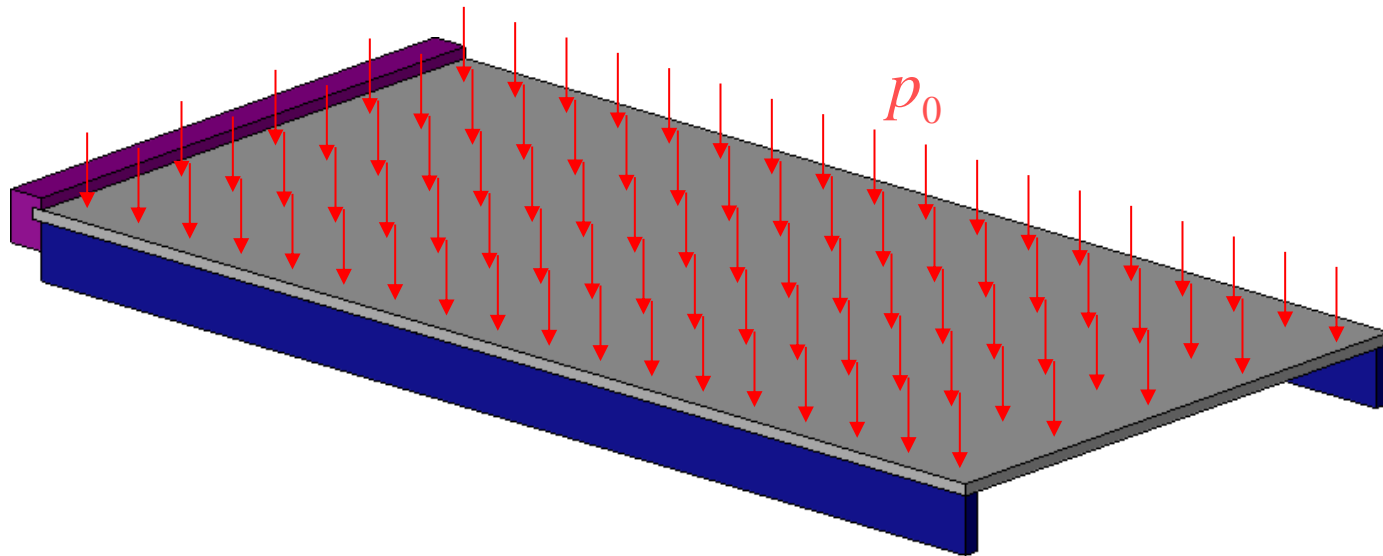
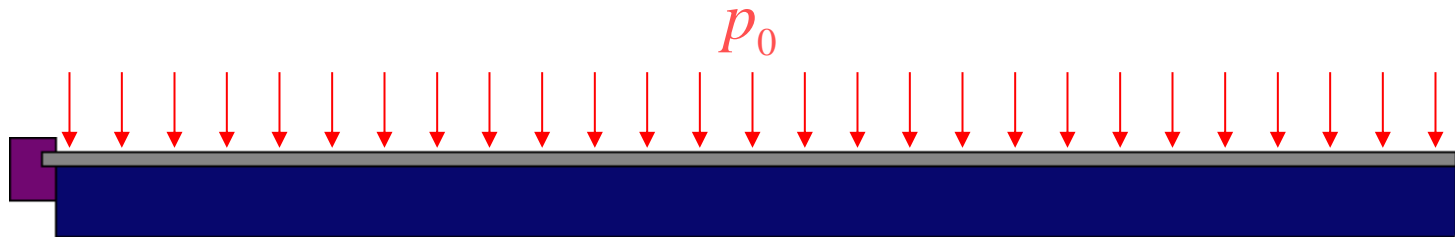


- primer reševanja volumskega mehanskega problema z MKE

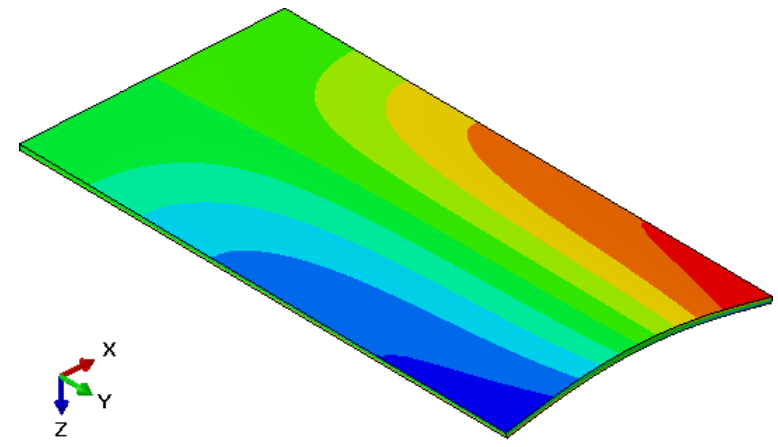
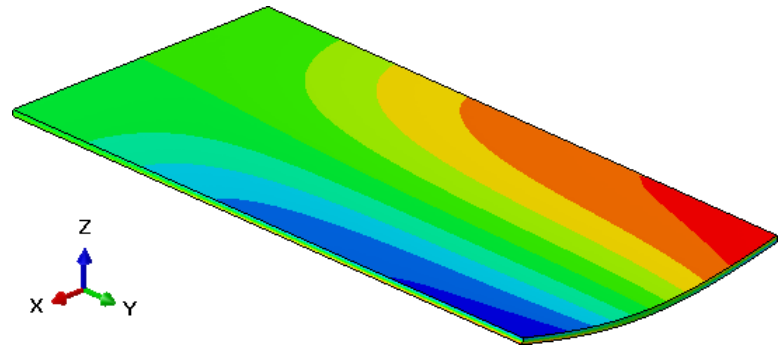
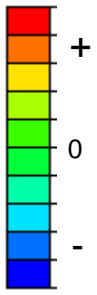


- primer reševanja volumskega mehanskega problema z MKE

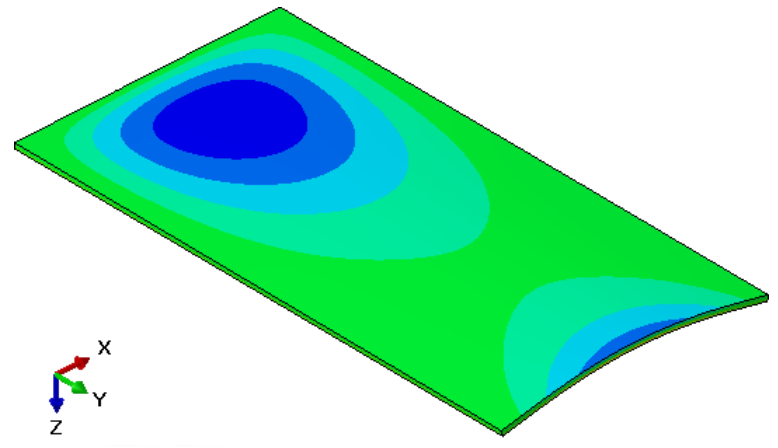
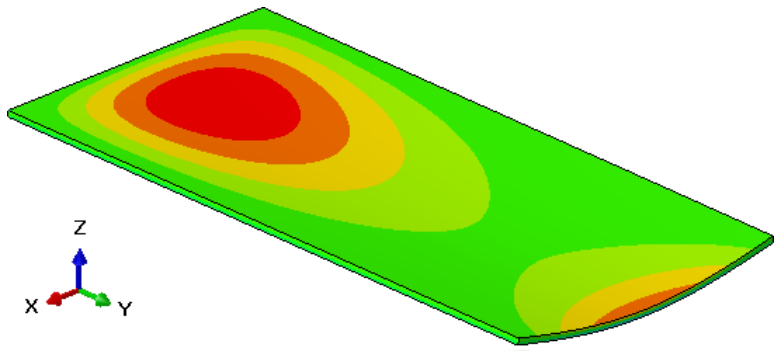
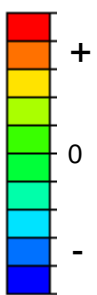


- pomiki v Kartezijevem koordinatnem sistemu

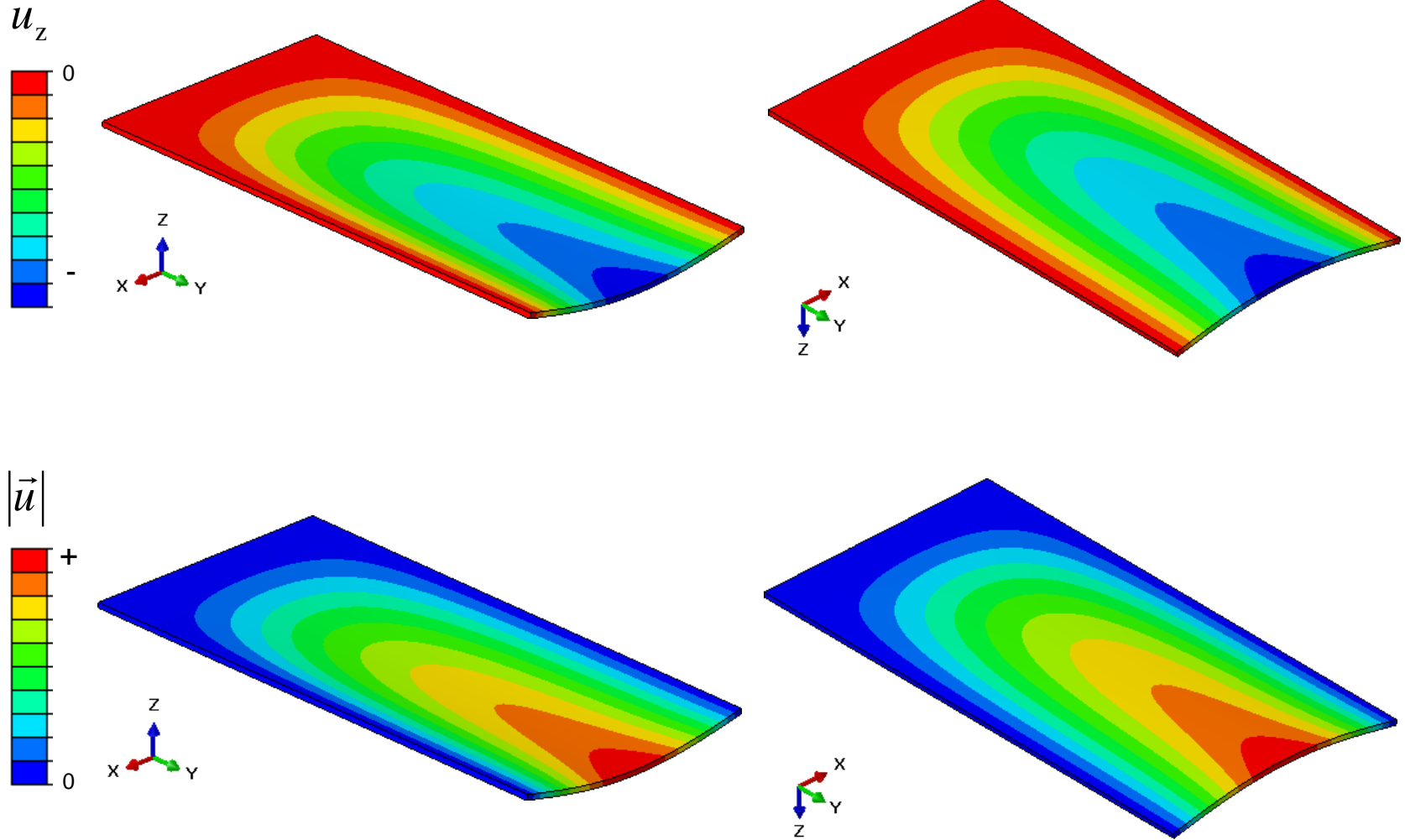
$u_x$



$u_y$

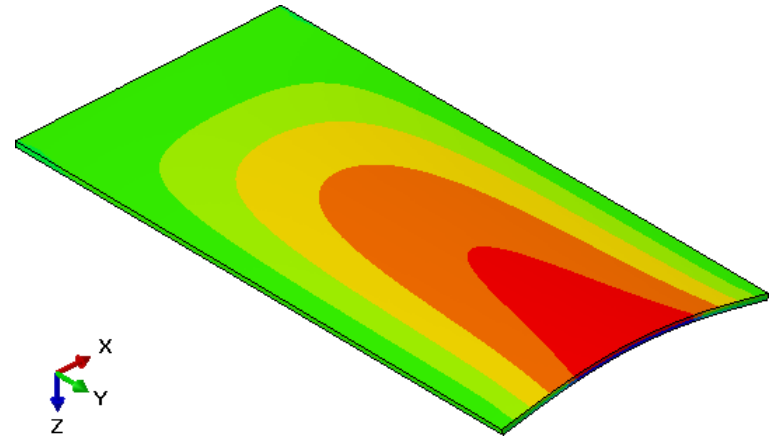
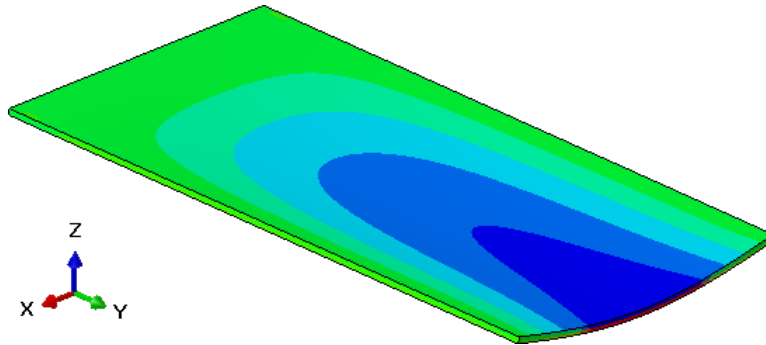
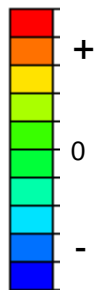


- pomiki v Kartezijevem koordinatnem sistemu

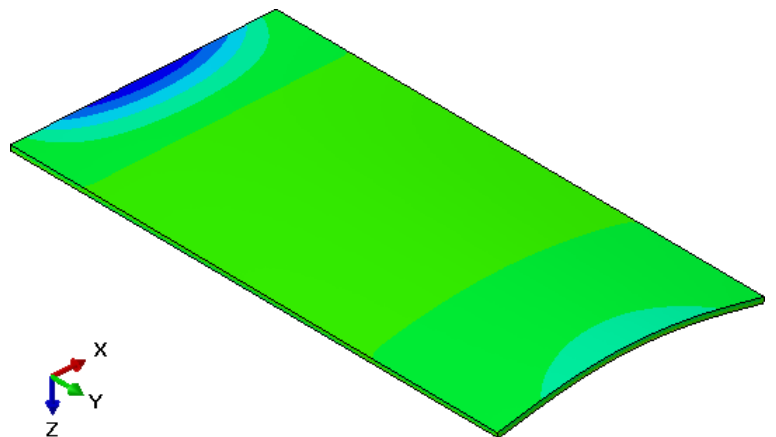
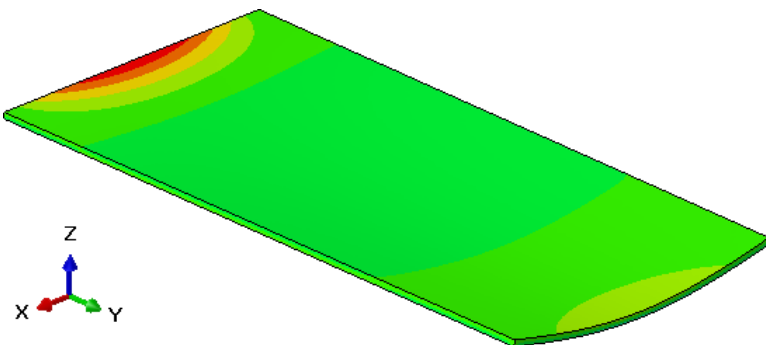
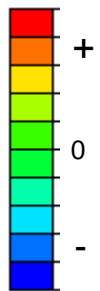


- deformacije v Kartezijevem koordinatnem sistemu

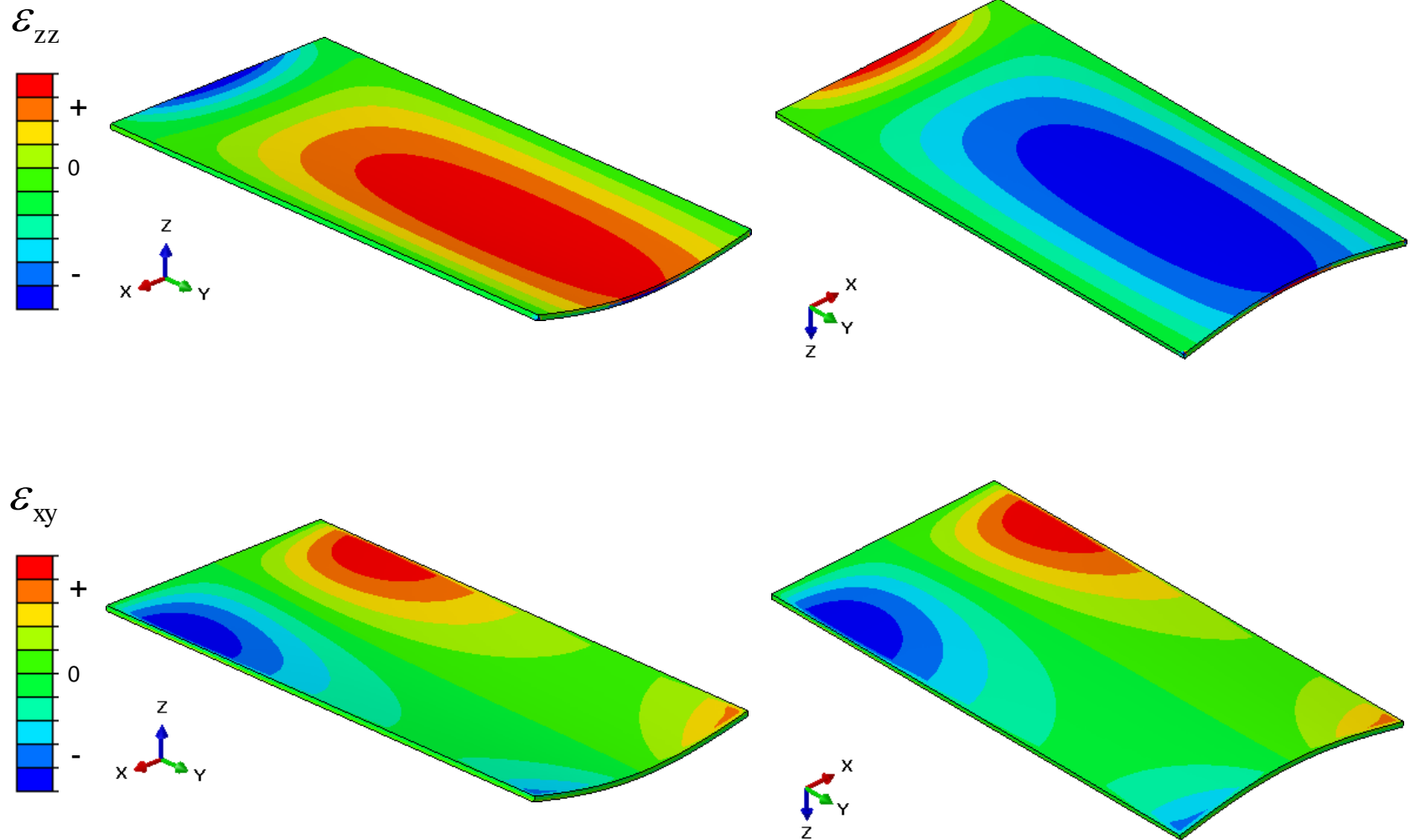
$\varepsilon_{xx}$



$\varepsilon_{yy}$

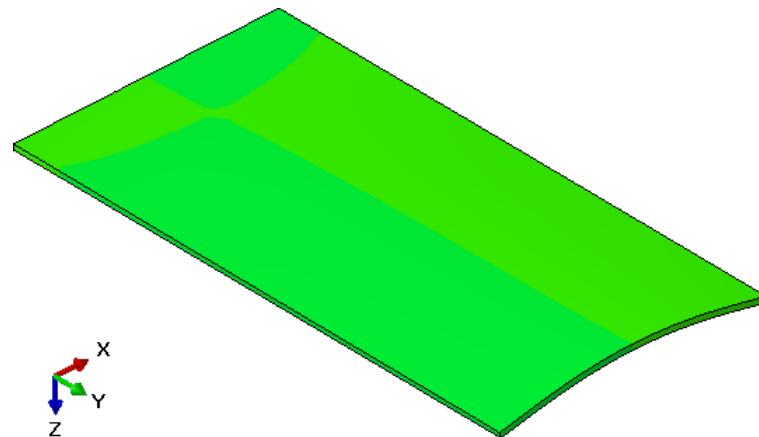
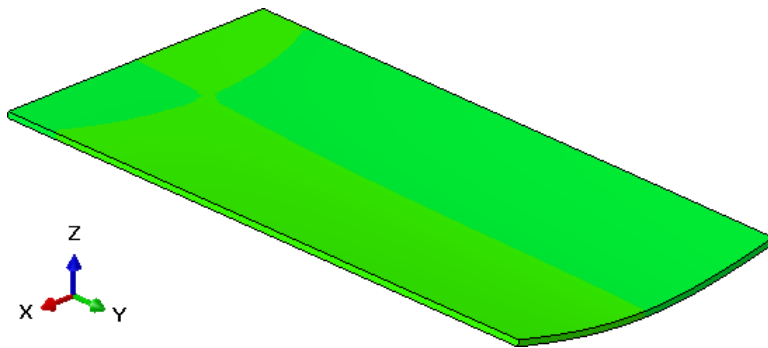
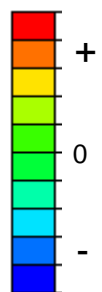


- deformacije v Kartezijevem koordinatnem sistemu

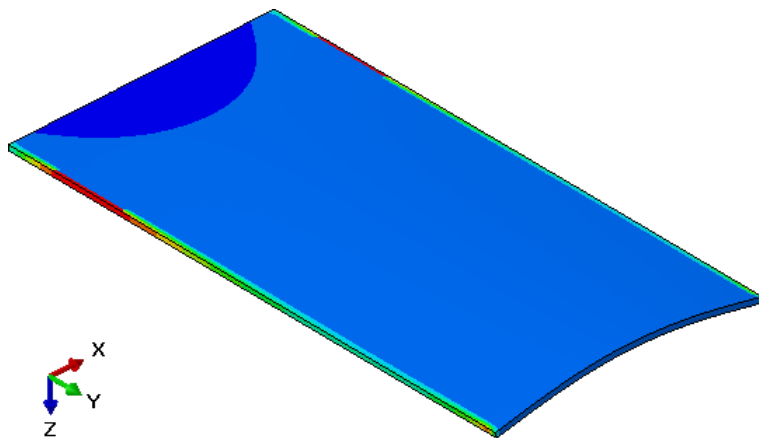
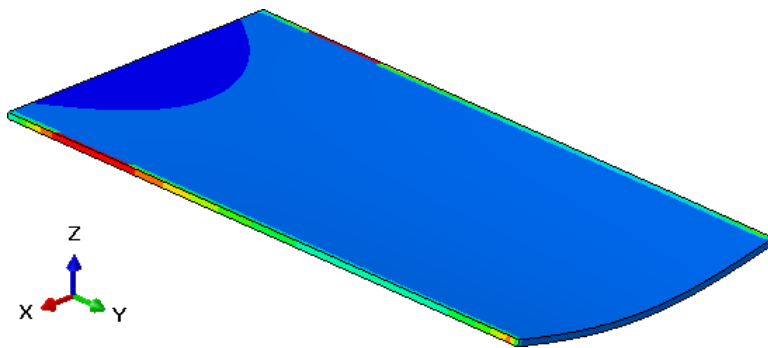
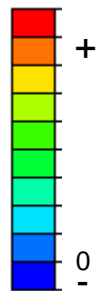


- deformacije v Kartezijevem koordinatnem sistemu

$\varepsilon_{xz}$

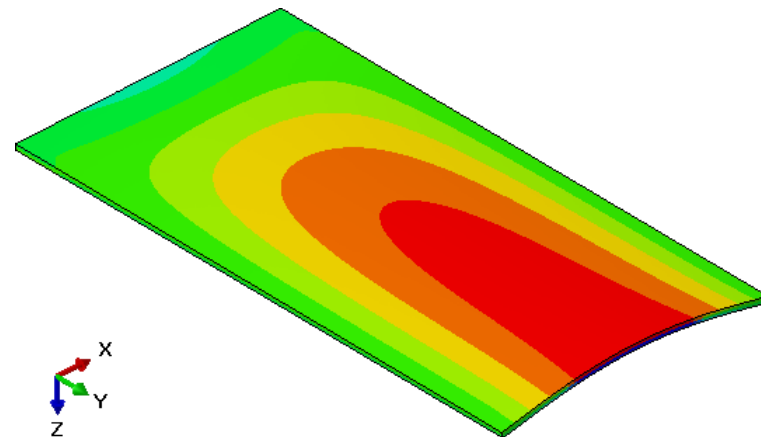
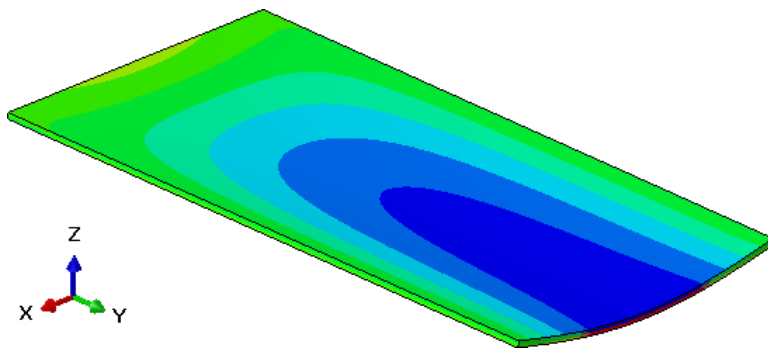
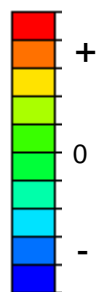


$\varepsilon_{yz}$

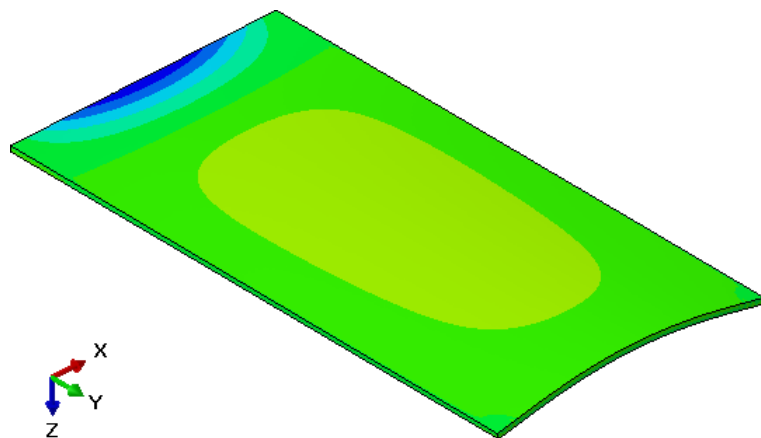
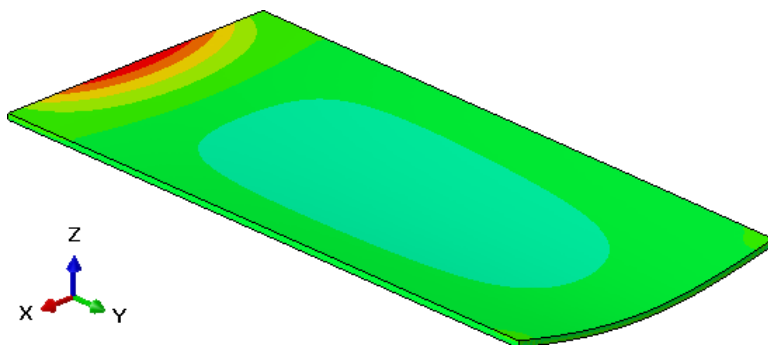
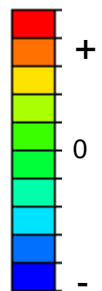


- napetosti v Kartezijevem koordinatnem sistemu

$\sigma_{xx}$

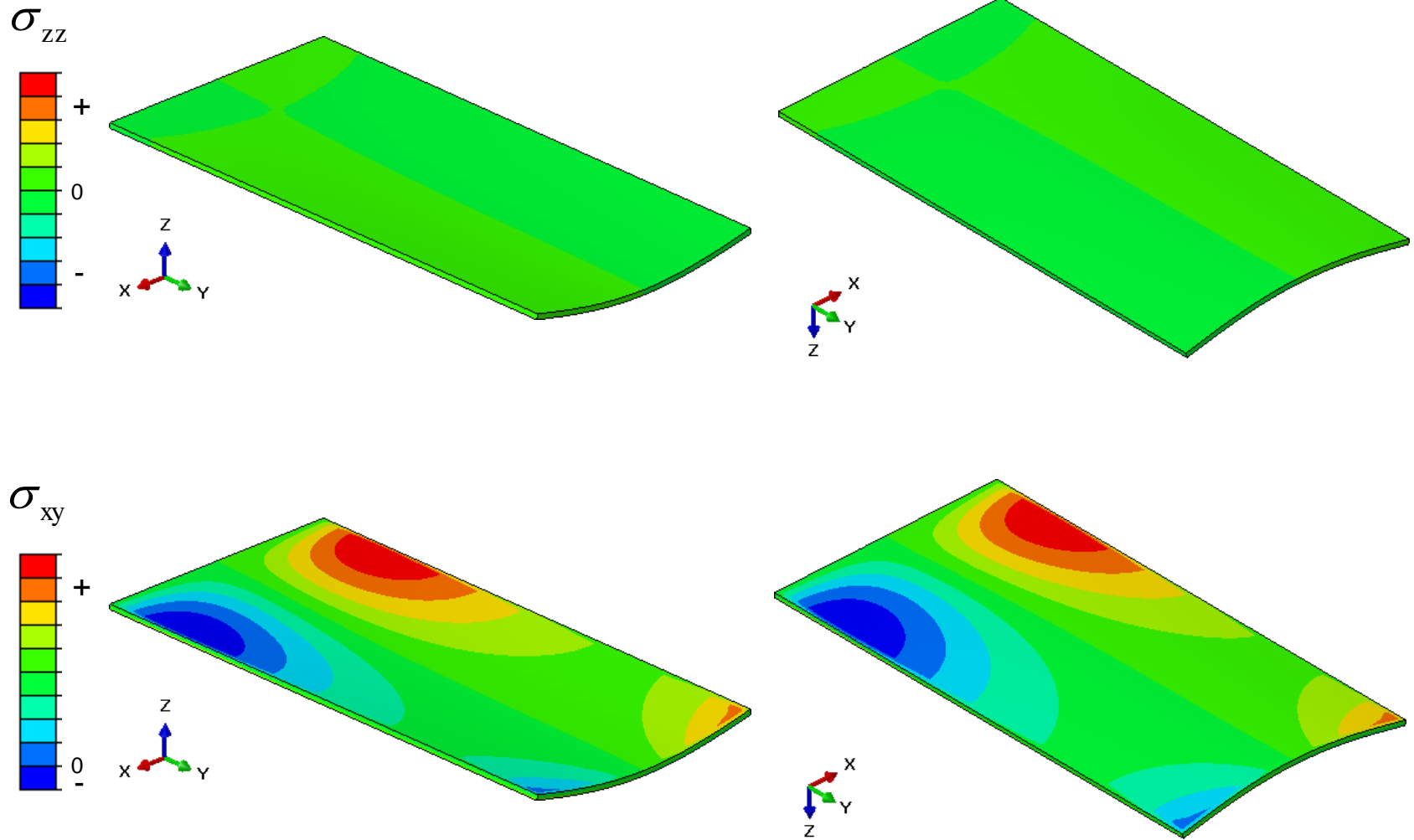


$\sigma_{yy}$



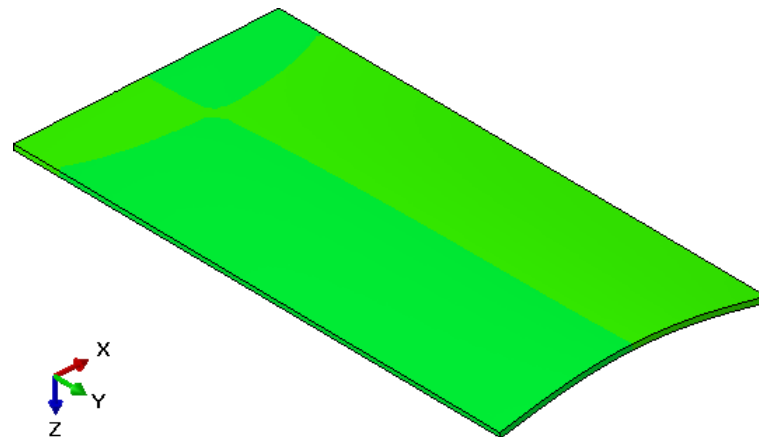
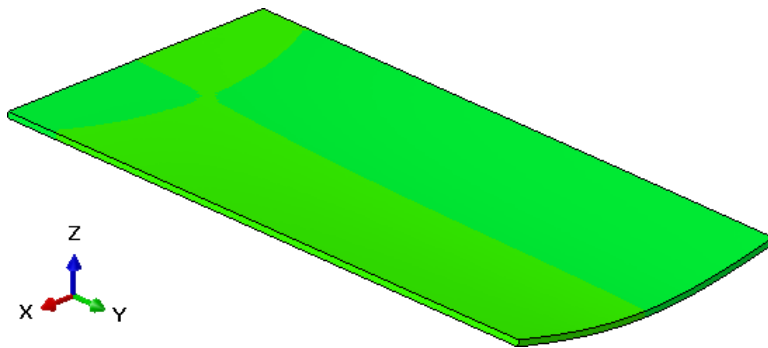
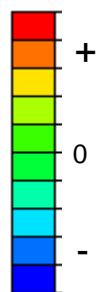


- napetosti v Kartezijevem koordinatnem sistemu

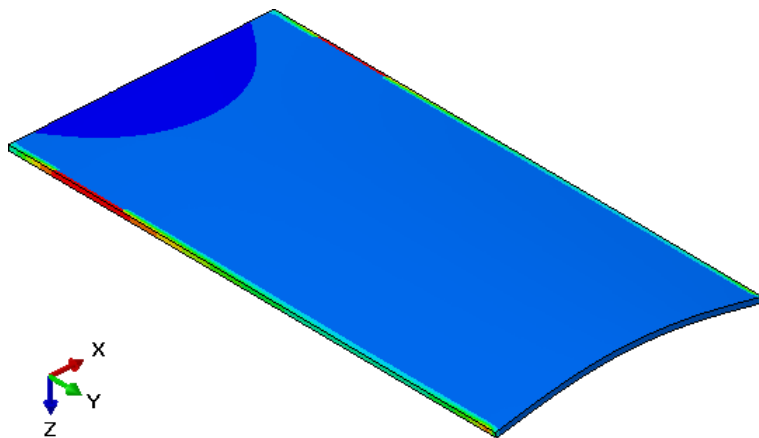
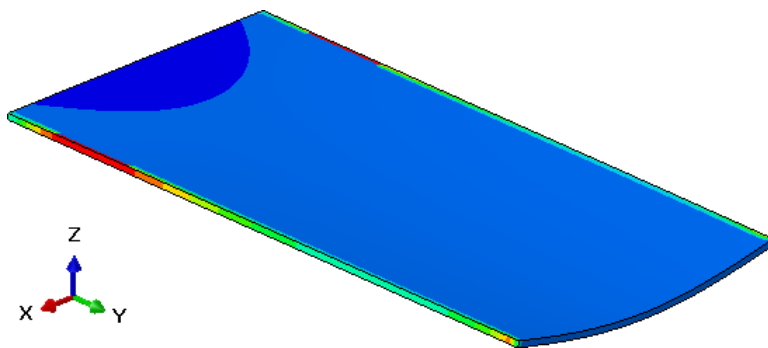
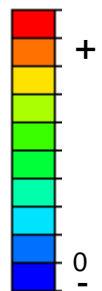


- napetosti v Kartezijevem koordinatnem sistemu

$\sigma_{xz}$

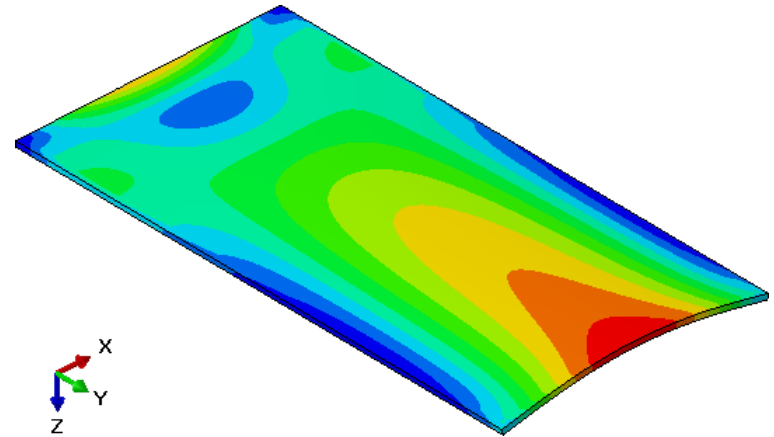
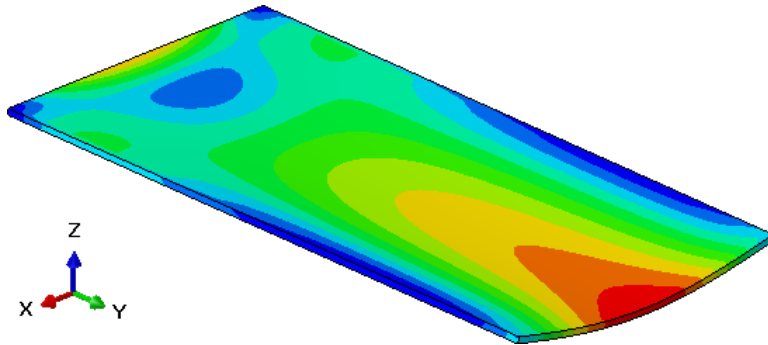
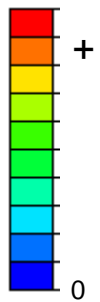


$\sigma_{yz}$



- Mises-ova primerjalna napetost

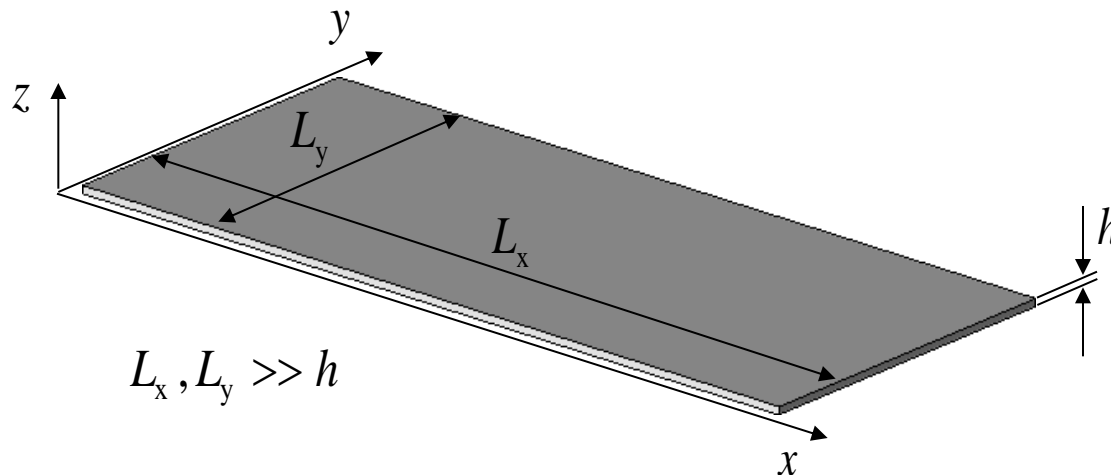
$\sigma_{\text{prim}}$



- kdaj lahko mehanski problem obravnavamo kot upogibno obremenjeno ploščo?

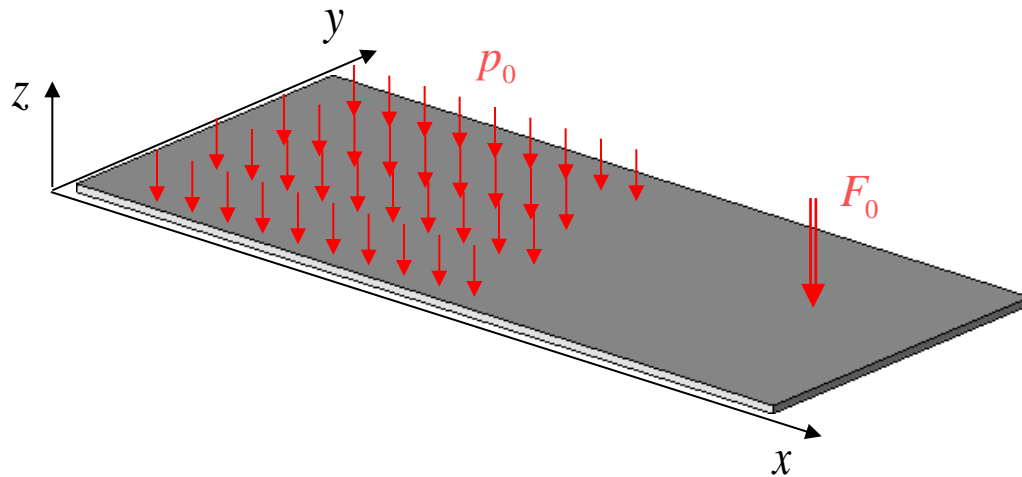
- da lahko problem obravnavamo kot upogibno obremenjeno ploščo (privzemimo da plošča leži v ravnini (x,y)), mora biti izpolnjeno:

1) obravnavano geometrijsko območje mora ležati v ravnini, pri čemer mora biti izmera v smeri “z” koordinatne osi majhna glede na ostale izmere obravnavanega območja



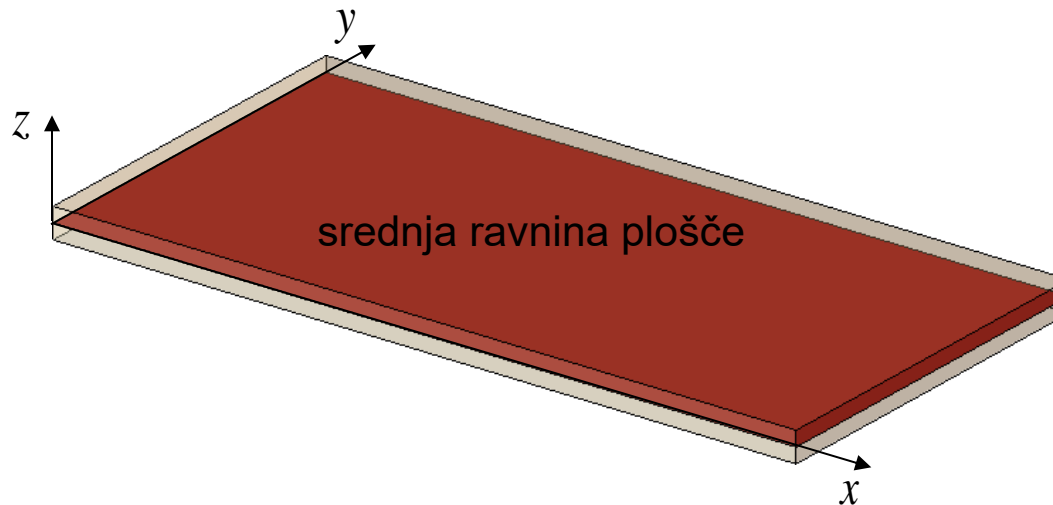
2) homogen material, katerega fizikalne lastnosti so lahko ortotropne

3) obremenitev je lahko usmerjena samo pravokotno na ravnino, v kateri leži obravnavano geometrijsko območje



4) komponenta napetostnega tenzorja  $\sigma_{zz}$  mora biti tako majhna, da jo lahko zanemarimo

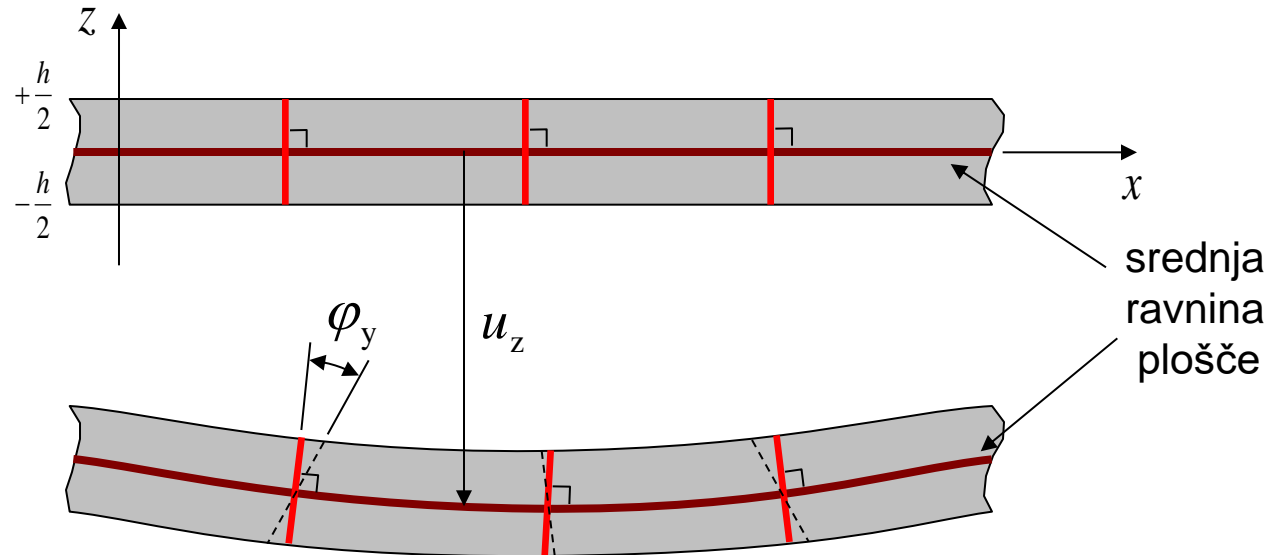
5) dimenzije srednje ravnine plošče se med obremenjevanjem le malo spremenijo, tako da lahko v tej ravnini komponente deformacijskega tenzorja  $\varepsilon_{xx}$ ,  $\varepsilon_{yy}$  in  $\varepsilon_{xy}$  zanemarimo



- upoštevajoč Reissner-Mindlin-ovo teorijo plošč, lahko pomike  $u_x$  in  $u_y$  v plošči izrazimo z zasuki  $\varphi_x$  in  $\varphi_y$

$$u_x = +z \varphi_y$$

$$u_y = -z \varphi_x$$



- Reissner-Mindlin-ova teorija plošč predpostavlja planost prereza v deformiranem stanju, pri čemer pa prerez v splošnem ni več pravokoten na srednjo ravnino plošče



- komponente deformacijskega tenzorja lahko v Kartezijevem koordinatnem sistemu zapišemo v odvisnosti od pomika in dveh zasukov v obravnavanem območju plošče

$$\varepsilon_{xx} = \frac{\partial u_x}{\partial x} = z \frac{\partial \varphi_y}{\partial x}$$

$$\varepsilon_{yy} = \frac{\partial u_y}{\partial y} = -z \frac{\partial \varphi_x}{\partial y}$$

$$\varepsilon_{xy} = \frac{1}{2} \left( \frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x} \right) = \frac{1}{2} \left( z \frac{\partial \varphi_y}{\partial y} - z \frac{\partial \varphi_x}{\partial x} \right)$$

$$\varepsilon_{xz} = \frac{1}{2} \left( \frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x} \right) = \frac{1}{2} \left( \varphi_y + \frac{\partial u_z}{\partial x} \right)$$

$$\varepsilon_{yz} = \frac{1}{2} \left( \frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y} \right) = \frac{1}{2} \left( -\varphi_x + \frac{\partial u_z}{\partial y} \right)$$

$$\varepsilon_{zz} = ?$$

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \\ \varepsilon_{xz} \\ \varepsilon_{yz} \end{Bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & 0 & 2z \frac{\partial}{\partial x} \\ 0 & -2z \frac{\partial}{\partial y} & 0 \\ 0 & -z \frac{\partial}{\partial x} & z \frac{\partial}{\partial y} \\ \frac{\partial}{\partial x} & 0 & 1 \\ \frac{\partial}{\partial y} & 1 & 0 \end{bmatrix} \begin{Bmatrix} u_z \\ \varphi_x \\ \varphi_y \end{Bmatrix} = [L]\{u\}$$





- od nič različne komponente napetostnega tenzorja v Kartezijevem koordinatnem sistemu za primer upogibno obremenjene plošče so naslednje

$$\sigma_{ij} = \begin{Bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_{zz} = 0 \end{Bmatrix}$$



- za homogeni, izotropni, linearno elastični material, lahko iz zveze med napetostmi in deformacijami, ki jo definira Hookov zakon, izračunamo komponento deformacijskega tenzorja  $\varepsilon_{zz}$  in od nič različne komponente napetostnega tenzorja

$$\sigma_{zz} = 0 = \frac{E}{(1+\nu)(1-2\nu)} [\nu \varepsilon_{xx} + \nu \varepsilon_{yy} + (1-\nu) \varepsilon_{zz}] \Rightarrow \varepsilon_{zz} = -\frac{\nu}{(1-\nu)} [\varepsilon_{xx} + \varepsilon_{yy}]$$

$$\sigma_{xx} = \frac{E}{(1+\nu)(1-2\nu)} [(1-\nu) \varepsilon_{xx} + \nu \varepsilon_{yy} + \nu \varepsilon_{zz}]$$

$$\sigma_{yy} = \frac{E}{(1+\nu)(1-2\nu)} [\nu \varepsilon_{xx} + (1-\nu) \varepsilon_{yy} + \nu \varepsilon_{zz}]$$

$$\sigma_{xy} = \frac{E}{(1+\nu)} \varepsilon_{xy} \quad , \quad \sigma_{xz} = \frac{E}{(1+\nu)} \varepsilon_{xz} \quad , \quad \sigma_{yz} = \frac{E}{(1+\nu)} \varepsilon_{yz}$$

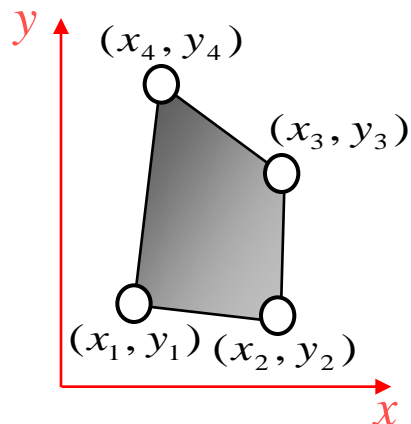


- izoparametrični 2D KE

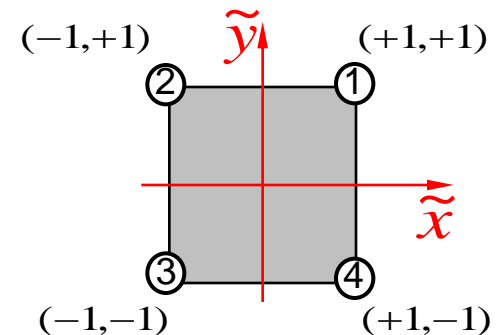
- interpolacija geometrije KE

$$x = x(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} x_j \tilde{\psi}_j(\tilde{x}, \tilde{y})$$

$$y = y(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} y_j \tilde{\psi}_j(\tilde{x}, \tilde{y})$$



Kartezijev 2D koordinatni sistem



naravni koordinatni sistem

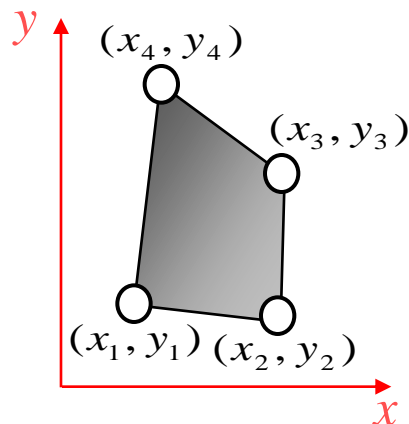
- interpolacija polja pomika in dveh zasukov po območju KE

$$\{u\}_e = \{u_z, \varphi_x, \varphi_y\}^T$$

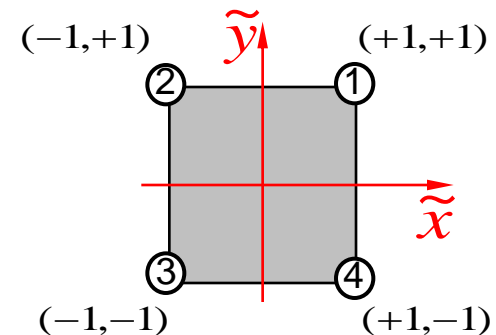
$$u_z(x, y) \approx \hat{u}_z(x, y) = \tilde{u}_z(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} U_j^z \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{U^z\} \{\tilde{\psi}\}$$

$$\varphi_x(x, y) \approx \hat{\varphi}_x(x, y) = \tilde{\varphi}_x(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \Phi_j^x \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\Phi^x\} \{\tilde{\psi}\}$$

$$\varphi_y(x, y) \approx \hat{\varphi}_y(x, y) = \tilde{\varphi}_y(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \Phi_j^y \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\Phi^y\} \{\tilde{\psi}\}$$



Kartezijev 2D koordinatni sistem



naravni koordinatni sistem



- matrični zapis enačbe KE za linearno elastični statično obremenjeni problem

- za posamezni KE dobimo toliko enačb, kolikor ima KE prostostnih stopenj
- v vozlišču KE so neznane tri primarne veličine – pomik in dva zasuka, tako da ima posamezni KE  $(3 \cdot N_v)$  prostostnih stopenj

$$[K]_e \{U\}_e = \{F\}_e$$

$$\begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} & \cdots & K_{1(3N_v)} \\ K_{21} & K_{22} & K_{23} & K_{24} & \cdots & K_{2(3N_v)} \\ K_{31} & K_{32} & K_{33} & K_{34} & \cdots & K_{3(3N_v)} \\ K_{41} & K_{42} & K_{43} & K_{44} & \cdots & K_{4(3N_v)} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ K_{(3N_v)1} & K_{(3N_v)2} & K_{(3N_v)3} & K_{(3N_v)4} & \cdots & K_{(3N_v)(3N_v)} \end{bmatrix}_e \begin{Bmatrix} U_{1z} \\ \Phi_{1x} \\ \Phi_{1y} \\ U_{2z} \\ \vdots \\ \Phi_{(3N_v)y} \end{Bmatrix}_e = \begin{Bmatrix} F_{1z} \\ M_{1x} \\ M_{1y} \\ F_{2z} \\ \vdots \\ M_{(3N_v)y} \end{Bmatrix}_e$$



- togostna matrika  $[K]_e$  za posamezni KE se izračuna na sledeči način

$$[K]_e = \int_{-\frac{h}{2}}^{+\frac{h}{2}} \int_{\Omega_e} ([L][N])^T [E] ([L][N]) d\Omega dz$$

$$\{u\}_e = \begin{Bmatrix} u_z \\ \varphi_x \\ \varphi_y \end{Bmatrix} = \begin{bmatrix} \{\psi\} & 0 & 0 \\ 0 & \{\psi\} & 0 \\ 0 & 0 & \{\psi\} \end{bmatrix} \begin{Bmatrix} \{U^z\} \\ \{\Phi^x\} \\ \{\Phi^y\} \end{Bmatrix} = [N]\{U\}_e$$

$$[L] = \frac{1}{2} \begin{bmatrix} 0 & 0 & 2z \frac{\partial}{\partial x} \\ 0 & -2z \frac{\partial}{\partial y} & 0 \\ 0 & -z \frac{\partial}{\partial x} & z \frac{\partial}{\partial y} \\ \frac{\partial}{\partial x} & 0 & 1 \\ \frac{\partial}{\partial y} & 1 & 0 \end{bmatrix}$$



- posamezni element vektorja  $\{F\}_e$  predstavlja v vozlišču KE delujočo silo usmerjeno vzporedno z “z” koordinatno osjo, oziroma moment, ki deluje okoli osi, ki je vzporedna osi “x” ali “y”

- v primeru, da je velikost pomika v smeri koordinatne osi “z” v vozlišču KE poznana, velikost sile v tej smeri ni poznana

$$U_{iz} = \checkmark \Rightarrow F_{iz} = ? , \quad i = 1, \dots, N_v$$

- v primeru, da je velikost zasuka okoli osi, ki je vzporedna koordinatni osi “x” ali “y”, v vozlišču KE poznana, velikost momenta okoli te osi ni poznana

$$\Phi_{ik} = \checkmark \Rightarrow M_{ik} = ? , \quad i = 1, \dots, N_v , \quad k = x, y$$



- v primeru, da velikost pomika v smeri koordinatne osi “z” v vozlišču KE ni poznana, je velikost sile v tej smeri možno izračunati

$$U_{iz} = ? \quad \Rightarrow \quad F_{iz} = \checkmark, \quad i = 1, \dots, N_v$$

- v primeru točkovne mehanske obremenitve v obliki sile mrežo KE generiramo tako, da točka, v kateri deluje točkovna obremenitev, sovpada z vozliščem KE

$$F_{Iz} = F_{Tz}, \quad I = \{1, \dots, N_{KE}\}$$





- v primeru, da velikost zasuka okoli osi, ki je vzporedna koordinatni osi “x” ali “y”, v vozlišču KE ni poznana, je velikost momenta okoli te osi možno izračunati

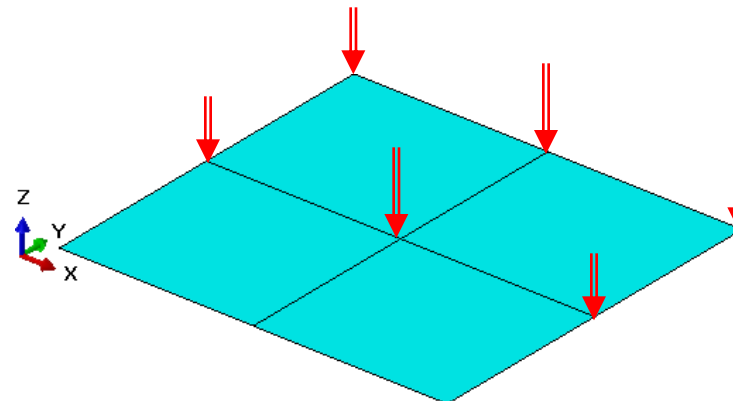
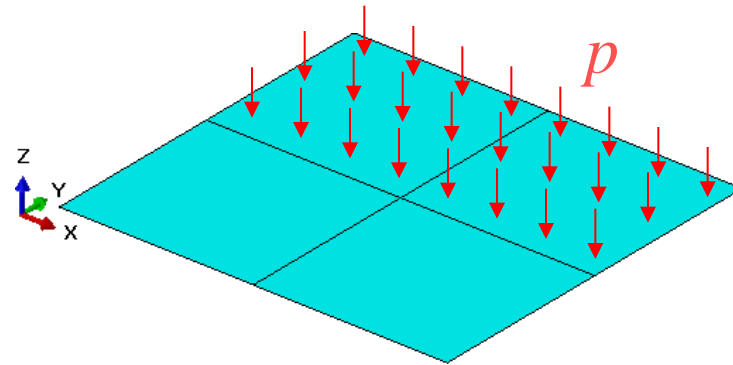
$$\Phi_{ik} = ? \quad \Rightarrow \quad M_{ik} = \checkmark, \quad i = 1, \dots, N_v, \quad k = x, y$$

- v primeru točkovne mehanske obremenitve v obliki momenta mrežo KE generiramo tako, da točka, v kateri deluje točkovna momentna obremenitev, sovpada z vozliščem KE

$$M_{Ik} = M_{Tk}, \quad I = \{1, \dots, N_{KE}\}, \quad k = x, y$$

- v primeru ploskovno porazdeljene mehanske obremenitve, ki deluje v smeri koordinatne osi “z”, izračunamo ekvivalentne vozliščne sile za posamezni KE

$$\{F_p\}_e = \int_{\Omega_e} p[N]^T d\Omega$$



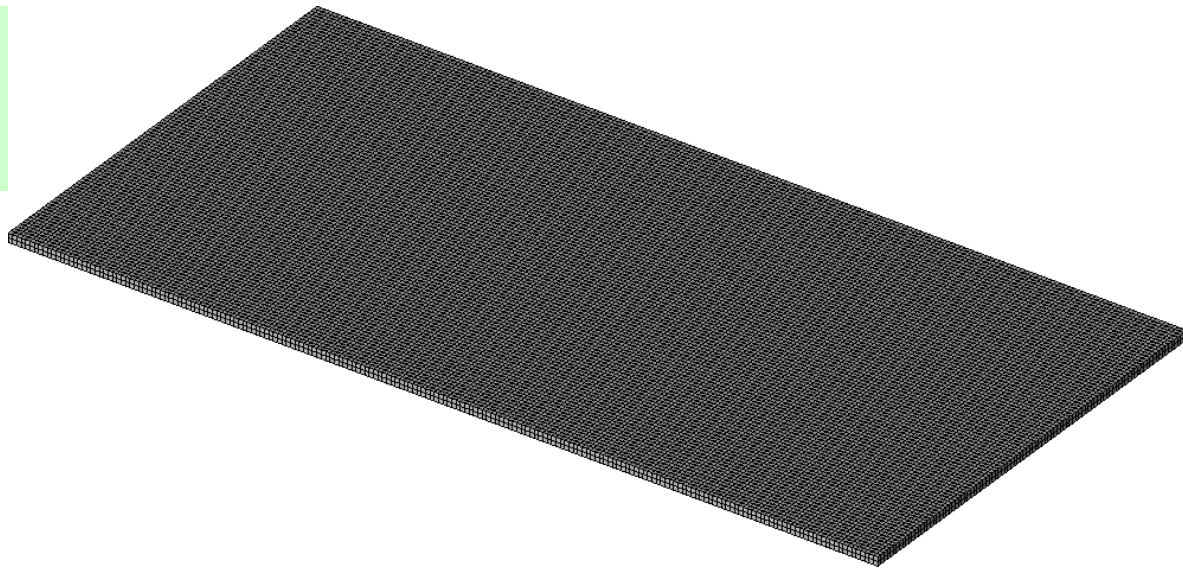
- primer reševanja upogibno obremenjene plošče z MKE

**3D KE:**

40000 KE (6 pl., 8 vozl.)

61000 vozlišč

183000 enačb

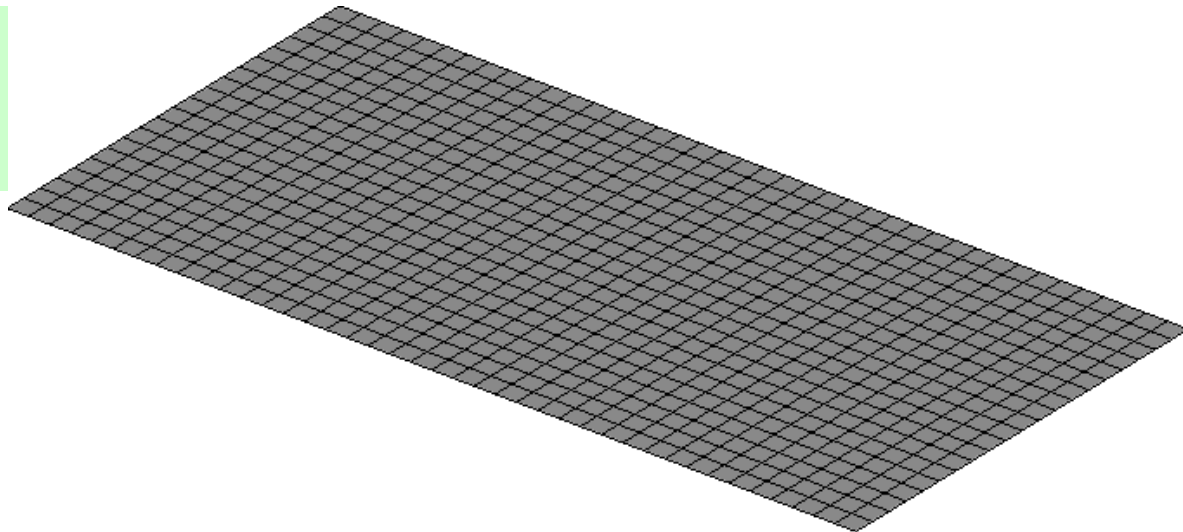


**2D KE:**

800 KE (4 str., 4 vozl.)

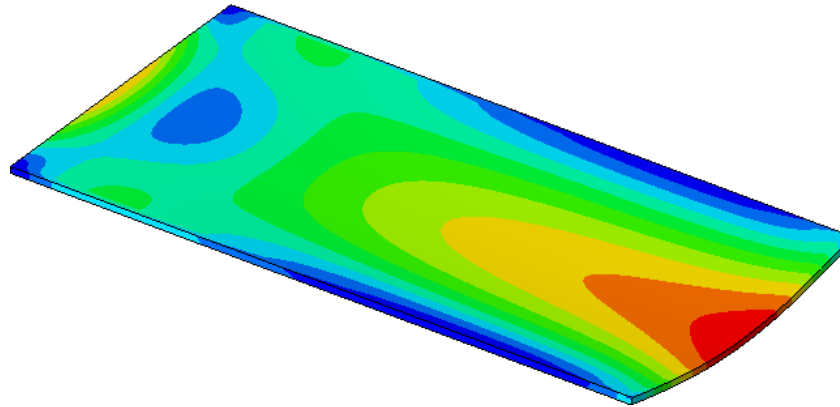
900 vozlišč

2700 enačb



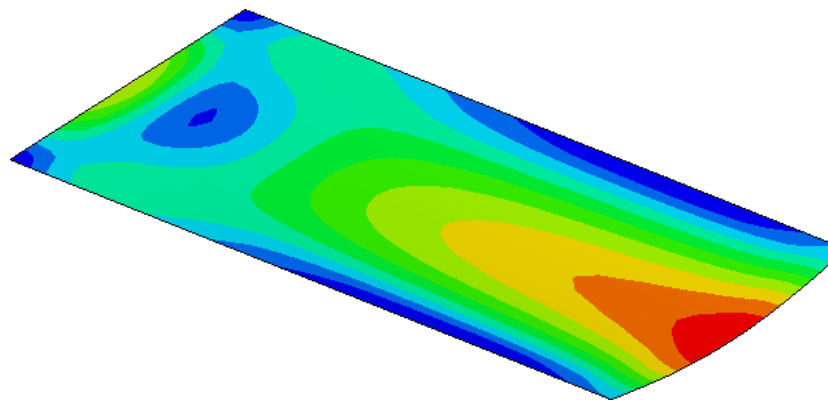
- primerjava Mises-ove primerjalne napetosti: 3D KE ↔ 2D KE

3D KE

 $\sigma_{\text{prim}}$ 

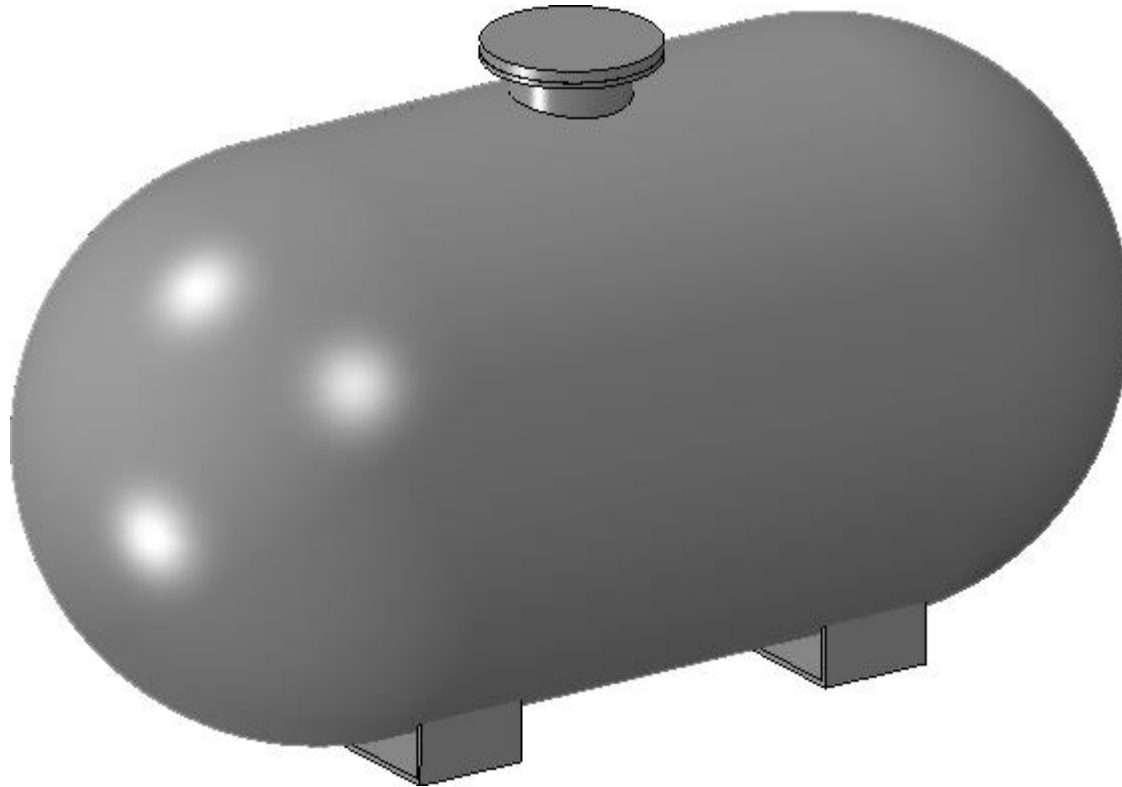
$$\sigma_{\text{prim,max}}^{2\text{D}} = 1.5 \sigma_{\text{prim,max}}^{3\text{D}}$$

2D KE

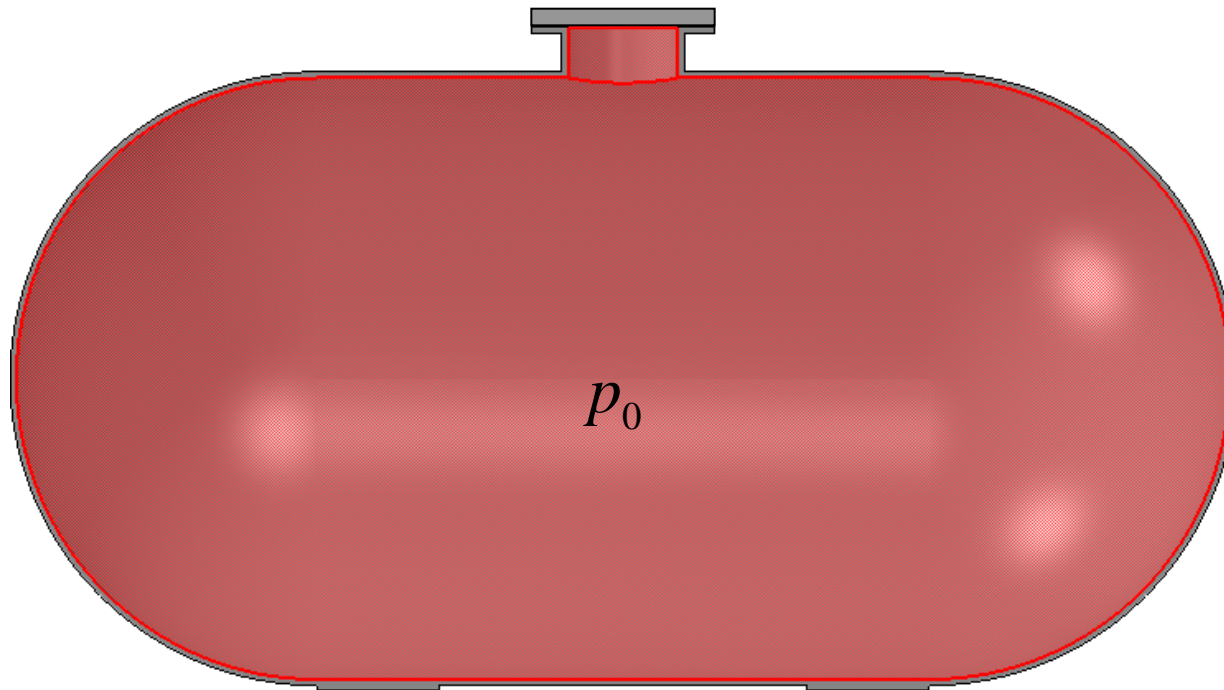
 $\sigma_{\text{prim}}$ 

- primerjalne napetosti se nanašajo na površino plošče in ne na srednjo ravnino, na kateri so prikazane

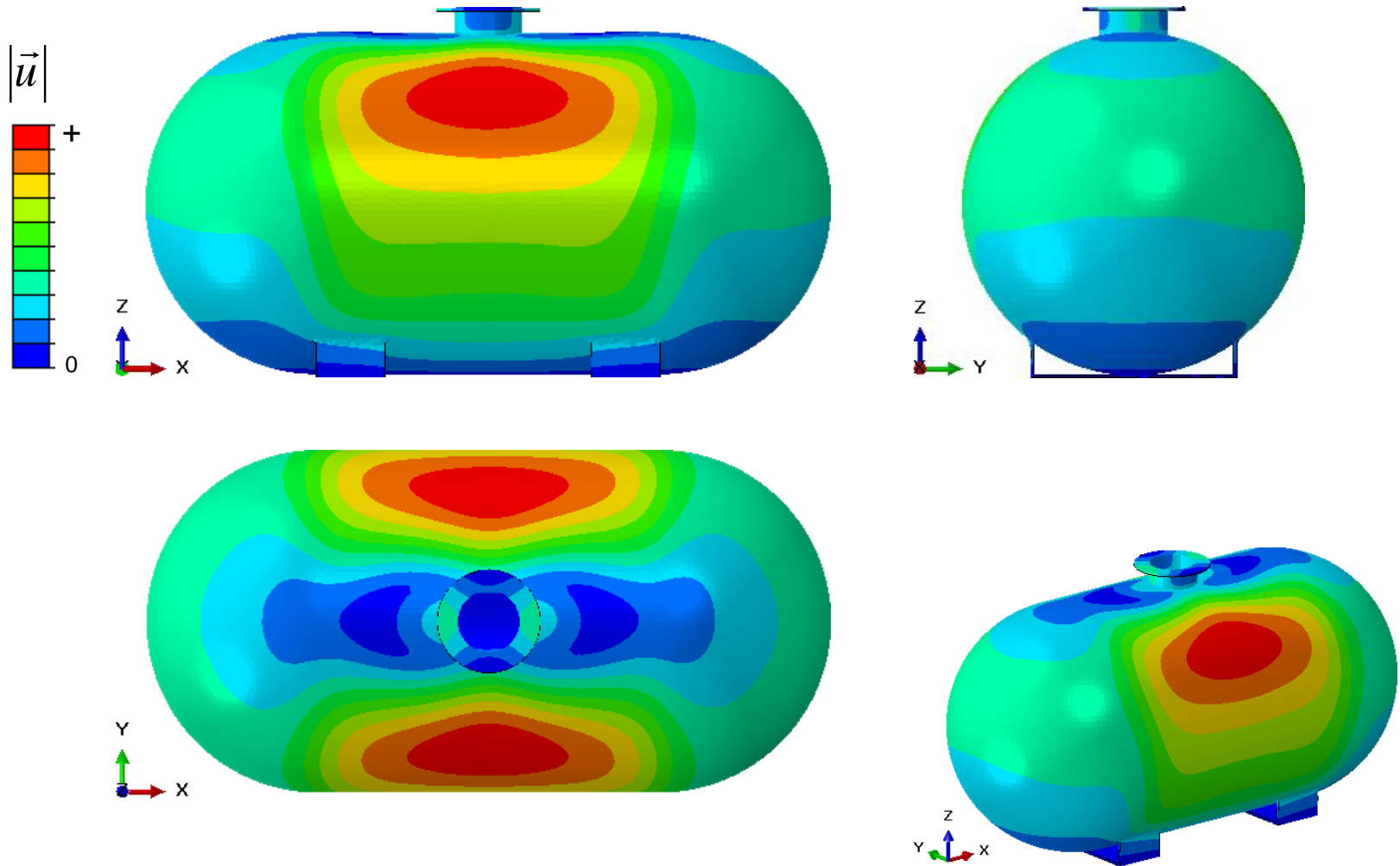
- primer reševanja volumskega mehanskega problema z MKE



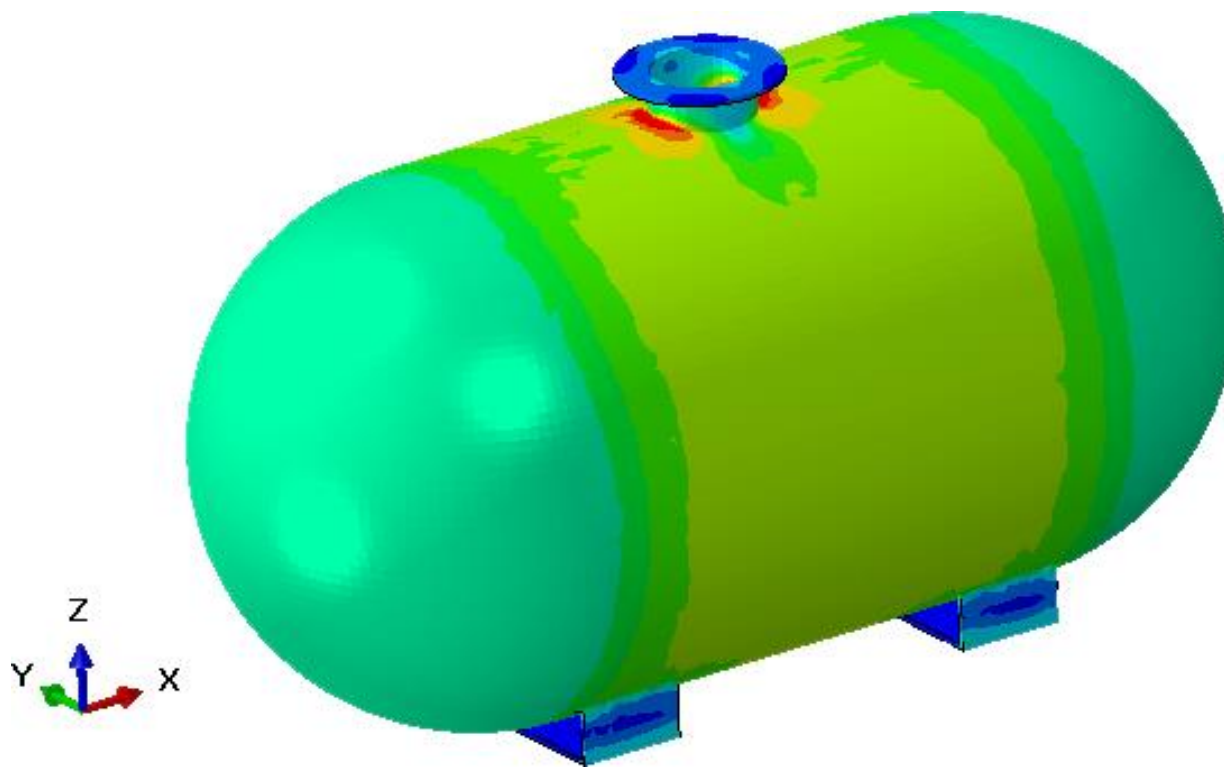
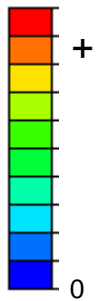
- primer reševanja volumskega mehanskega problema z MKE



- pomiki v Kartezijevem koordinatnem sistemu



- Mises-ova primerjalna napetost

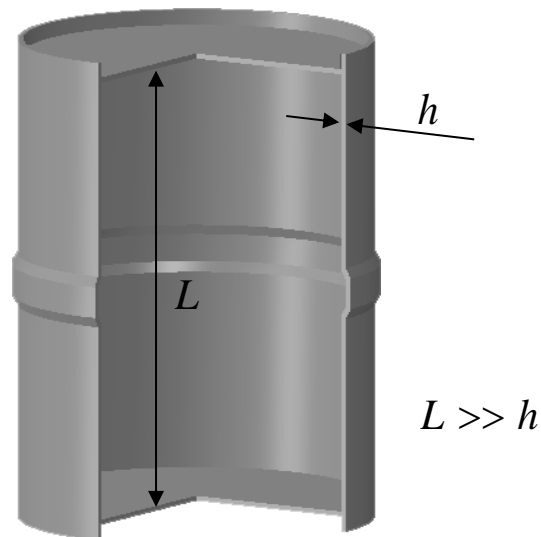
 $\sigma_{\text{prim}}$ 



- kdaj lahko mehanski problem obravnavamo kot upogibno obremenjeni lupinski konstrukcijski element?

- da lahko problem obravnavamo kot upogibno obremenjeni lupinski element:

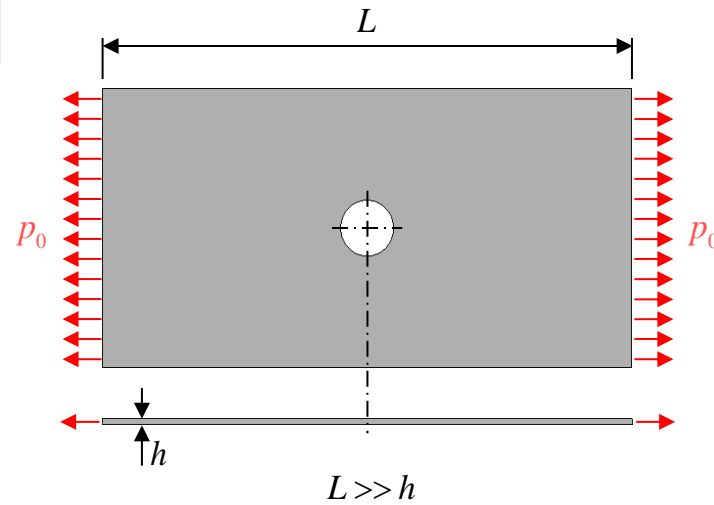
1) obravnavano geometrijsko območje mora izkazovati lupinsko obliko, pri kateri je debelina bistveno manjša od ostalih izmer



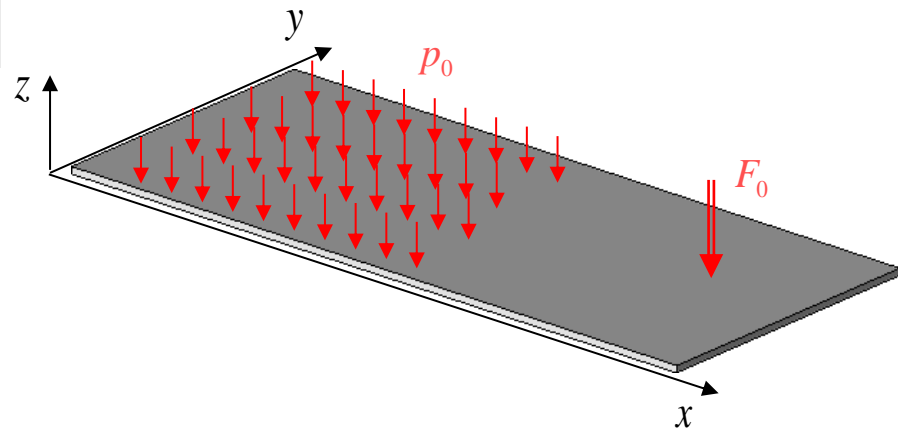
2) komponenta napetostnega tenzorja v smeri debeline lupine mora biti zanemarljive velikosti

- lupinski KE izkazuje lastnosti 2D KE za popis ravninskega napetostnega stanja in 2D KE za popis upogibno obremenjenih plošč

ravninsko napetostno stanje



upogibno obremenjena plošča





- lupinski KE izkazuje lastnosti 2D KE za popis ravninskega napetostnega stanja in 2D KE za popis upogibno obremenjenih plošč

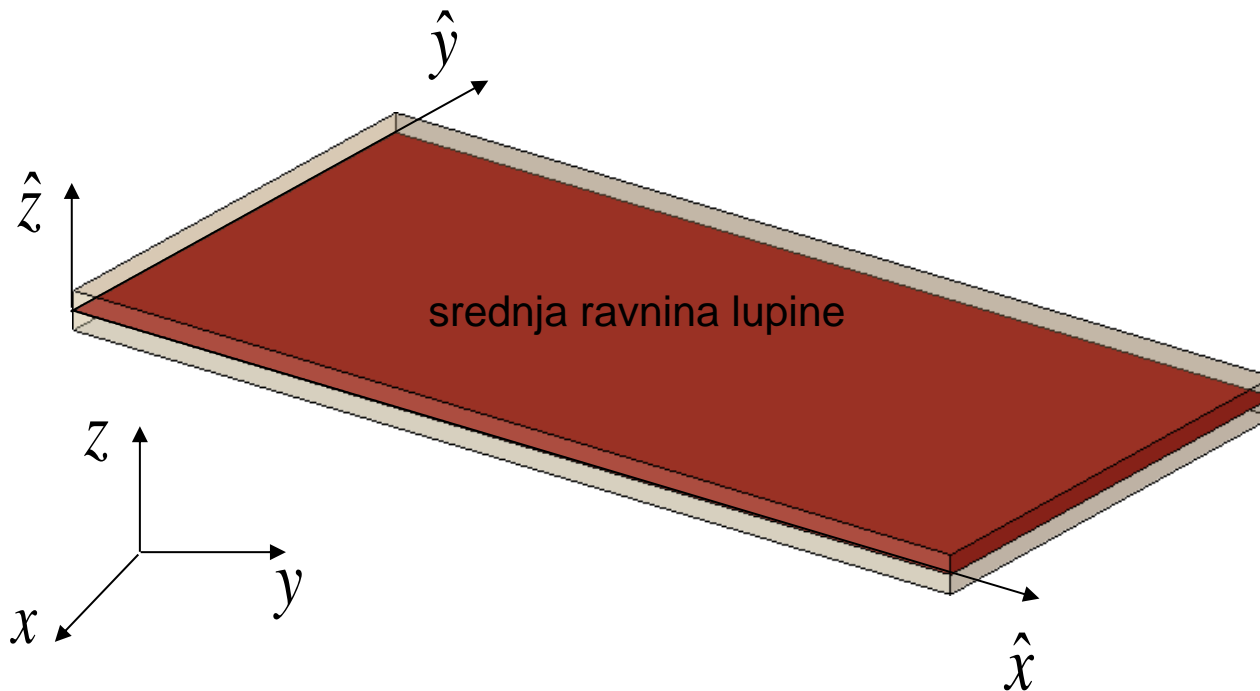
ravninsko napetostno stanje

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x} & 0 \\ 0 & \frac{\partial}{\partial y} \\ \frac{1}{2} \frac{\partial}{\partial y} & \frac{1}{2} \frac{\partial}{\partial x} \end{bmatrix} \begin{Bmatrix} u_x \\ u_y \end{Bmatrix}$$

upogibno obremenjena plošča

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \\ \varepsilon_{xz} \\ \varepsilon_{yz} \end{Bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & 0 & 2z \frac{\partial}{\partial x} \\ 0 & -2z \frac{\partial}{\partial y} & 0 \\ 0 & -z \frac{\partial}{\partial x} & z \frac{\partial}{\partial y} \\ \frac{\partial}{\partial x} & 0 & 1 \\ \frac{\partial}{\partial y} & 1 & 0 \end{bmatrix} \begin{Bmatrix} u_z \\ \varphi_x \\ \varphi_y \end{Bmatrix}$$

- globalni in lokalni Kartezijev koordinatni sistem lupine



- geometrija obravnavnega območja je podana v globalnem koordinatnem sistemu
- deformacijski in napetostni tenzor sta definirana v lokalnem koordinatnem sistemu



- komponente deformacijskega tenzorja v lokalnem Kartezijevem koordinatnem sistemu lupine zapišemo v odvisnosti od treh pomikov in dveh zasukov glede na lokalne koordinatne osi

$$\begin{Bmatrix} \varepsilon_{\hat{x}\hat{x}} \\ \varepsilon_{\hat{y}\hat{y}} \\ \varepsilon_{\hat{x}\hat{y}} \\ \varepsilon_{\hat{x}\hat{z}} \\ \varepsilon_{\hat{y}\hat{z}} \end{Bmatrix} = \begin{bmatrix} \frac{\partial}{\partial \hat{x}} & 0 & 0 & 0 & \hat{z} \frac{\partial}{\partial \hat{x}} \\ 0 & \frac{\partial}{\partial \hat{y}} & 0 & -\hat{z} \frac{\partial}{\partial \hat{y}} & 0 \\ \frac{1}{2} \frac{\partial}{\partial \hat{y}} & \frac{1}{2} \frac{\partial}{\partial \hat{x}} & 0 & -\frac{1}{2} \hat{z} \frac{\partial}{\partial \hat{x}} & \frac{1}{2} \hat{z} \frac{\partial}{\partial \hat{y}} \\ 0 & 0 & \frac{\partial}{\partial \hat{x}} & 0 & 1 \\ 0 & 0 & \frac{\partial}{\partial \hat{y}} & 1 & 0 \end{bmatrix} \begin{Bmatrix} u_{\hat{x}} \\ u_{\hat{y}} \\ u_{\hat{z}} \\ \varphi_{\hat{x}} \\ \varphi_{\hat{y}} \end{Bmatrix}$$



- za homogeni, izotropni, linearno elastični material lahko iz zveze med napetostmi in deformacijami, ki jo definira Hookov zakon, izračunamo komponento deformacijskega tenzorja  $\varepsilon_{\hat{z}\hat{z}}$  in od nič različne komponente napetostnega tenzorja, določene v lokalnem Kartezijevem koordinatnem sistemu lupine

$$\sigma_{\hat{z}\hat{z}} = 0 = \frac{E}{(1+\nu)(1-2\nu)} [\nu \varepsilon_{\hat{x}\hat{x}} + \nu \varepsilon_{\hat{y}\hat{y}} + (1-\nu) \varepsilon_{\hat{z}\hat{z}}] \Rightarrow \varepsilon_{\hat{z}\hat{z}} = -\frac{\nu}{(1-\nu)} [\varepsilon_{\hat{x}\hat{x}} + \varepsilon_{\hat{y}\hat{y}}]$$

$$\sigma_{\hat{x}\hat{x}} = \frac{E}{(1+\nu)(1-2\nu)} [(1-\nu) \varepsilon_{\hat{x}\hat{x}} + \nu \varepsilon_{\hat{y}\hat{y}} + \nu \varepsilon_{\hat{z}\hat{z}}]$$

$$\sigma_{\hat{y}\hat{y}} = \frac{E}{(1+\nu)(1-2\nu)} [\nu \varepsilon_{\hat{x}\hat{x}} + (1-\nu) \varepsilon_{\hat{y}\hat{y}} + \nu \varepsilon_{\hat{z}\hat{z}}]$$

$$\sigma_{\hat{x}\hat{y}} = \frac{E}{(1+\nu)} \varepsilon_{\hat{x}\hat{y}} \quad , \quad \sigma_{\hat{x}\hat{z}} = \frac{E}{(1+\nu)} \varepsilon_{\hat{x}\hat{z}} \quad , \quad \sigma_{\hat{y}\hat{z}} = \frac{E}{(1+\nu)} \varepsilon_{\hat{y}\hat{z}}$$

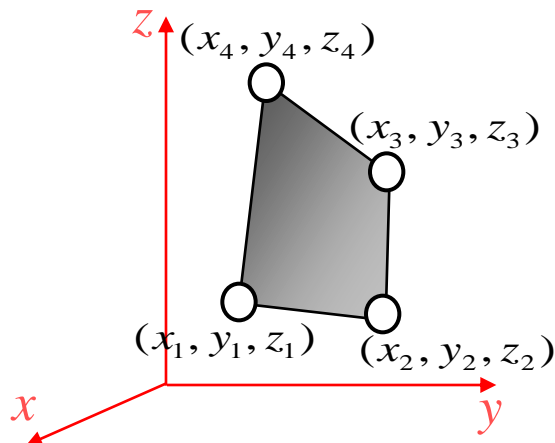
- izoparametrični 2D KE

- interpolacija geometrije KE

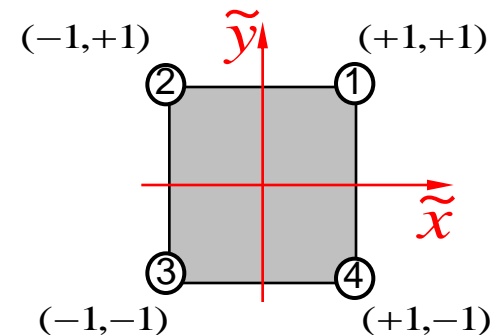
$$x = x(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} x_j \tilde{\psi}_j(\tilde{x}, \tilde{y})$$

$$y = y(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} y_j \tilde{\psi}_j(\tilde{x}, \tilde{y})$$

$$z = z(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} z_j \tilde{\psi}_j(\tilde{x}, \tilde{y})$$



Kartezijev 3D koordinatni sistem



naravni koordinatni sistem



- interpolacija polja pomikov in dveh zasukov po območju KE

$$\{\bar{u}\}_e = \{u_{\hat{x}}, u_{\hat{y}}, u_{\hat{z}}, \varphi_{\hat{x}}, \varphi_{\hat{y}}\}^T$$

$$\bar{u}_x(\hat{x}, \hat{y}, \hat{z}) \approx \tilde{u}_x(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \hat{U}_j^x \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\hat{U}^x\} \{\tilde{\psi}\}$$

$$\bar{u}_y(\hat{x}, \hat{y}, \hat{z}) \approx \tilde{u}_y(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \hat{U}_j^y \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\hat{U}^y\} \{\tilde{\psi}\}$$

$$\bar{u}_z(\hat{x}, \hat{y}, \hat{z}) \approx \tilde{u}_z(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \hat{U}_j^z \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\hat{U}^z\} \{\tilde{\psi}\}$$

$$\bar{\varphi}_x(\hat{x}, \hat{y}, \hat{z}) \approx \tilde{\varphi}_x(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \hat{\Phi}_j^x \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\hat{\Phi}^x\} \{\tilde{\psi}\}$$

$$\bar{\varphi}_y(\hat{x}, \hat{y}, \hat{z}) \approx \tilde{\varphi}_y(\tilde{x}, \tilde{y}) = \sum_{j=1}^{N_v} \hat{\Phi}_j^y \tilde{\psi}_j(\tilde{x}, \tilde{y}) = \{\hat{\Phi}^y\} \{\tilde{\psi}\}$$





- sistem enačb lupinskega KE za linearno elastični statično obremenjeni problem
- za posamezni KE dobimo toliko enačb, kolikor ima KE prostostnih stopenj
- pri preslikavi iz lokalnega koordinatnega sistema lupinskega KE v globalni koordinatni sistem dobimo v posameznem vozlišču KE šest primarnih veličin – tri pomike v smereh globalnih koordinatnih osi in tri zasuke okoli globalnih koordinatnih osi
- v vozlišču KE je šest primarnih veličin, tako da ima posamezni KE ( $6 \cdot N_v$ ) prostostnih stopenj