window edge is pulled together, the window pane is deposited on the spacer and cannot deform any further. This is rather a possibility for scientific purposes.

### 3.5 Elastic edge supports

- The elastic edge supports describe the bearing conditions of a panel which is elastically supported at its borders.
- Contrary to the conditions of the edge supports, which are a rigid (stiff), here the elastic effects of a bearing can be regarded.
- Additionally contact conditions can be chosen, when lifting plate corners may arise.
- If a shear modulus G other than zero is used, this elastic support also acts in the plane direction. This corresponds to bonding. (structural glazing) (default value: G = 0)
- The default value for a EPDM strip is: E-modulus = 5 – 40 N/mm<sup>2</sup> with a width and height of the really used elastic profile.

### 3.6 Elastic line supports

- This boundary condition behaves exactly the same as the elastic edge supports, only that it can be located anywhere within the plate. As this supports may not lie at the edges of the panel, it is calculated in another manner, for what here a separate register card is used.
- This elastic line support can as well use contact conditions, so that separation can take place.

### 3.7 Edge bonding

- For bonded glass edges this kind of bearing can be set.
- All layers of all packages will then be glued with an elastic material.
- When the shear modulus G is set to zero, only normal forces to the glass edge can be transmitted. In tangential direction moving of the pane will then be possible (like laid on).
- The stresses and reaction forces within the bonding is written into the protocol.

### 3.8 Edge beam

- At the edges an additional elastic beam can be set. This beam then will bear some loads and will bend in addition to the glass edge.
- For definition the moment of inertia, the cross section area and the density has to be given.
- The kind of bearing at the beginning (A) and ending (B) depends upon the way the edge is supported, where the beam will start and end. Additionally to the taken degrees of freedom further D.O.F. can be set. In this way a beam can be simply supported, when no D.O.F's are set for the enframing borders (e.g. type 0).
- The beginning and ending of the beam is defined in the same direction as the orientation of the corner points (counter clockwise).
- It's not possible to use beams at curved borders.

## 4 Loads

### 4.1 Face loads

#### Constant distributed face loads:

- Face loads results from wind or snow, which acts normal onto the entire panel area in perpendicular direction.
- Positive are loads, which act in positive z-direction. Thus usually wind and snow loads must be given with a negative sign, as they act against the z-direction onto the panel. Suction wind loads at projecting edges or in the lee of buildings must against it be positive defined, as they are pulling at the glass panels.
- The loads must be given in the unit N/mm<sup>2</sup>, so that values in kN/m<sup>2</sup> must be divided by 1000. Or the value is furthermore written in units kN/m<sup>2</sup> and „e-3“ is added to this value (so this value is multiplied by 10<sup>-3</sup>). Example: 2.0 kN/m<sup>2</sup> = 0.002 N/mm<sup>2</sup> or 2.0e-3 N/mm<sup>2</sup>.

#### Linear distributed face loads:

- A linear increasing face load (may be constant as well) like water pressure or unequal snow loading can be defined by the use of 2 reference points in y-direction. In between these data  $y_0$  and  $y_1$  the loaded area will be set.
- The calculation of the loaded area is underlying a little approximation at the border lines, which usually do not result in an error force greater than 0.5 N. (see theory handbook)

### 4.2 Dead weight

- The dead weight can act in any desired direction onto the glass panel.
- This direction is defined by a vector with 3 components ( $V_x, V_y, V_z$ ), which describes the gravity direction (and so the steric position of the panel).

- Alternatively the inclination angle can be given for a rotation around the x-axis. From this angle, the vector is automatically calculated.
- Examples:

Position of panel	inclination angle	$V_x$	$V_y$	$V_z$
Horizontal	0°	0	0	-1
vertical (dead weight acts in positive x-direction)	not possible	1	0	0
vertical (dead weight acts in negative y – direction)	90°	0	-1	0
Panel is turned around the x-axis by 45°	45°	0	-1	-1

#### 4.3 Concentrated loads

- Concentrated loads may act at any desired position within the plate.
- The definition of loads take place in the unit of forces [N], which are uniformly distributed over the defined loading area ( $L_x \cdot L_y$ ) and therefore again acts as face loads.
- The position is defined by the center co-ordinates of this loading area.
- Shall loads due to walking persons be set, the load distribution area can be set e.g. to 100x100mm with a total load of –1000N (= 100kg weight of a person).

#### 4.4 Line loads

- Line loads can be defined anywhere and as often you need.
- The used unit is [N/mm] or without conversion [kN/m].
- The starting and ending point of the line can lie anywhere. Loaded parts outside the panel are not considered.
- Along this line 3 load directions  $q_x$ ,  $q_y$ , and  $q_z$  can be defined.
- The loading width along the line is zero.

#### 4.5 Border Line loads

- Along each border line loads may be set, which act transversal onto the border or normal in-plane direction.
- This can be done for straight or curved borders.

#### 4.6 Climate loads

- There could be set all kind of climate loads:
  - o Internal pressure of the gas in the gap
  - o barometric pressure (outside the insulating unit)
  - o temperature differences for the filling gas
  - o differences of height between the production and the installation of the insulating unit
- According to the German standard two load cases can automatically be considered:

Load case	Production	Installation	Pressure difference [mbar]	Temperature difference [°]	Note
Winter	Summer +27° / 990 mbar	Winter +2° / 1030 mbar	+40	2-27= -25°	Pane arches inside
Summer	Winter +19° / 1030 mbar	Summer 38° / 1010 mbar	-20	38-19 = 19°	Pane arches outside

These load cases are specified in SJ MEPLA as follows:

Load case	Internal pressure $p_i$ [N/mm <sup>2</sup> ]	Outside pressure $p_a$ [N/mm <sup>2</sup> ]	Temperature difference $\Delta T$	Difference of height $\Delta H$ [m]
Winter	0.099	0.103	-25°	when lower installed than produced → $\Delta H = -300\text{m}$
Summer	0.103	0.101	+19	when higher installed than produced → $\Delta H = 600\text{m}$

- These loading conditions can automatically be inserted using the pop up menu Winter/Summer.
- Other climatic loads can be defined separately in a database.

#### 4.7 Pendulum impact (twin tire impactor)

- When glass panels are planned with drop securing function, the German standard TRAV (“Technische Regeln für die Verwendung absturzsichernder Verglasungen”) or DIN18008-4 must be observed to avoid expensive tests. Otherwise pendulum impact tests according to the European Standard DIN EN 12600 must be carried out at side.
- SJ MEPLA can be taken to design the glass panels.
- The dynamic calculation of impact takes place by selecting the point of impact and the drop height of the pendulum body.
- These points of impact shall lie 250 mm away from the edges and corners of the plate or the fixings. Three points of impact shall be examined:
  - In the centre,
  - at the corner, and
  - at the edge of the glass plate.
- The panels will pass the simulation, if the maximal principal stresses are not exceeded (only for pendulum test):
  - Float glass 80 N/mm<sup>2</sup>
  - heat strengthened glass 120 N/mm<sup>2</sup>
  - heat toughened glass 170 N/mm<sup>2</sup>

- For the pendulum simulation the option „non linear calculation“ must be chosen, as the results are otherwise not exact.
- Furthermore no other loads shall act for this analysis. That is,
  - o no face loads,
  - o no concentrated loads,
  - o no dead weight,
  - o no temperature differences,
  - o internal pressure = outside pressure for insulating glass units.Otherwise these loads would be considered as well in parallel, which will lead to uncontrolled vibrations of the plate, before the pendulum impacts the pane.
- The pendulum impact onto the first (inside) or last glass package (from outside).

#### 4.8 Enhanced Kelvin-Voigt Impactor Modell

- Here you can describe an extended impact model with freely selectable settings.
- In contrast to the fixed pendulum body, 2 masses, a spherical contact surface and internal damping values can be described here.

#### 4.9 Load case

- Starting with new predefined loads for wind acting onto the outside and inside pane and snow only loading the outside pane, load combinations with respect to other loads can be set here.
- For this, the loads (suction, pressure or nothing) can be chosen, combined with the selected load case.
- This combination can additionally be defined with safety factors multiplied with the selected loads.
- Line loads and point loads cannot be chosen new. They are taken from the definition under *<loads>*.
- To consider the climate loads, 4 presets can be chosen:
  - o Winter condition (the pane are contracting or by any changed value)
  - o Summer condition (the panes will expand, by changed values too)
  - o predefined load case (definition took place under *<layer>*)
  - o no climate loads
- As well other new defined climatic loads can be stored in a database and may be used here.
- The load cases are automatically calculated and written into the protocol.
- In parallel a more condensed table for the loadcase results is written. Here also the proof of stresses according to a chosen standard is done.
- Additionally for the given loads the load cases can be generated automatically by using also the combination factors according to a specified Standard.
- Related to each load case it can be set, if
  - o only the stresses and deflections shall be evaluated, or
  - o the Ultimate Limit State (observing design resistances, stresses) according to a Standard shall be evaluated and proven, or if sole or combined

- a Servability Limit State (observing of deflection limits) shall be checked.
- Within the graphics surface these calculations can be shown by selecting <STEP>.

## 5 Options

### 5.1 Linear and non-linear calculations

- Optional linear or non-linear geometric calculation can be set (large deflection lateral to the plane).
- The approach of large deflections may become significant, when the deflections of a simply supported plate are larger than the thickness of the plate. The plate activates the load carrying mechanism of membran forces which will increase the stiffness and decreased stresses will occur – in contrast to linear calculations, which is a linearization of the full approach, which is only valid for small deflections in an order of  $t/2$ .

### 5.2 Stress results

- At any desired positions within the plate points can be selected, where results in form of stresses and displacements shall be obtained (printouts in the protocol).
- These points are determined by their position (x and y) and the according package.

### 5.3 Maximum stresses

- It can be defined which extreme stresses will be written into the protocol.
- You can chose the maximum principal stresses, the minimal principal stresses and the VonMises stress for metallic panels.

### 5.4 Verification

- If stresses shall directly been checked according to a norm, the Standard to be used must be chosen and additionally some special settings.
- So the type of glass, the strength to be used, safety factors, and some special settings according to the Standard, must be given.
- Related to these settings, the stresses and/or deflections will be checked and verified, if the proof was successful.

## 6 General notes

### 6.1 Mesh refinement

- The element size is by default set to 80 mm. The element discretisation is automatically chosen, so that quadrilateral elements are build.

- This standard element size of 80mm is only a suggestion and may be changed according to the desired accuracy. Therefore it's advisable to check the mesh quality by using the "system preview" before the calculation is started.
- Even when point fixings are used, it is very important to get a uniform, fine mesh around the point fixings to guarantee a good mesh quality for the calculation.
- It may arise, that the mesh for point fixings can't be created. Then the element size must be slightly in- or decreased to achieve a well formed mesh.
- Other reasons for problems with point fixings are holes located too near to borders, so that there is not enough space left to build the finite element mesh at these positions.

## 6.2 Contact approaches

- Many calculations can be carried out with contact approaches.
- For separation of the two touching components, the program has to iterate to build a convergent solution.
- The definition of detachment takes place by considering the tolerance value. This tolerance describes the distance changes between the two parts until they uncouple. Basically: The stiffer one of the two components is, the smaller the tolerance must be chosen.
- Example:
  - o A plate lies upon a weak rubber strip of  $E = 5 - 20 \text{ N/mm}^2$ . A usable value for tolerance is 0.01mm.
  - o When a stiffer strip of plastic is used (e.g. POM with  $E = 3000 \text{ N/mm}^2$ ) the tolerance shall be set to 0.0001mm.
  - o If the glass panel is lying even in direct contact to aluminium ( $E = 70000 \text{ N/mm}^2$ ), the tolerance must be further decreased (e.g. 1.0e-6mm).
- Through detachment, the static system may be changed. Attention must be paid to not achieve an unstable undetermined behaviour. To avoid this, springs can be used which must be defined in a way that they doesn't affect the intended mechanical system.

## 6.3 Calculations of insulated glass unit

- The calculation approaches here used, describe the exact Boyle's law of gas and isn't an approximation.
- As well the gas rearrangements are considered, whereby the program needs in some cases up to approx. 200 iterations until the gas pressure inside the unit has been adjusted to the same value at any position.
- Pendulum impact calculations can be carried out for insulating glass units too.
- When point fixings are used in insulating units, automatically spacers are set at the bore hole rim. Therefore the definition in spacers will be used, even when no free edge has been selected!

#### 6.4 Proof of stresses

- For glass components the proof of stresses can be done by comparing the maximum principal stresses with the allowed stresses due to the table below. (Old guideline TRLV/TRAV)
- These calculated values can be found in the protocol under the item „Maximum principal stresses“ and are listed there for each package.
- Alternatively for load case calculations this proof of stresses and deflections can be done automatically according to any preset Norm. A short protocol informs about settings, load cases and if the proof was successful.

Allowable principal stress [N/mm<sup>2</sup>] : (old German Guideline TRLV)

Kind of glass	Horizontal glazing	Vertical glazing
heat toughened glass form float glass (fully tempered FT)	50	50
heat toughened glass from cast glass	37	37
enamelled heat toughened glass form float glass * (fully tempered FT)	30	30
heat strengthened glass (HS)	29	29
enamelled heat strengthened glass* (HS)	18	18
float glass (annealed glass AN)	12	18
cast glass	8	10
laminated glass from float glass (AN)	15 (25**)	22,5

\* enamel on tension side

\*\* is only for the bottom laminated glass of a horizontal insulating glass unit for the load case of failure for the upper glass panel allowed