CHAPTER 10. CALCULATION OF PRINCIPAL AND EQUIVALENT STRESSES

When calculating building structures, there is no need to determine the stresses for all directions passing through a given point, but it is enough to know the minimum and maximum stress values. The minimum and maximum normal stresses are called the principal stresses, and the directions on which they act are called the main directions.

10.1 PRINCIPAL STRESSES

Principal stresses and unit vectors of the normals to the main areas completely characterize the stress state at the point [10.1], that is, they allow calculating all components of the stress tensor.

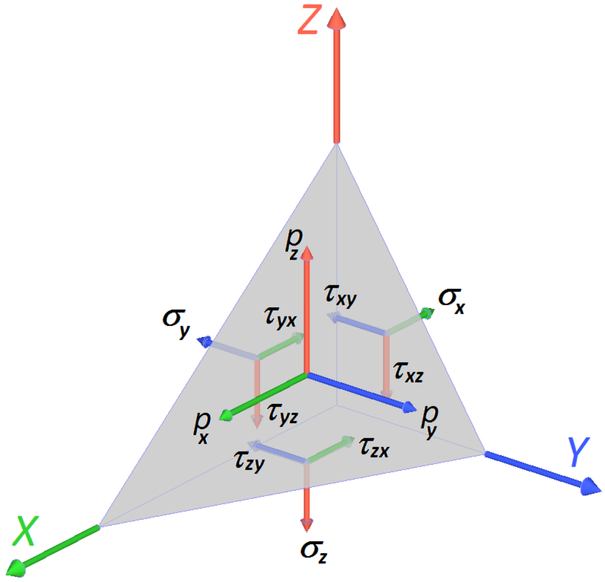

Fig. 10.1. Elementary tetrahedron with stress state components

Normal stresses are defined by the letter σ with an index corresponding to the normal to the direction *on which they act. Tangential stresses are defined by the letter τ with two indices: the first corresponds to the normal to the* direction, *and the second corresponds to the direction of the stress itself.*

It is assumed that the plane crossing the coordinate axes has a unit normal vector $\vec{n}$ with the components n_x, n_y, n_z. On the faces of the infinitely small tetrahedron obtained in this way, the stresses shown in Fig. 10.1. In this case, the stress vector $\vec{p}$ on the inclined direction is decomposed into components p_x, p_y, p_z along the coordinate axes. The areas of the faces orthogonal to the coordinate axes and the normal vector will be defined by dF_x, dF_y, dF_z, dF_p respectively.

These areas are related by:

$$dF_x = dF_p \cdot n_x, \;\; dF_y = dF_p \cdot n_y, \;\; dF_z = dF_p \cdot n_z, \qquad (10.1)$$

arising from the fact that the faces orthogonal to the coordinate axes are projections of the inclined directions onto the corresponding coordinate plane.

By projecting the forces acting on the faces of the elementary tetrahedron onto the coordinate axes, we obtain the equilibrium equations for the considered volume. For example, the projections of all surface forces on the x-axis give:

$$p_x dF - \sigma_x dF_x - \tau_{yx} dF_y - \tau_{zx} dF_z = 0.$$

Taking into account relations (10.1), after reduction by dF_p we obtain an equation relating the projection p_x of the stress vector with the corresponding components of the stress tensor. Combining this equation with two similar equations obtained by projecting forces on the Y and Z axes, we result in the Cauchy formulas:

$$\begin{aligned} p_x &= \sigma_x n_x + \tau_{yx} n_y + \tau_{zx} n_z, \\ p_y &= \tau_{xy} n_x + \sigma_y n_y + \tau_{zy} n_z, \\ p_z &= \tau_{xz} n_x + \tau_{yz} n_y + \sigma_z n_z, \end{aligned} \qquad (10.2)$$

These formulas define the stress vector on an arbitrarily chosen area with the normal vector $\vec{n}$ through the components of the stress tensor $[\sigma]$:

$$[\sigma] = \begin{bmatrix} \sigma_x & \tau_{yx} & \tau_{zx} \\ \tau_{xy} & \sigma_y & \tau_{zy} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix},$$

From which, according to the law of pairing of shear stresses, it goes:

$$\tau_{xy} = \tau_{yx}, \tau_{yz} = \tau_{zy}, \tau_{xz} = \tau_{zx},$$

And only six stress components will be independent [10.2].

Formulas (10.2) allow to calculate through the components of the stress tensor the following:

- full stress

$$p_n = \sqrt{p_x^2 + p_y^2 + p_z^2}; \qquad (10.3)$$

- normal stress

$$\sigma_n = p_x n_x + p_y n_y + p_z n_z; \qquad (10.4)$$

- tangential stress

$$\tau_n = \sqrt{p_n^2 - \sigma_n^2}. \qquad (10.5)$$

Among all the possible directions of the normal vector $\vec{n}$ there are those for which the stress vector $\vec{p}$ is parallel to the vector $\vec{n}$. Only normal stresses act on the corresponding directions, and there are no tangential stresses - such directions are called principal, and normal stresses on these directions are called principal stresses. Let the direction with a unit normal vector be the main one. The conditions for the parallelism of the vectors $\vec{p}$ и $\vec{n}$ are the conditions for the proportionality of their components:

$$p_x = \sigma \cdot n_x, p_y = \sigma \cdot n_y, p_z = \sigma \cdot n_z.$$

Taking into account the Cauchy formulas, we obtain a system of linear homogeneous equations for the unknown components n_x, n_y, n_z of the normal vector to the main direction:

$$\begin{aligned} (\sigma_x - \sigma) n_x + \tau_{yx} n_y + \tau_{zx} n_z &= 0, \\ \tau_{xy} n_x + (\sigma_y - \sigma) n_y + \tau_{zy} n_z &= 0, \\ \tau_{xz} n_x + \tau_{yz} n_y + (\sigma_z - \sigma) n_z &= 0. \end{aligned} \qquad (10.6)$$

This system of equations has a non-zero solution if the determinant composed of the coefficients of the equations vanishes:

$$\begin{vmatrix} \sigma_x - \sigma & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y - \sigma & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z - \sigma \end{vmatrix} = 0. \qquad (10.7)$$

Expanding the determinant, we arrive at the cubic equation:

$$\sigma^3 - J_1\sigma^2 + J_2\sigma - J_3 = 0. \qquad (10.8)$$

And the following notation is introduced for the coefficients:

$$J_1 = \sigma_x + \sigma_y + \sigma_z,$$

$$J_2 = \begin{vmatrix} \sigma_x & \tau_{xy} \\ \tau_{xy} & \sigma_y \end{vmatrix} + \begin{vmatrix} \sigma_x & \tau_{xz} \\ \tau_{xz} & \sigma_z \end{vmatrix} + \begin{vmatrix} \sigma_y & \tau_{yz} \\ \tau_{yz} & \sigma_z \end{vmatrix} = \sigma_x\sigma_y + \sigma_x\sigma_z + \sigma_y\sigma_z - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2, \qquad (10.9)$$

$$J_3 = \begin{vmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{vmatrix} = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{xz}\tau_{yz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2.$$

Equation (10.7) is called the characteristic equation for the stress tensor. The cubic equation (10.8) has three real roots $\sigma_i, i = 1,2,3$, which are usually ordered $\sigma_1 \geq \sigma_2 \geq \sigma_3$. Principal stresses do not depend on the choice of coordinate system and they are invariant. The equation (10.8) can be written as:

$$(\sigma_1 - \sigma)(\sigma_2 - \sigma)(\sigma_3 - \sigma) = 0.$$

Having compared with (10.8), we obtain formulas for the coefficients:

$$J_1 = \sigma_1 + \sigma_2 + \sigma_3, J_2 = \sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_2\sigma_3, J_3 = \sigma_1\sigma_2\sigma_3,$$

The coefficients of the characteristic equation are called stress tensor invariants.

Each value of σ_i corresponds to the vector $\vec{n}_i$, which characterizes the position of the i -th main direction, with components n_{ix}, n_{iy}, n_{iz}, vectors $\vec{n}_i$ *and* $\vec{n}_j$ are orthogonal at $i \neq j$. To find the components of the vectors $\vec{n}_i$ it is sufficient to substitute the found value σ_i into equations (10.6) and solve any two of these equations together with the normalization condition:

$$n_{ix}^2 + n_{iy}^2 + n_{iz}^2 = 1.$$

Having solved the system (10.6) three times, the matrix of direction cosines is obtained:

$$[A] = \begin{bmatrix} n_{1x} & n_{1y} & n_{1z} \\ n_{2x} & n_{2y} & n_{2z} \\ n_{3x} & n_{3y} & n_{3z} \end{bmatrix}. \qquad (10.10)$$

The direction of principal stresses can also be determined by three Euler's angles relative to the local coordinate system (Figure 10.2):

- θ (nutation angle) is the angle between the positive directions of the OZ_1 and σ_3 $(0 \leq \theta \leq \pi)$ axes.
- ψ (precession angle) is the angle between the OX_1 and OA axes (the line of intersection of the X_1OY_1 and $\sigma_1 O \sigma_2$), the positive direction of which is chosen so that OA, OZ_1 and σ_1 form a right triple. The angle ψ is measured from the OX_1 axis to the OY_1 axis $(0 \leq \psi \leq 2\pi)$.
- ϕ (pure rotation angle) — the angle between the OA and σ_1 axes is measured from the σ_1 axis to σ_2 $(0 \leq \phi \leq 2\pi)$.

Euler's angles are defined as follows: $\theta = arccos(n_{3z})$. For $\theta = 0$, $\phi = 0$, $\psi = arcsin(n_{1y})$, and if $n_{1x} < 0$, then $\psi = \pi - arcsin(n_{1y})$. If $\psi < 0$, then $\psi = \psi + 2\pi$.

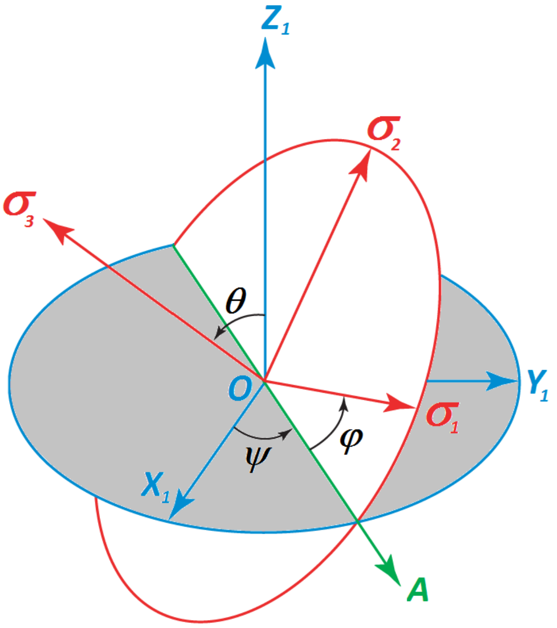

Fig. 10.2. Euler's angles relative to the local coordinate system

Further, $\phi = arcsin\left(\frac{n_{3z}}{\sqrt{1-n_{3z}^2}}\right)$, and if $\left(\frac{n_{2z}}{\sqrt{1-n_{3z}^2}}\right) < 0$, then $\phi = \pi - arcsin\left(\frac{n_{1z}}{\sqrt{1-n_{3z}^2}}\right)$. If $\phi < 0$, then $\phi = \phi + 2\pi$.

Using Hook's law, we obtain the main total relative elongations in the direction of the main stresses:

$$\varepsilon_1 = \frac{1}{E}[\sigma_1 - v \cdot (\sigma_2 + \sigma_3)],$$
$$\varepsilon_2 = \frac{1}{E}[\sigma_2 - v \cdot (\sigma_1 + \sigma_3)],$$
$$\varepsilon_3 = \frac{1}{E}[\sigma_3 - v \cdot (\sigma_1 + \sigma_2)].$$

For an isotropic body, angular deformations do not affect linear ones and vice versa.

To characterize the stress-strain state, the Lode-Nadai coefficient is calculated, which characterizes the type of stress-strain state [10.3]:

$$\mu = 2\frac{\sigma_2-\sigma_3}{\sigma_1-\sigma_3} - 1. \quad (10.11)$$

Using the formula (10.11), the value of the parameter μ (Lode Nai) is calculated. And with the following values (1,0,-1), the structure or the studied area undergoes (tension, compression or shear)

$\mu = 1$ —pure compression;
$\mu = 0$ — pure shift;
$\mu = -1$ — pure tension.

✍ *Principal stresses have an important property: compared to all other* directions, *the normal stresses on the principal* directions *take on extreme values. To prove this property, it is necessary to study the normal stress for an extremum as a function of n_x, n_y, n_z with an additional constraint $n_{ix}^2 + n_{iy}^2 + n_{iz}^2 = 1$.*

Let us introduce the concept of average stress (hydrostatic pressure):

$$\sigma_0 = (\sigma_x + \sigma_y + \sigma_z)/3 = (\sigma_1 + \sigma_2 + \sigma_3)/3.$$

The stress tensor can be represented as the sum of two tensors $[\sigma] = [\tilde{s}] + [\tilde{d}]$,
where

$$[\tilde{s}] = \begin{bmatrix} \sigma_0 & 0 & 0 \\ 0 & \sigma_0 & 0 \\ 0 & 0 & \sigma_0 \end{bmatrix}, [\tilde{d}] = \begin{bmatrix} \sigma_x - \sigma_0 & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y - \sigma_0 & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z - \sigma_0 \end{bmatrix}.$$

The first tensor is called spherical and it characterizes the change in the volume of the body without changing its shape. The second tensor, called the deviator, characterizes the change in shape. A feature of the stress deviator is the equality to zero of its first invariant $J_1 = \sigma_x + \sigma_y + \sigma_z - 3\sigma_0 = 0$.

Three-dimensional elasticity problem

For solid finite elements, using the above formulas, the following are calculated:

- principal stresses σ_1, σ_2 and σ_3;
- Euler's angles θ, ψ and ϕ;
- maximum tangential stress $\tau \frac{\sigma_1 - \sigma_3}{2}_{max}$;
- principal strains ε_1, ε_2 and ε_3;
- Lode-Nadai coefficient μ.

The determination of the principal stresses in this case is made from the cubic equation constructed for the stress deviator:

$$S^3 + pS + q = 0, \quad (10.12)$$

where

$$p = (S_x S_y + S_x S_z + S_y S_z - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2),$$
$$q = -(S_x S_y S_z + 2\tau_{xy}\tau_{xz}\tau_{yz} - S_x \tau_{yz}^2 - S_y \tau_{xz}^2 - S_z \tau_{xy}^2),$$
$$S_x = \sigma_x - \sigma_0, S_y = \sigma_y - \sigma_0, S_z = \sigma_z - \sigma_0,$$
$$\sigma_0 = (\sigma_x + \sigma_y + \sigma_z)/3, S_x + S_y + S_z = 0.$$

Equation roots (10.12):

$$S_1 = 2 \cdot \sqrt{r} \cdot cos(\omega),$$
$$S_3 = -2 \cdot \sqrt{|r|} \cdot cos\left(\omega + \frac{\pi}{3}\right),$$
$$S_2 = -2 \cdot \sqrt{|r|} \cdot cos\left(\omega - \frac{\pi}{3}\right), \quad (10.13)$$

where

$$\omega = \frac{1}{3} arccos\left(-\frac{q}{2 \cdot r\sqrt{r}}\right). r = p/3,$$

Principal stresses are calculated by the formula:

$$\sigma_i = S_i + \sigma_0. \quad (10.14)$$

Then the direction cosine matrix is calculated (10.10).

Plane elasticity problem

A plane stress state is modeled in the X_1OZ_1 plane. The characteristic equation in the case of a plane stress state has the form:

$$\begin{vmatrix} \sigma_x - \sigma & \tau_{xz} \\ \tau_{xz} & \sigma_z - \sigma \end{vmatrix} = 0,$$

and in the case of plane deformation:

$$\begin{vmatrix} \sigma_x - \sigma & 0 & \tau_{xz} \\ 0 & \sigma_y - \sigma & 0 \\ \tau_{xz} & 0 & \sigma_z - \sigma \end{vmatrix} = 0.$$

Principal stresses are calculated on the mid-surface at the center of gravity of each finite element. In the case of a plane stress state, principal stresses are equal to:

$$\sigma_{1,3} = \frac{\sigma_x+\sigma_z}{2} \pm \sqrt{\left(\frac{\sigma_x+\sigma_z}{2}\right)^2 + \tau_{xz}^2}, \sigma_2 = 0, \quad (10.15)$$

and in the case of plane deformation:

$$\sigma_{1,3} = \frac{\sigma_x+\sigma_z}{2} \pm \sqrt{\left(\frac{\sigma_x+\sigma_z}{2}\right)^2 + \tau_{xz}^2}, \sigma_2 = \sigma_y. \quad (10.16)$$

The angle of inclination of the largest principal stress σ_1 to the axis OX_1:

$$\phi = arctg\left(\frac{\sigma_1-\sigma_x}{\tau_{xz}}\right), \quad (10.17)$$

if $\tau_{xz} = 0$, then $\phi = 0$.

FE of plate

The stress state in the X_1OY_1, plane, characterized by bending forces, is simulated. Stresses are calculated for the bottom and top surfaces:

$$\sigma_x^{B/H} = \pm\frac{6M_x}{h^2}, \sigma_y^{B/H} = \pm\frac{6M_y}{h^2}, \tau_{xy}^{B/H} = \pm\frac{6M_{xy}}{h^2}, \quad (10.18)$$

where *h* is the plate thickness.

Principal stresses and their slope angles are calculated by formulas (10.15) and (10.17).

Tangential stresses occur in the middle surface:

$$\tau_{xz} = 1.5\frac{Q_x}{h}, \tau_{yz} = 1.5\frac{Q_y}{h}, \quad (10.19)$$

which are ignored when calculating the principal stresses.

FE of shell

The stress state is simulated (in the X_1OY_1 plane), which is characterized by normal and tangential stresses in the middle surface, as well as by bending forces. Stresses are calculated for the bottom and top surface:

$$\sigma_x^{B/H} = N_x \pm \frac{6M_x}{h^2}, \sigma_y^{B/H} = N_y \pm \frac{6M_y}{h^2}, \tau_{xy}^{B/H} = N_{xy} \pm \frac{6M_{xy}}{h^2}, \quad (10.20)$$

In the middle surface $\sigma_x = N_x, \sigma_y = N_y, \tau_{xy} = N_{xy}$, the effect of stresses τ_{xz}, τ_{yz} (10.19) from shear forces is ignored. Principal stresses for these surfaces and their angles of inclination are calculated by the formula (10.15) и (10.17).

10.2 EQUIVALENT STRESSES

The strength calculation of simple stress states, particularly, uniaxial and pure shear, is relatively simple, since these stress states are reproduced in tensile and torsion tests of rods. The danger of acting stresses can be judged by comparing them with the experimentally obtained value (with the yield strength for plastic materials or with the tensile strength for brittle bodies). But more often there are cases when the stress state is not uniaxial, but complex. It is technically impossible to test materials under a complex stress state due to the infinite number of these stress states. Therefore, the way was chosen to reduce the complex stress state to its equivalent simple, uniaxial, and compare the equivalent stress with the limiting uniaxial, determined experimentally. When reducing a complex stress state to an equivalent one, a certain criterion is usually used, namely, the theory of strength. Strength theories make it possible to find the equivalent stress as a function of principal stresses.

Determining the true cause of the destruction of the material is a difficult task, which did not allow the creation of a unified general theory of strength and led to the emergence of many theories of strength, each of which is based on its own failure criteria [10.4].

Table 10.1 shows the characteristics of the implemented strength theories.

Table 10.1

№	The strength theory title	Formula	Geometric interpretation	Notes
1	2	3	4	5
1	Maximum principal stresses	$\sigma_E = \sigma_1$, $\sigma_S = \sigma_3$	A cube with a center shifted relative to the origin in the direction of hydrostatic pressure	Historically, the first theory of strength was proposed by G. Galilei. It satisfactorily describes the limit state of very brittle, sufficiently homogeneous materials, such as glass, gypsum, some types of ceramics
2	Maximum principal strains	$\sigma_E = \sigma_1 - \nu \cdot (\sigma_2 + \sigma_3)$, $\sigma_S = \sigma_3 - \nu \cdot (\sigma_1 + \sigma_2)$	An equilateral oblique parallelepiped with an axis of symmetry equally inclined to the coordinate axes	It was proposed by E. Mariotte and developed by Saint-Venant. Due to low reliability, currently it is used very rarely.
3	Maximum shear stresses	$\sigma_E = \sigma_1 - \sigma_3$, $\sigma_S = 0$	Regular hexagonal prism, equally inclined to the coordinate axes	It was proposed by C. Coulomb. It satisfactorily describes the limiting state of plastic low-hardening materials (tempered steels), characterized by localization of plastic deformations

Table 10.1 (continuation)

1	**2**	**3**	**4**	**5**
4	Energy of Huber-Hencky-von Mises	$\sigma_E = \sigma_i$, $\sigma_S = 0$	Circular cylinder circumscribed around a prism interpreting the theory of maximum shear stresses	It was proposed by M. Huber, H. Hencky, R. von Mises and describes the limit state of a wide class of ductile materials (copper, nickel, aluminum, carbon and chromium-nickel steels) rather well
5	Mohr theory	$\sigma_E = \sigma_1 - \chi \cdot \sigma_3$, $\sigma_S = \frac{\sigma_1}{\chi} - \sigma_3$	Hexagonal pyramid equally inclined to the axes	It is applied to establish the limit state of sufficiently homogeneous materials that resist tension and compression in different ways
6	Drucker-Prager theory	At $\sigma_0 \leq 0$ $\sigma_E = (\chi - 1) \cdot \sigma_0 + \frac{\sigma_i}{3}(\chi + 2)$. At $\sigma_0 > 0$ $\sigma_E = \left(1 - \frac{1}{\chi}\right) \cdot \sigma_0 + \frac{\sigma_i}{3}\left(1 + \frac{2}{\chi}\right)$. $\sigma_S = 0$	Two-sheeted paraboloid of revolution, equally inclined to the coordinate axes	It satisfactorily describes the limiting state of relatively plastic materials, for which the parameter $\chi > 0.3$
7	Pisarenko-Lebedev theory	$\alpha = \frac{27 J_3}{2\sigma_i^3}$ at $\sigma_i \leq 0$ — $\alpha = 0$. At $\sigma_0 \leq 0$ $\sigma_E = (\chi - 1)\sigma_0 + \frac{\sigma_i}{3}\left[3 - (1 - \chi)\left(\sqrt{3}\cos\psi - \sin\psi\right)\right]$. At $\sigma_0 > 0$ $\sigma_E = \left(1 - \frac{1}{\chi}\right)\sigma_0 + \frac{\sigma_i}{3\chi}\left[3 - (1 - \chi)\left(\sqrt{3}\cos\psi - \sin\psi\right)\right]$. $\sigma_S = 0$	It is a conical surface circumscribed around the Mora pyramid. In the section of the octahedral plane there is an equilateral curvilinear triangle	It describes the limiting state of a wide class of fairly homogeneous structural materials rather well. When $R_t = R_c$ it is converted into an energy theory. In the case when $R_t << R_c$ (very brittle materials), the calculation results practically coincide with the calculation data according to the theory of the largest principal stresses
8	Geniev threory	At $\sigma_0 \leq 0$ $\sigma_E = -3\sigma_0(1 - \chi) + \beta\sigma_i^2$. At $\sigma_0 > 0$ $\sigma_E = -3\sigma_0\left(\frac{1}{\chi} - 1\right) + \frac{\beta}{\chi}\sigma_i^2$. $\sigma_S = 0$	—	Describes the limit state of concrete rather well
9	Coulomb – Mohr theory	$\sigma_E = (1 - \chi)\left(\sigma_0 - \frac{\sigma_i \sin\psi}{3}\right) + (1 + \chi)\frac{\sigma_i \cos\psi}{\sqrt{3}}$, $\sigma_S = 0$	—	Soil
10	Botkin theory	$\sigma_E = \frac{1}{2}[3\sigma_0(1 - \chi) + \sigma_i(1 - \chi)]$, $\sigma_S = 0$	—	Soil

Type Codes

σ_E — is the equivalent tensile stress;

σ_S — is the equivalent compressive stress;

$\sigma_1, \sigma_2, \sigma_3$ — Principal stresses;

$\sigma_0 = \frac{\sigma_1+\sigma_2+\sigma_3}{3}$ — is the mean stress;

$\sigma_i = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}}$ — stress intensity;

$\alpha = \frac{27J_3}{2\sigma_i^3}, \psi = \frac{1}{3} arcsin(\alpha), J_3 = (\sigma_1-\sigma_0)(\sigma_2-\sigma_0)(\sigma_3-\sigma_0);$

σ_t, σ_c — ultimate tensile and compressive stresses, for soils $\sigma_t = \frac{2C\cos\phi}{1+\sin\phi}, \sigma_c = \frac{2C\cos\phi}{1-\sin\phi};$

C — specific cohesion;

ϕ — angle of internal friction;

$\chi = \left|\frac{\sigma_t}{\sigma_c}\right|, \beta = \left|\frac{1}{\sigma_c}\right|.$

Calculation of principal and equivalent stresses in plate and solid finite elements by forces from individual load cases, as well as by design combination of loads (DCL) or design combination of forces (DCF) is performed at the moment of displaying this information on the screen.

To visualize principal and equivalent stresses in plate finite elements, the **Principal and Equivalent Stresses of Plates** mode is provided in the calculation results. Switching to the mode is carried out using the menu command **Results ⇨ Stresses in plates** of the same command name **Results** on the ribbon tab or the button  on the toolbar.

To visualize principal and equivalent stresses in solid finite elements, the **Principal and Equivalent Stresses of Solid Elements** mode is provided in the calculation results. Switching to the mode is carried out using the menu command **Results ⇨ Stresses in Solid FE**, the command of the same name on the **Results** tab of the ribbon, or the button  on the toolbar.

The modes are described in detail in paragraph 3.4.