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6. Sheeting structures

The programs „**Sheeting design**" and „**Sheeting check**" are designed to analyze sheeted structures.

The program „**Sheeting design**" allows, using the static equations of equilibrium, determination of the length of fixed end of a sheeting wall in a soil (not-anchored wall anchored wall with both simply supported and fixed heal). It computes internal forces on a structure together with forces developed in anchors. It does not determine the displacement field. The applied loading is assumed either in the form of active or passive pressure, respectively with the possibility of its reduction.

The program „**Sheeting check**" serves for the analysis of a structure with know geometry. The analysis employs the method of dependent pressures. In particular, the loading due to earth pressure corresponds to the deformation of the structure. The analysis further respects the process of construction and individual load cases (stages of gradual construction) including gradual development of deformation. The program enables modeling of the real behavior of the structure resulting in economical designs. The program further allows verification of internal stability of anchorage system.

6.1 Program „Sheeting design"

Analyses in the program can be divided into two groups:

- analyses of not-anchored walls (e.g. sheet pile wall)
- analyses of anchored walls

6.1.1 Analysis of sheet pile wall

A sheet pile wall is analyzed when there is active pressure acting behind the structure and passive pressure in front of the structure (computation of earth-pressures including surcharge and water influence is enlightened in **Chapter 2**).

Using the iteration process, the program searches a point on the wall for which the moment equation of equilibrium, $M_{oveturninng,}=M_{resisting,}$ is satisfied. Once this is accomplished, the program continues by determining the wall heel location for which the equilibrium of shear forces is fulfilled (evaluation of length of fixing). This way is found the overall length of the structure.

In the „**Analysis**" dialog window, we can put in two pieces of input data that influence the analysis. When switching to the „**Minimum dimensioning pressure**" option, the program assumes, the minimum pressure value of $0.2\sigma_z$ (Section **2.3**). In addition, the „Coefficient of reduction of passive pressure" can be put in with the magnitude less or equal to one. This coefficient reduces the magnitude of passive pressure in front of a sheet pile wall. Since in majority of cases the deformation of wall is not sufficient to fully mobilize the passive earth pressure (rotation of about *10 mRad* – i.e. deformation of *10 mm* per *1m* of structure height) it is necessary to reduce the magnitude of passive pressure. It holds approximately that when reducing the magnitude into *2/3* the deformations drop by one half, when the magnitude into *1/2* the deformation drop up to 20% of their original values.

6.1.2 Computation of anchored wall

An anchored wall is analyzed as a continuous beam using the deformation variant of the finite element method such that assumptions of either simply supported or fixed heel of a structure are satisfied. The loading due earth pressure is determined in several steps prior to actual analysis.

The pressure behind a structure is considered as active pressure. The program enables to ways of its determination depending on actual input in the "**Pressure determination**" dialog window.

- When selecting the active pressure **„Run",** the loading due to active pressure is computed (up to depth of ditch) based on inputted parameters of a soil, water, surcharge, terrain (recall **Chapter 2**). Soil parameters are reduced depending on input in the "**Settings**" dialog window. When switching to the "**Minimum dimensioning pressure**" option in the "**Analysis**" dialog window, it is possible to consider, the minimum pressure value of $0.2\sigma_z$ (**Section 2.3**).
- When selecting the active pressure **„Input",** the user may put in an arbitrary distribution of earth pressure up to a depth of zero-value point.

Zero-value point, i.e. the point at which the overall pressure equals zero is determined by the following expression

$$u = \frac{\sigma_a}{\gamma K}$$

where:

u - depth of zero-value point,

σ_a - magnitude of active pressure behind a structure at the bottom of a ditch (when using the active pressure „**Input**" it is inputted in the "Determination of pressures" dialog window independently),

K - coefficient of overall pressure (will be explained later),

γ - bulk weight of soil bellow the bottom of a ditch (will be explained later),

The pressure below the zero-value point is determined assuming that the soil below the bottom of a ditch is **homogeneous**. Parameters of such a soil can be put in the "Geometry" dialog window. The program, when computing the stresses below the bottom of a ditch, uses these parameters only – other inputted variables (surcharge, terrain shape, water) are not accounted for during the analysis. Of the soil below the bottom of a ditch is under water, then it is required to switch from γ to $\gamma_{su.}$ The coefficient of overall pressure is then found from the following formula:

$$K = kK_p \cos\delta_p - K_a \cos\delta_a$$

where

k - coefficient of reduction of passive pressure – for input use the "**Analysis**" dialog window, k is set to one when computing the location of the zero-value point,

K_p - coefficient of passive pressure for a soil below the bottom of a ditch,

K_a - coefficient of active pressure for a soil below the bottom of a ditch,

δ_a, δ_p - active and passive soil-structure frictional angles.

Coefficients K_a and K_p are determined from reduced parameters of a soil based on input in the "**Settings**" dialog window (see **Sections 2.3, 2.4, 2.6**)

The subsequent steps of the analysis differ depending on a type of structure – clamped or simply supported structure at its heel. The analysis is explained for anchored walls with a single anchor (see the following figures). An identical approach is used when solving walls with more anchors.

6.1.2.1 Clamped structure

The analysis assumes that the point of zero loading *N* (at depth *u*) is identical with the point of zero moment. The structure is divided into two parts – an upper part (upper beam) up to zero-value point and a lower beam (**Fig**. 6.1). The upper beam is analyzed first together with evaluation anchor forces (*F*) and reaction of the zero-value point *R*. Then the lower beam length (x) is determined such that the moment equilibrium condition with respect to the heel is satisfied (the beam is loaded the reaction R and by the difference of earth pressures).

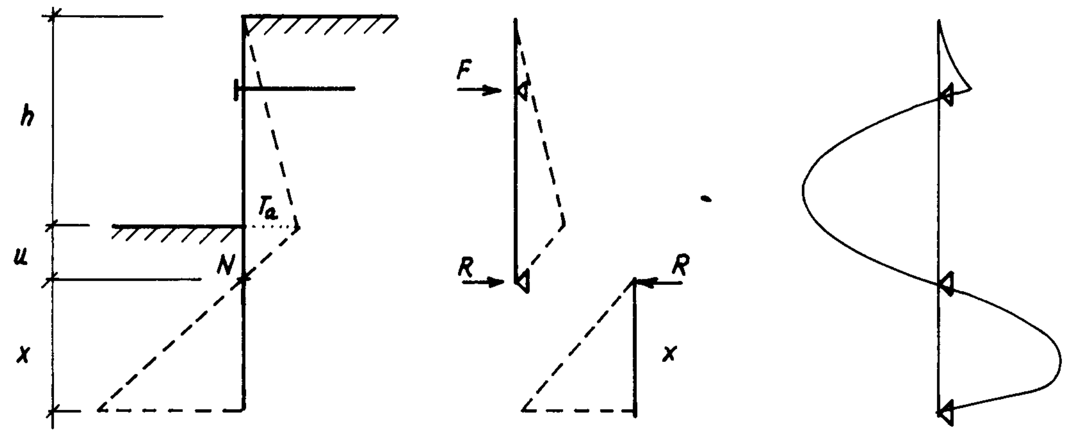

Fig. 6.1 Analysis of clamped wall

To satisfy the shear force equilibrium the computed length of fixing is extended by Δx according to **Fig**. 6.2.

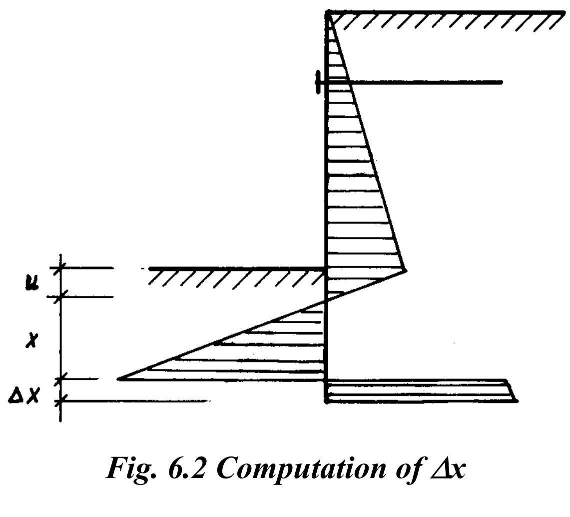

Fig. 6.2 Computation of Δx

Simply supported structure

For simply supported structures it is assumed that the moment and shear force are zero at the heel. The program first places the end of a structure into the zero-value point, and then it looks for the end beam location (x), where the above condition is fulfilled.

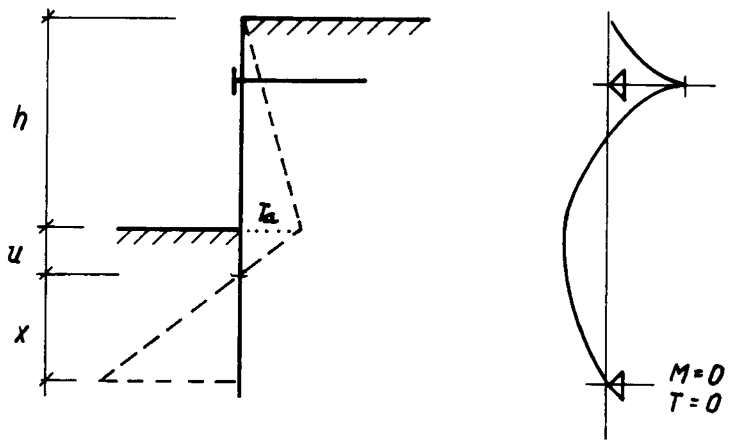

Fig. 6.3 Analysis of simply supported wall

6.2 Program „Sheeting check"

6.2.1 The method of dependent pressures

The basic assumption of the method is that the soil or rock in the vicinity of wall behaves as ideally elastic-plastic Winkler material. This material is determined by the modulus of subsoil reaction k_h (*kN/m³*), which characterizes the deformation in the elastic region and by additional limiting deformations. When exceeding these deformations the material behaves as ideally plastic.

The following assumptions are used:

- the pressure acting on a wall may attain arbitrary value between active and passive pressure – but it cannot get off these bounds.
- the pressure at rest acts on an undeformed structure ($w=0$)

The pressure acting on a deformed structure is given by:

$$\sigma = \sigma_r - k_h w$$

$$\sigma = \sigma_a \quad pro \quad \sigma < \sigma_a$$

$$\sigma = \sigma_p \quad pro \quad \sigma > \sigma_p$$

The computational procedure is as follows:

- the modulus of subsoil reaction k_h is assigned to all elements and the structure is loaded by the pressure at rest (**Fig. 6.4**).

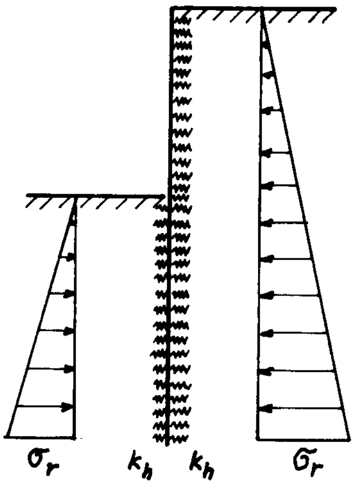

Fig. 6.4 Scheme of structure before the first iteration

- the analysis is carried out the condition of magnitudes of pressures acting on the wall is checked. In locations at which these conditions are violated the program assigns the $k_h=0$ and the wall is loaded by active or passive pressure, respectively (**Fig 6.5**).

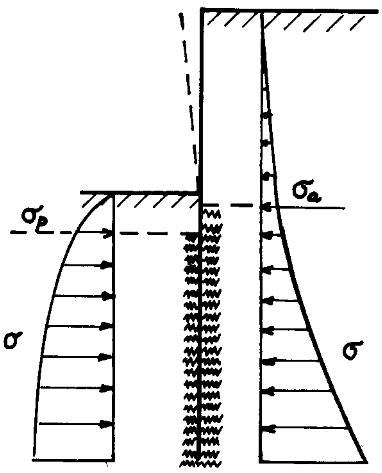

Fig. 6.5 Scheme of structure during iterations

The above iteration procedure continues until all required conditions are satisfied.

6.2.2 Analysis setup, computation of limit pressures

The parameters, which will be used in the entire analysis of a sheeting wall, can be inputted in the "**Settings**" dialog window (**Fig. 6.6**).

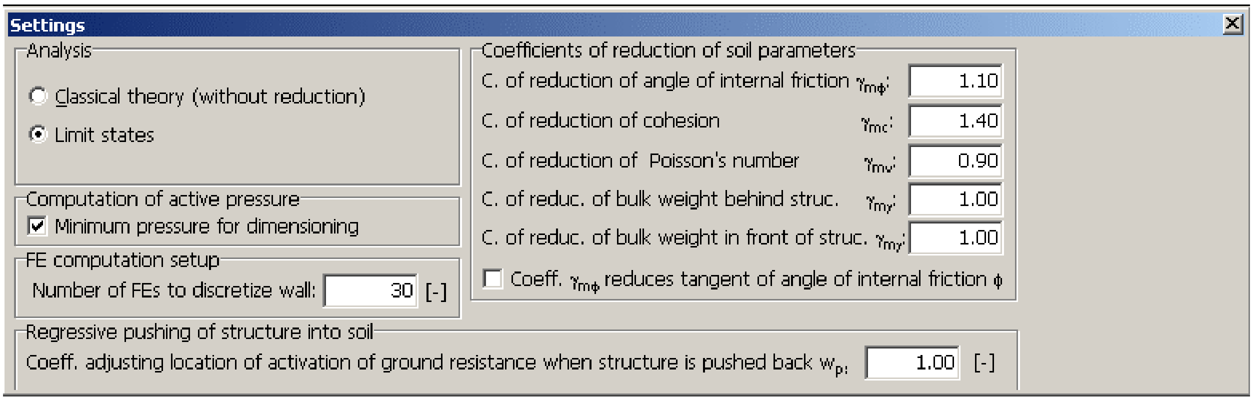

Fig. 6.6 Dialog window to set up parameters of analysis

The window enables to select the way of reduction of parameters of soils for computation of earth pressures – see **Section 2.4**. The pressured can be computed either without reduction of input parameters or with their reduction according to the theory of limit states. The minimum dimensioning pressure option can also be used (see **Section 2.3**). When analyzing anchored structures it is advisable to use the actual parameters without their reduction. This is essentially the only way how to get a feeling for the real behavior of a structure. The analysis according to limit states is suitable when studying the behavior of not-anchored walls or for parametric studies.

The next step is to select the subdivision into finite elements (20-100). Mesh density affects the overall analysis. A finer mesh generates more accurate results. The computation, however, is more demanding.

The last input parameter is "Coeff.", which adjusts the location of activation of ground resistance when the structure is pushed back w_p – its function is described in **Section 6.2.3**

Computation of limit pressures (active, passive and pressure at rest) is outlined in details in **Chapter 2.** The only essential change is determination of earth pressures when analyzing soldier beam displayed in **Fig**. 6.7. Up to depth of ditch (*h*) the pressures are determined per *1m (b)* of the structure width – below the bottom of the ditch the pressures are multiplied by the coefficient of reduction *k* (the "Reduc.C. of pressures bellow ditch bott." – can be inputted in the "**Geometry**" dialog window) – the pressured are determined with respect to a reduced structure width *k.b*.

In case of continuous wall the coefficient is set to one and there is no reduction of pressures. If the "**Landing of soil**" above the ditch ("**Excavation**" dialog window) is put in then the pressures, within this section, are computed with respect to the whole width of wall (*k=1*).

The coefficient *k* can be approximately determined using the following formula

$$k = \frac{t}{t + m}$$

The notation is evident from **Fig. 6.7**

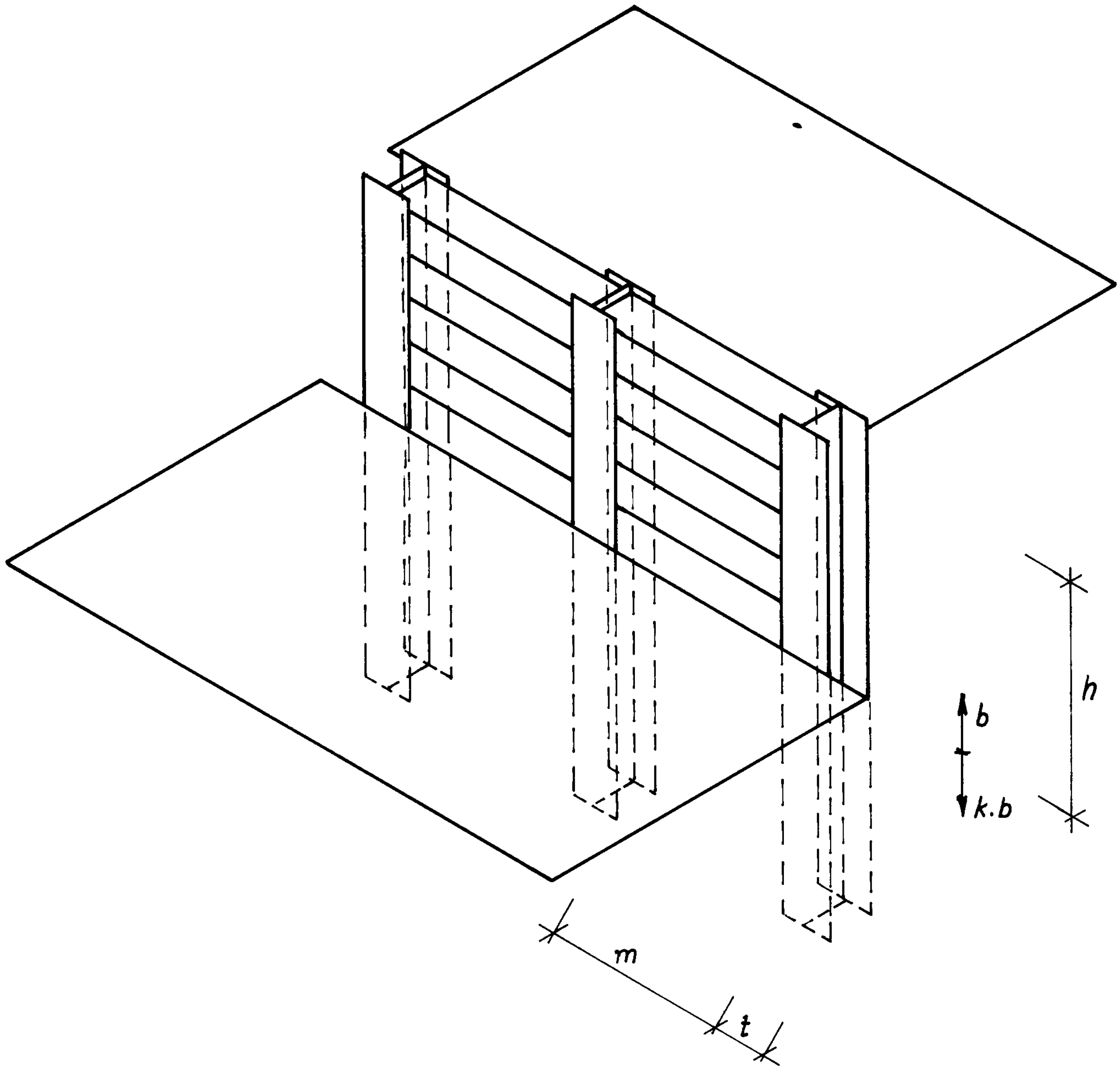

Fig. 6.7 Soldier beam

6.2.3 Computational model

The actual analysis is carried out using the deformation variant of the finite element method. Displacements, internal forces and the modulus of subsoil reaction are evaluated at individual nodes. Procedure for subdivision of the structure into finite elements is the following:

- - First, the nodes are inserted into all topological points of a structure (starting and end points, points of location of anchors, points of soil removal, points of change of cross-sectional parameters).
- - Based on selected subdivision the program computes the remaining nodes such that all elements are of similar size.

A value of the modulus of subsoil reaction is assigned to each element – it is considered as the Winkler spring of the elastic subsoil.

Supports are placed onto already deformed structure – each support then represents a forced displacement applied to the structure.
Anchors, in the load case at which they were put in or post-stressed, are considered as forces (variant I in **Fig. 6.8**). In other load cases, the anchors are modeled by a force and a spring of stiffness *k* (variant II. in **Fig. 6.8**).

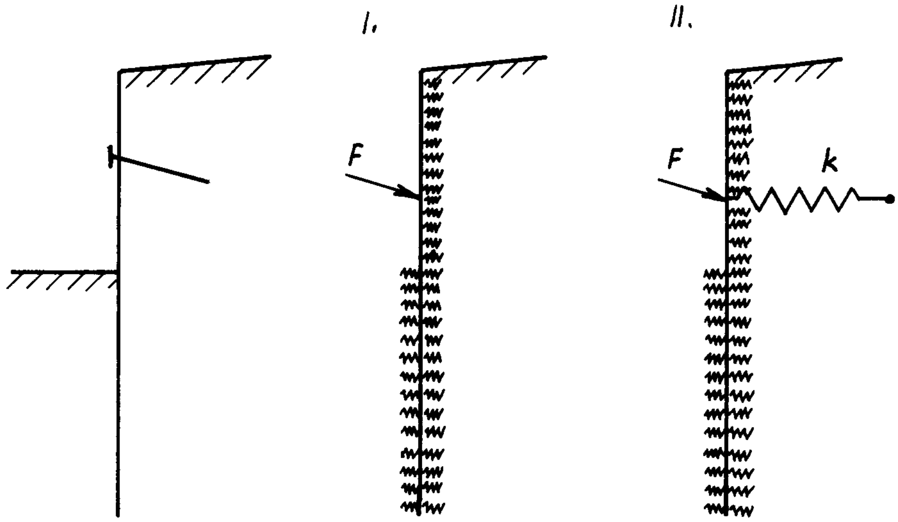

Fig. 6.8 Computational model of anchors

The change of anchor force due to deformation is provided by

$$\Delta F = \frac{k.v.\Delta w}{\cos\alpha}$$

$$k = \frac{EA}{l}$$

where

- v - horizontal distance between anchors
- Δw - increment of deformation at the point anchor application
- E - anchor Young's modulus,
- A - anchor cross-sectional area,
- l - anchor length,
- k - anchor stiffness,
- α - anchor inclination.

6.2.4 Verification of internal stability of anchored sheeting structure

The internal stability of an anchorage system of sheeting is determined for each layer independently. The verification analysis determines an anchor force, which equilibrates the system of forces acting on a block of soil. The block is outlined by sheeting, terrain, line connecting the heel of sheeting with anchor root and by a vertical line passing through the center of anchor root and terrain. The analysis is performed per 1m of sheeting structure. Anchor forces are therefore computed with respect to their spacing in individual layers.

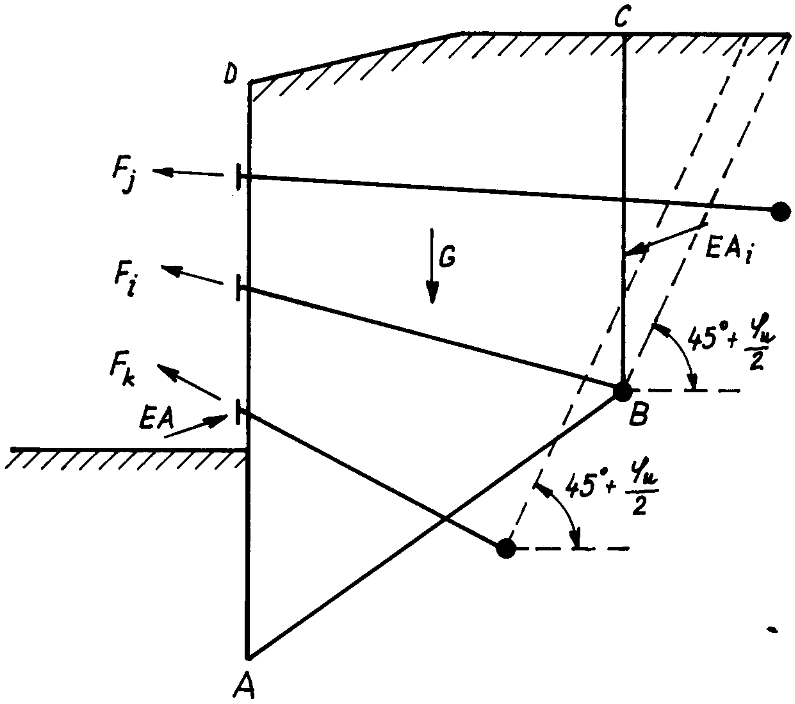

Fig. 6.12 Analysis of internal stability

Scheme for verification of the i^{th} layer of anchors is shown in **Fig. 6.12**. The force equilibrium for the block ABCD is being determined. The following forces enter the analysis:

E_A – resultant of active earth pressure acting on sheeting (computation is performed without reduction of input parameters).

E_{Ai} - resultant of active earth pressure above the root of verified anchor (computation is performed without reduction of input parameters).

F_j, F_k, … - forces developed in other anchors; only some of them enter the equilibrium analysis of the i^{th} layer. The anchor force (say the m^{th} one) that will be taken into account in the analysis is determined as follows:

From two anchors m, i select the lower one (m is an arbitrary anchor except the i^{th} one, i denotes the anchor being analyzed). A plane slip surface, inclined by 45^o-$\varphi_n/2$ from a vertical line, is placed in a body such that it passes through the center of the selected anchor (lines AB and BC in **Fig. 6.12**); φ_n is an average value of the angle of internal friction above the root of lower anchor.

Location of the root of an anchor found above the inserted slip surface is then decisive. If the i^{th} root is found above the m^{th} one and the i^{th} root is located out of the block cut by the slip surface, then the m^{th} anchor force is included into the analysis. Fig. 6.12 shows an example in which the force F_j is included while the force F_k is excluded from the stability analysis of the i^{th} block.
G_i – weight of the soil block ABCD. In addition, this value incorporates a terrain surcharge p providing the slip surface slope is greater than an average value of the angle of internal friction.

F_i – force in the analyzed anchor. The maximum allowable magnitude comes out as a result of equilibrium analysis of the i^{th} block.

Stability analysis provides a safety factor for each row of anchors. For the i^{th} layer of anchors is found as a ratio of the maximum allowable force in the i^{th} anchor and the real force in the i^{th} anchor.