

# **PROGRAM MANUAL**

# **"PREPNT"**

**REV. 3.0**

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## 1. INTRODUCTION

### 1.1. GENERAL DESCRIPTION

The program "**PREPNT**" consists of a preprocessor oriented to the problem of calculating retaining walls by elasto-plastic methods.

The effective calculation is carried out by **the program "PANTNT" which** is a program of finite elements of general purpose that incorporates in its library of elements "springs" of bilinear elastoplastic behavior with different rigidity according to the sign of the relative displacement.

The introduction of the problem data is done through a plain text file in which by defining a small amount of numerical data it is possible to describe complex structural configurations and processes or construction phases.

In the definition of the meta language chosen for the introduction of numerical data it has been decided to follow the guidelines established by Professor E. L. Wilson in the development of the popular **calculation program "SAP"**. Therefore, the language consists of a **series of \*labels** indicating the beginning of a data entry block, and then a series of tags that identify the particular data(s) that is entered.

In order to be able to visualize the results graphically, **the program POSPNT** has been developed, which in addition to providing a very simple and intuitive graphical interface, generates two result files: \*.fef extension (Frame Extreme Forces) and the \*.dpa file (Displacements, Pressures and Anchors Forces).

Now the background color is white, in order to make it easy to obtain hardcopies to include in a word or whatever document might be needed. If you select such output, the program generates light whatever you call **.png** files (if POSPNT finds the free software "BMP2PNG.EXE") otherwise the program generates heavy whatever you call **.bmp** files.

**Note:** Originally the programs were developed in Spanish language, as it is my mother language, but some users asked me to translate it completely in English and that is what I did in this new release.

### 1.2. DESCRIPTION OF THE FILES

It allows file names of up to 32 characters to designate a particular problem, leaving the dot and extension of three (3) mandatory characters for the proper functioning of the three programs to each other.

In this way the data entry file must be up to 32 characters long, and must be \*.inp its extension (e.g. ABCDEFGH.inp).

For reading data file validation, the program writes the file ABCDEFGH.pre, that you should read to check all values were ok read.

Finally, the only results files of interest to the user for possible post processing are those generated by POSPNT as already commented with the extensions \*.fef and \*.dpa (e.g.: ABCDEFGH.fef and ABCDEFGH.dpa).

Every of the above files are plain text files that you can read with any notepad.

All three programs must be run in the corresponding natural order and can be run both from the file explorer and from a DOS command window on the Windows system, which is more convenient for the user.

A data entry file named TANOX.inp is accompanied, which is a simple example case for running and testing the program.

**NOTE:** The program is completely unitless, except by the friction angle of the soil that must be in sexagesimal degrees ( $\pi.\text{rad}=180.\text{deg}$ ). It the responsibility of the user, introduce the numerical data in any consistent unit system.

## 2. COMMAND SUMMARY

title

\*GENER(AL)

LOP=lop TOL=tol GW=gw Y0T=y01,y02 Y0P=y0p APO=apos,apoi

SUB=sub

ITMX=itmx DIVC=divc NINT=ndivx,ndivy EFLAG=eflag ANCHO=ancho

PRESH=presh

%GENER(AL)

\*SOILS

i CH=cter FI=fi RZ=rza,rzp EE=ea,eb,ec,ed,ee,ef GS=gs GN=gn

KC=kca,kcp (KH=k0,ka,kp)

...

%SOILS

\*LAYER(S)

i YL=y1,y2 ST=t1,t2

...

%LAYER(S)

\*LOADS

i UL=ul1,ul2 TRV=ytrv,x0,q0,(xf),(qf)

i PRH=yh1,qh1,yh2,...,yh6,qh6

i PCO=yp1,ph1,mc1,pv1,yp2,...,yp3,ph3,mc3,pv3

...

%LOADS

\*RETWA(LL)

SH=hwall EL=elas II=iner (DIAM=diam BB=bb DD=dd)

...

%RETWA(LL)

\*ANCHO(RS)

i YA=yanc GAP=gap GDL=gdl KS=kp,kn PC=p0,pp,pn

...

%ANCHO(RS)

\*PHASE(S)

i YEX=ye2,(ye1) WL=wl1,wl2 ACA=ai,aj,ak ACD=al,am,an

l LOA=si,sj,sk LOD=sl,sm,sn

i STC=icol,jest,cter

...

%PHASE(S)

### 3. DETAILED EXPLANATION OF EACH COMMAND

#### 3.1. AUXILIARY DEFINITIONS

##### 3.1.1. Title of the problem

title

It is the first line of the file and consists of a text string up to 78 characters in length, which the user must fill in in order to identify the problem in question.

##### 3.1.2. Blank line

It is a line that does not contain any text except blanks.

##### 3.1.3. Information command

\*COMAN(DO)

This is an identifier for the start of an information section. this identifier must start with an \* and then the corresponding text, only the first six (6) characters including the \* are significant.

%COMAN(DO)

This is an identifier for the end of an information section. this identifier must start with a % and then the corresponding text, only the first six (6) characters including the % are significant.

##### 3.1.4. Label

It is an identifier that precedes the introduction of the numeric value of some variable its format is LABEL= and for it to be recognized the = must go next to the text. As for the numeric information it should be placed after the label and if they are more than one numeric value they must be separated by commas or blanks.

##### 3.1.5. Default, optional and mandatory values

Brackets and next to each label's explanation indicate the default value for labels whose definition is optional. Labels whose definition is required are indicated in place of the default value as OB!.

### 3.2. \*GENER(AL)

\*GENER(AL)

LOP=lop TOL=tol GW=gw Y0S=y01,y02 Y0P=y0p APO=apos,apoi

SUB=sub

ITMX=itmx DIVC=divc NINT=ndivx,ndivy EFLAG=eflag WIDTH=width

PRESH=presh

%GENER(AL)

lop = Optimal length of frame retaining wall finite elements. OB!

tol = tolerance in both a lop to avoid generating very short bars. This is that two separate joints a length  $< \text{lop} * \text{tol}$  are merged into one. [0.1]

gw = Gamma of Water [0]

y0i = Soil start level on each side of the wall [0]

y0p = Start level in retwall coronation (coordinate source) [0]

apos = Support condition at the top end of the retwall [0]

- 0 Free Edge
- 1 Articulated support
- 2 Guided recess
- 3 Total recess

apoi = Support condition at the lower end of the retwall [0]  
(Meaning idem apos)

sub = Enables the use of subpressure [0]  
= 0 The effect of subpressure is not activated  
= 1 The effect of subpressure is activated

itmx = The maximum number of iterations in the calculation program [5000]

divc = is the divider for convergence control [10000]. So for iteration i and for gdl j (where at least one spring operates) if the maximum quotient  $(j(i) - j(i-1)) / j(i) \leq 1 / \text{divc}$  is met the process reaches convergence

ndivx = The number of intervals at which the length is divided ( $\text{Abs}(x_f - x_0)$ ) at which vertical trapeze overloads (TRV) act for the integration of their effects. [20]

ndivy = The number of intervals at which the influence height of each joint in the structure is divided for the integration of the effects of trapeze overloads (RV). [20]

eflag = Switch that sets the independent parameter to be adopted in the rigidity function of the ground springs. [0]

= 0 Effective pressure (pv) at the joint dimension is adopted as a parameter in such a way that the formula is:  $\text{Rigidity} = a + b \times (pv)^c$

= 1 The depth relative to the free surface of the soil in the column in which it is calculated is adopted as a parameter, with the formulation being:  $\text{Rigidity} = a + b \times (y - y_{0\text{ter}})^c$  . (y0ter level of the free surface of the soil for the phase and column in question).

- = 2 The depth relative to the start of the layer in question is adopted as a parameter, even if the start of the layer is above the free surface of the soil, the formulation being :  $Rigidity = a + b \times (y_{rel})^c$  .  
Note: Rigidity units are Force / Length<sup>3</sup>

width = Width outside the 2D retwall plane. This affects pressures generated by distributed loads, water, and ground springs, but does not affect Concentrated Loads or Anchors, or the stiffness of the wall, which act directly with the values set.

presh = Defines the formulation to be used for the calculation of horizontal pressures due to vertical loads TRV [0]

- = 0 Formulation established by Terzagui and contemplating the existence of a rigid wall, see "Geoguide 1 - Guide to Retaining Wall Design - Geotechnical Eng. Office - Civil Eng. Dep. - Hong Kong Nov. '94.

- = 1 Boussinesq formulation for the plane stress problem, see Geotechnical and Cimientos\_II (ap. 3.3.2) Jimenez Salas



### 3.3. \*SOILS

```
*SOILS
i CH=cter FI=fi RZ=rza,rzp EE=ea,eb,ec,ed,ee,ef GS=gs GN=gn (KC=kca,kcp)
i (KH=ka,kp) (K0=k0)
...
%SOILS
```

i = soil type identifier OB!  
 cter = Soil cohesion [0]  
 fi = Fi angle of internal friction of the soil (deg) [0]  
 rza = Ratio between the friction angle (ground = structure) active and fi [0]  
 rzp = Ratio between friction angle (ground - structure) passive and fi [0]  
 ea = Ctte coefficient. active ground stiffness [0,pv]  
 eb = Linear coefficient of active ground stiffness [0,pv]  
 ec = Exponent coefficient of active soil stiffness [1,pv]  
 ed = Ctte coefficient. passive ground stiffness [ea,pv]  
 ee = Linear coefficient of passive soil stiffness [eb,pv]  
 ef = Exponent coefficient of passive soil stiffness [ec,pv]

Formulation used:

Active spring stiffness  $R_a = (ea + eb * pi^{ec}) * hi$ .  
 Passive spring stiffness  $R_p = (ed + ee * pi^{ef}) * hi$

pi being the independent parameter defined by eflag  
 hi being the segment heigh  $(y_{i+1}-y_i-1)/2$  of the joint i of the structure to put the spring element

Special cases:

If  $ed < 0$  and Not ee nor ef are set the following relationship apply:  
 $ee = eb * Abs(ed)$   
 $ed = ea * Abs(ed)$   
 $ef = ec$

With this what is achieved is that, for a law of variation of active rigidity, passive stiffness varies in the same way, but affected by a coefficient.

if  $ea < 0$  and  $eb > 0$  and  $ec > 0$  and ed, ee, and ef Do not exist you have to:

$R_a = Abs (P_a - P_0) / eb$   
 $R_p = Abs (P_p - P_0) / ec$

This gives you the possibility to set the soil plastification limits by a preset fixed displacement, then resulting in stiffness that increases with the depth for a given soil layer.

gs = Saturated soil gamma [0,pv]

gn = Natural soil gamma [0,pv]

k0 = At rest Coefficient [0] ( $\geq 0$ )

ka = Coefficient in the active state [0] ( $\geq 0$ )

kp = Coefficient in passive state [0] ( $\geq 0$ )

kca = Cohesion coefficient in the active state [0] ( $\geq 0$  is subtracted)

kcp = Cohesion coefficient in passive state [0] ( $\geq 0$  is added)

**note:**

For special cases where the formulation of **Coulomb** is not adequate, direct introduction of ground **coefficients** is allowed. It should be known that **this specification cannot coexist** with that of fi and rza, rzp. Therefore, for a given SOIL **you should choose** between the Coulomb model or the direct introduction of the coefficients, but never both at the same time.

if rzp  $\leq$  fi/3 see D.M. 7.02 7.2-69 or ROM05-05 fig. 3.7.24. COULOMB

kp according to coulomb, valid

$kp = \sqrt{\sin(fi+rzp) * \sin(fi+bt) / \cos(af-rzp) / \cos(af-bt)}$

$kp = \cos(af+fi)^{**2} / (1 - kp)^{**2} / \cos(af)^{**2}$

else

kp according to plasticity see rom05-05 fig. 3.7.23.

end if

Bell's formulation

pa = sv \* ka - 2 \* cter \*  $\sqrt{ka}$  (ka obtained with Coulomb formulation)

pp = sv \* kp + 2 \* cter \*  $\sqrt{kp}$  (kp obtained with Coulomb formulation)

pa = sv \* ka - kca \*  $\sqrt{ka}$  (ka obtained with Coulomb formulation)

pp = sv \* kp + kcp \*  $\sqrt{kp}$  (kp obtained with Coulomb formulation)

k0 value is calculated by the fault using jaky formula that is  $k0 = 1 - \sin(fi)$ , in case you have a different value you can set K0= to any value  $> 0$ .

When you activate KH or KC, the formulation is as follows:

pa = sv \* ka - kca \* cter (ka introduced with KH=)

pp = sv \* kp + kcp \* cter (kp introduced with KH=)

### 3.4. \*LAYER(S)

```
*LAYER(S)
i      YL=y1,y2    ST=t1,t2
...
%LAYER(S)
```

i = stratum identifier OB!  
y1 = Level of stratum i in column 1 OB!  
y2 = Level of stratum i in column 2 [y1]  
t1 = soil type in stratum i in column 1 [pv]  
t2 = soil type in stratum i in column 2 [t1]

**Note:** The number of strata is unique, the yi of each soil column are free.

### 3.5. \*LOADS

\*LOADS

i      UL=ul1,ul2    TRV=ytrv,x0,q0,(xf),(qf)

i      PRH=yh1,qh1,yh2, . . . ,yh6,qh6

i      PCO=yp1,ph1,mc1,pv1,yp2, . . . ,yp3,ph3,mc3,pv3

...

%LOADS

i      = Load set identifier (must be in increasing order) OB!

ulj    = Uniform load to be applied all over on j column of soil [0]

ytrv   = Level of acting trapezium load. [0]

x0    = x0 coordinate of the start of the trapezium load ( $x > 0$  in soil side 2) [0]

q0    = Surface load value (Force/Area) at starting x0 [0]

xf    = xf coordinate of the end of the trapezium load ( $x > 0$  in ground 2) [x0]

qf    = Surface overload value (force/area) in ending xf [q0]

yhi    = Level in which the qhi pressure acts.

qhi    = Pressure Horizontal (force / Area) acting at the yhi level.

Note: i can be from 1 to 6.

ypj    = Level in which a concentrated load operates (Horizontal moment or vertical load).

phj    = Value of the horizontal concentrated load (positive from left to right).

mcj    = Value of the concentrated moment (Positive with clockwise direction of rotation, right turn).

pvj    = Vertical concentrated load value (Positive from top to bottom).

Note: j can be from 1 to 3. The vertical concentrated load currently has no effect, it is included for future program improvements.

### 3.6. \*RETWA(LL)

```
*RETWA(LL)
SH=hwall   EL=elas   II=iner (DIAM=diam BB=bb DD=dd)
...
%RETWA(LL)
```

hwall = height of the retwall segment that must be greater than the fixed lop.  
ob!

elas = elasticity module of the infinite elastic material of the retwall segment.  
ob!

iner = inertia moment of the section of the retwall segment. op! (optional  
input)

diam = diameter of the section of the retwall segment. op! (optional input)

bb = width of the section of the retwall segment. op! (optional input)

dd = height of the section of the retwall segment. op! (optional input)

**Note:** iner can be only one of: iner or  $\pi/64 * \text{diam}^4$  or  $\text{bb}/12 * \text{dd}^3$ , that is  
you only can use one of: II= or DIAM= or BB= & DD=

### 3.7. \*ANCHO(RS)

```
*ANCHO(RS)
i YA=yanc GAP=gap GDL=gdl KS=kp,kn PC=p0,pp,pn
...
%ANCHO(RS)
```

i = anchor identification number (must be in increasing order) OB!  
 yanc = anchor location dimension measured from the coronation (must be in increasing order) OB!  
 gap = generalized dr that must be produced for the generalized force p0 to act on the anchor [0]  
 gdl = degree of freedom in which the anchor operates [1]  
       = 1 acts on the global axis x  
       = 6 acts according to the z-axis

kp = Anchor spring ctte for dr positives OB!  
 kn = Anchor spring ctte for dr negatives [kp]  
 p0 = OB Anchor Preload!  
 pp = Anchor limit load for dr positives [p0 + 1.e10] (simulates indefinite elastic)  
 pn = Anchor limit load for dr negatives [p0 - 1.e10] (simulates indefinite elastic)

**note:**

**dr** is the relative displacement of the anchor from the one it had, the gdl in which it operates, at the time of its activation.

A normal anchor designed to hold the retwall should push against it, therefore and according to the adopted coordinate system, the stiffness (kp,kn) of the anchor are negative, as are the loads of the Preload. In order to simplify the input of data this is taken internally into account by the program changing the sign of the values automatically, so in common situations all this numerical data must be entered positive.

### 3.8. \*PHASE(S)

\*PHASE(S)

i YEX=ye2,(ye1) WL=wl1,wl2 ACA=ai,aj,ak ACD=al,am,an

l LOA=si,sj,sk LOD=sl,sm,sn

i STC=icol,jest,kter

...

%PHASE(S)

l = # identification of the phase in study (can be repeated in the following lines for convenience in the definition of the construction process.  
OB!

yei = excavation depth or level in each column [y0i,pv]

wli = water table level in each soil column [1.e30,pv]

ai = # of the 1st anchor to activate

aj = #' of the last anchor to activate [ai]

ak = # of the increment from ai to aj [1]

al = # of the 1st anchor to be deactivated

am = # of the last anchor to be deactivated [to]

an = # of the increase from al to am [1]

si = # of the 1st set of loads to activate

sj = # of the last set of loads to activate [ai]

sk = # of increment from si to sj [1]

sl = # of the 1st set of loads to be deactivated

sm = # of the last set of loads to be deactivated [at]

sn = # of the increment from sl to sm [1]

icol = # of the soil column to change soil type

jest = # of the soil stratum to which you want to assign another soil type

kter = # of soil type to be assigned to the soil stratum jest of the soil column  
icol

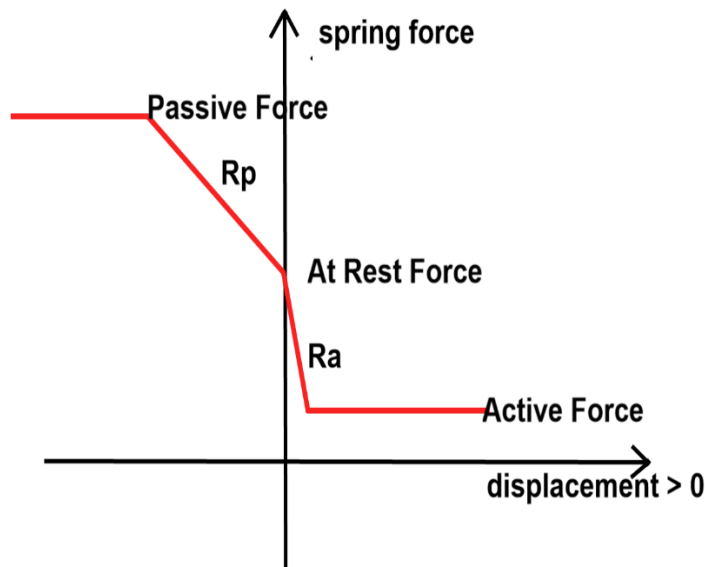
#### note:

It is the user's responsibility to "play" with the above series of commands in order to reproduce as best as possible the construction process under study. This allows the activation of anchors that, because they are temporary, may have to be removed at some stage of the construction process. And the same goes for the concept of a group of loads that act at any given time and then cease to exist. It is also noted that any activated (disabled) element remains in that state until it is changed, therefore a k-anchor activated in phase i and that it will remain active until phase j will suffice to activate it in phase i using the AA=k tag and then deactivate it in phase j+1 with the AD=k tag. It was added the possibility, in a given column and stratum, **to change** the existing soil type, it must be taken into account that in this case, the pressure at rest acts for the displacement existing in the stratum in question at the time of activation.

## 4. ANALITIC FORMULAE REFERENCE

### 4.1. Non-Linear Spring Model

In the following picture it can be seen the five parameters non-linear spring model, in this case the spring local positive axis is coincident with the positive global displacement ( $X > 0$ ) and would represent a spring soil in the left soil column or soil column 1. The soil column 2 is the same but with local axis opposite to Global  $X > 0$ . During the calculation process the program keeps track of the displacement in local coords. of each spring and if its properties change (due to excavation or what else) it changes in accordance at the beginning of the following phase, but keeping the displacement value from the previous phase.



### 4.2. Lateral Forces due to Vertical Loads and Horizontal soil coefficients

In the following, they are reproduced the page(s) from the reference mentioned that are used by the program to calculate the lateral effect of vertical forces and the calculation of  $K_a$ ,  $K_{ca}$ ,  $K_p$  and  $K_{cp}$  for active and passive coefficients.

Note: In the case of a vertical trapezoidal force, it is divided into  $ndivx$  for integration of its horizontal effects.

if  $presh = 0$

uses Terzagui's solution that contemplates the existence of a rigid wall. See D.M. 7 or Geoguide 1 pg. 195

if  $presh = 1$

uses the elastic solid solution integrating for the case plane the boussinesq equation. See Jimenez Salas Geotecnia y Cimentos II apt. 3.3.2 pg. 199



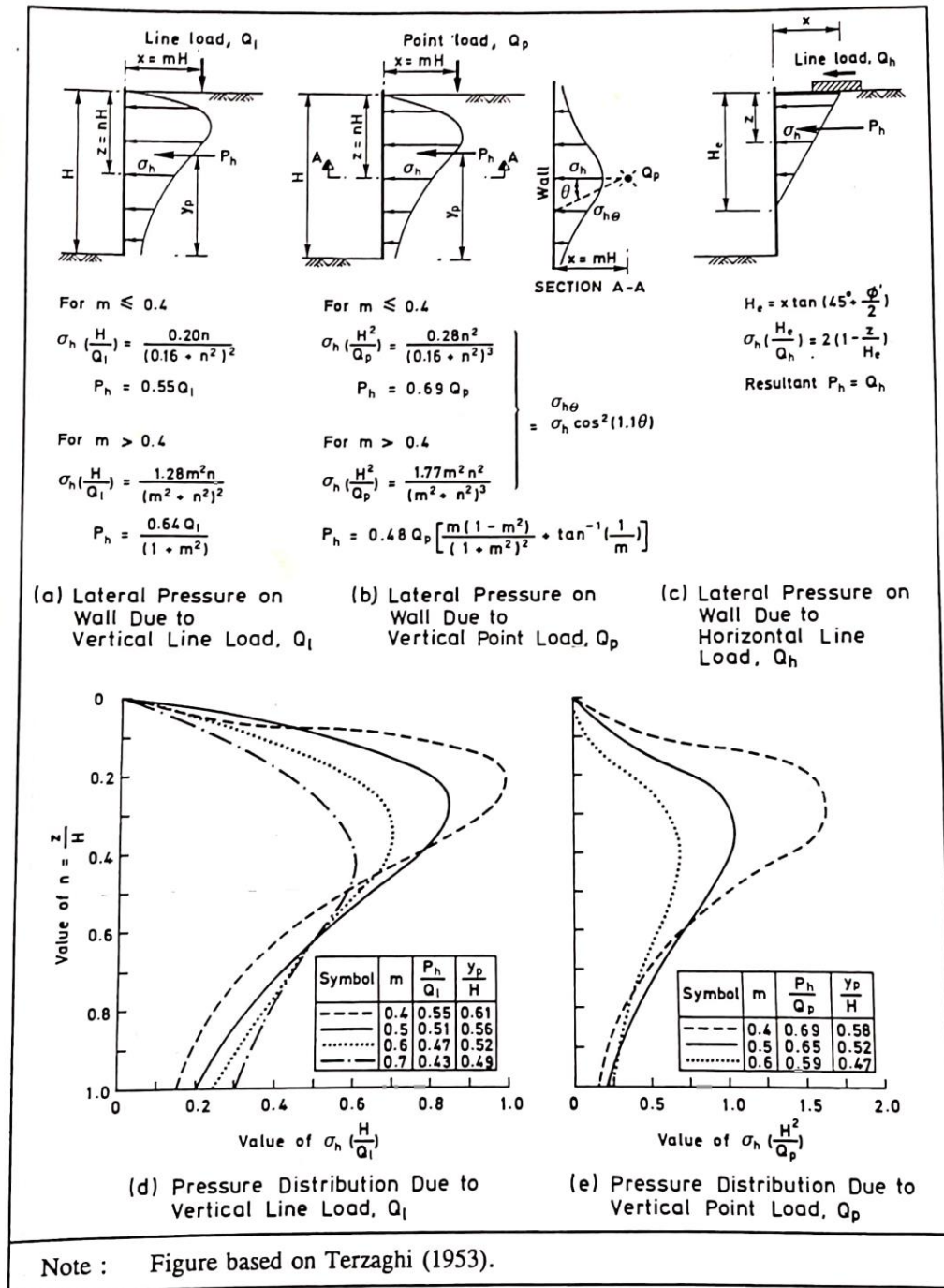


Figure 29 - Calculation of Lateral Pressure on a Vertical Retaining Wall Due to Vertical and Horizontal Loads

## CAP. 3.- EL SOLIDO ELASTICO

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Estas fórmulas corresponden a la integración de la solución del problema de Kelvin.

Este caso no tiene gran interés práctico.

### 3.3.2. Carga lineal aplicada sobre la superficie de un semiespacio elástico infinito

Cuando la carga es vertical, la solución de este caso corresponde a la integración de la del problema de Boussinesq.

En la figura 3.28 se recogen las fórmulas que expresan la distribución de tensiones.

$$\sigma_x = \frac{2p}{\pi} \frac{x^2 z}{R^4} \quad (3.27-a)$$

$$\sigma_z = \frac{2p}{\pi} \frac{z^3}{R^4} \quad (3.27-b)$$

$$\sigma_y = \frac{2p\nu}{\pi} \frac{z}{R^2} \quad (3.27-c)$$

$$\tau_{xz} = \frac{2p}{\pi} \frac{xz^2}{R^4} \quad (3.27-d)$$

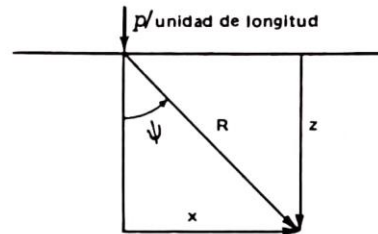


Fig. 3.28.-Carga lineal vertical en la superficie del semiespacio de Boussinesq. Distribución de tensiones.

Como este caso tiene cierto interés práctico, ya que se puede asimilar a algunos problemas geotécnicos, por ejemplo la cimentación de zapatas corridas o muros muy estrechos, nos detendremos analizando algunas de las propiedades de la distribución de tensiones.

Las tensiones principales vienen dadas por

$$\begin{aligned} \sigma_1 = \sigma_R &= \frac{2pz}{\pi R^2} \\ \sigma_2 = \sigma_\psi &= 0 \\ \sigma_3 &= \sigma_y \end{aligned} \quad (3.28)$$

La tensión cortante máxima por

Se supone, además, que el empuje del agua está situado a una altura “ $h_3$ ” respecto a la base del muro igual a la tercera parte de la diferencia de cotas entre B y C, esto es:

$$h_3 = \frac{1}{3} \cdot (H - h_2) \quad (\text{Ver Fig. 3.7.11})$$

La presión vertical efectiva de referencia en un punto del muro situado a una profundidad «h» bajo la coronación se calcula mediante la expresión:

$$\sigma'_v = \gamma_{ap} \cdot h_1 + (\gamma' + l_v \cdot \gamma_w) \cdot (h - h_1)$$

donde:

- $\gamma_{ap}$  = peso específico aparente.
- $\gamma'$  = peso específico sumergido.
- $l_v$  = gradiente hidráulico descendente.

este gradiente se define como el cociente entre la pérdida del nivel piezométrico del agua del trasdós entre F y B y la altura que separa a esos dos puntos, esto es:

$$l_v = 1 - \frac{u_B}{\gamma_w (H - h_1)}$$

Cuando el empuje del agua se calcula como se indica y cuando la presión vertical efectiva de referencia tiene el significado definido antes, se entiende en esta ROM que el coeficiente de empuje activo es el cociente que se indica en la parte superior de la Fig. 3.7.11.

### 3.7.5.2 Valor del coeficiente de empuje activo

El coeficiente de empuje activo puede estimarse mediante la teoría de Coulomb, cuya solución se indica en la Fig. 3.7.12 para el caso de un terreno granular, seco y homogéneo.

El ángulo “ $\delta$ ” es un parámetro de entrada, de manera que el ingeniero tiene que decidir su valor para calcular el coeficiente de empuje correspondiente. En el apartado 3.7.3 se dan criterios para evaluar el valor de este ángulo.

Para facilitar el cálculo de empujes según el método de Coulomb se incluye la Tabla 3.7.2 que indica el valor de  $K_{ah}$ :

$$K_{ah} = K_a \cdot \cos(\sigma + \delta)$$

para distintos valores de los ángulos  $\phi$ ,  $\alpha$  y  $\beta$ .

El coeficiente de empuje activo de Coulomb es aplicable siempre para el cálculo de empujes activos.

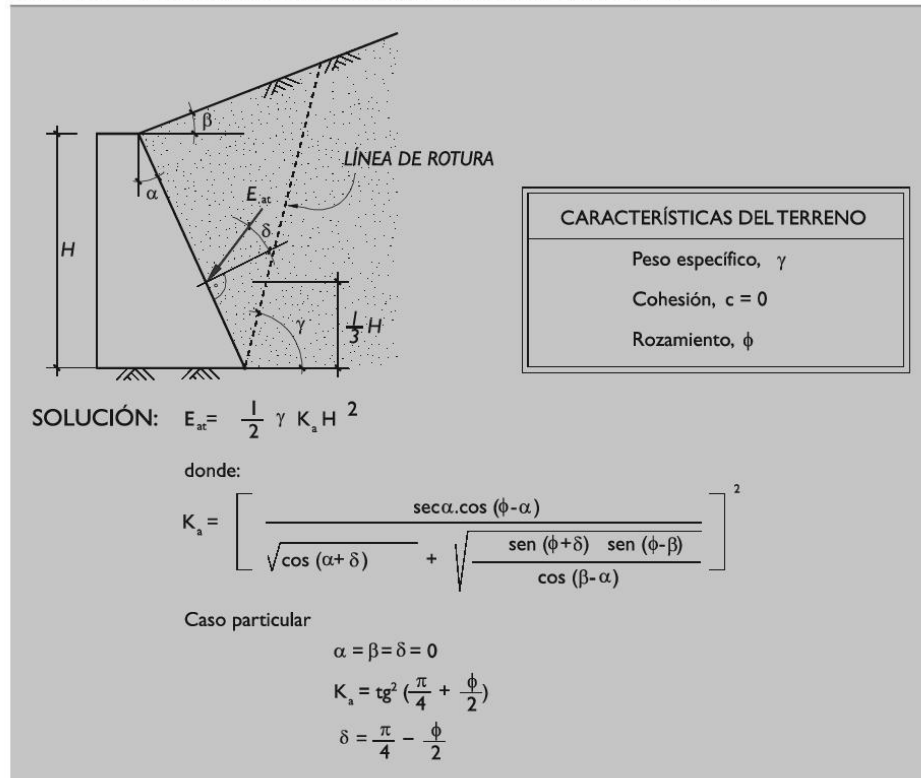
La inclinación de la línea de rotura del trasdós que resulta de la teoría de Coulomb para el caso de un terreno granular seco y homogéneo viene dada por la expresión:

$$\operatorname{tg}(\zeta - \beta) = \frac{\cos \rho \sqrt{\cos(\alpha - \beta) \operatorname{sen}(\phi - \beta)}}{\sqrt{\cos(\alpha + \delta) \operatorname{sen}(\phi + \delta) - \operatorname{sen} \rho \sqrt{\cos(\alpha - \beta) \operatorname{sen}(\phi - \beta)}}}$$

siendo "p" el ángulo auxiliar:

$$p = \phi + \alpha + \delta - \beta$$

**Figura 3.7.12. Geometría y solución del problema resuelto analíticamente por Coulomb**



Para el caso particular de muros verticales con trasdós horizontal ( $\alpha = \beta = 0$ ) la expresión anterior se simplifica:

$$\tan \zeta = \tan \phi + \frac{1}{\cos \phi} \sqrt{\frac{\sin \phi \cos \delta}{\sin (\phi + \delta)}}$$

Si, además, la dirección del empuje coincidiese con la normal al trasdós ( $\delta = 0$ ), resultaría:

$$\zeta = \frac{\pi}{4} + \frac{\phi}{2}$$

la estructura del terreno (entumecimiento causado por la humectación o la saturación) o por la fisuración que puede producirse debido a los movimientos del muro o a los cambios climáticos (fisuración por desecación).

Una vez investigado el valor de la cohesión que razonablemente puede existir en el material que trasdosa el muro en el momento correspondiente a la situación de proyecto que se trata de analizar, su efecto en el empuje activo se puede estimar como se indica a continuación.

El efecto de la cohesión en la resistencia de un material que además tiene fricción ( $\phi \neq 0$ ) es equivalente a la mejora que supondría comprimir todo el terreno con una tensión isotrópica de intensidad:

$$q = \frac{c}{\operatorname{tg} \phi}$$

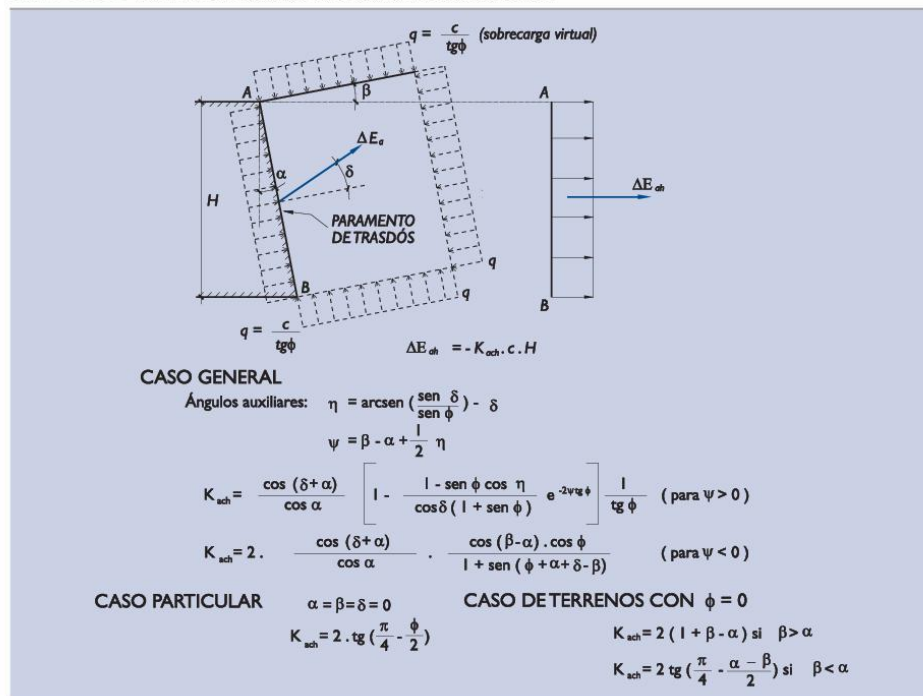
De hecho, una succión capilar de esa intensidad "q" da a las arenas húmedas no saturadas una cohesión aparente controlada por la expresión anterior.

Basándose en ese principio básico y utilizando como modelo de cálculo la teoría de la plasticidad simplificada, que se describe con más detalle en el punto 3.7.7.2, se puede deducir el valor del coeficiente de empuje activo debido a la cohesión,  $K_{ac}$ . Su componente horizontal es:

$$K_{ach} = K_{ac} \cdot \cos (\alpha + \delta)$$

El valor de  $K_{ach}$  se puede estimar con las fórmulas indicadas en la Fig. 3.7.16.

**Figura 3.7.16. Efecto de la cohesión en el empuje activo horizontal**



Nota: En estas fórmulas se supone que los arcos se expresan en radianes.



La presión vertical de referencia que se utiliza aquí es la misma que se define en el apartado 3.7.5.1.

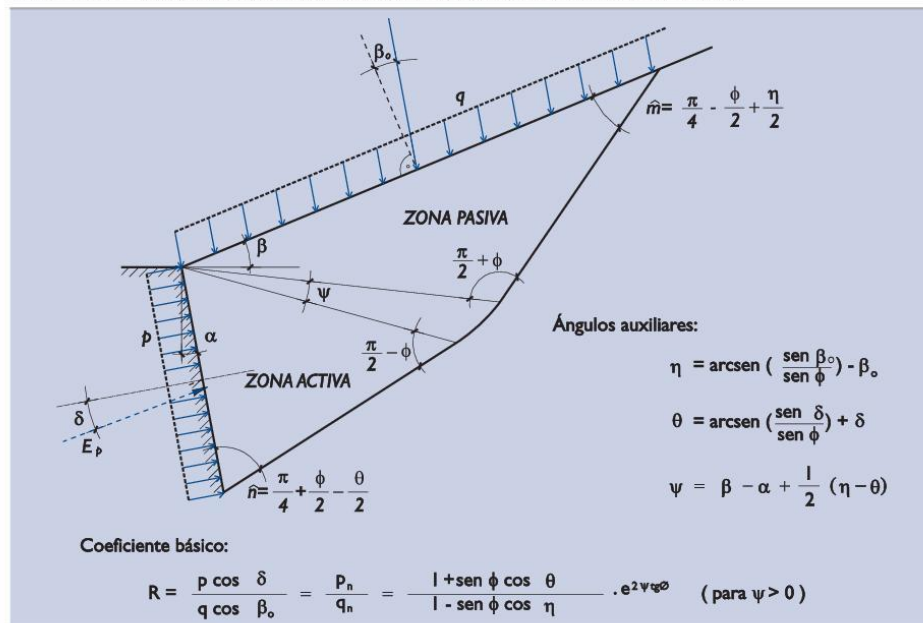
Como quiera que la definición de la presión vertical de referencia implica un determinado modo de considerar el efecto del agua, esa forma de proceder se debe de mantener en la posterior evaluación del empuje debido a la presión intersticial del agua.

### 3.7.7.2 Valor del coeficiente de empuje pasivo

El coeficiente de empuje pasivo no es una propiedad del terreno sino un parámetro de cálculo controlado principalmente por la resistencia al corte del terreno y que depende, además, de los ángulos característicos que definen la orientación del paramento del muro, la dirección del empuje y la inclinación del terreno.

La idea básica del método de evaluación del coeficiente de empuje pasivo es la teoría de la plasticidad, cuya expresión más simple se representa en la Fig. 3.7.23.

Figura 3.7.23. Teoría simplificada de la plasticidad aplicada al cálculo de empujes pasivos



Esta misma teoría es la utilizada para estudiar la carga de hundimiento de las cimentaciones superficiales y de la que se deducen los factores de capacidad de carga que se citan en el apartado 3.5.

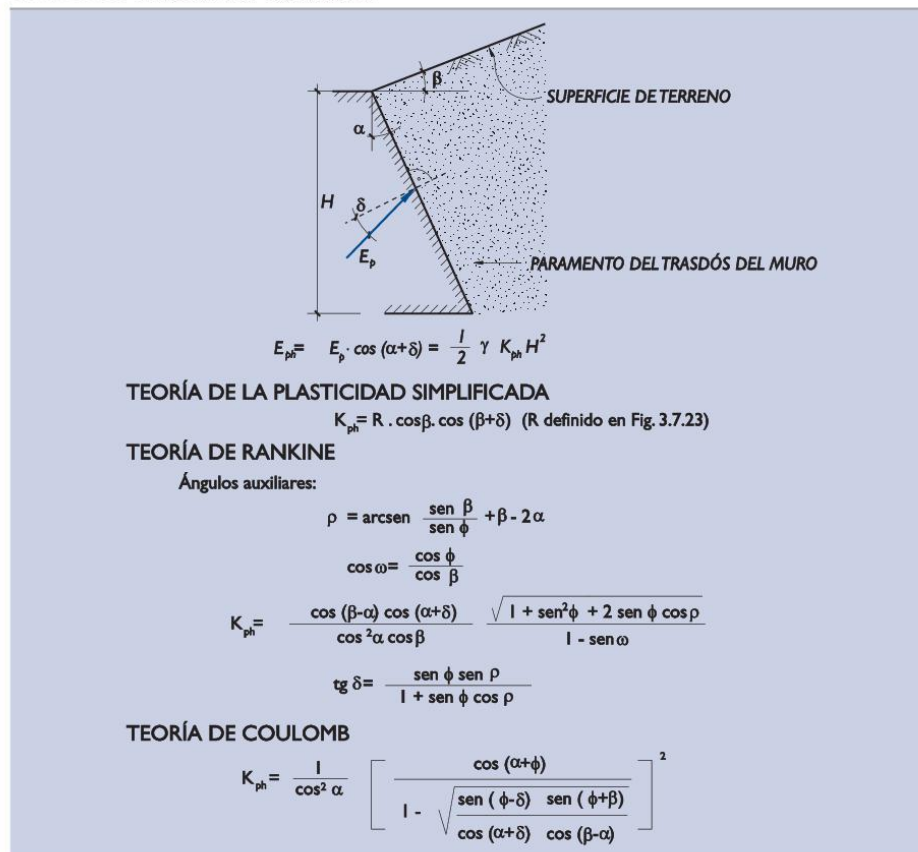
Con esa base teórica y con un esquema de extrapolación teoría-realidad similar al que se hizo para el caso de las cargas de hundimiento, se pueden recomendar los coeficientes de empuje pasivo horizontal:

$$K_{ph} = K_p \cdot \cos (\alpha + \delta)$$

que se indican en la Fig. 3.7.24.

Los métodos de Rankine y de Coulomb, considerados en el cálculo del coeficiente de empuje activo, permiten también el cálculo del coeficiente de empuje pasivo sin más que cambiar el signo al ángulo de rozamiento interno.

Figura 3.7.24. Coeficientes de empuje pasivo



Existen, sin embargo, razones para no aplicar de manera general la teoría de la plasticidad que se comenta en el cálculo de empujes activos (ya se citaron en el apartado 3.7.5.2) y existen razones para no utilizar sistemáticamente ni el método de Coulomb ni el método de Rankine en el cálculo de coeficiente de empuje pasivo. Esas razones se exponen a continuación.

Como se ha dicho, la línea de rotura observada en las roturas pasivas dista mucho de ser plana, sin embargo, tanto el método de Coulomb como el de Rankine implican una rotura plana.

De la misma forma, la teoría de la plasticidad sería aplicable al cálculo del empuje activo. La misma expresión analítica que da el coeficiente de empuje pasivo sería válida, sin más que cambiar el signo al ángulo de rozamiento interno, para obtener el coeficiente de empuje activo.