

**TECHNICAL GUIDES ON DAM SAFETY**  
**CRITERIA FOR THE DESIGN OF DAMS**  
**AND THEIR APPURTENANT WORKS**  
**VOLUME II: EMBANKMENT DAMS**



**COLEGIO DE INGENIEROS DE  
CAMINOS, CANALES Y PUERTOS**



**COMITÉ NACIONAL ESPAÑOL  
DE GRANDES PRESAS**





- 1. INTRODUCTION**
- 2. DESIGN SEQUENCE**
- 3. COMMON DESIGN ASPECTS**
- 4. HOMOGENEOUS AND ZONED DAMS**
- 5. CORE DAMS**
- 6. DAMS WITH IMPERVIOUS FACING**
- 7. EVALUATION OF SAFETY**
- 8. REFERENCES**

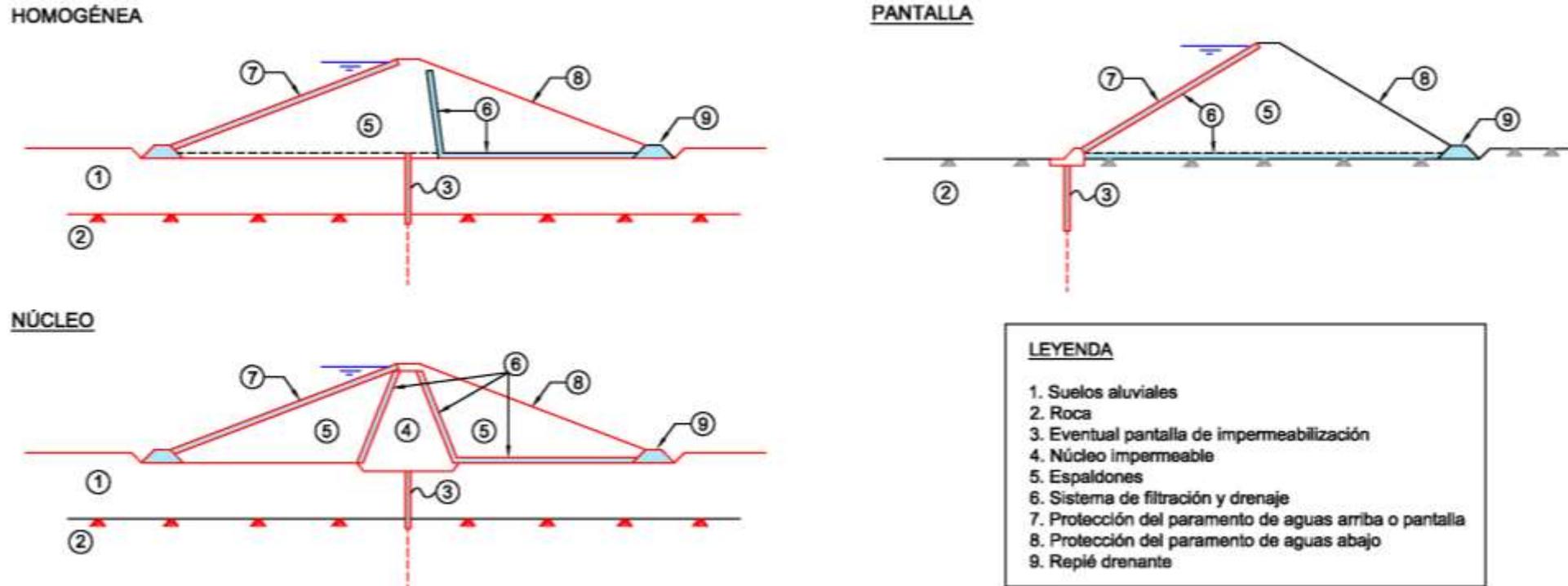
ANNEX: DAMS OF VARIOUS TYPES IN SPAIN

# **1. INTRODUCTION**

**1.1 Embankment dams in Spain**

**1.2 Statistics of incidents, accidents and failures**

# MAIN ELEMENTS OF THE DIFFERENT TYPES OF EMBANKMENT DAMS



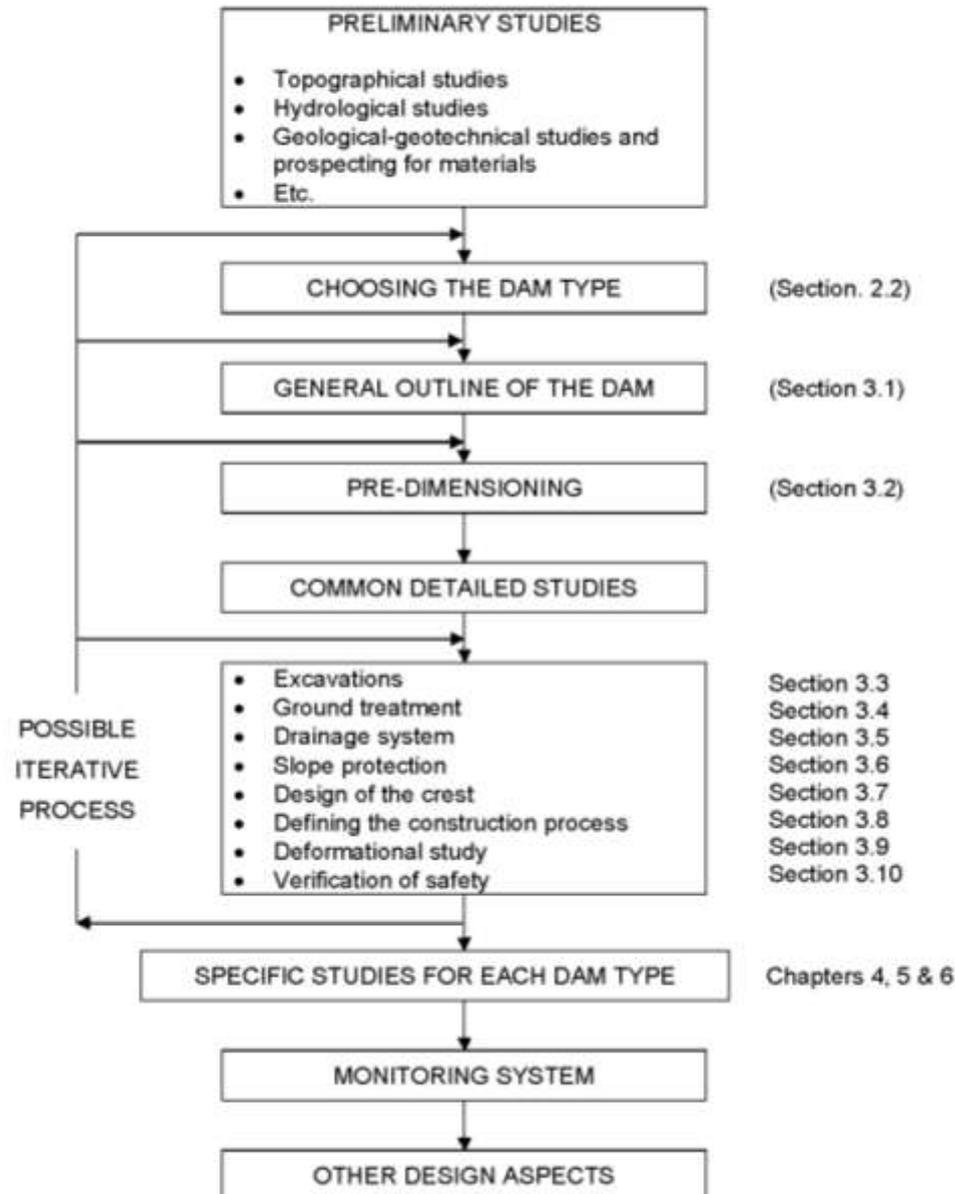
# **2. DESIGN SEQUENCE**

**2.1. Preliminary studies**

**2.2. Selection of the dam type**

# SKETCH OF THE DESIGN PROCESS

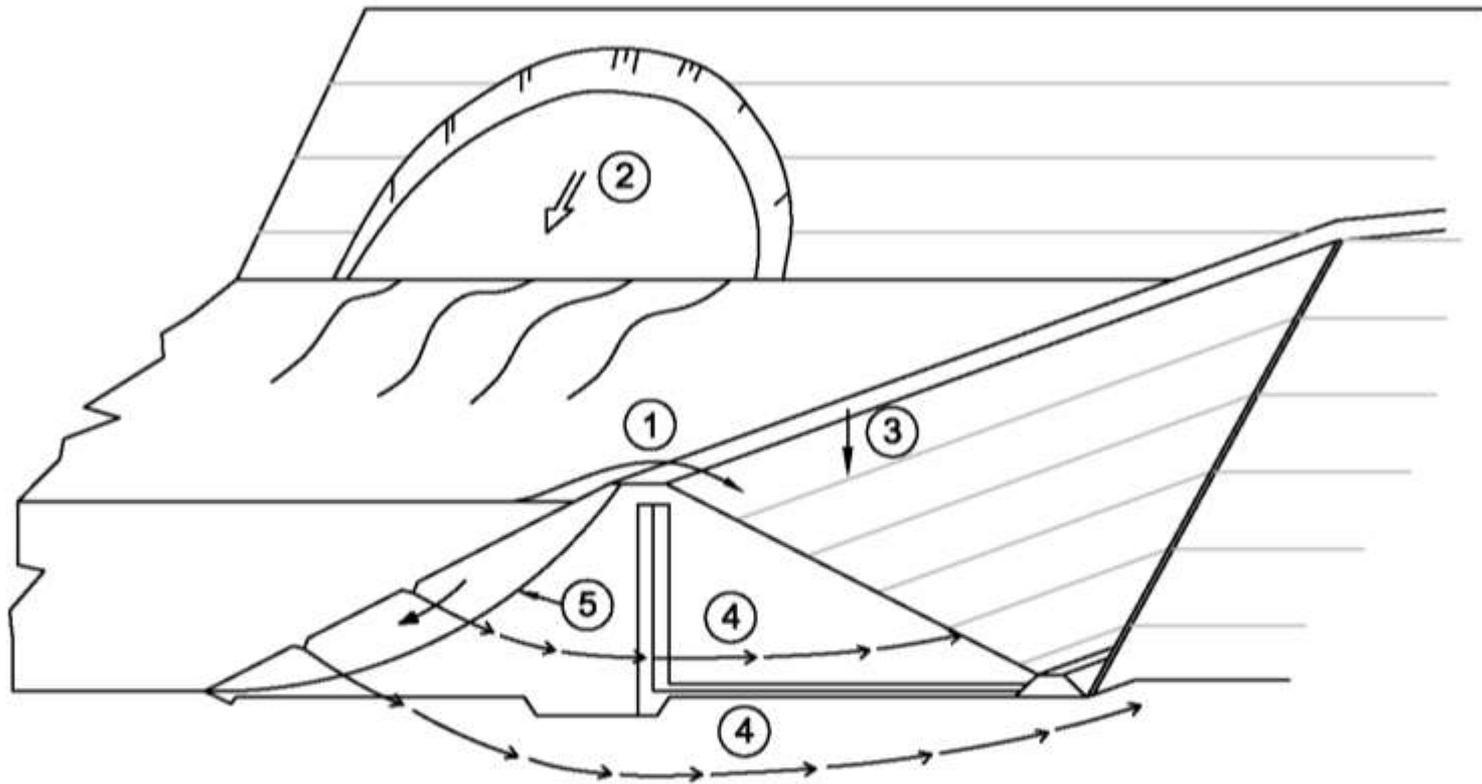
## FOR EMBANKMENT DAMS



# **3. COMMON DESIGN ASPECTS**

- 3.1. General layout of the dam and its appurtenant works**
- 3.2. Geometrical definition of the typical cross-section. Pre-dimensioning**
- 3.3. Excavations**
- 3.4. Ground treatment. Possible use of galleries in the foundation**
- 3.5. Design of the drainage system**
- 3.6. Definition of the protection of outer slopes**
- 3.7. Freeboard, crest and possible berms**
- 3.8. Specifying the construction process**
- 3.9. Deformational study**
- 3.10. Verification of safety**

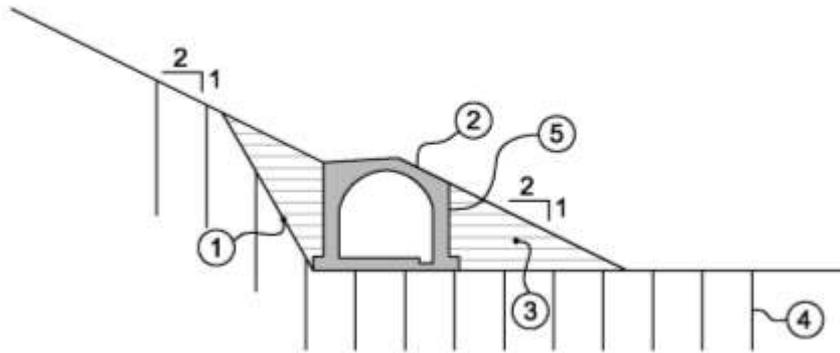
# MAIN FAILURE MODES IN AN EMBANKMENT DAM



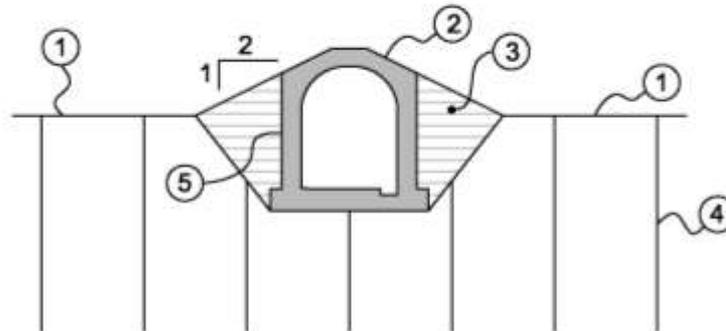
1. Desbordamiento por coronación.
2. Deslizamiento de laderas.
3. Asientos anómalos (sismos u otras causas).
4. Erosión interna del cuerpo de presa o del cimiento.
5. Inestabilidad del cuerpo de presa.

# SKETCH OF GALLERIES ON THE IMPERVIOUS AREAS AT THE BASE OF EMBANKMENT DAMS

**GALERÍAS DE DESAGÜE TRANSVERSALES**  
(ZONAS DONDE ATRAVIESE EL NÚCLEO DE PRESA O ZONA IMPERMEABLE EN PRESAS HOMOGÉNEAS Y ZONADAS)

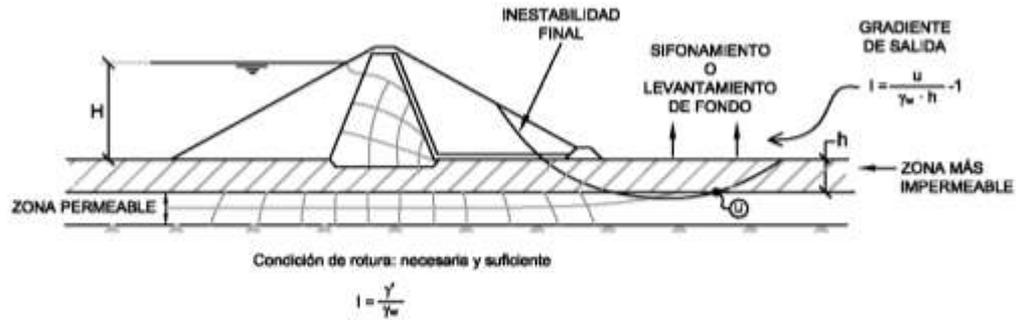


1. Regularización de la excavación.
2. Estructura.
3. Relleno de hormigón.
4. Inyecciones de consolidación en la base de la zona impermeable.
5. Tratamiento de impermeabilización del contacto entre hormigones.

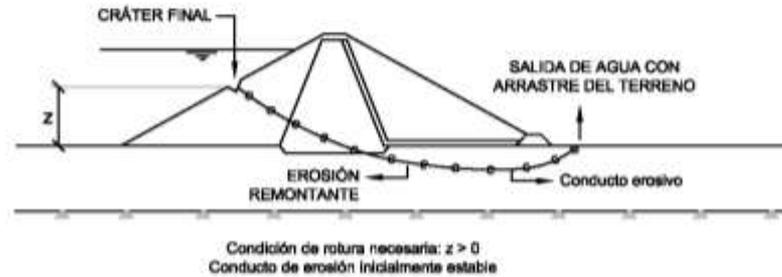


# FAILURE MECHANISMS THAT WATER FLOW CAN TRIGGER

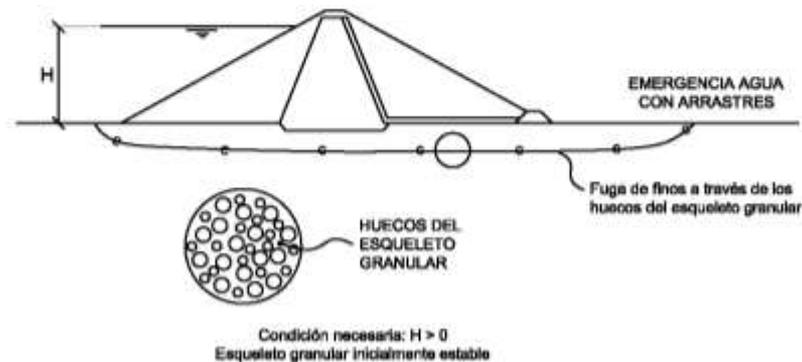
## 1. LEVANTAMIENTO DE FONDO (SIFONAMIENTO)



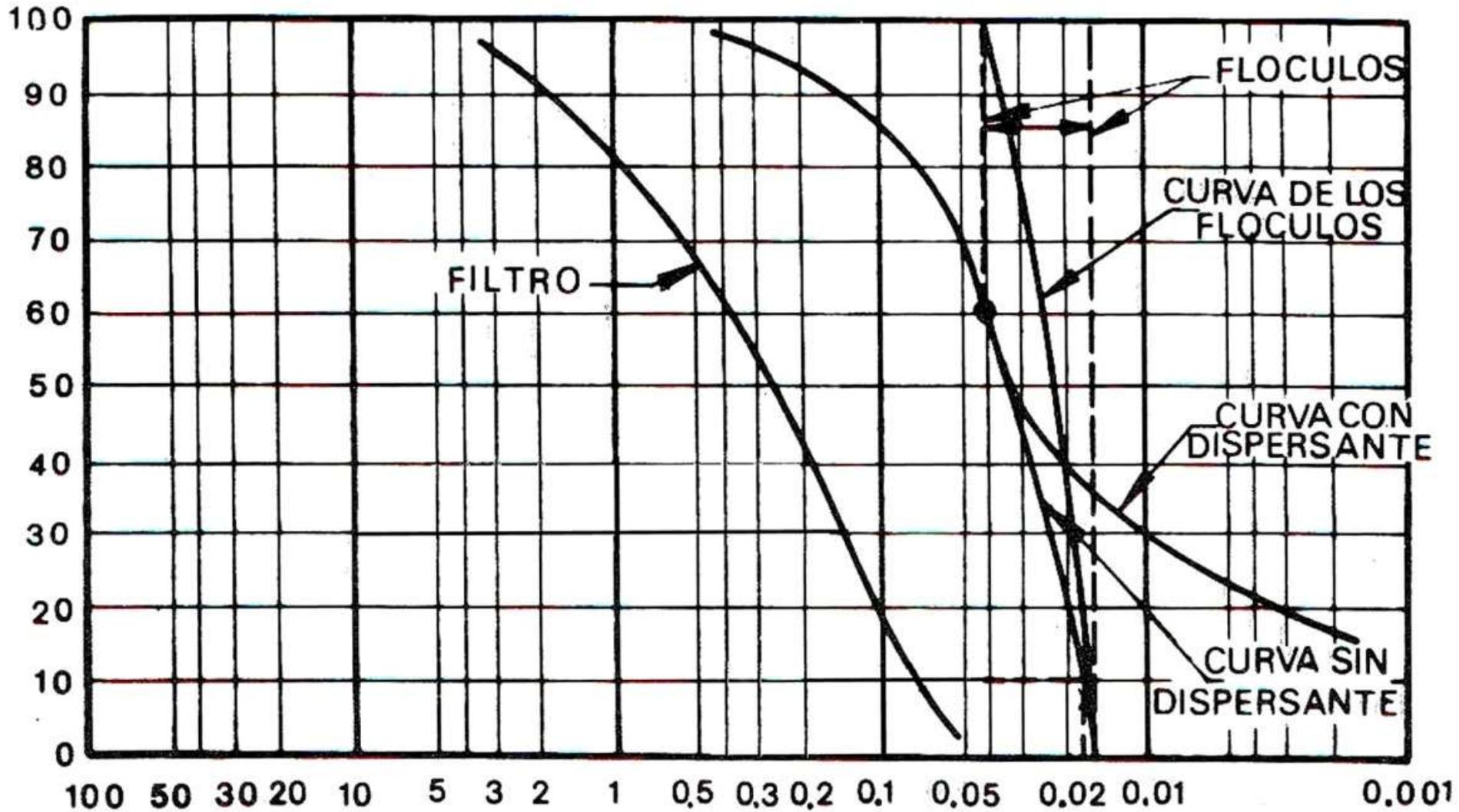
## 2. EROSIÓN INTERNA



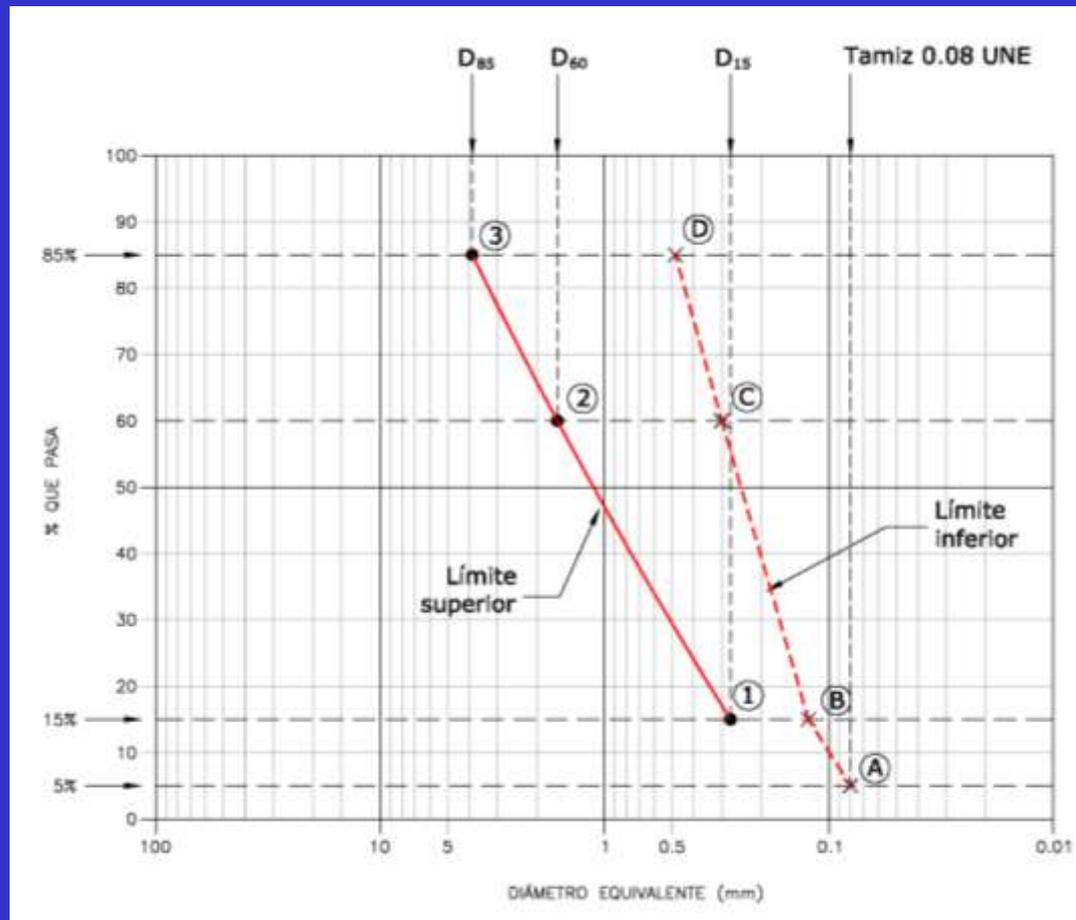
## 3. SUFUSIÓN (ARRASTRE DE FINOS)



# DEFINITION OF FLOCCULE SIZE



# RECOMMENDED GRADING FOR FILTERS



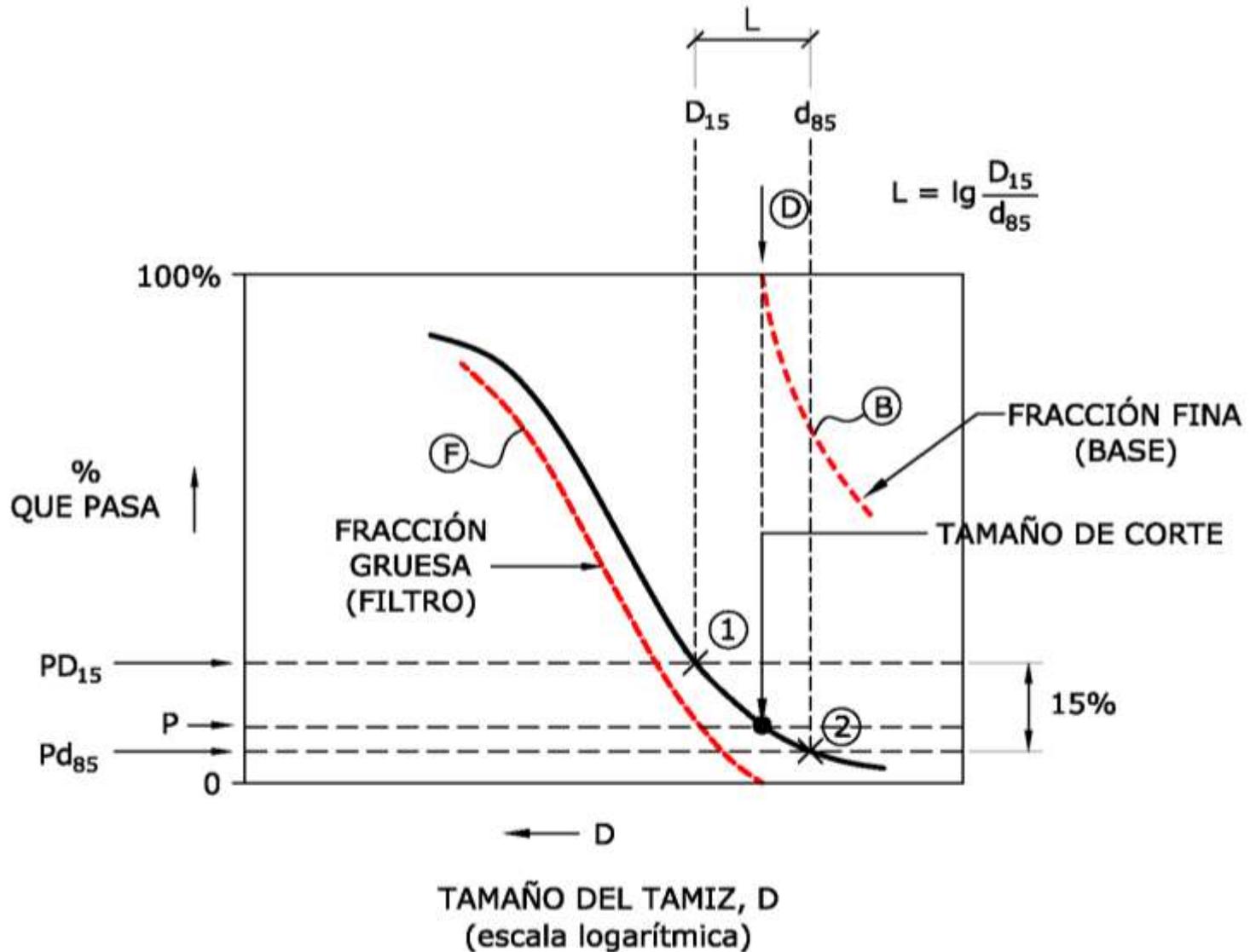
## Determinación de los límites superiores

- ①  $D_{15} \text{ máx} \cdot - \text{ Ver Tabla 3.5.1}$
- ②  $D_{60} \text{ máx} = 6 D_{15}$
- ③  $D_{85} \text{ máx} = 15 D_{15}$

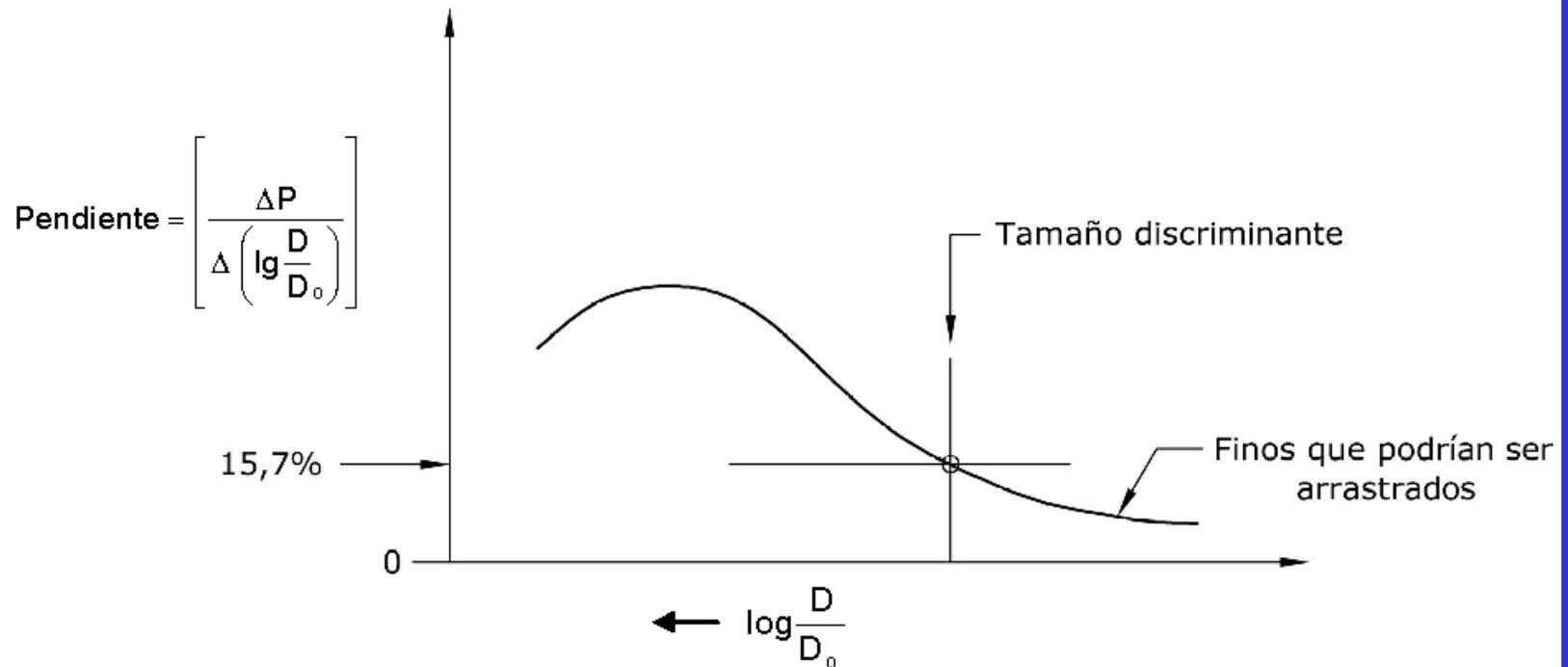
## Determinación de los límites inferiores

- Ⓐ Porcentaje de finos < 5%
- Ⓑ  $D_{15} \text{ mín: mayor de los dos valores: } 0,4 D_{15} \text{ ó } 0,12 \text{ mm}$
- Ⓒ  $D_{60} \text{ mín} = 1/5 D_{60} \text{ máx}$
- Ⓓ  $D_{85} \text{ mín} = 1/8 D_{85} \text{ máx}$

# DIAGRAM OF THE THEORETICAL STUDY OF FINES ENTRAINMENT (SUFFUSION)

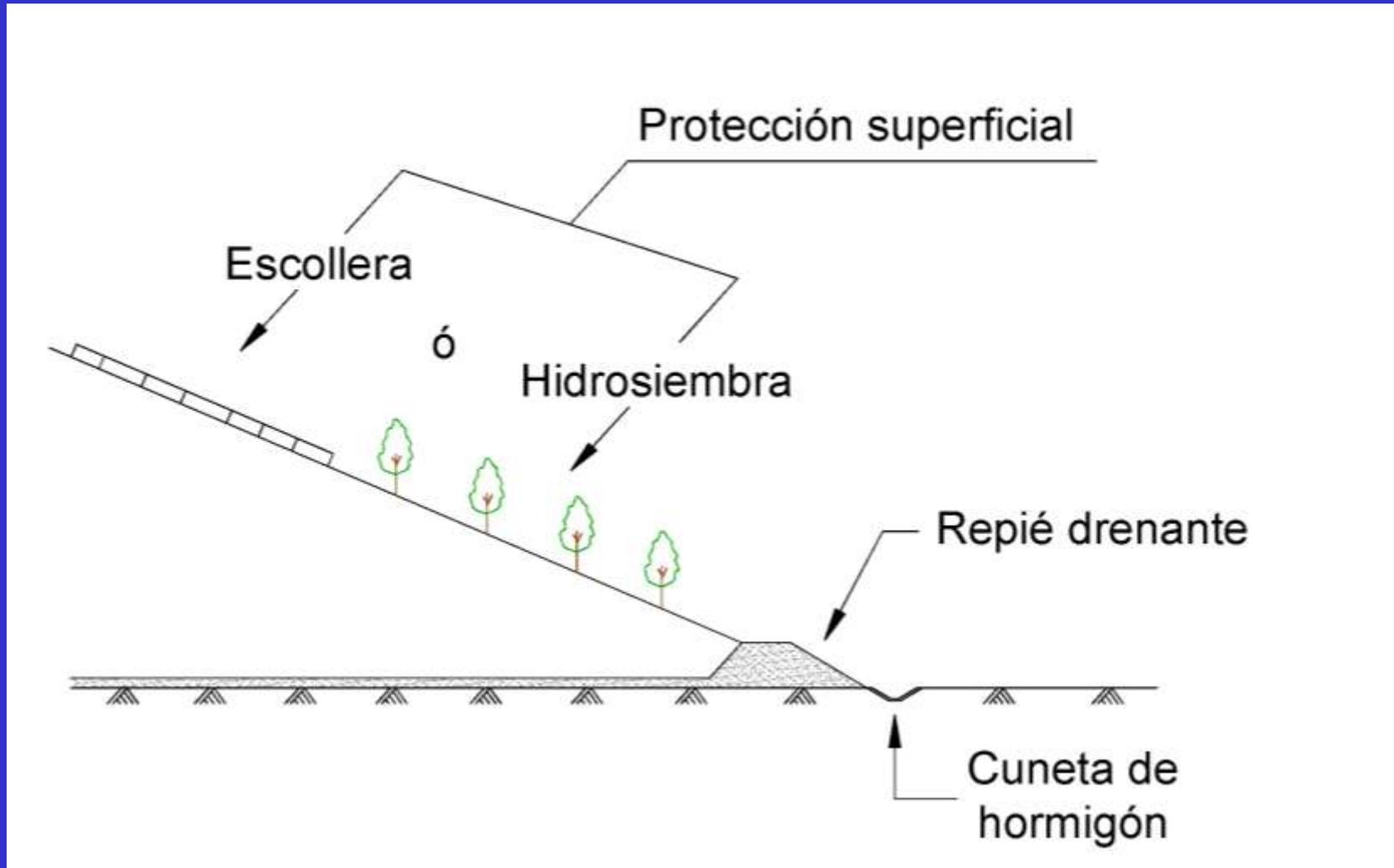


# DIAGRAM OF THE DERIVED CURVE. SLOPE OF THE GRADING CURVE. URIEL'S CONDITION FOR SELF-STABILITY

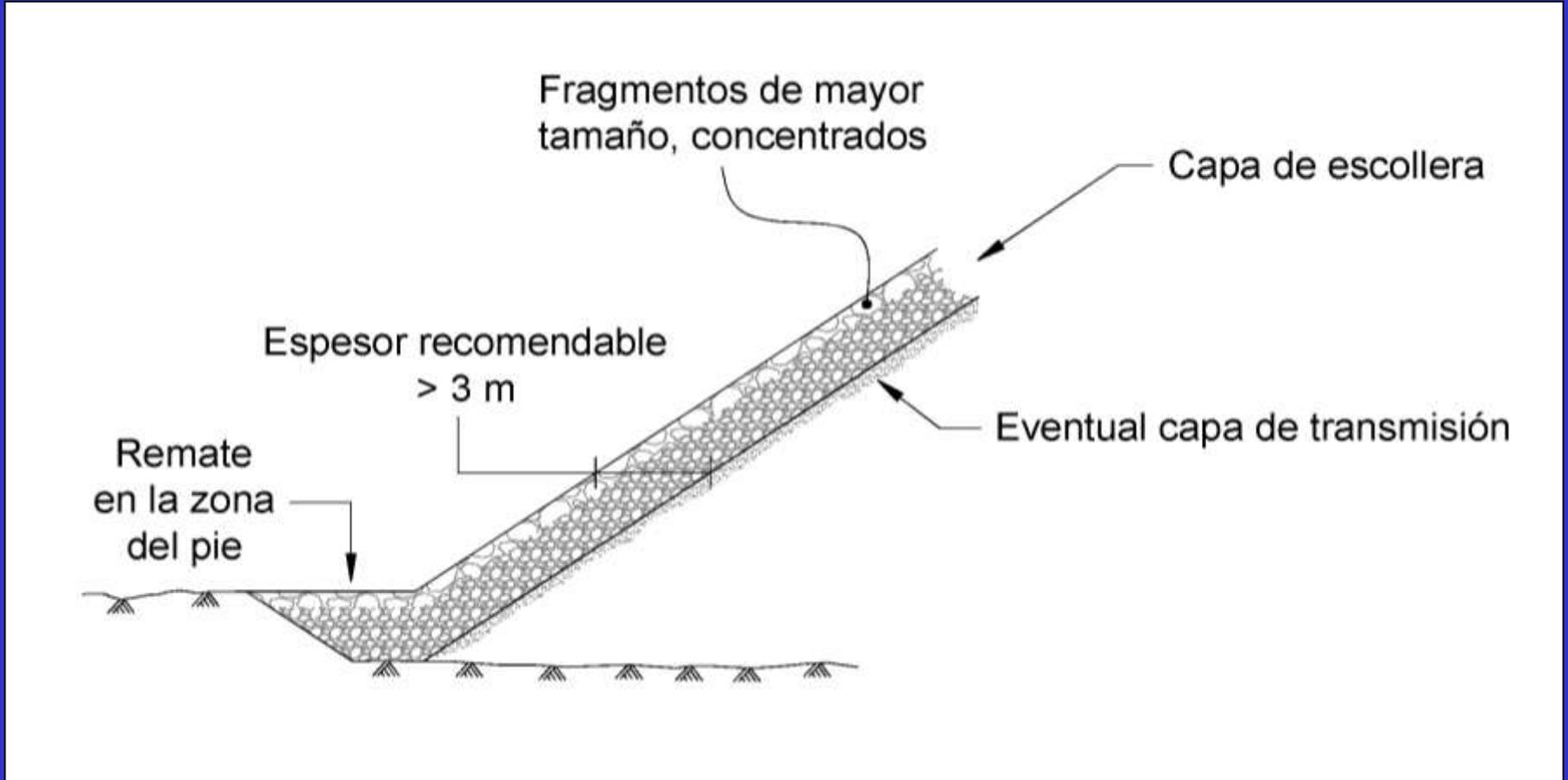


Nota: El valor de  $D_0$  puede ser cualquier tamaño característico, p.ej.  $D_0 = 1 \text{ mm}$

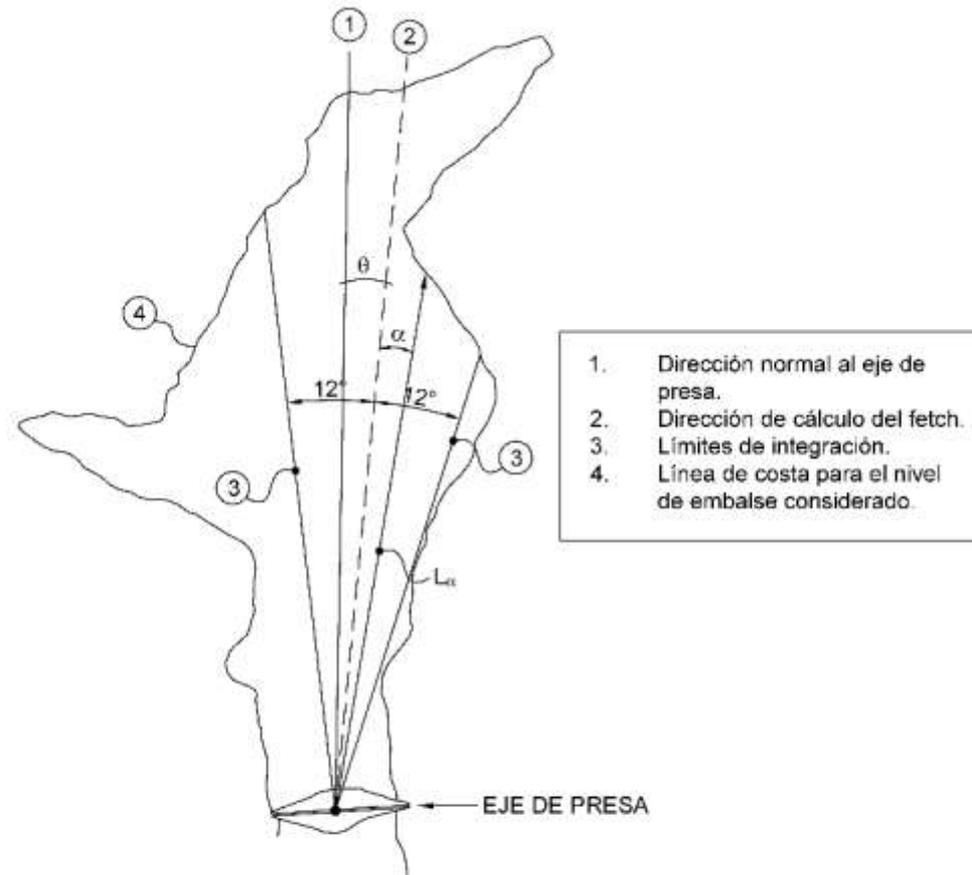
# SKETCH OF THE DOWNSTREAM SLOPE PROTECTION



# DRAWING OF AN UPSTREAM SLOPE PROTECTION WITH RIP-RAP



# DEFINITION OF THE DESIGN FETCH



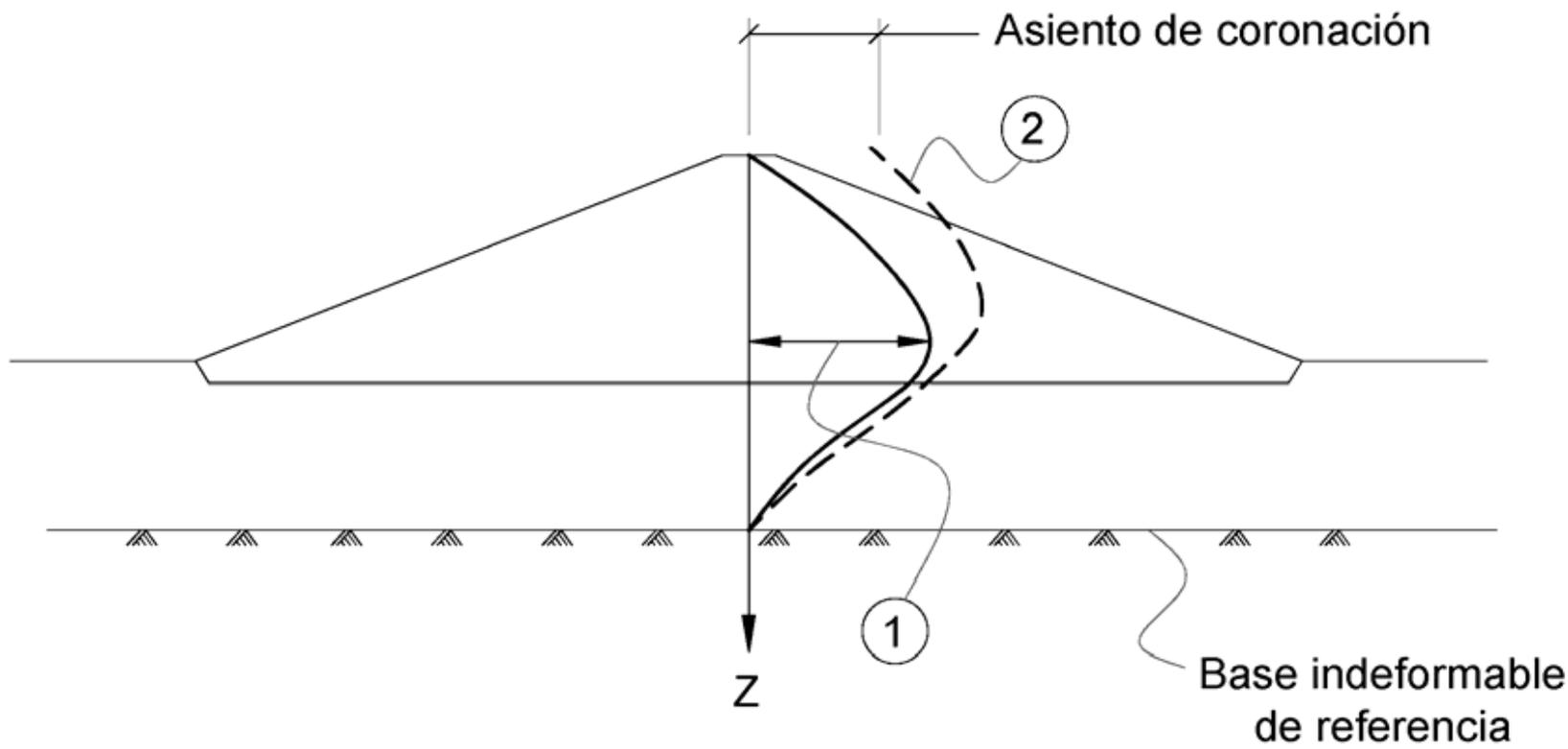
Fetch según la orientación  $\theta$

$$F(\theta) = \frac{1}{2\alpha_0} \int_{-\alpha_0}^{\alpha_0} L_{\alpha} \cdot d\alpha \quad ; \quad \alpha_0 = 12^{\circ}$$

Fetch de cálculo

$$F = \max [F(\theta)]$$

# DIAGRAM OF THE MAIN SETTLEMENTS IN EMBANKMENT DAMS



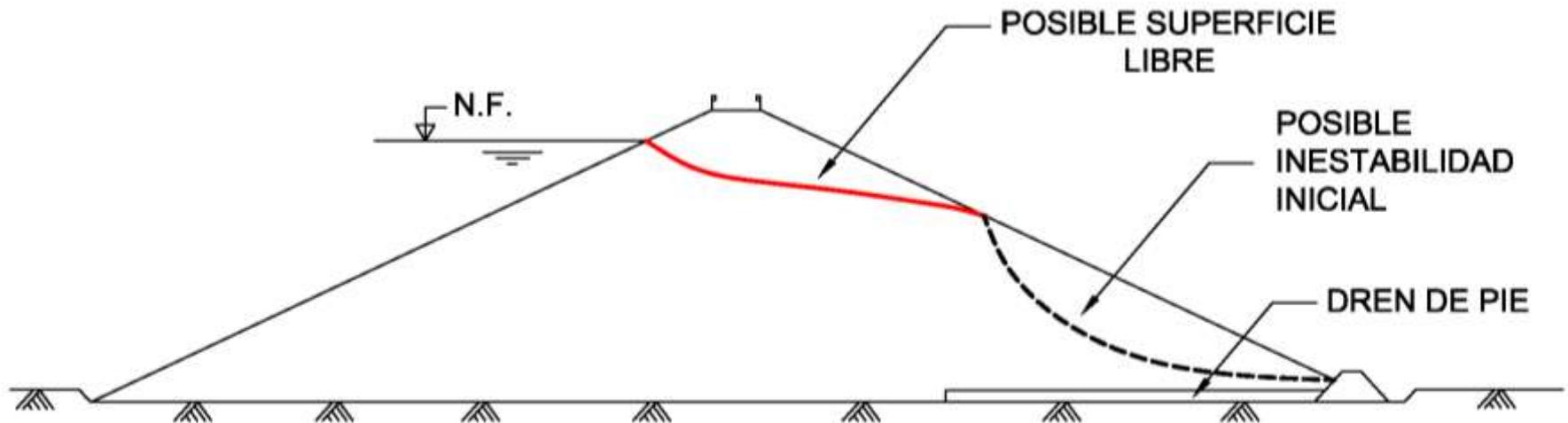
① Al final del proceso constructivo

② A largo plazo

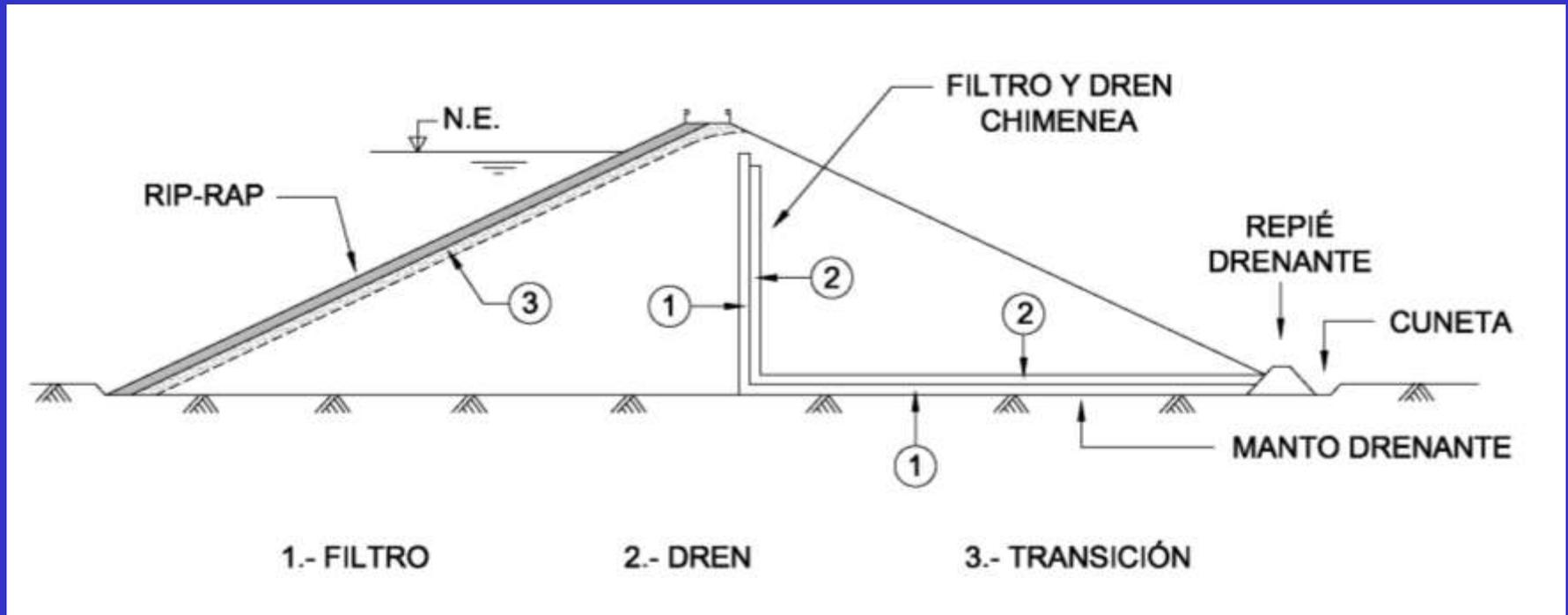
# **4. HOMOGENEOUS AND ZONED DAMS**

- 4.1. General layout of the dam body**
- 4.2. Precautions against internal erosion**
- 4.3. Dam body materials**
- 4.4. Possible horizontal drains in the dam body**
- 4.5. Dimensioning of the upstream protection. Stability during drawdown**
- 4.6. Some examples of homogeneous and zoned dams in Spain**

# UNACCEPTABLE WATER TABLE IN A SEEPAGE NET, WHICH COULD OCCUR IN A THEORETICAL DAM – PERFECTLY HOMOGENEOUS AND ON A IMPERVIOUS FOUNDATION



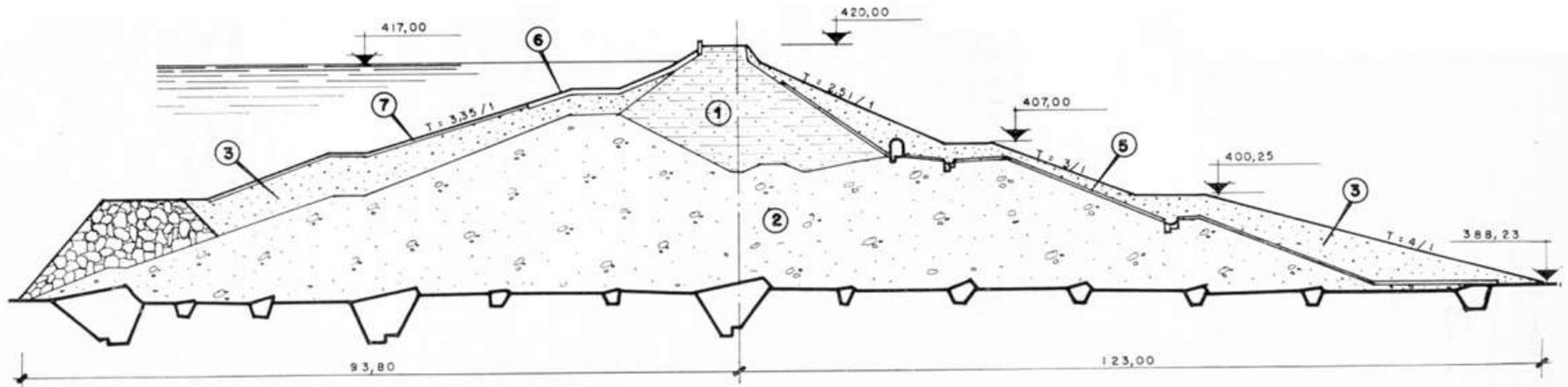
# SCHEMATIC LOCATION OF DRAINING ELEMENTS IN A HOMOGENEOUS



# CRACK IN THE SOIL-CEMENT COATING USED AS AN ANTI-EROSION PROTECTION ON THE UPSTREAM SLOPE OF THE C. W. BILL YOUNG DAM

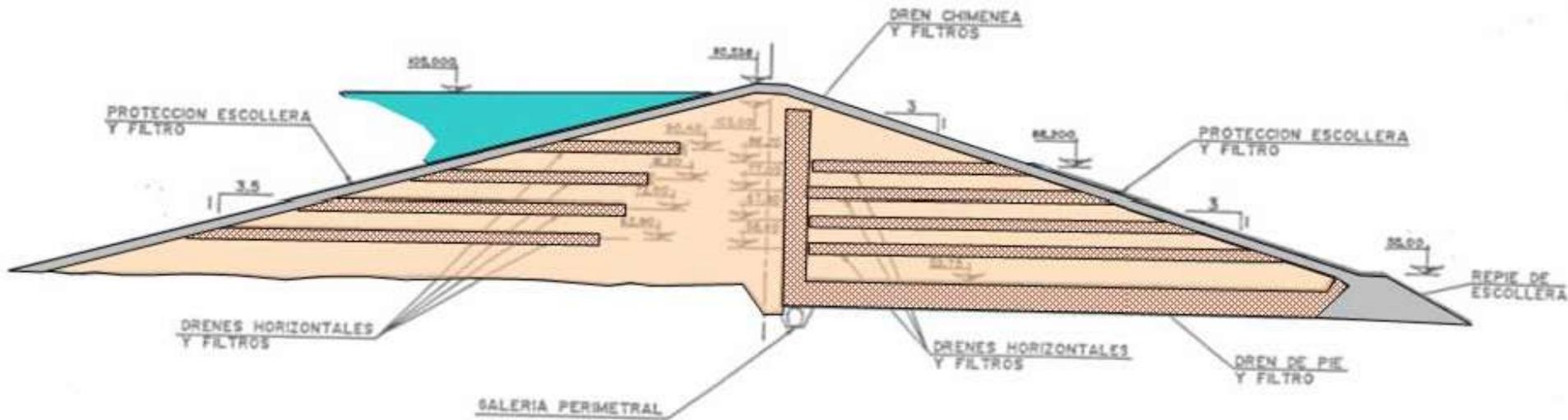


# TYPICAL CROSS-SECTION OF LA SOTONERA DAM

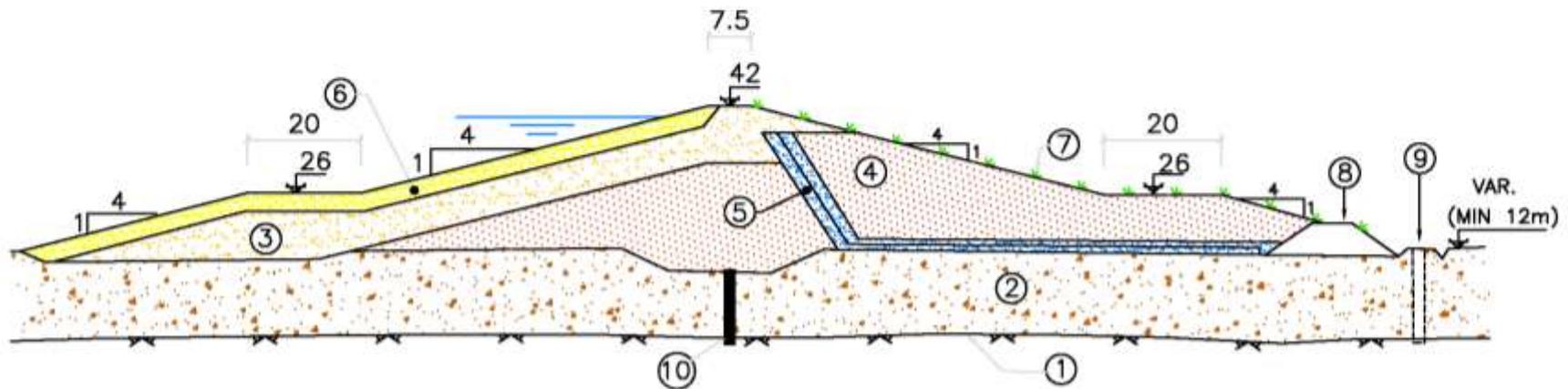


- |   |                     |   |                   |
|---|---------------------|---|-------------------|
| 1 | Arcilla             | 5 | Filtro            |
| 2 | Hormigón de arcilla | 6 | Losas de hormigón |
| 3 | Gravas              | 7 | Mampostería       |

# TYPICAL CROSS-SECTION OF LA PEDRERA DAM



# TYPICAL CROSS-SECTION OF THE BARBATE DAM

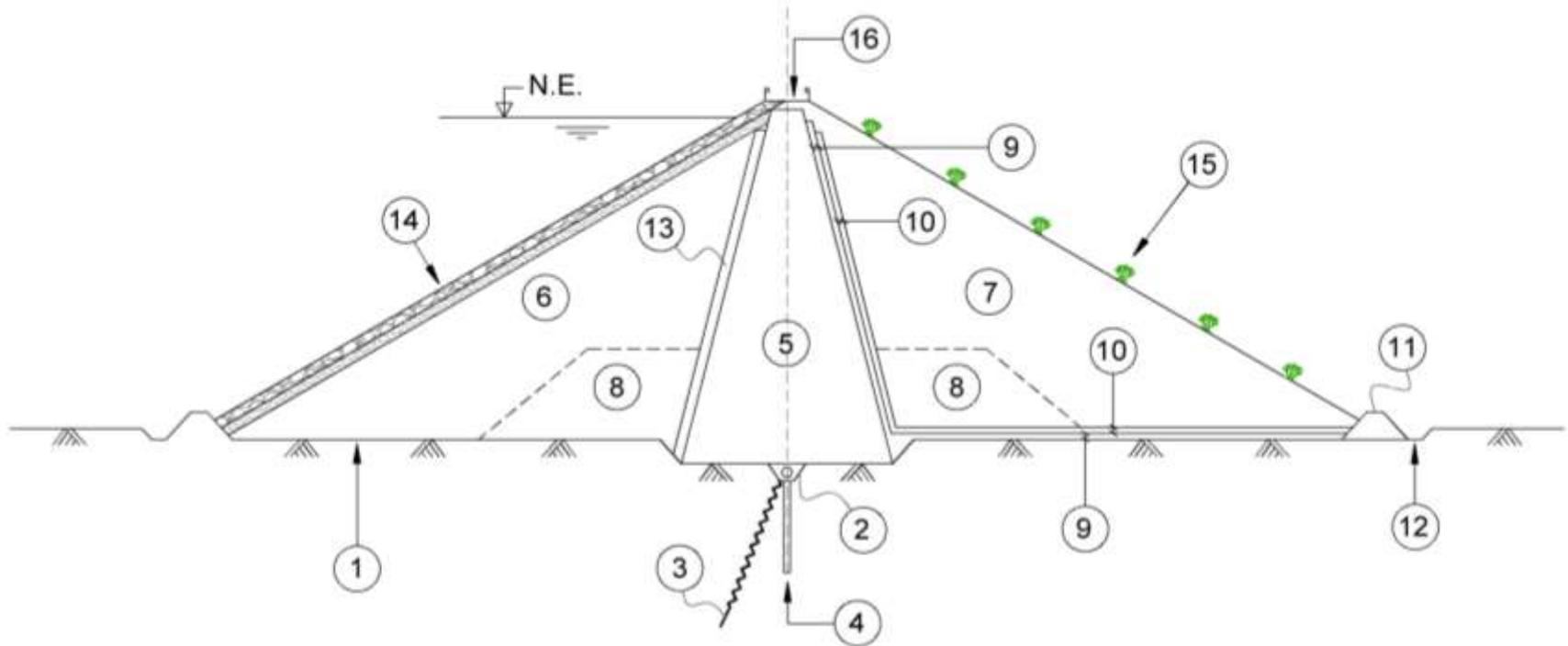


- |  |  |
|--|--|
| <ol style="list-style-type: none"> <li>1. Sustrato margoso terciario.</li> <li>2. Aluvial. Granulometría fina heterogénea.</li> <li>3. Espaldón de aguas arriba. Suelos aluviales más arenosos.</li> <li>4. Espaldón de aguas abajo. Préstamos aluviales.</li> <li>5. Sistema de drenaje.</li> </ol> | <ol style="list-style-type: none"> <li>6. Protección granular de aguas arriba.</li> <li>7. Hidrosiembrá de aguas abajo.</li> <li>8. Rapié drenante.</li> <li>9. Pozos de alivio.</li> <li>10. Pantalla continua de impermeabilización del cimiento.</li> </ol> |
|--|--|

# 5. CORE DAMS

- 5.1. General layout of the typical cross-section
- 5.2. Materials for the impervious core
- 5.3. Materials for the dam shells
- 5.4. Other materials. Shadow zones
- 5.5. Foundation of the core
- 5.6. Core cracking. Hydraulic fracturing
- 5.7. Some examples of core dams in Spain

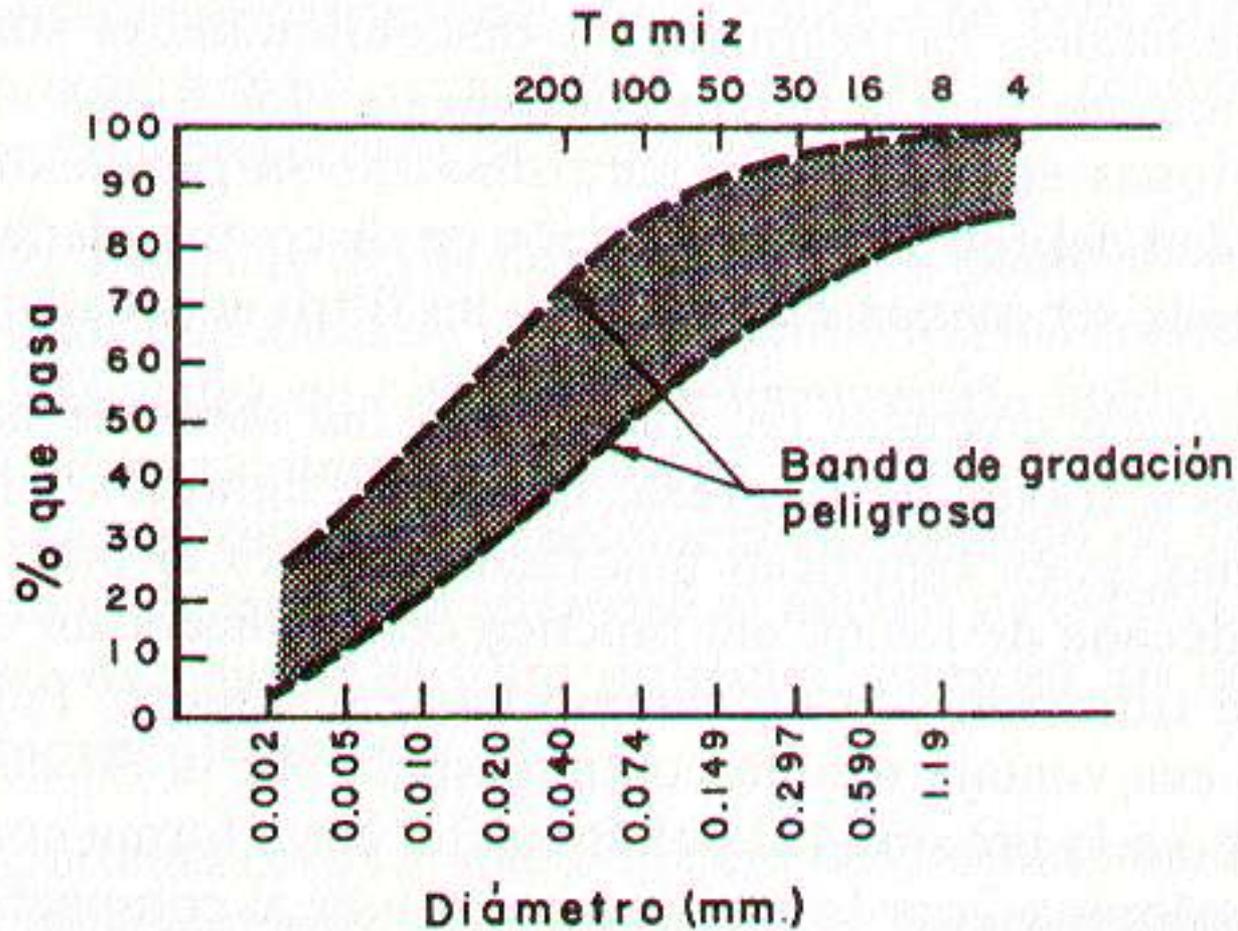
# ESSENTIAL ELEMENTS IN THE BODY OF CORE DAMS



1. Excavación de implantación.
2. Eventual galería perimetral.
3. Pantalla de inyección.
4. Pantalla de drenaje.
5. Núcleo impermeable.
6. Espaldón de aguas arriba.
7. Espaldón de aguas abajo.
8. Zonas de sombra.

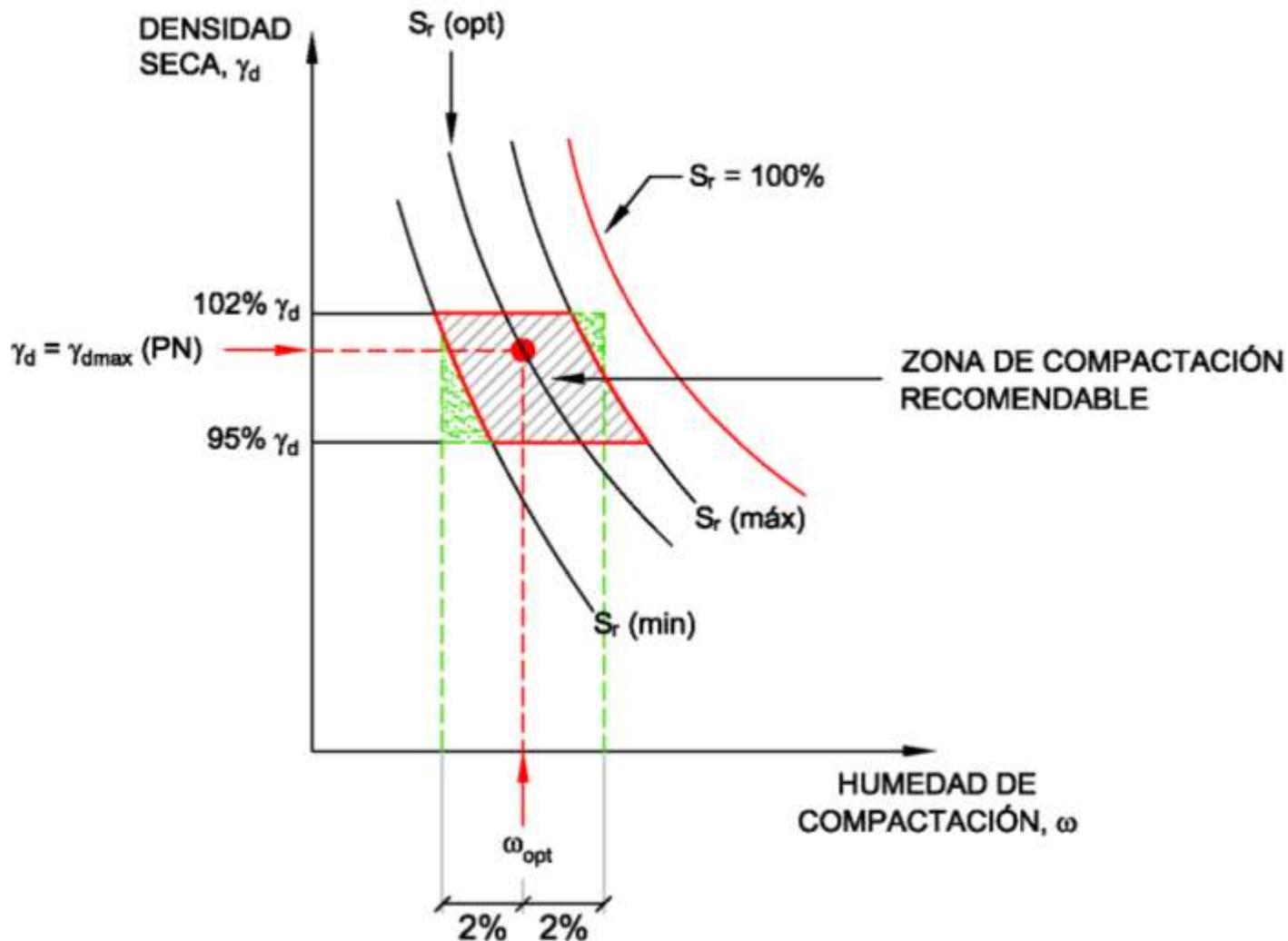
9. Filtro de arena.
10. Dren de gravilla.
11. Repié drenante.
12. Cuneta de recogida de filtraciones.
13. Transición núcleo-espaldón.
14. Rip-rap de protección aguas arriba.
15. Protección de aguas abajo.
16. Coronación.

# GRADING BAND WITH A LARGER RISK OF CRACKING

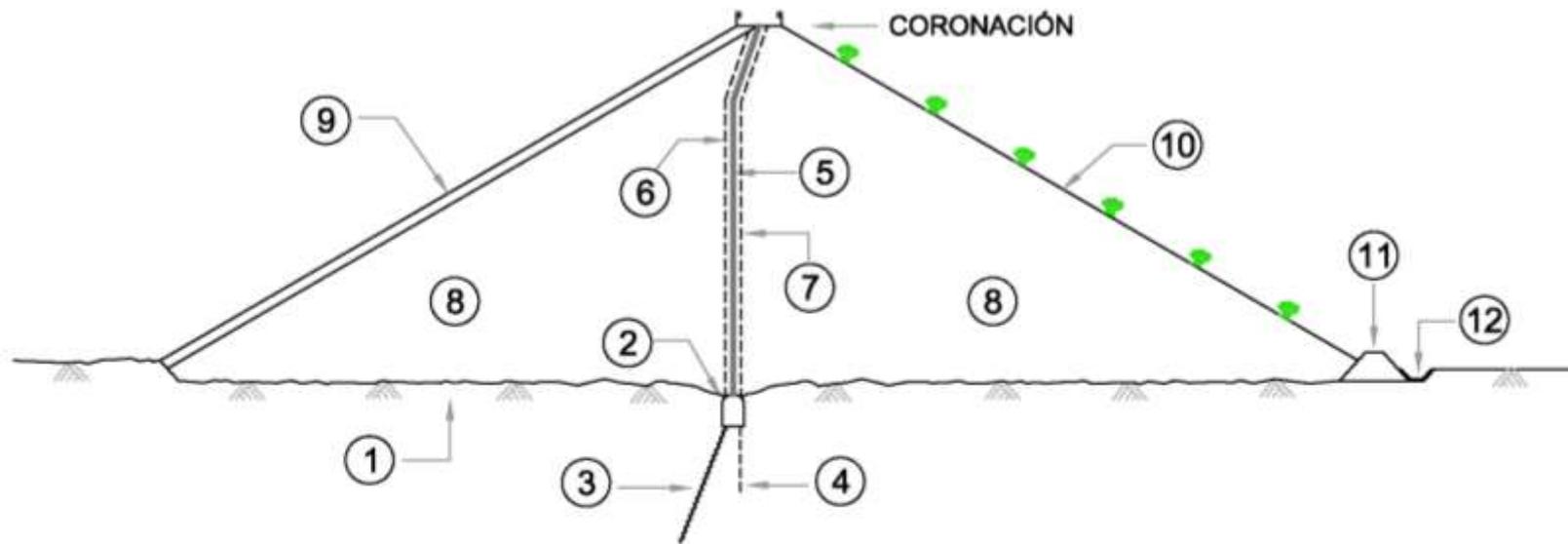


Tomado de S. Uriel (1980)

# DIAGRAM OF THE COMPACTION CONDITIONS OF A CLAY CORE

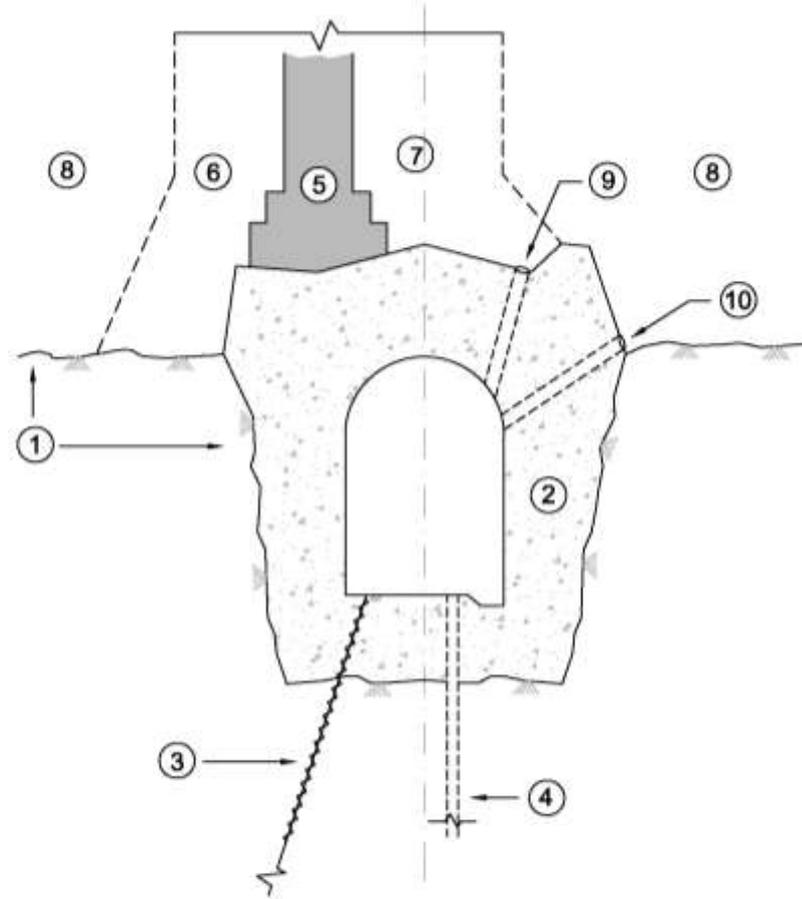


# SECCIÓN TIPO DE UNA PRESA DE NÚCLEO ASFÁLTICO



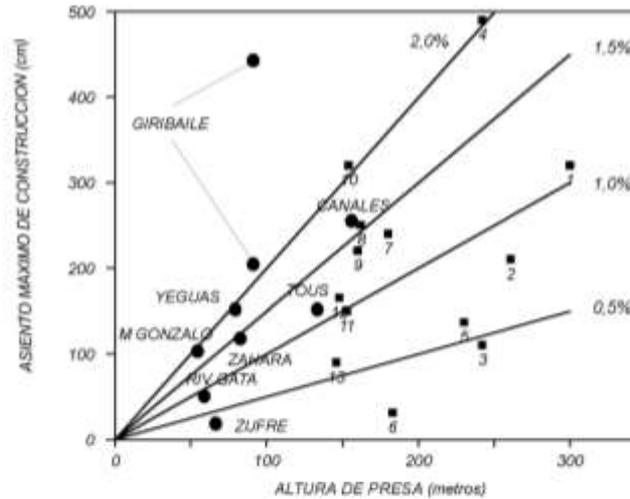
- |                                |  |
|--------------------------------|--|
| 1. Excavación de implantación  | 7. Transición de aguas abajo           |
| 2. Eventual galería perimetral | 8. Espaldones granulares               |
| 3. Pantalla de inyección       | 9. Protección de aguas arriba          |
| 4. Pantalla de drenaje         | 10. Protección de aguas abajo          |
| 5. Núcleo impermeable          | 11. Repié drenante                     |
| 6. Transición de aguas arriba  | 12. Cuenta de recogida de filtraciones |

# DETALLE DEL APOYO DEL NÚCLEO ASFÁLTICO Y DE LA EVENTUAL GALERÍA PERIMETRAL DE INSPECCIÓN Y DRENAJE



- |                               |                               |
|-------------------------------|-------------------------------|
| 1. Excavación en roca         | 6. Transición de aguas arriba |
| 2. Galería de hormigón armado | 7. Transición de aguas abajo  |
| 3. Pantalla de inyección      | 8. Espaldones granulares      |
| 4. Pantalla de drenaje        | 9. Drenaje del núcleo         |
| 5. Núcleo impermeable         | 10. Drenaje del espaldón      |

# TYPICAL VALUES OF MAXIMUM DAM SETTLEMENT OBSERVED DURING CONSTRUCTION



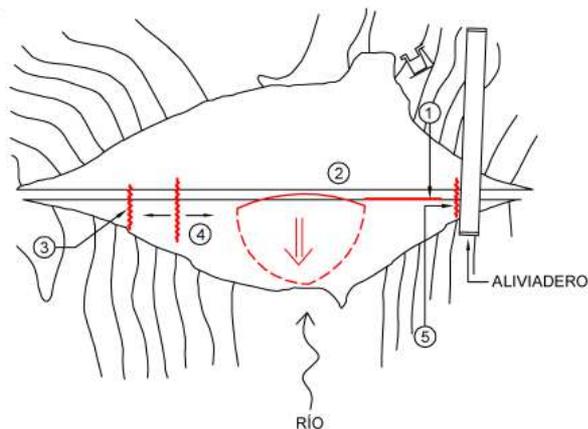
Nº	Nombre	H (m)	Smáx/H (%)	E <sub>eq</sub> (MPa)
1	Nurek	300	1,07	154
2	Chicoasen	261	0,80	179
3	Mica	242	0,45	296
4	Guavio	242	2,02	68
5	Oroville	230	0,60	211
6	Bennet	183	0,17	592
7	Darmouth	180	1,33	74
8	Talbingo	162	1,54	58
9	Grand Maison	160	1,38	64
10	Tedorigawa	154	2,08	41
11	Getpasch	153	0,98	88
12	Infiernillo	148	1,11	73
13	Angostura	146	0,62	129

Nota: Para estimar el módulo E<sub>eq</sub> se ha supuesto  $\gamma = 22 \text{ KN/m}^3$  y, además, que el asiento del cimiento de las presas de referencia hubiese sido pequeño (despreciable a los efectos de este cálculo).

Figura tomada de A. Soriano et al (1999)

# DIAGRAM OF DIFFERENT POTENTIAL CRACKS IN THE CORE

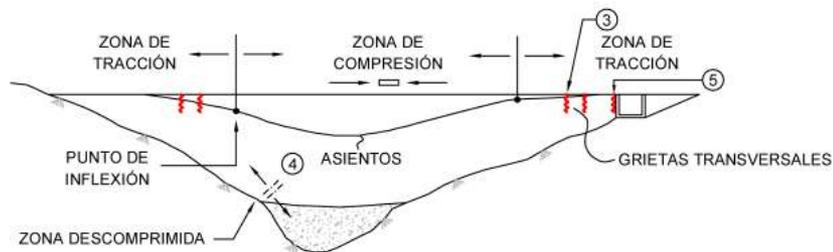
a) PLANTA



b) SECCIÓN TRANSVERSAL

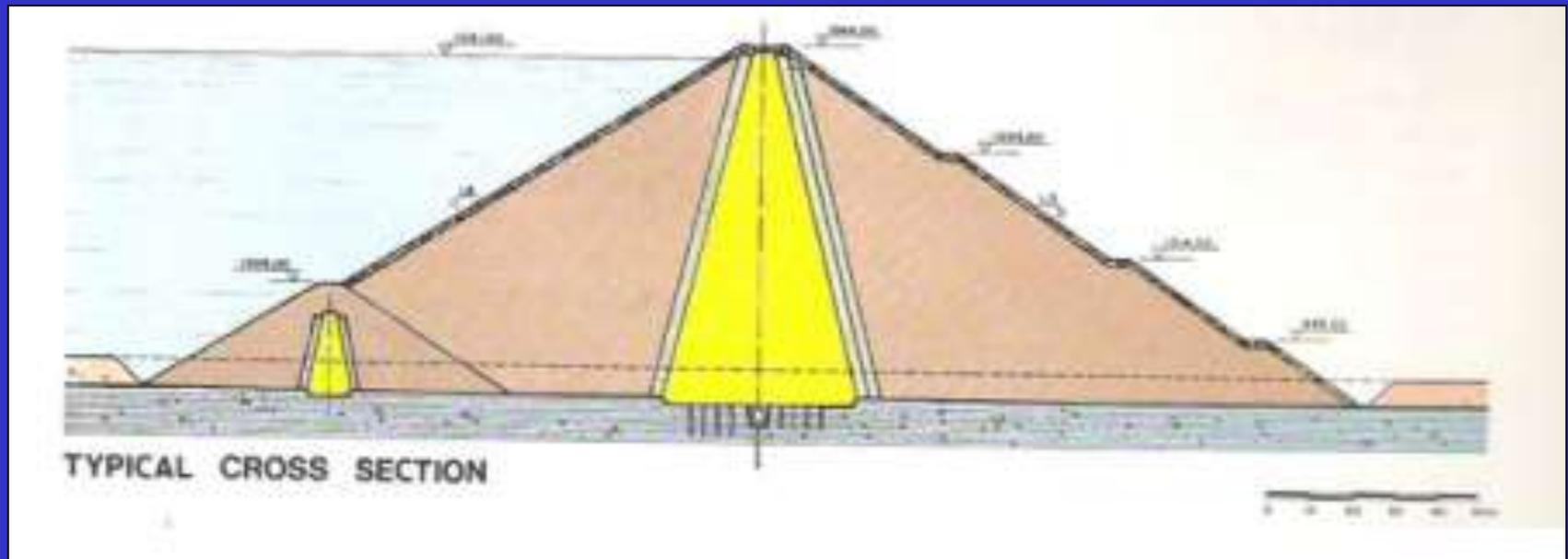


c) PERFIL LONGITUDINAL

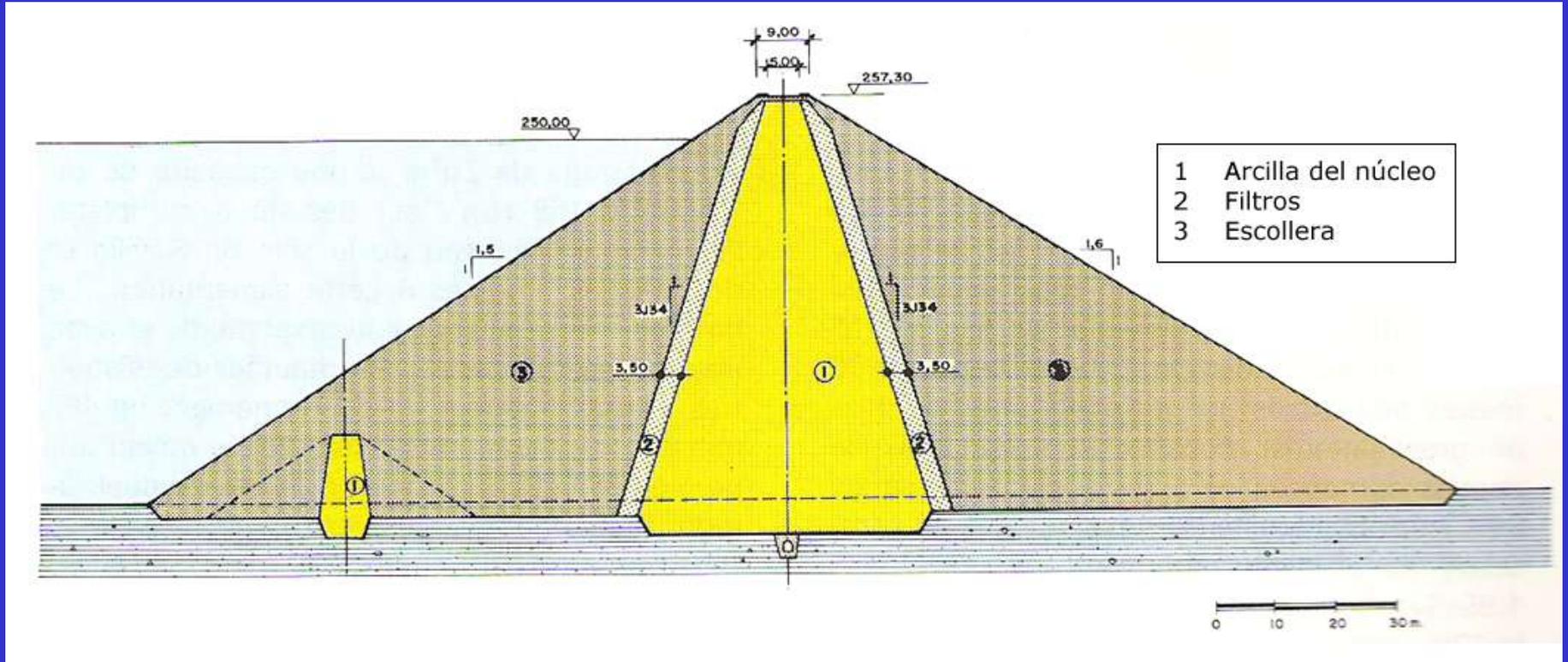


1. Fisuración longitudinal por deformación del cuerpo de presa.
2. Fisura longitudinal, en arco, síntoma de inestabilidad.
3. Fisuras transversales.
4. Descompresiones internas.
5. Contacto con estructuras.

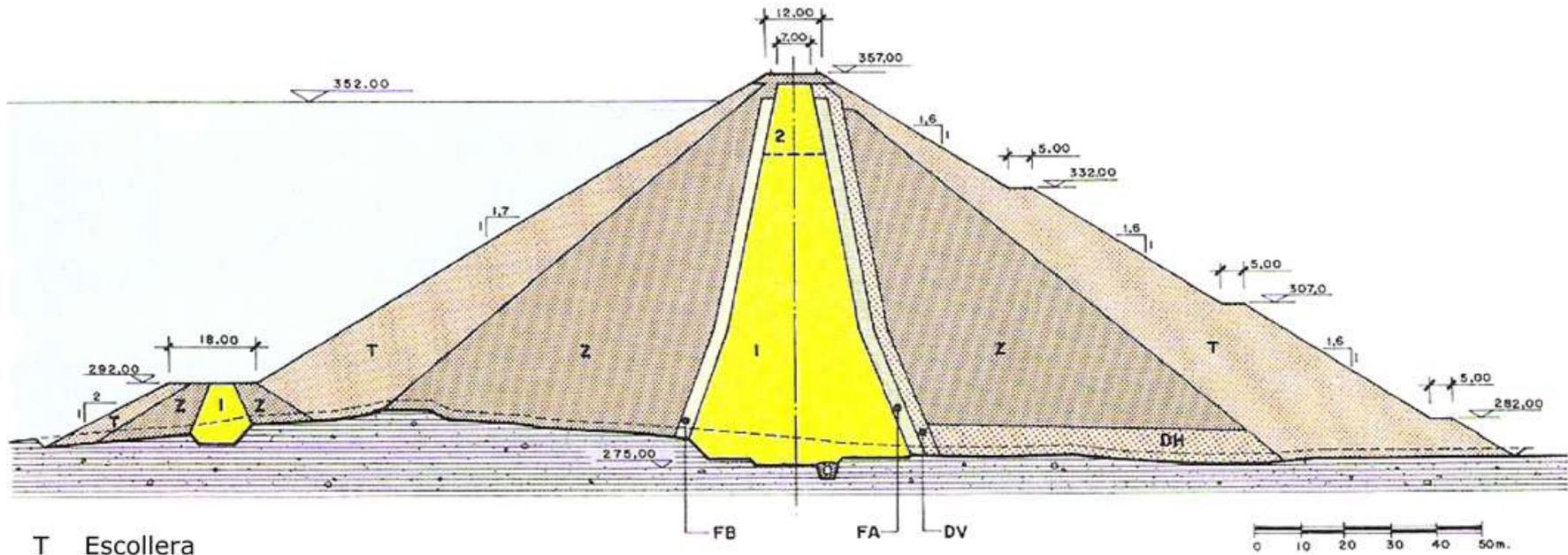
# TYPICAL CROSS-SECTION OF THE SAN CLEMENTE DAM



# TYPICAL CROSS-SECTION OF THE ZUFRE DAM



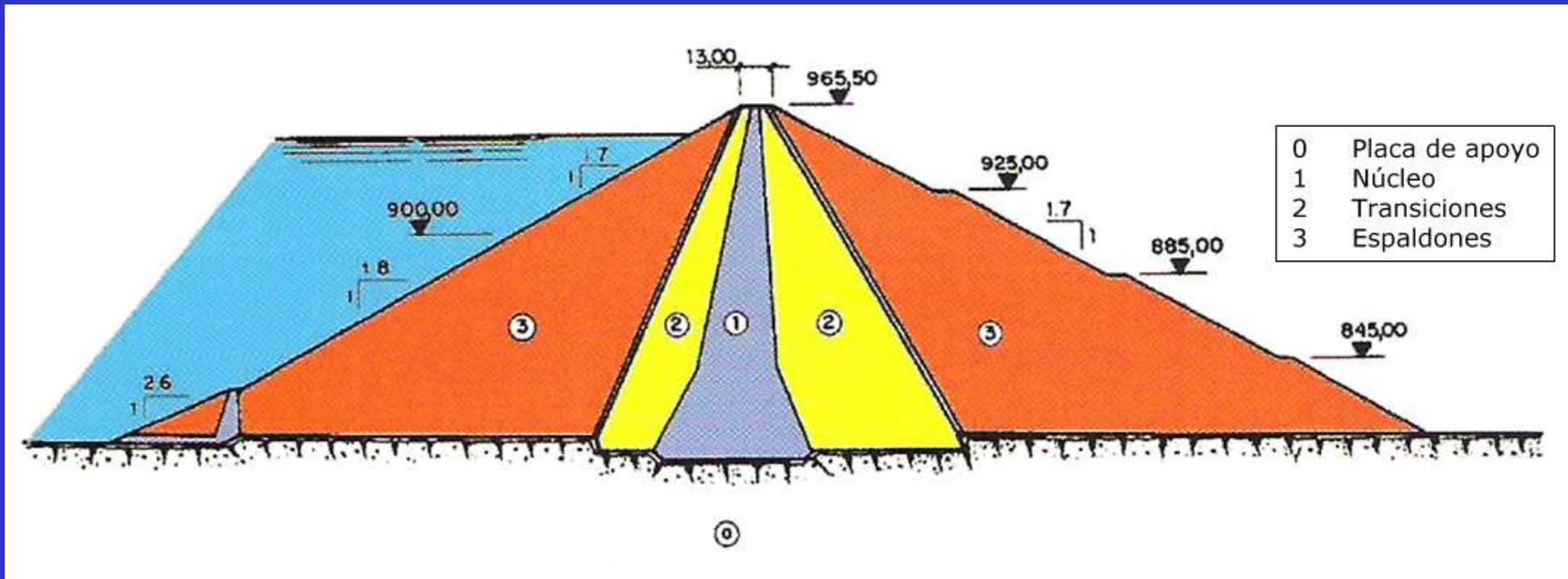
# TYPICAL CROSS-SECTION OF THE ZAHARA EL GASTOR DAM



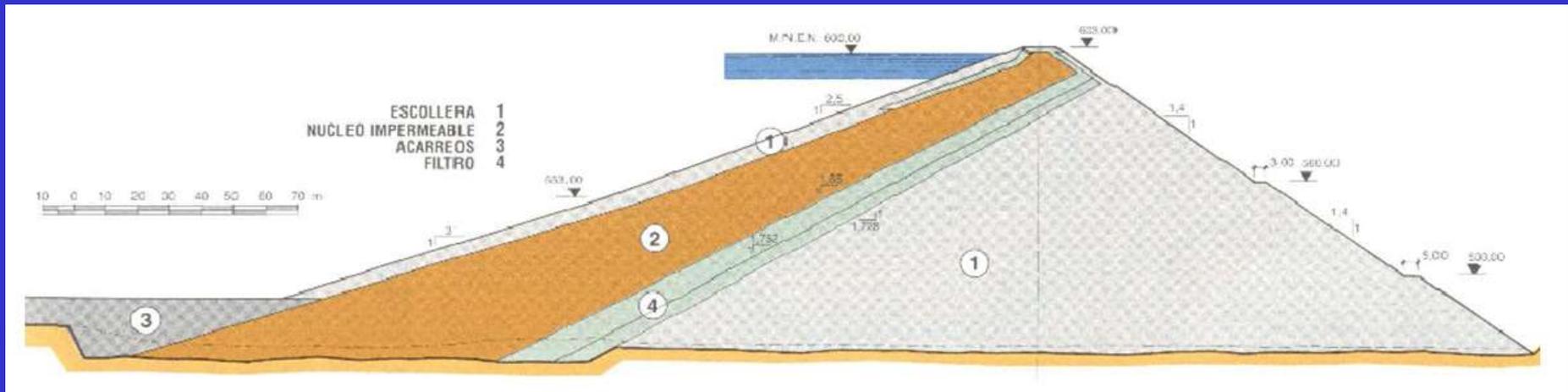
- |   |                      |       |         |
|---|----------------------|-------|---------|
| T | Escollera            | DV-DH | Drenes  |
| Z | Zahorras             | FA-FB | Filtros |
| I | Arcilla del núcleo   |       |         |
| 2 | Arcilla no expansiva |       |         |



# TYPICAL CROSS-SECTION OF THE CANALES DAM

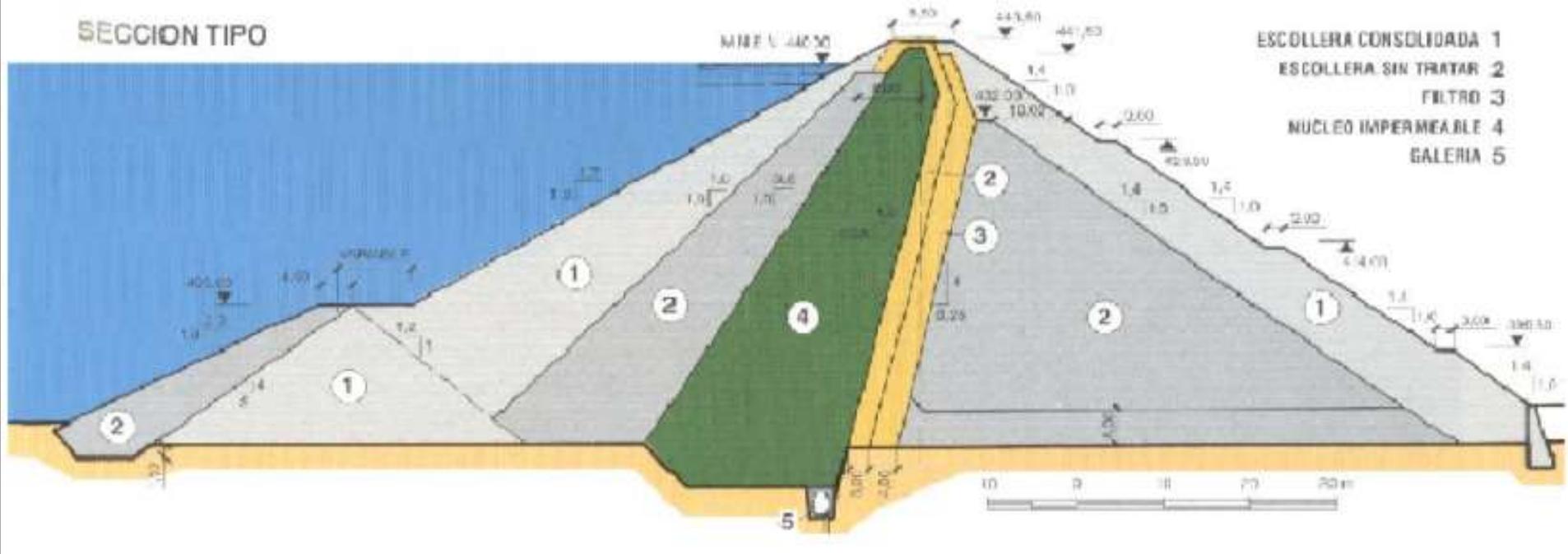


# TYPICAL CROSS-SECTION OF THE ARENÓS DAM



# TYPICAL CROSS-SECTION OF THE CALANDA DAM

SECCION TIPO





# TYPICAL CROSS-SECTION OF THE LA LOTETA DAM

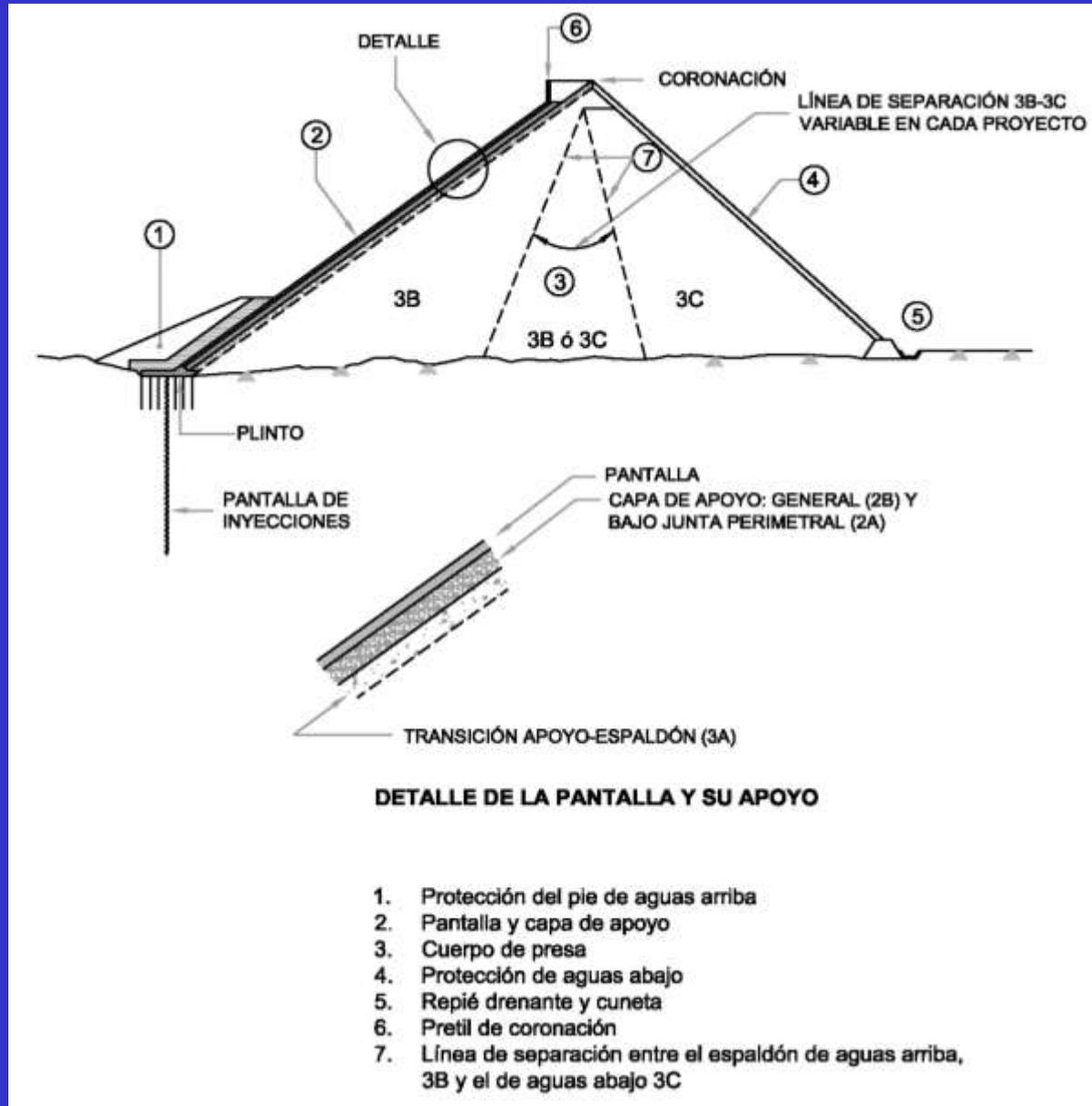
- ① NÚCLEO Y TAPIZ IMPERMEABLE AGUAS ABAJO
- ② FILTRO FINO
- ③ FILTRO GRUESO
- ④ ESPALDONES
- ⑤ TRANSICIÓN
- ⑥ REPIÉ AGUAS ABAJO
- ⑦ PROTECCIÓN PARAMENTO AGUAS ARRIBA
- ⑧ PROTECCIÓN PARAMENTO AGUAS ABAJO



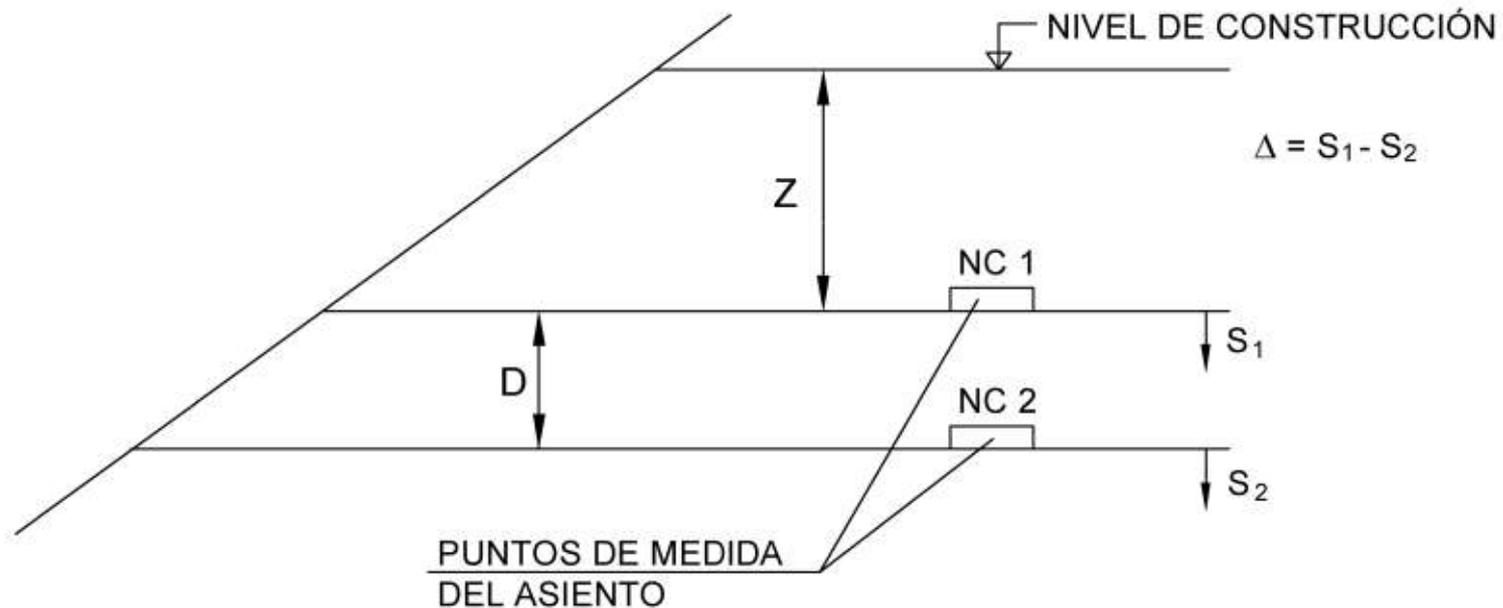
# **6. DAMS WITH IMPERVIOUS FACING**

- 6.1. Criteria for the selection of this type of solution at the design stage**
- 6.2. Definition of the typical cross-section**
- 6.3. Treatment of the dam body foundation**
- 6.4. Materials for the dam body**
- 6.5. Support layer for the facing**
- 6.6. Dimensioning of the plinth**
- 6.7. Reinforced concrete facing**
- 6.8. Asphaltic facing**
- 6.9. Some dams with impervious facing in Spain**

# TYPICAL CROSS-SECTION OF A CONCRETE-FACE ROCKFILL DAM



# VERTICAL DEFORMATION MODULUS. DEFINITION



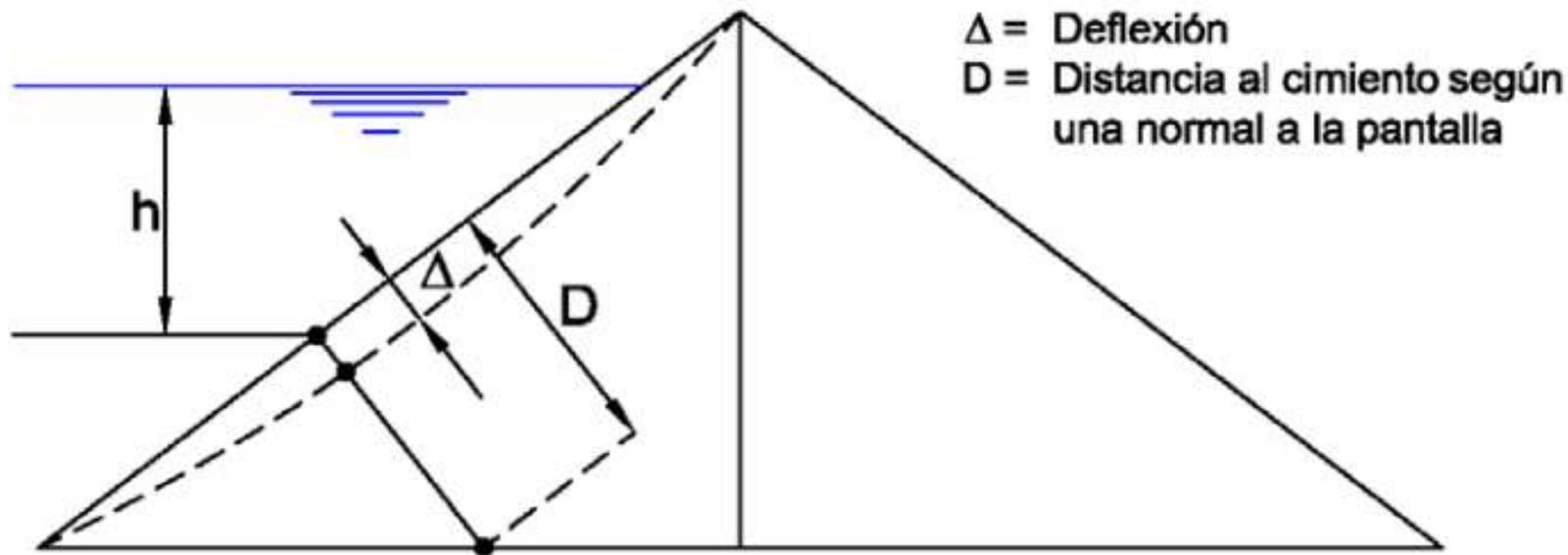
MÓDULO DE DEFORMACIÓN VERTICAL (en construcción);  $E_v = \frac{\gamma \cdot Z \cdot D}{\Delta}$

$\gamma$  = peso específico aparente del espaldón.

$S_1$  y  $S_2$  = asientos de las células 1 y 2 cuando el nivel de construcción es el indicado

NC = nivel de construcción de la zona de interés

# TRANSVERSE MODULUS OF DEFORMATION OF THE DAM BODY. DEFINITION

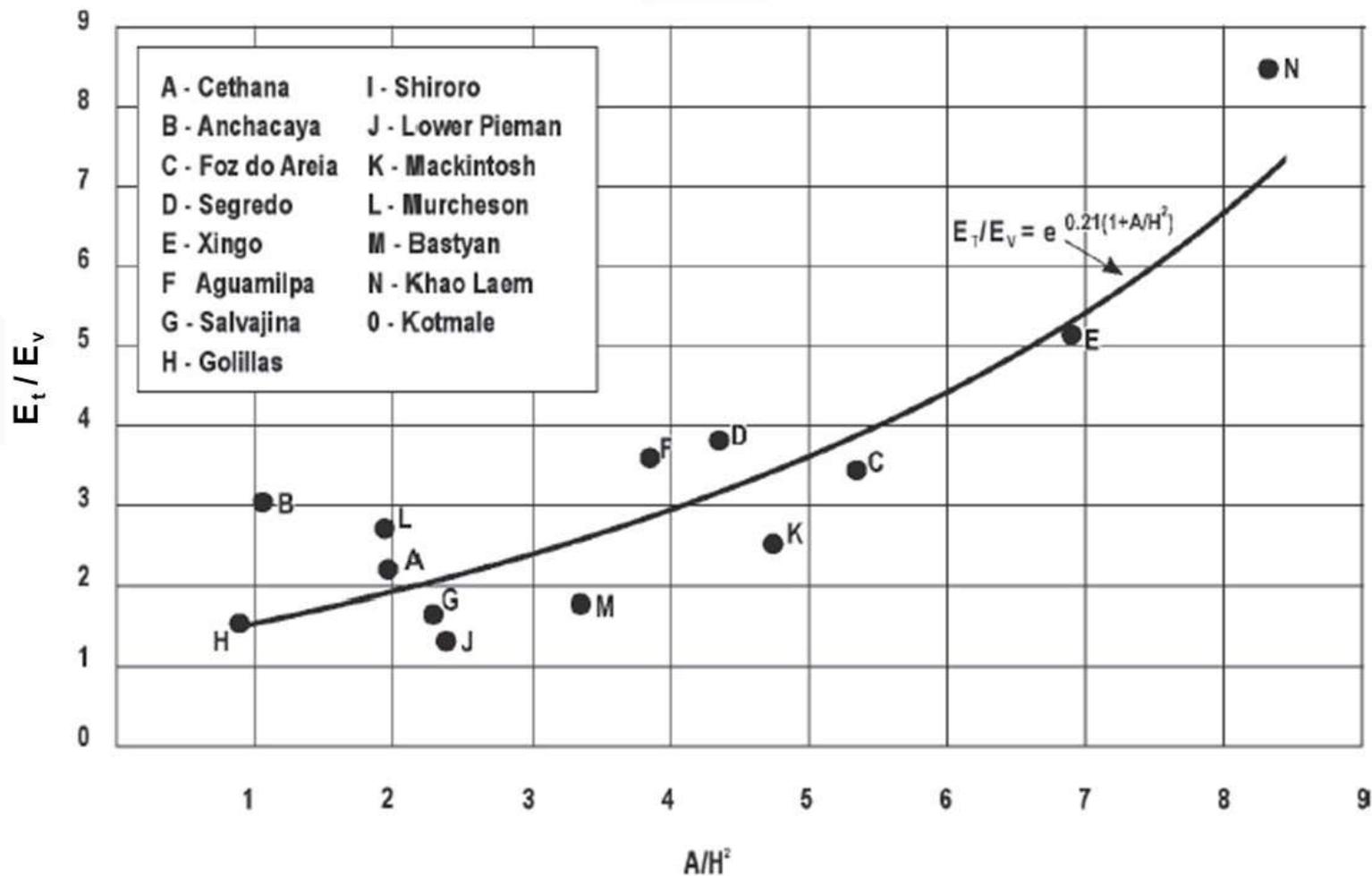


MÓDULO DE DEFORMACIÓN TRANSVERSAL (puesta en carga);  $E_t = \frac{\gamma_w \cdot h \cdot D}{\Delta}$

$h$  = calado

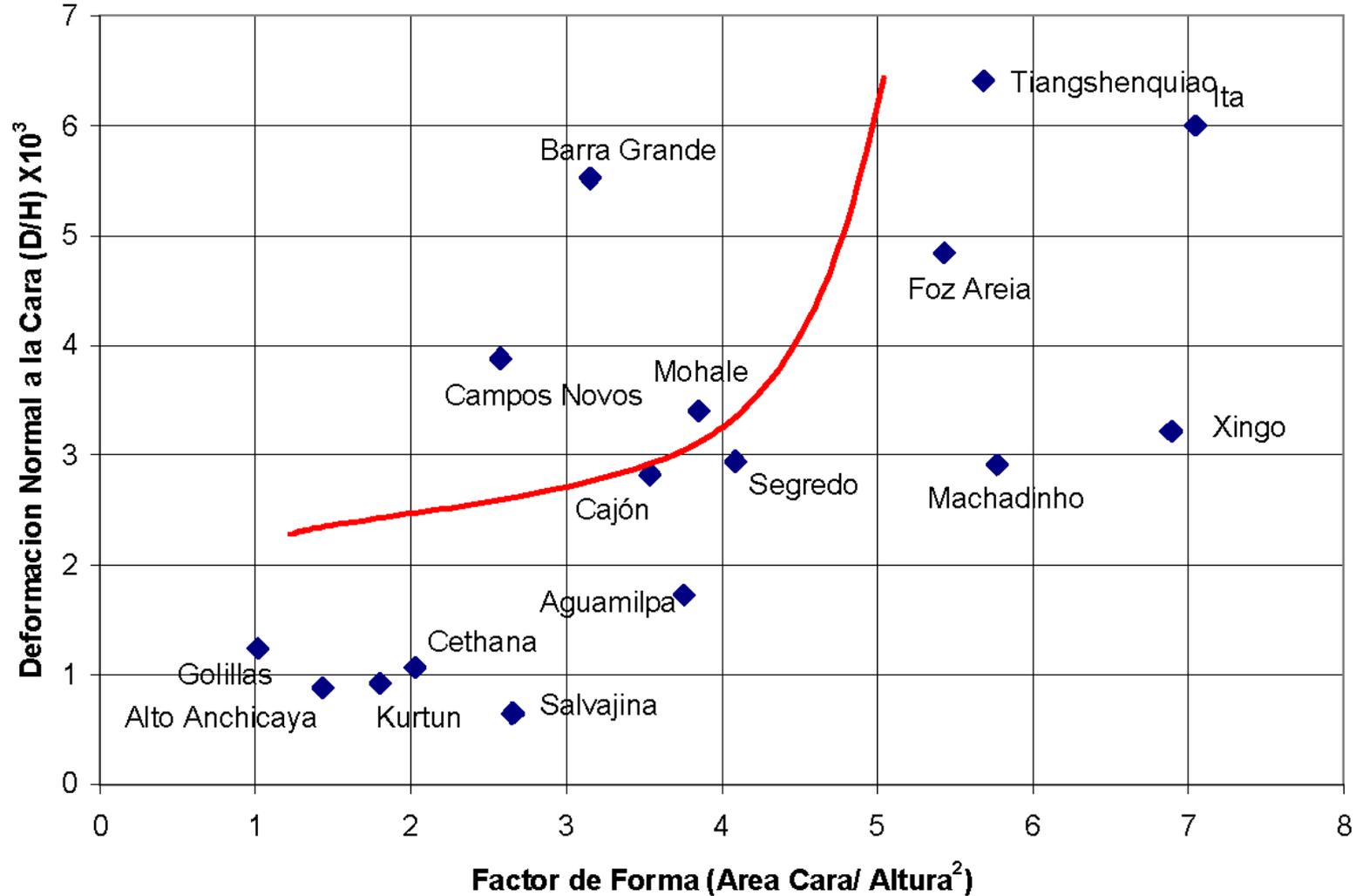
$\gamma_w$  = peso específico del agua

# DEFORMATION MODULUS RATIO IN RELATION TO THE SHAPE FACTOR OF THE FACE SLAB



Tomado de ICOLD (2010)

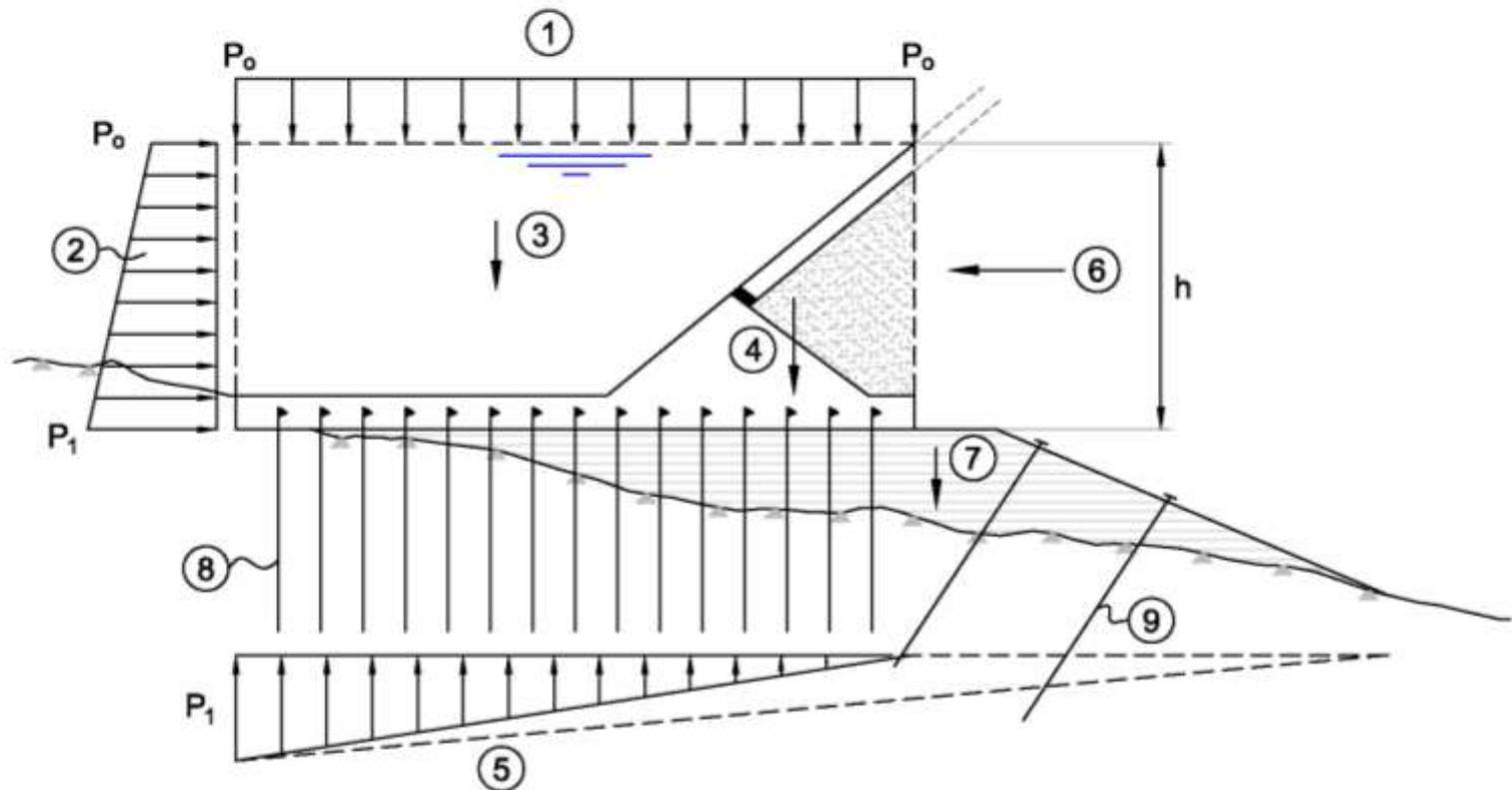
# MAXIMUM DISPLACEMENT OF THE CONCRETE FACE AS A FUNCTION OF THE ITS SHAPE FACTOR



Tomado de ICOLD (2010)

# DIAGRAM OF ACTIONS ON THE PLINTH OF CONCRETE FACED DAMS (A)

## A) PLINTO PLANO

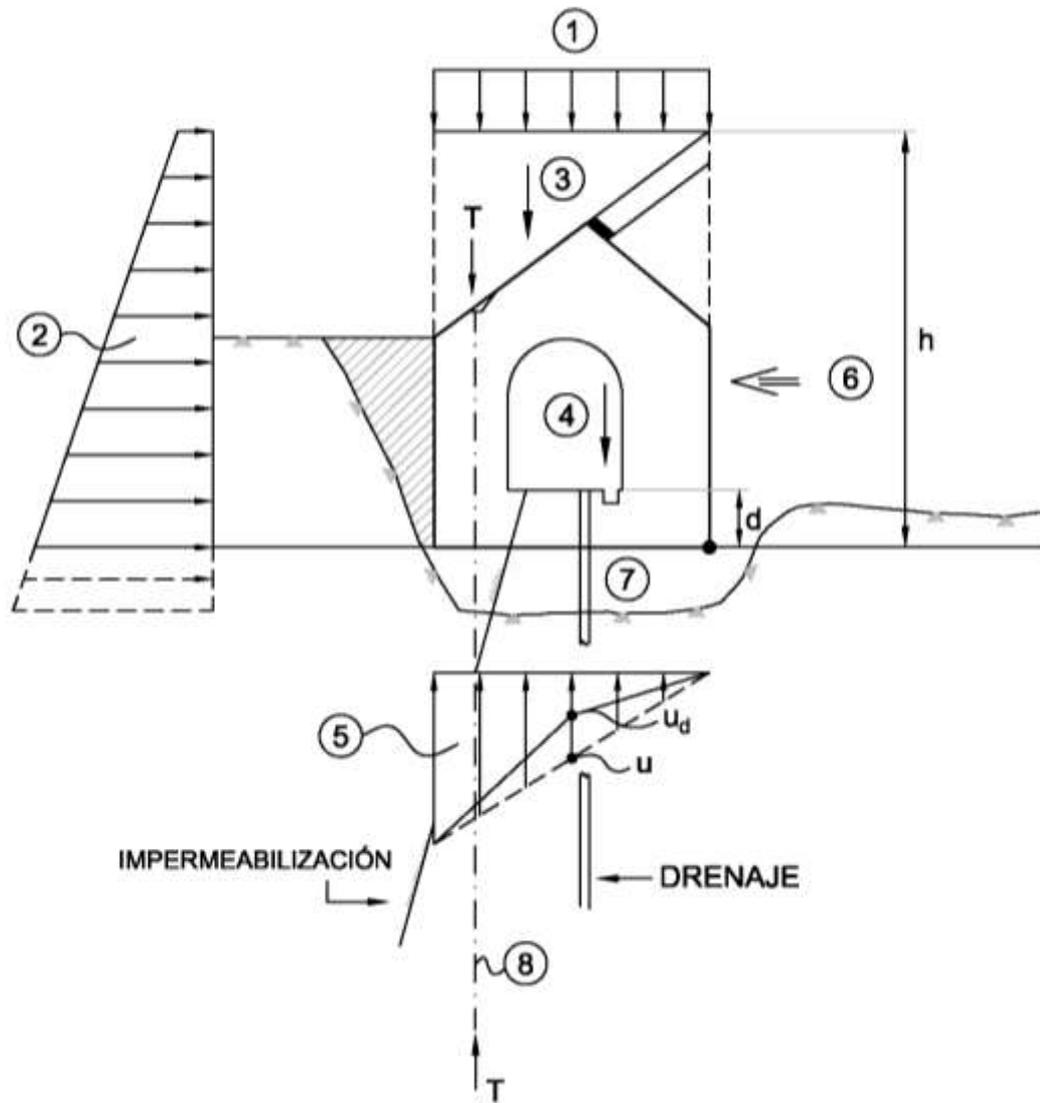


1. Presión vertical del embalse.
2. Presión frontal del embalse.
3. Peso del agua añadida.
4. Peso propio del plinto.
5. Subpresión.

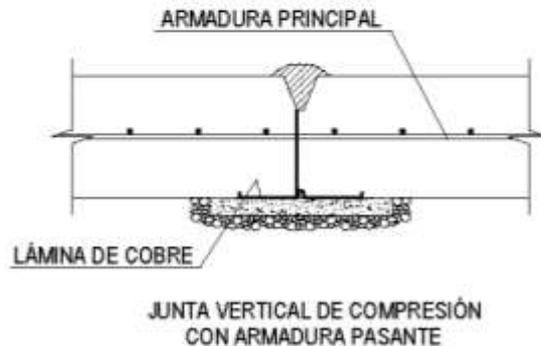
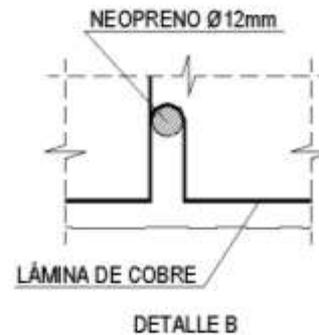
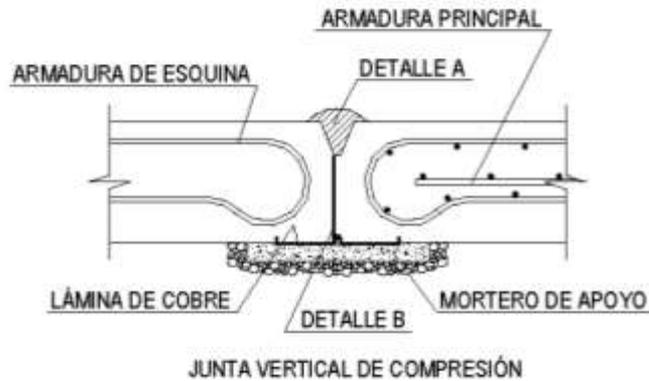
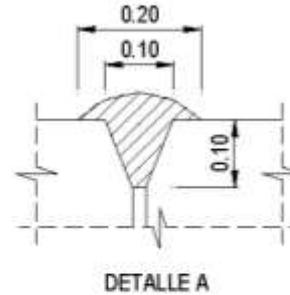
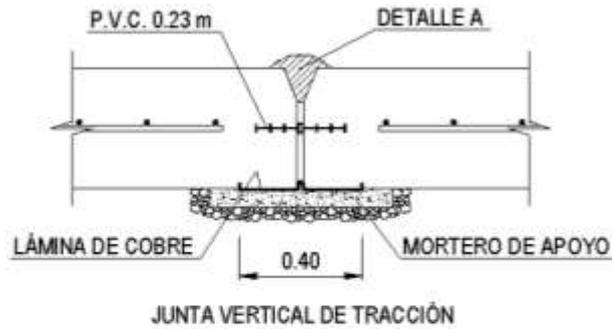
6. Empuje del cuerpo de presa.
7. Peso propio hormigón añadido.
8. Anclajes del plinto.
9. Anclajes del hormigón añadido.

# DIAGRAM OF ACTIONS ON THE PLINTH OF CONCRETE FACED DAMS (B)

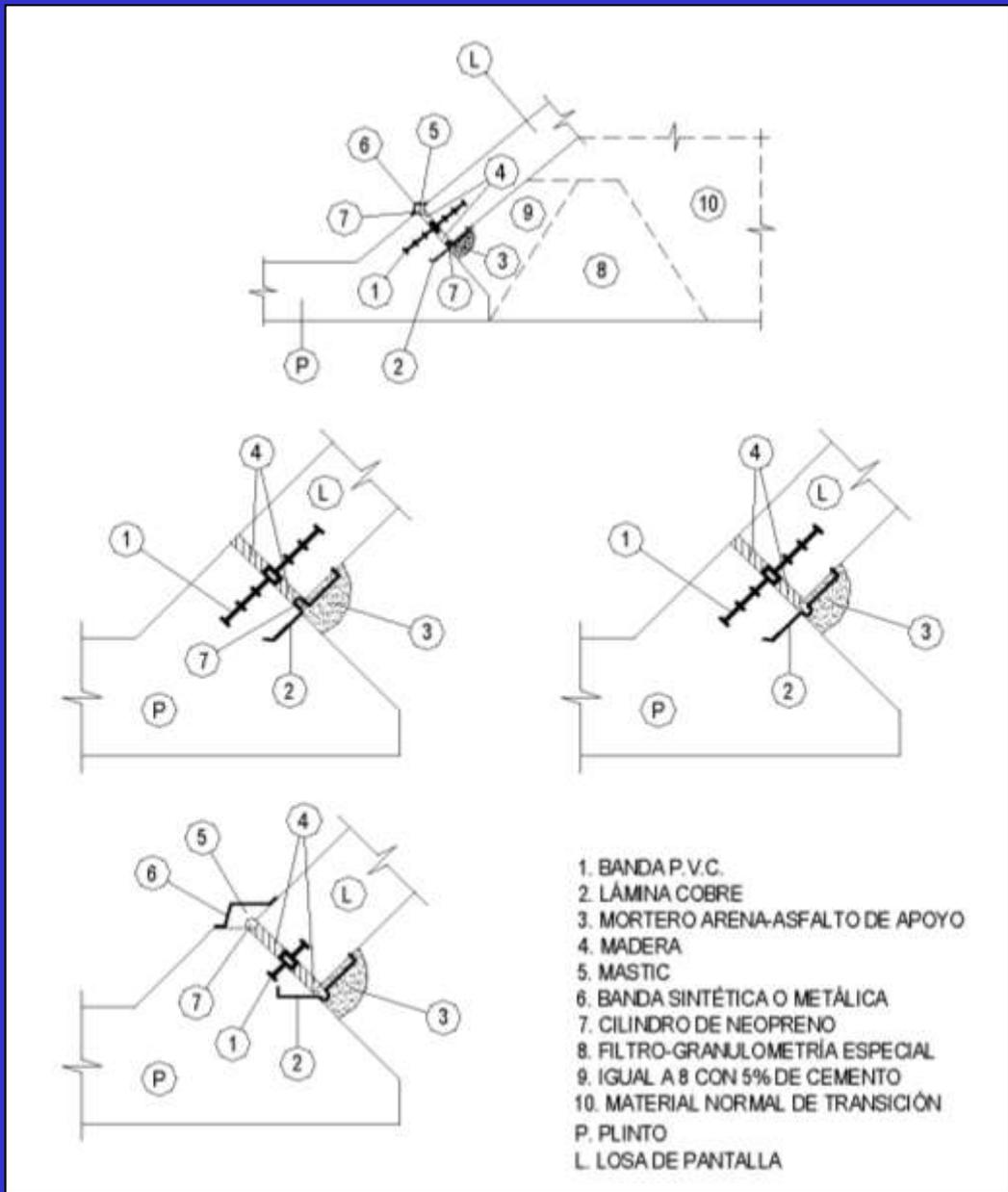
B) PLINTO CON GALERÍA



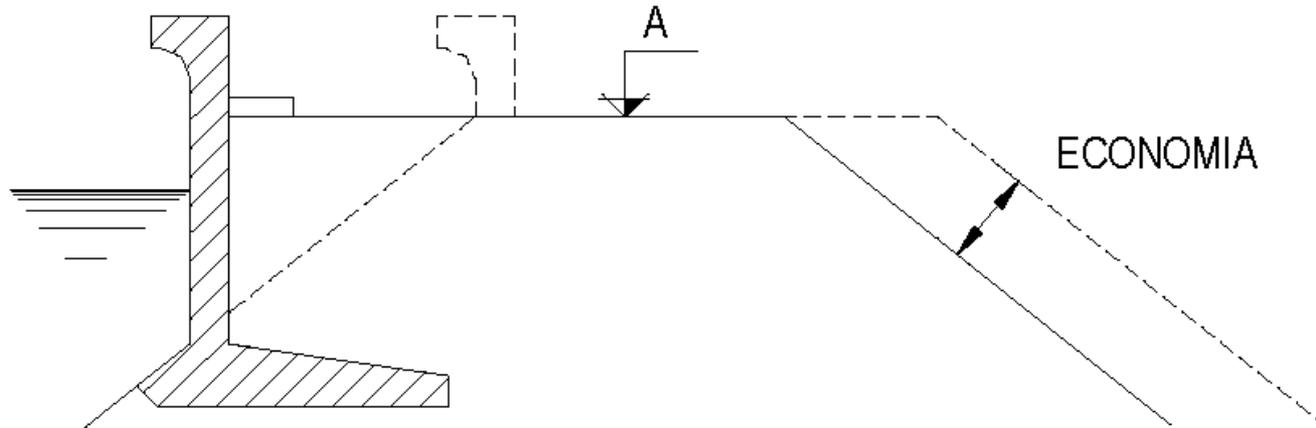
# SCHEMATIC DRAWING OF JOINTS IN THE FACE SLAB ITSELF



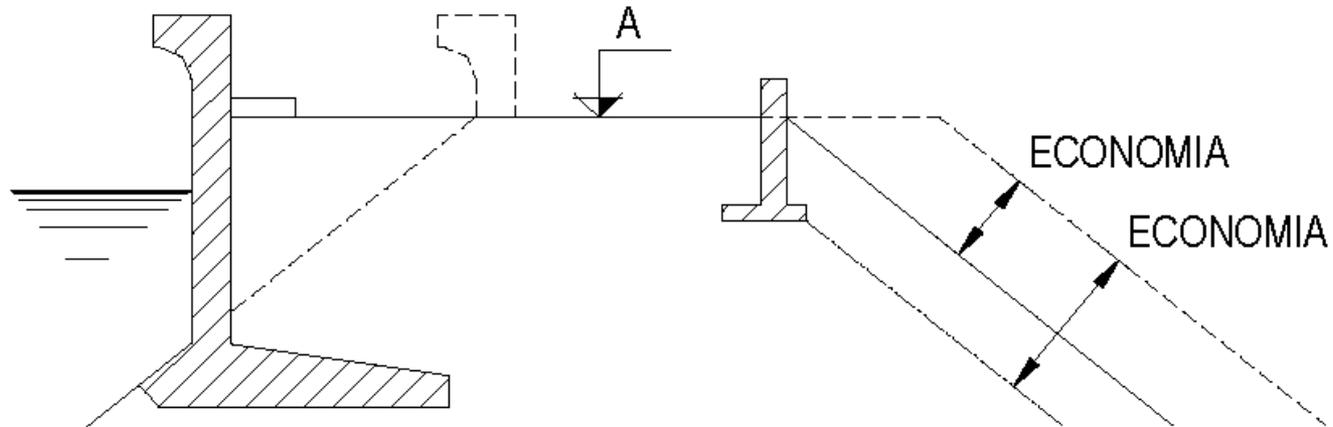
# DIFFERENT TYPES OF PERIMETER JOINTS ALREADY EMPLOYED



# DIFFERENT PARAPET WALLS AT THE CREST

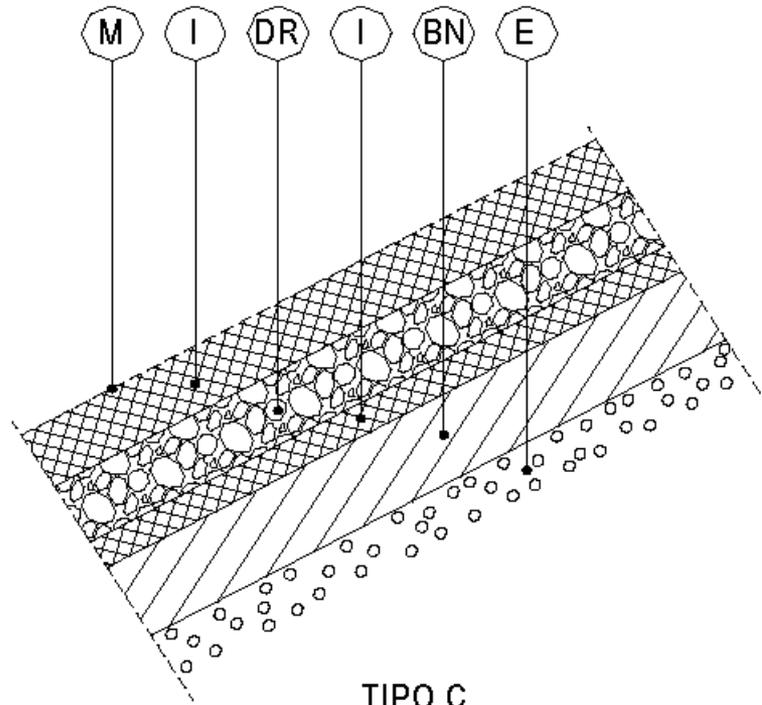


A) PARAPETO UNICO

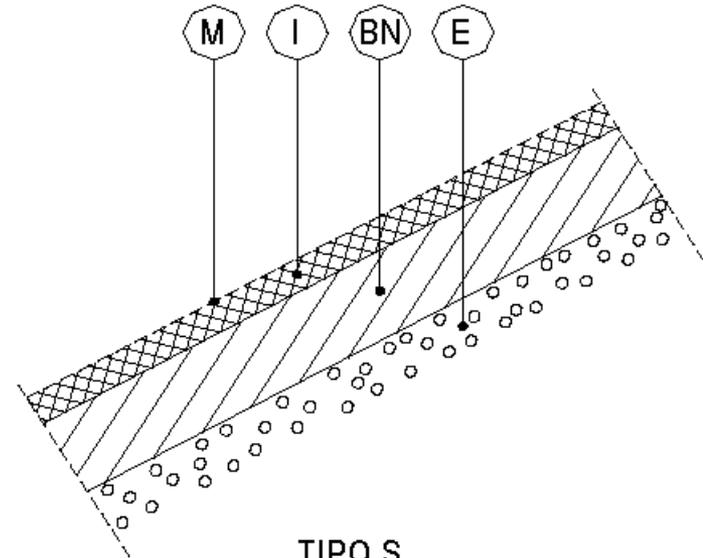


B) PARAPETO DOBLE

# LAYOUT OF THE TWO MOST COMMON TYPES OF BITUMINOUS FACING



TIPO C

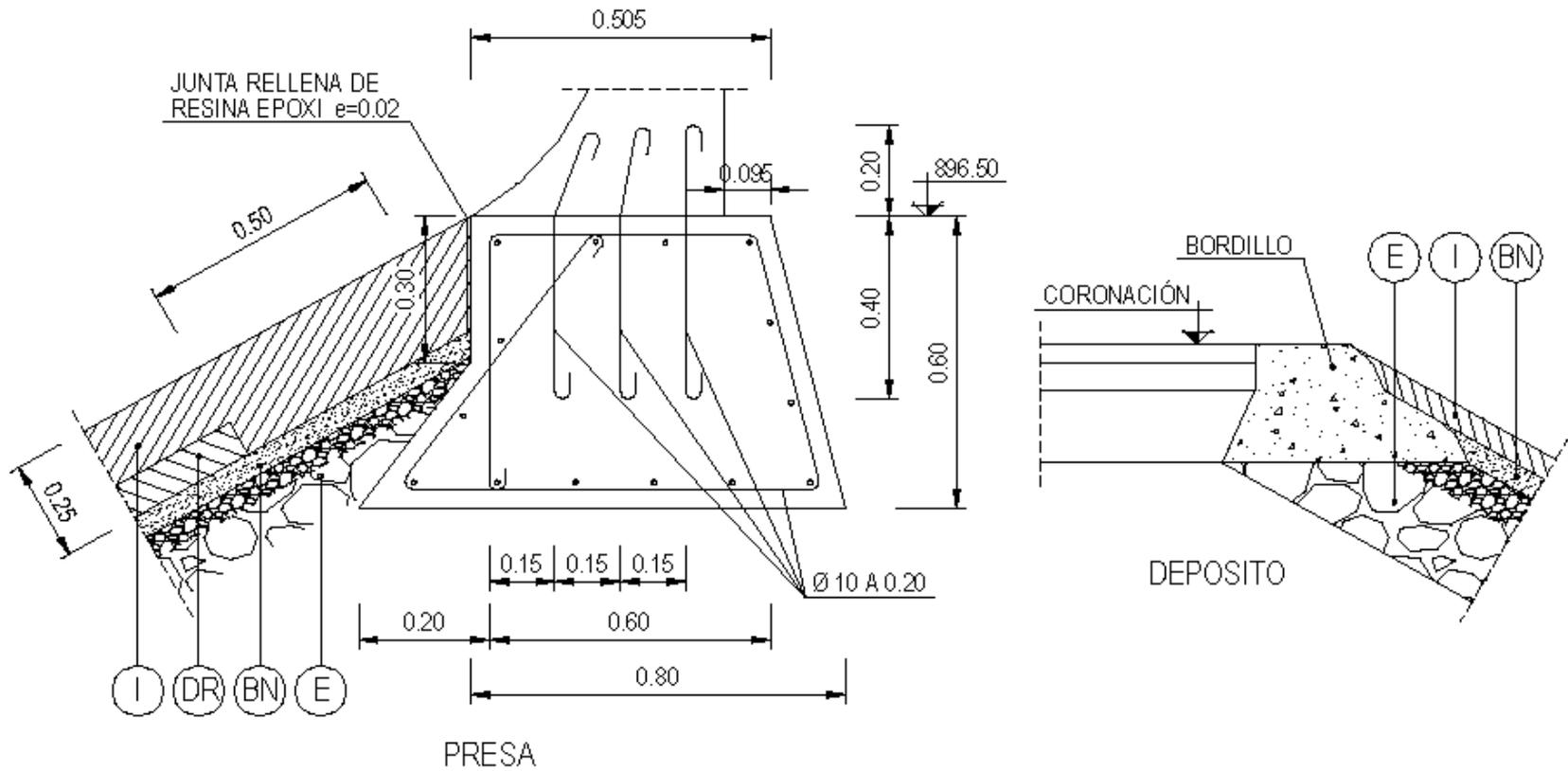


TIPO S

E - CAPA DE REGULARIZACIÓN Y TRANSICIÓN  
BN - CAPA BINDER  
I - CAPA IMPERMEABLE  
DR - CAPA DRENANTE  
M - MASTIC



# CONSTRUCTION DETAILS OF THE CONNECTION OF BITUMINOUS FACINGS TO CONCRETE ELEMENTS (2)



- I - CAPA IMPERMEABLE
- DR - CAPA DRENANTE
- BN - CAPA BINDER
- E - CAPA DE REGULARIZACIÓN Y TRANSICIÓN

## 2.- REMATE DE UNA PANTALLA ASFÁLTICA CON LA ESTRUCTURA DE CORONACIÓN

# **7. EVALUATION OF SAFETY**

- 7.1. Actions**
- 7.2. Water pore pressure**
- 7.3. Material strength**
- 7.4. Design situations**
- 7.5. Calculation methods**
- 7.6. Required factors of safety**

## PERÍODOS DE RETORNO DE LAS AVENIDAS, EN AÑOS

<b>Categoría de la presa</b>	<b>Avenida de proyecto</b>	<b>Avenida extrema</b>
A	1.000	5.000 - 10.000
B	500	1.000 - 5.000
C	100	100 - 500

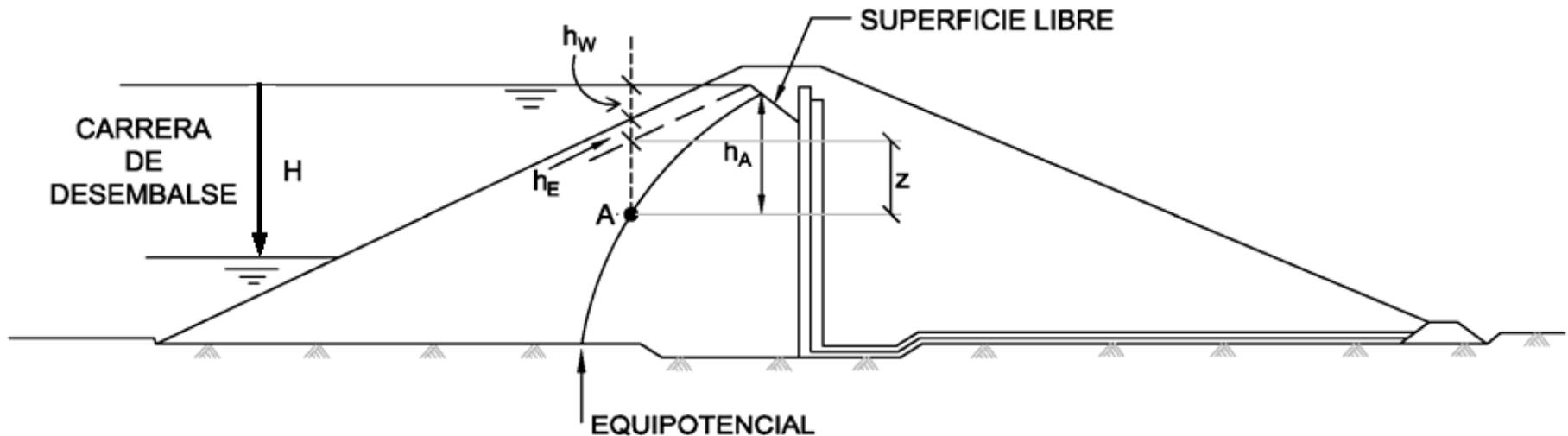
# RESUMEN DE LOS PERÍODOS DE RETORNO DE LOS SISMOS DE CÁLCULO

Clasificación de la presa	Sismicidad		
	Baja	Media	Elevada
C y B	NA	TP = 1.000 años	
A	NA	TP = 1.000 años	TP = 1.000 años
		TE = 3.000 a 5.000 años	TE = 10.000 años

## RESUMEN DE LAS ACELERACIONES DE CÁLCULO (COMPONENTE HORIZONTAL)

Clasificación de la presa	Sismicidad		
	Baja	Media	Elevada
C y B	NA	TP, $a_c = 1.3 a_b$	
A	NA	TP, $a_c = 1,3 a_b$	EE
		TE, $a_c = 2 a_b$	

# DIAGRAM OF PORE WATER PRESSURES DURING A DRAWDOWN



Presión intersticial a embalse lleno

$$u_A = \gamma_w \cdot h_A$$

Presión intersticial después del desembalse

$$u_A = \gamma_w \cdot h_A - \bar{B} (\gamma_w h_w - (\gamma_{sat} - \gamma_{ap}) h_E)$$

(Para conocer el significado de las variables, ver texto)

# STABILITY AGAINST SLIDING OF EMBANKMENT DAMS. MINIMUM RECOMMENDED SAFETY FACTORS AS A FUNCTION OF THE DAM CATEGORY

TYPE OF ACTION OR COMBINATION OF ACTIONS	CATEGORY A	CATEGORY B	CATEGORY C
NORMAL	1.4	1.4	1.3
ACCIDENTAL	1.3	1.2	1.1
EXTREME	>1.0	>1.0	>1.0

**TECHNICAL GUIDES ON DAM SAFETY**  
**CRITERIA FOR THE DESIGN OF DAMS**  
**AND THEIR APPURTENANT WORKS**  
**VOLUME II: EMBANKMENT DAMS**



**COLEGIO DE INGENIEROS DE  
CAMINOS, CANALES Y PUERTOS**



**COMITÉ NACIONAL ESPAÑOL  
DE GRANDES PRESAS**