Second International Symposium on Rockfill Dams

October 27 to 28, 2011

Windsor Barra da Tijuca Hotel - Rio de Janeiro - Brazil

XXVIII SNGB

National Seminar on Large Dams

October 25 to 28, 2011

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RELEVANT ASPECTS OF THE GEOTECHNICAL DESIGN FOR 'LA YESCA' HYDROELECTRIC PROJECT AND OF ITS BEHAVIOR DURING THE CONSTRUCTION STAGE: THE MEXICAN EXPERIENCE IN CONCRETE FACE ROCKFILL DAMS

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La Yesca CFRD

210 m height

Currently under construction (progress Sep 2011, amounts to 95% in the placement of materials in the embankment)

Slope stability. Good. Normally very good quality of materials

Deformations in concrete slab can be very important.

- Construction stage
- First filling
- Accidental loads (earthquakes)

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Compressibility properties (specially material 3B, support to concrete face) should be carefully analyzed:

- Grain size distribution
- Grain shape, size and mineralogy of the particles (hardness)
- Relative density (void ratio or the dry unit weight)
- State of confining stresses
- Degree of saturation
- Load application date

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Compaction process used during construction is fundamental in the values of the module of compressibility:

- type of compaction equipment (usually a vibratory roller compactor)
- static weight of the drum´s compactor
- number of passes
- thickness of the layer
- for rockfill, addition of water during compaction (spraying).

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Dam design

Field works

Alluvial and rockfill test embankments were constructed to a height of 10 m.

Gravel. Layer thicknesses (0.6, 0.8 and 1.0 m)

Rockfill. Layer thicknesses (0.8, 1.0 and 1.2 m)

The layers were compacted with a 12.2 ton vibratory roller by varying the number of passes and determining the void ratio every two passes.

In the rockfill test embankment 200 l/m^3 of water were added before the compaction of each layer.

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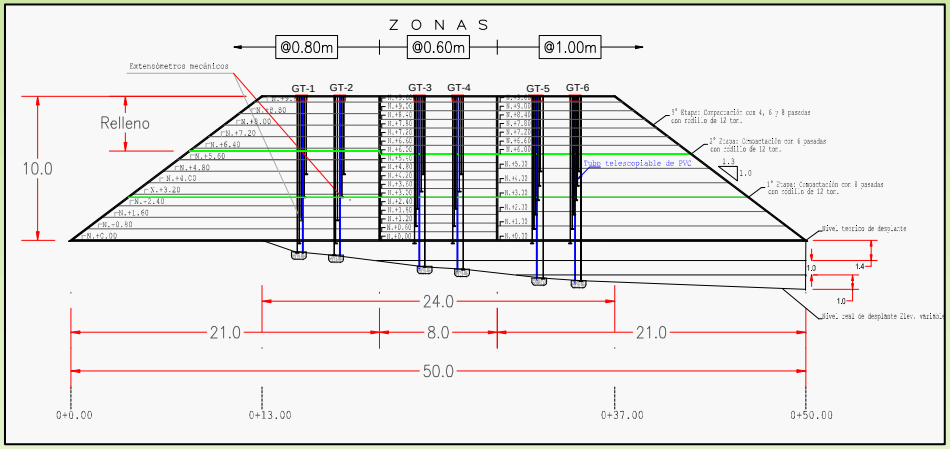
Dam design

Field works

Alluvial and rockfill test embankments



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Dam design

Field works

Alluvial and rockfill test embankments

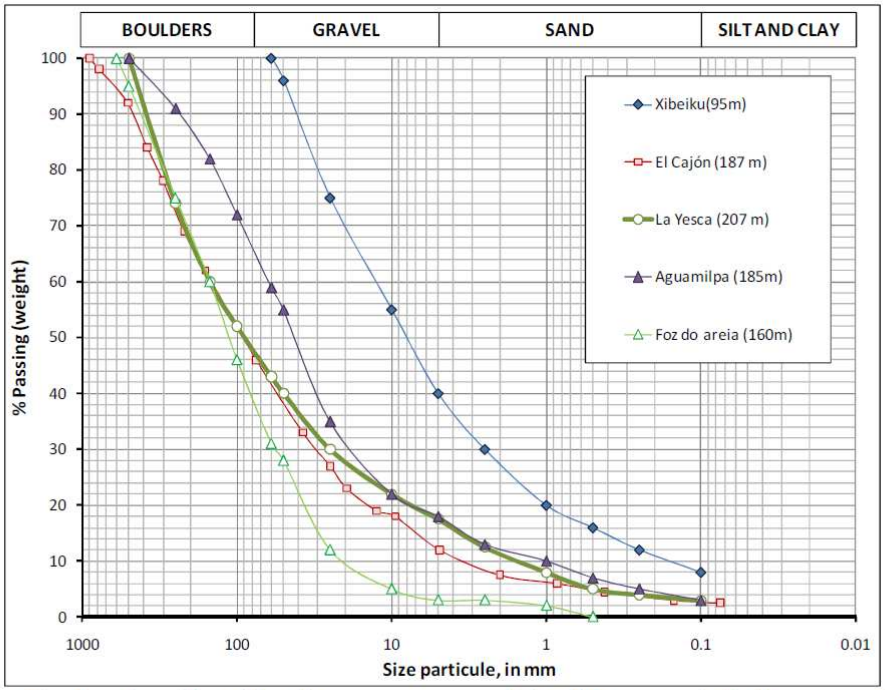

Fig. 11 Grain size distribution curves used in 3B materials in several dams

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Dam design

Field works

Alluvial and rockfill test embankments

Layer thickness M	Gravel void ratio			Layer thickness m	Rockfill void ratio*	
	Number of passes				Fluidal dacite	Porphyritic dacite
	4	6	8			
0.60	0.258	0.247	0.233	0.80	0.336	0.361
0.80	0.250	0.25	0.239	1.0	0.331	0.410
1.0	--	0.257	0.292	1.2	0.368	0.422

* For 8 passes of 12.2 ton roller

Table 1 Void ratio variation in gravel and rockfill test embankments

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Dam design

Field works

Alluvial and rockfill test embankments

.Layer thickness m	Average deformability modulus *E*, in MPa		
	Gravel	Rockfill [1]	Rockfill [2]
0.60	277		
0.80	256	148	174
1.00	246	135	158
1.20		126	150

1: Fluidal dacite rockfill; 2: Porphyritic dacite rockfill

Table 2 Average deformability modulus for materials used in the test embankments

- Plate tests
- Instrumentation results

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Dam design

Laboratory tests

Shear strength and deformability in giant triaxial tests

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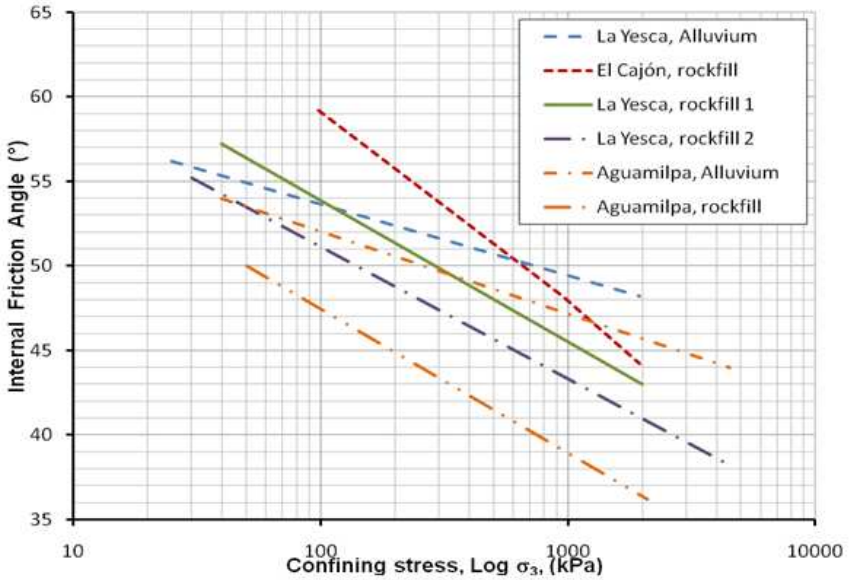
Dam design

Laboratory tests

Shear strength and deformability in giant triaxial tests



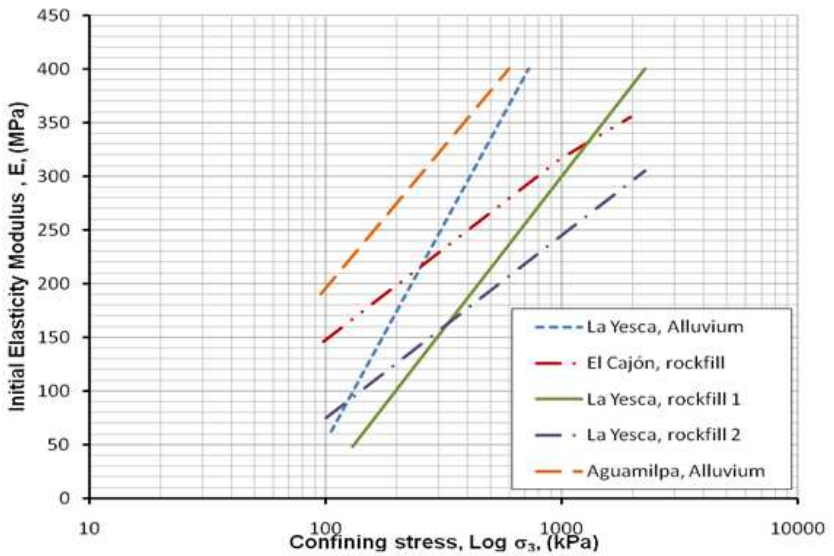


Figure 5. Effect of the confining stress on the friction angle and confining stress effect on initial tangent deformability modulus (E_{ti})

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Triaxial CD, 30 cm in diameter and 70 cm high on samples with a maximum particle size of 38 mm

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Geometry and zoning of the high CFRD La Yesca

Material 2.
•5 to 7.5 cm, well graded
•non plastic fines 7 to 12%
•sand content of 35% or higher

Material 3B.
•well graded
•maximum particle sized of 60 cm for alluvium and 80 cm for rockfill.

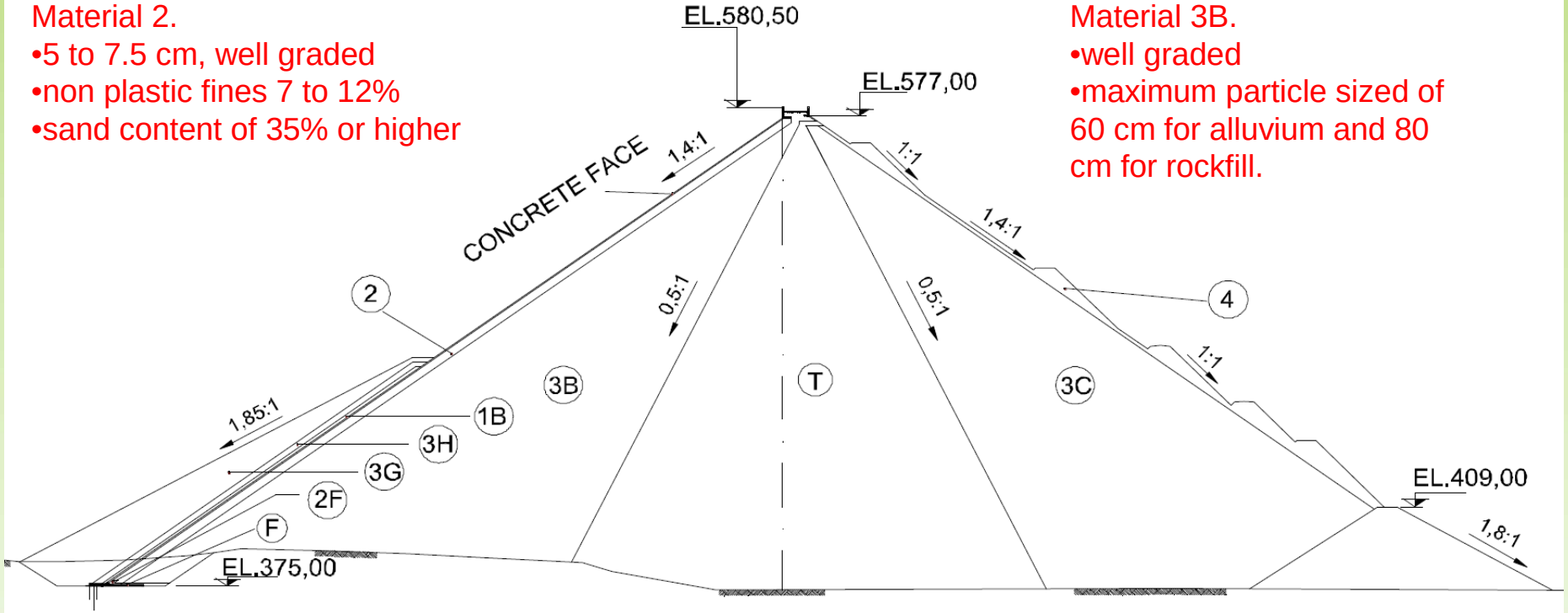

Fig. 3 Maximum cross section of La Yesca Dam

Material T and 3C.
•Generally well graded
•maximum particle size from 80 to 120 cm

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Analysis and design

The zoning design of La Yesca Dam was made to meet the following criteria:

- Achieve low deformability of the 3B zone in the rockfill embankment
- Get a transition zone between the 3B zone material and the 3C zone rockfill at the embankment.
- Keep the deformability modulus ratio among adjacent zones in the embankment smaller than 2 in order to avoid stress concentrations.
- Attain effectiveness and efficiency of construction materials this is, proper behaviour at a reasonable cost.

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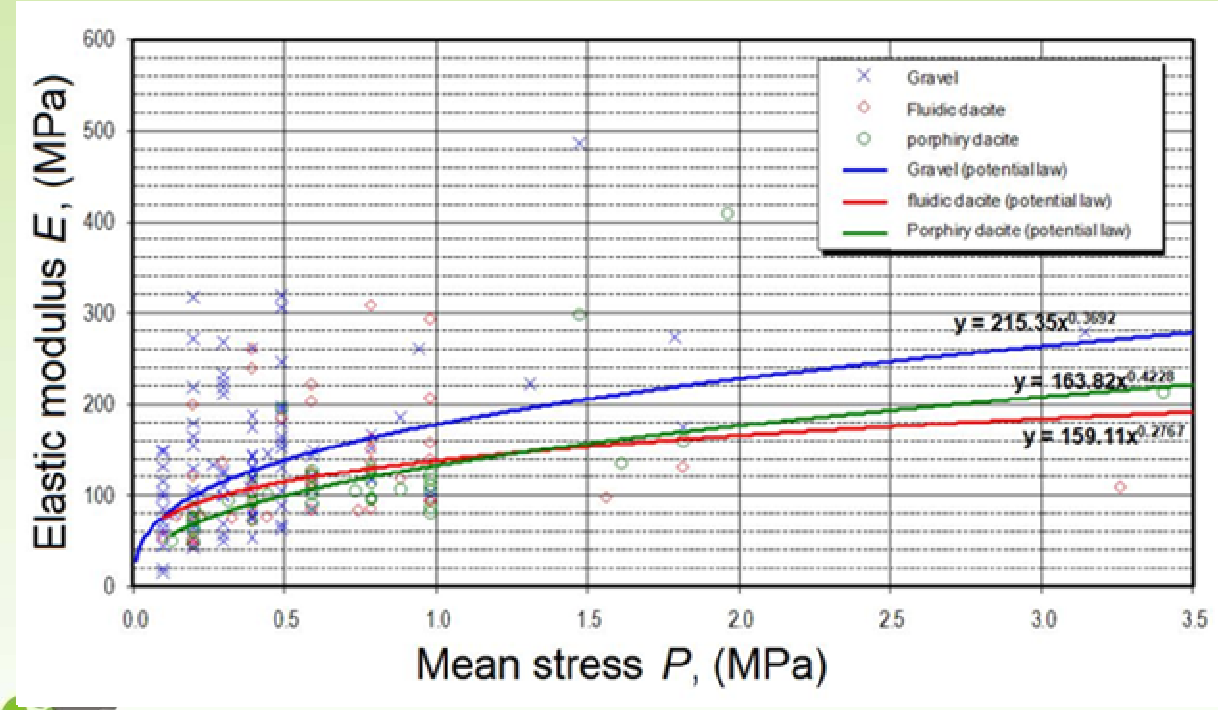
Analysis and design

2D finite-element and 3D finite-differences analyses were carried out to assess the magnitude of the settlements in the dam. The deformability modulus values were calculated with the different field and laboratory tests for the alluvial and rockfill test embankments :

Vertical, horizontal and estimated octahedral stresses were calculated for dam materials 3B, T and 3C, by using FLAC 3D software in one third of its total height.



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Analysis and design

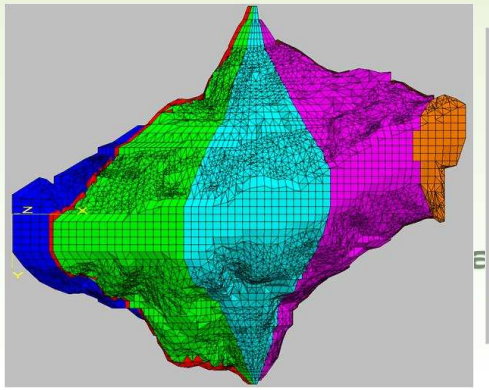
Analysis of stresses and strains in three dimensions (3D)

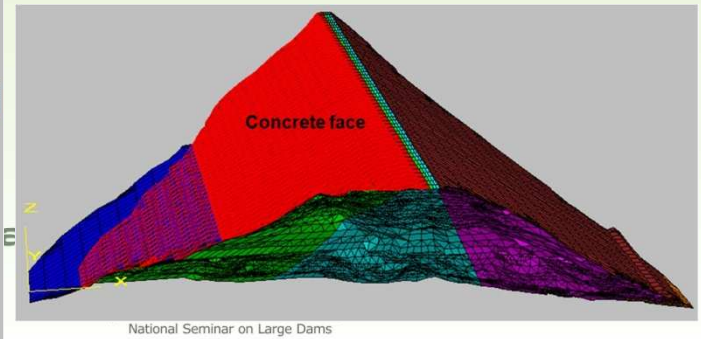
Calculated dam behaviour at the end of construction

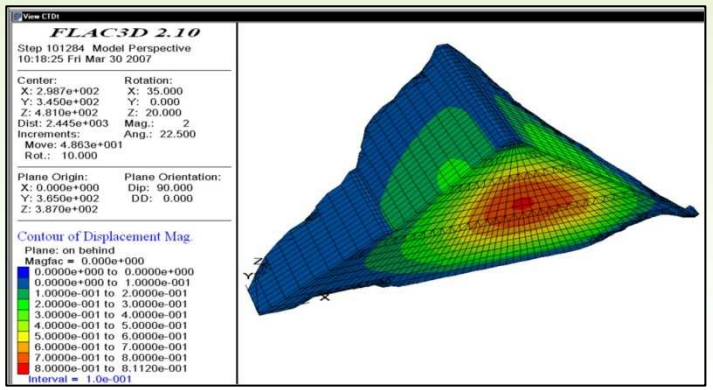
The calculated maximum vertical stress at Zone T at the end of the construction was in the order of 3.5 MPa.

The calculated maximum vertical displacement in a cross-section of the dam was equal to 0.81 m

The calculated maximum horizontal displacement was variable between 0.04 m in the area of material 3B (upstream) and 0.11 m at the 3C material (downstream).







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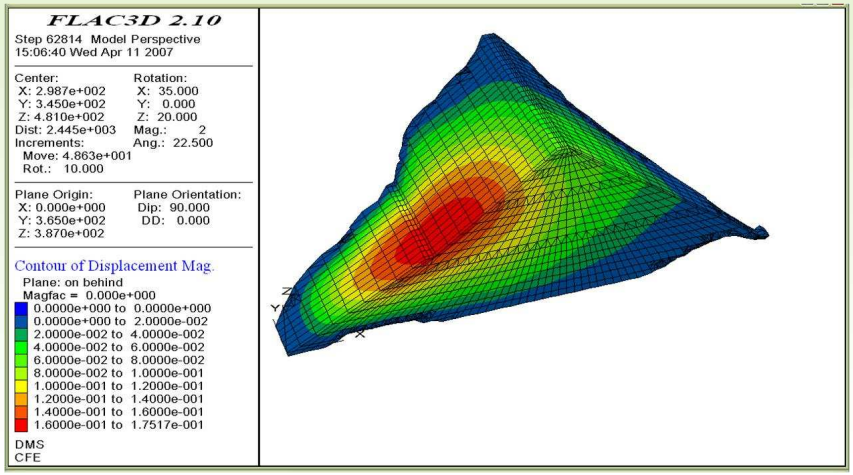
Analysis and design

Analysis of stresses and strains in three dimensions (3D)

Calculated embankment and concrete face behaviour upon reservoir filling

•For first filling a maximum total displacement of the concrete face of 0.17 m was calculated, approximately, at the center of its height and length.

• The maximum horizontal displacement in the concrete face, along the dam axis was 0.03 m.



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BEHAVIOR OF THE DAM

Contours of settlement at the end of the construction for La Yesca, with 95% constructed, was of 0.45 m and it is not expected that it exceeds 0,65 m at the end the construction

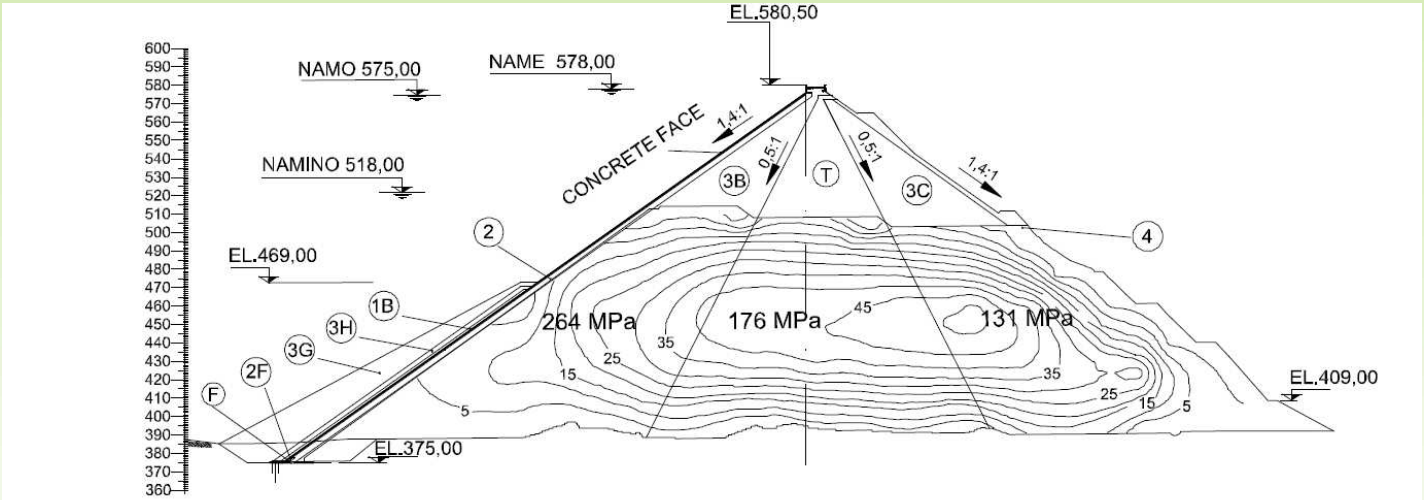

Fig. 12 Contours of settlements and modules of deformability determined with hydraulic levels in La Yesca Dam (April 2011) Courtesy of Structural Safety Department, CFE

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BEHAVIOR OF THE DAM

Behavior during first filling

Currently, La Yesca Dam is under construction and it is expected to begin the first filling in first quarter of 2012. However, based its behavior during the construction, it is considered that the displacement of the concrete face will be less than 20 cm predicted in the analyses carried out, and so it will not present cracking problems.

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CONCLUSIONS

•Geotechnical studies and designs allow to define the site requirements and the use of materials for the dam (test embankments).

•The results of the analyses made it possible to establish the importance of using transitions in the zoning of the dam to prevent sudden changes in the module of deformability of materials that could induce undesirable stress concentrations and lead to tensions and cracking on the concrete face.

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CONCLUSIONS

•It was found that the use of very well compacted gravel-sand in the 3B area will ensure a proper behavior of the concrete face by keeping the maximum displacements in values less than 20 cm, and maximum compression stresses at the central concrete face at lower than permissible values.

• There is no doubt that the characteristics of compressibility of the materials constituting La Yesca dam, their geometry and the compaction procedures adopted in the field have been determinant in the magnitudes of the settlements measured as up to date and those expected in the long term.

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CONCLUSIONS

•To get a rockfill with low deformability, we need to use a sound rocks, well-graded grain size distribution curves, addition of water during compaction, layer thickness less than 0.8 m in 3B zone and less than 1.2 m in 3C zone, and a heavy vibratory roller compactor (12.2 t of mass in the drum).

• Addition of water during compaction also reduces the long term settlement of the embankment.