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Universidad Politécnica de Valencia

Departamento de Ingeniería Hidráulica y Medio Ambiente

II SEMANA INTERNACIONAL SOBRE LA APLICACION DEL ANALISIS DE RIESGOS A LA SEGURIDAD DE PRESAS

2nd INTERNATIONAL WEEK ON RISK ANALYSIS AS APPLIED TO DAM SAFETY AND DAM SECURITY

FRIDAY/VIERNES

PROBABILITY CALCULATION /CALCULOS DE PROBABILIDAD

Valencia, 29 de Febrero de 2008

Valencia, February 29th 2008

Dr. Ignacio Escuder Bueno

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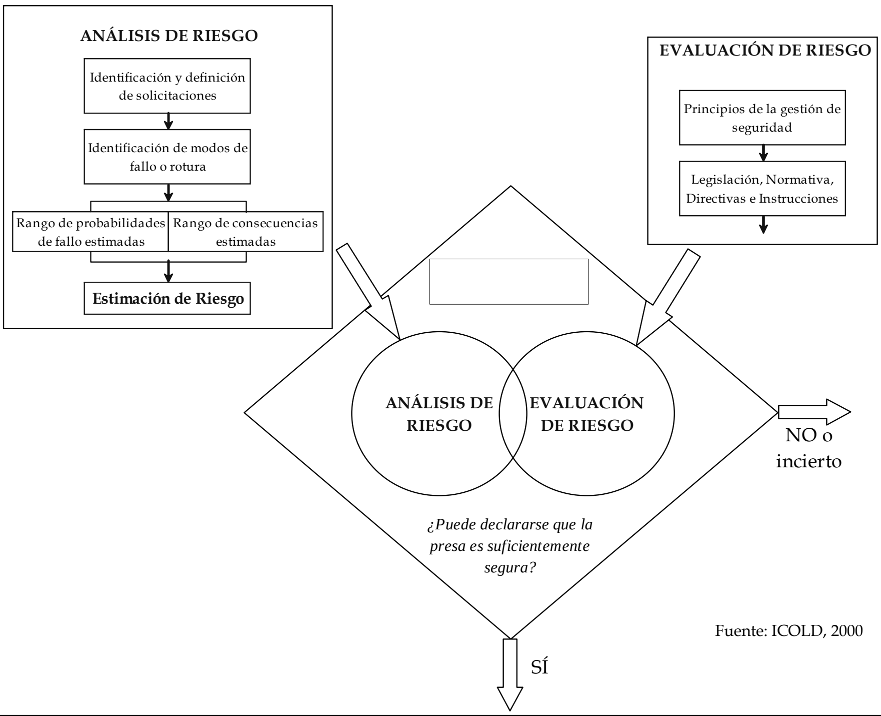

Fuente: ICOLD, 2000

Consideración de los tres escenarios de solicitación con relevancia en la gestión de seguridad

Se añade la influencia del factor humano y los medios en las condiciones de explotación

Escenario de solicitación	A. Factor de carga	B. Factor de respuesta	C. Indice de rotura	D. Factor de pérdida de vidas humanas	E. Indice de riesgo	F. Población en riesgo	G. Indice socio-económico	H. Factor de consecuencias
Explotación ordinaria	1	**75**	75	**404.62**	30,346.81	**10,131**	760	
Hidrológico			**0**	**404.64**	0.00	**10,110**	0	
Sísmico	**0**	**100**	0	**404.64**	0.00	**10,110**	0	
Factor humano y coyuntural			**0**	0.1	0			
Totales			**75.00**		**30,346.81**		**760**	**M**

El **INDICE DE ROTURA** combina las dos primeras componentes de la ecuación del riesgo:

las CARGAS y la RESPUESTA ESTRUCTURAL

Escenario de solicitación	A. Factor de carga	B. Factor de respuesta	C. Indice de rotura	D. Factor de pérdida de vidas humanas	E. Indice de riesgo	F. Población en riesgo	G. Indice socio-económico	H. Factor de consecuencias
Explotación ordinaria	1	**75**	75	**404.62**	30,346.81	**10,131**	760	
Hidrológico			**0**	**404.64**	0.00	**10,110**	0	
Sísmico	**0**	**100**	0	**404.64**	0.00	**10,110**	0	
Factor humano y coyuntural			**0**	0.1	0			
Totales			**75.00**		**30,346.81**		**760**	**M**

El **FACTOR DE PÉRDIDAS** considera la tercera componente del riesgo:

las CONSECUENCIAS SOBRE LA VIDA HUMANA

Escenario de solicitación	A. Factor de carga	B. Factor de respuesta	C. Indice de rotura	D. Factor de pérdida de vidas humanas	E. Indice de riesgo	F. Población en riesgo	G. Indice socio-económico	H. Factor de consecuencias
Explotación ordinaria	1	**75**	75	**404.62**	30,346.81	**10,131**	760	
Hidrológico			**0**	**404.64**	0.00	**10,110**	0	
Sísmico	**0**	**100**	0	**404.64**	0.00	**10,110**	0	
Factor humano y coyuntural			**0**	0.1	0			
Totales			**75.00**		**30,346.81**		**760**	**M**

Combinando las tres componentes se obtiene el **INDICE DE RIESGO**: una representación simplificada del RIESGO

Escenario de solicitación	A. Factor de carga	B. Factor de respuesta	C. Indice de rotura	D. Factor de pérdida de vidas humanas	E. Indice de riesgo	F. Población en riesgo	G. Indice socio-económico	H. Factor de consecuencias
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Sísmico	**0**	**100**	0	**404.64**	0.00	**10,110**	0	
Factor humano y coyuntural			**0**	0.1	0			
Totales			**75.00**		**30,346.81**		**760**	**M**

El Factor de consecuencias trata de considerar de forma global, y a este nivel, las consecuencias sobre la vida humana, la economía y el medio ambiente

Escenario de solicitación	A. Factor de carga	B. Factor de respuesta	C. Indice de rotura	D. Factor de pérdida de vidas humanas	E. Indice de riesgo	F. Población en riesgo	G. Indice socio-económico	H. Factor de consecuencias
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Hidrológico			**0**	**404.64**	0.00	**10,110**	0	
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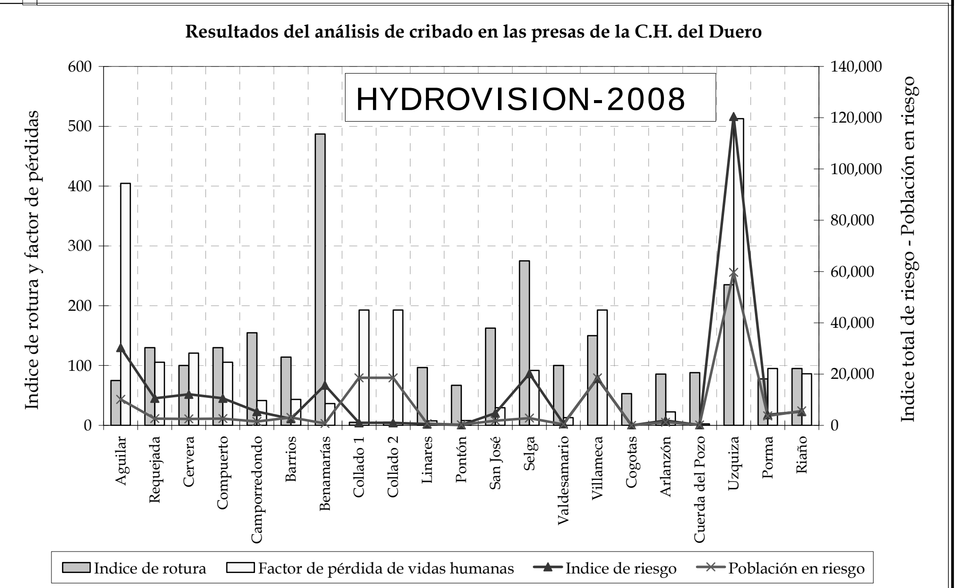
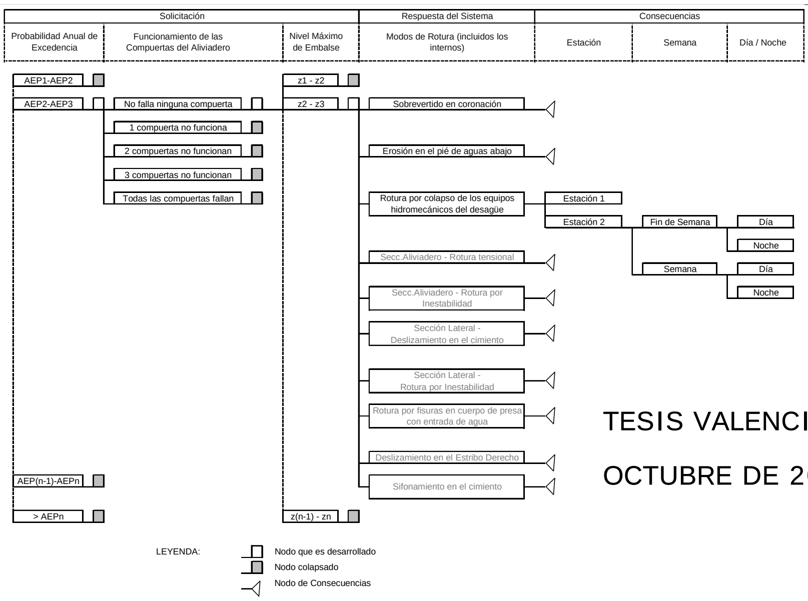
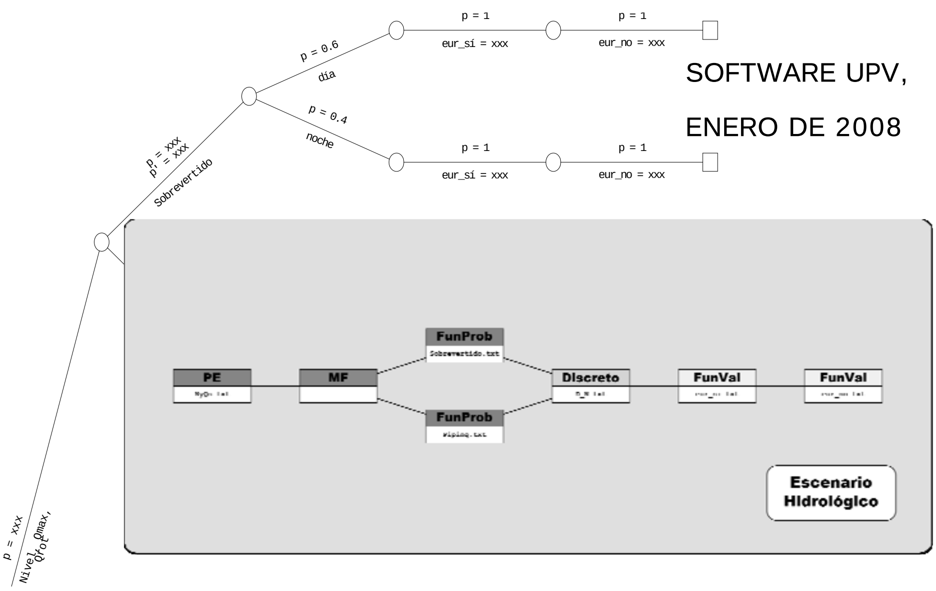
Factor humano y coyuntural			**0**	0.1	0			
Totales			**75.00**		**30,346.81**		**760**	**M**





TESIS VALENCIA,

OCTUBRE DE 2007



SOFTWARE UPV,

ENERO DE 2008

11

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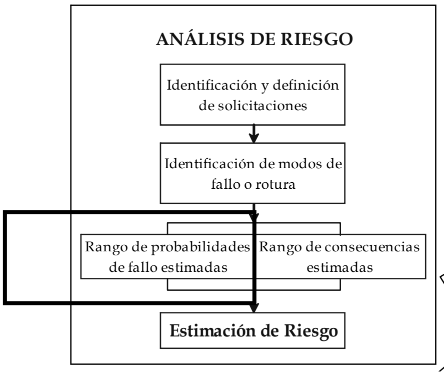
12



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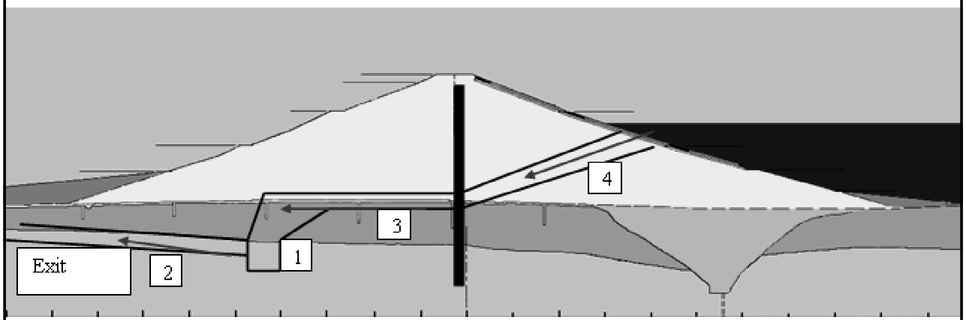
b) Sequence of failure process for each Failure Mode

A description of the sequence of steps identified in Working Session 1 for each failure mode is given below. Some preliminary event tree diagrams are shown on Figures 3 and 4_for FM.3 and FM.4, respectively. Consideration is being given to representing failure modes using fault trees or a combination of event trees and fault trees.

FM.3 (See Figures 1 and 3)

i. **Initiation:** Cavity in the downstream Karst foundation collapses.
ii. **Continuation:** Loss of alluvial or embankment material into the collapsed cavity.
iii. **Continuation:** Material moves into and through the Karst foundation system of voids and channels to an exit point.
iv. **Progression:** Backward erosion through the alluvium to the diaphragm wall. The embankment material is capable of forming a roof for the backward erosion process.
v. **Progression:** The backward erosion either finds a window in the diaphragm wall or causes a break in the wall.
vi. **Progression:** Backward erosion continues through the alluvium/embankment to the reservoir.
vii. **Progression:** Rapid enlargement of the pipe.
viii. **Breach:** Failure of the dam.

15



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16

GENERAL BEHAVIOR	PARTICULAR ISSUES	MODEL QUALITY	PZ-CODE	X-SEC	GEO-LOC	2006-BEHAVIOR
Lower in 1999-2001, higher in 2002-2004, normal after 2005	Data available since 1996	Good	WA-48	¿?	¿?	"As predicted"
	Data available since 1996	Good	WA-47	¿?	¿?	"As predicted"
	Misleading data before 1991	Good	**D-321**	37+00	ROCK-DW-CA	"As predicted" and a little higher
		Good	**WP-50**	38+50L	ALL-DW	"As predicted" and little lower
	Peaks 1995-1996	Good	**WP-56**	38+50L	ALL-DW	"As predicted" and little lower
	Peaks 1995-1996	Good	**WP-30**	36+00L	ROCK-DW-CA	"As predicted" and little lower
	High Peaks 1993. NA after 05/2006	Good	**WP-32**	36+00L	ALL-DW	"As predicted"
	NA after 05/2006	Good	**WP-35**	36+00L	ALL-DW	"As predicted"
	Bad data/Flowing 2002-2004	Good	**WP-22**	37+00L	ROCK-DW-CA	"As predicted"
		Good	WA-38R	52+92L	ROCK-DW	"Peaks Higher than Predicted"
	Peaks 1995	Good-Fair	D-275A	46+06L	ROCK-DW-CA	"As predicted"
		Fair	WA-59R	32+40L	ROCK-DW	"As predicted"
	Peaks 1989, 1993 and 1995	Fair	DC-265R	29+75R	ROCK-DW	"As predicted"
	Peaks 1993-1998	Fair	WA-66	34+97L	ROCK-DW-CE	"As predicted"
	Lows 1992-1993. Peaks 1994	Good-Fair	WA-3	42+97L	ALL-DW	"Peaks Higher than Predicted"
		Good	D-326	35+03L	¿?	"As predicted"
	Peaks 1996-1997	Good	WP-35	35+89L	ALL-DW	"As predicted"
	Peaks 1996-1997	Good-Fair	D-269	36+14L	ALL-DW	"As predicted"
	Peaks-1997-1999	Good	WA-35	30+65L	ROCK-DW-CE	"As predicted"
		Good	D-320	35+61L	ROCK-DW	"As predicted"
	Peaks 1996-1998	Good	WA-60R	32+96L	ROCK-DW	"As predicted"
	Peaks 1996-1997	Good-Fair	WA-20	34+30L	ROCK-DW-CE	"As predicted"
		Good-Fair	D-325	33+99L	ROCK-DW-CE	"As predicted"
		Good	D-320	35+61L	ROCK-DW	"As predicted"
		Good	WP-82	40+54L	ROCK-DW-CA	"As predicted"
		Good-Fair	WO-3	43+23L	ROCK-DW-CA	"As predicted"
		Good	WO-31	42+51L	ROCK-DW-CA	"As predicted"
	Readings available from 1996	Good	WO-37	31+60L	¿?	"As predicted"
	Readings available from 1989	Fair	WP-58	33+75L	¿?	"As predicted"
	Readings available from 1996	Good	WO-38	32+06L	¿?	"As predicted"
	Readings available from 1996	Good	WO-18	31+09L	ALL-DW	"As predicted"
	Readings available from 1996	Good	WO-12	33+12L	¿?	"As predicted" and a little lower
	Readings available from 1996	Good	WA-21	31+35L	¿?	"As predicted" and a little lower
	Readings available from 1996	Good	WP-18	32+65L	¿?	"As predicted"
	Readings available from 1996	Bad	WA-22B	30+67L	¿?	"As predicted"
	Bad Readings 2006	Fair	WO-21	33+23L	ROCK-DW	Bad Readings 2006
	Peaks 1984	Fair	WO-20	32+30L	ROCK-DW	"As predicted"

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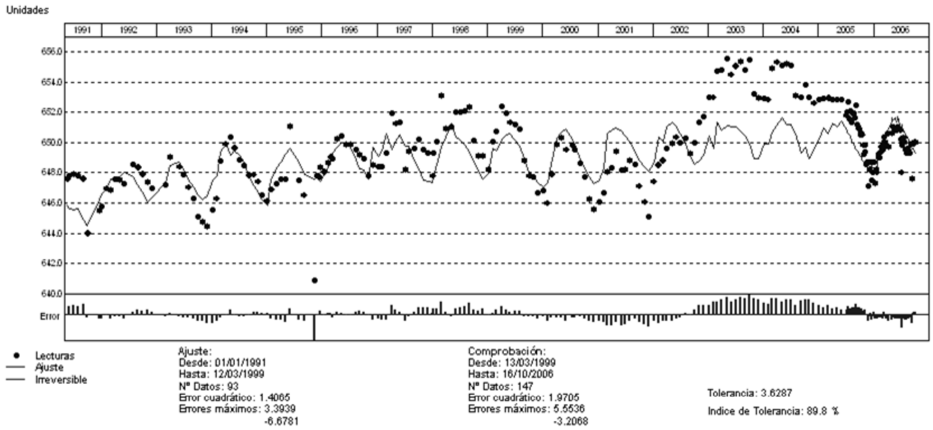
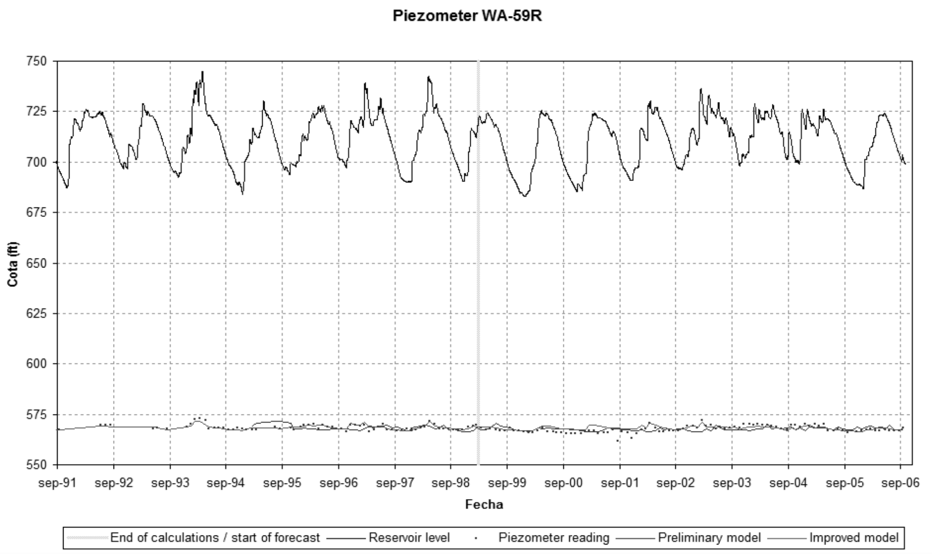
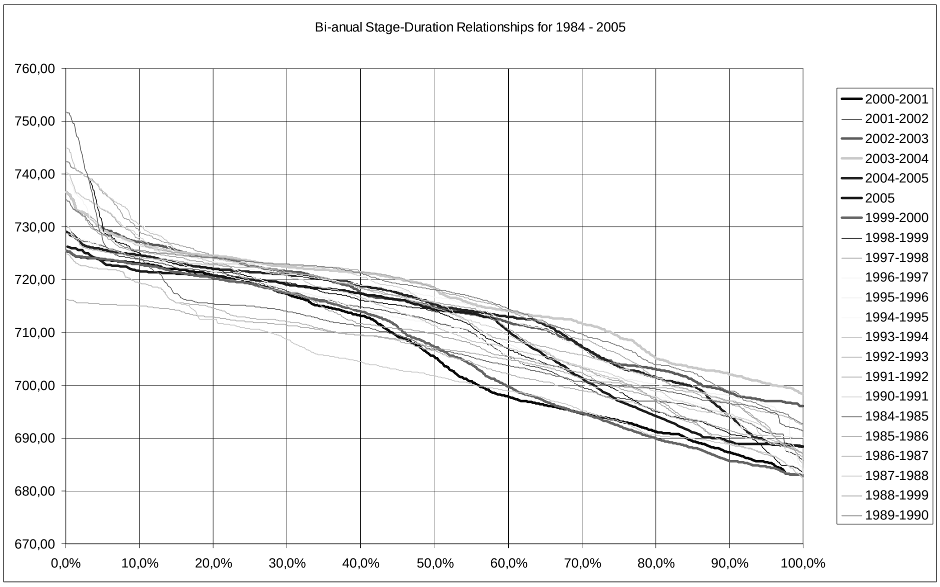
1


Unidades
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
656.0
654.0
652.0
650.0
648.0
646.0
644.0
642.0
640.0
Error
Lecturas
Ajuste
Irreversible
Ajuste:
Desde: 01/01/1991
Hasta: 12/03/1999
Nº Datos: 93
Error cuadrático: 1.4065
Errores máximos: 3.3939
-6.6781
Comprobación:
Desde: 13/03/1999
Hasta: 16/10/2006
Nº Datos: 147
Error cuadrático: 1.9705
Errores máximos: 5.5536
-3.2068
Tolerancia: 3.6287
Indice de Tolerancia: 89.8 %


Piezometer WA-59R
750
725
700
675
650
625
600
575
550
Cota (ft)
sep-91
sep-92
sep-93
sep-94
sep-95
sep-96
sep-97
sep-98
sep-99
sep-00
sep-01
sep-02
sep-03
sep-04
sep-05
sep-06
Fecha
End of calculations / start of forecast
Reservoir level
Piezometer reading
Preliminary model
Improved model

19



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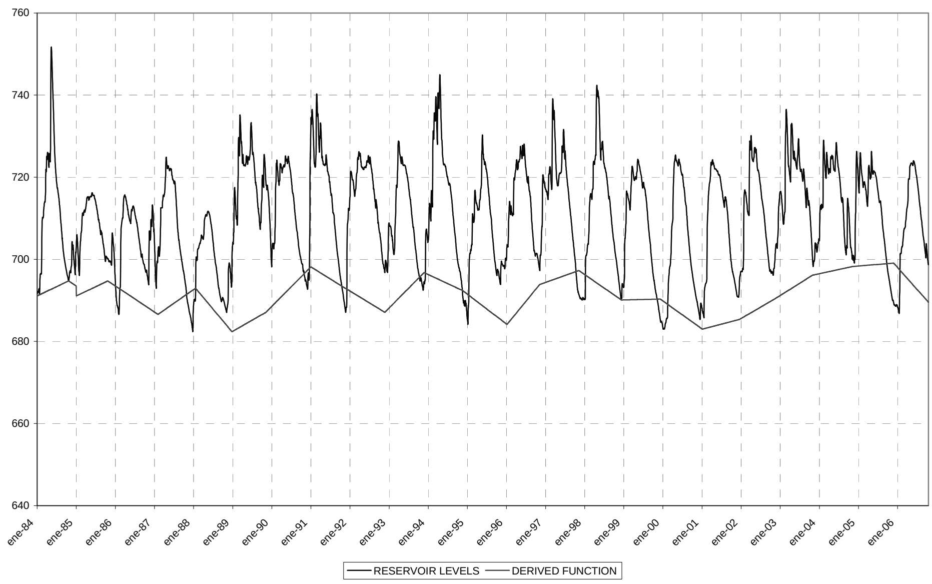
20



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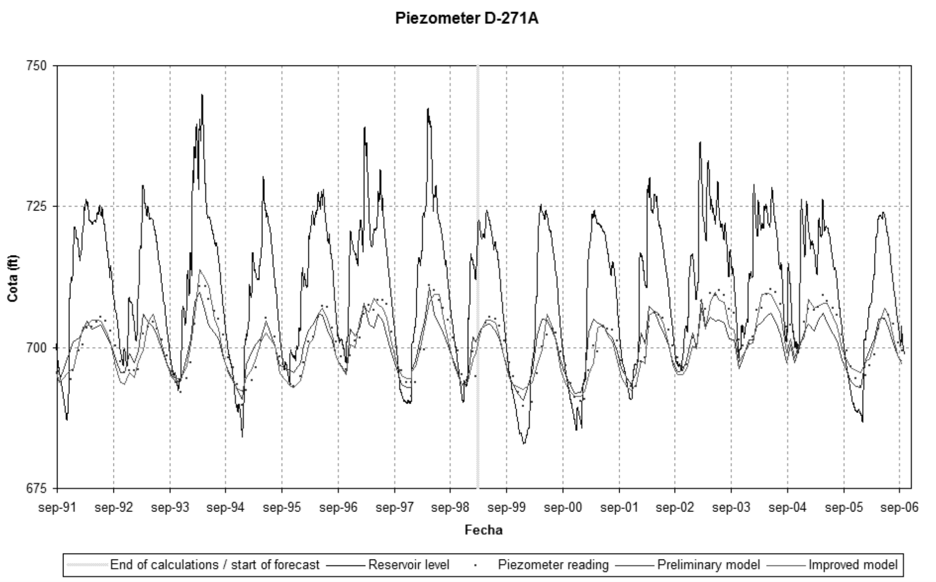

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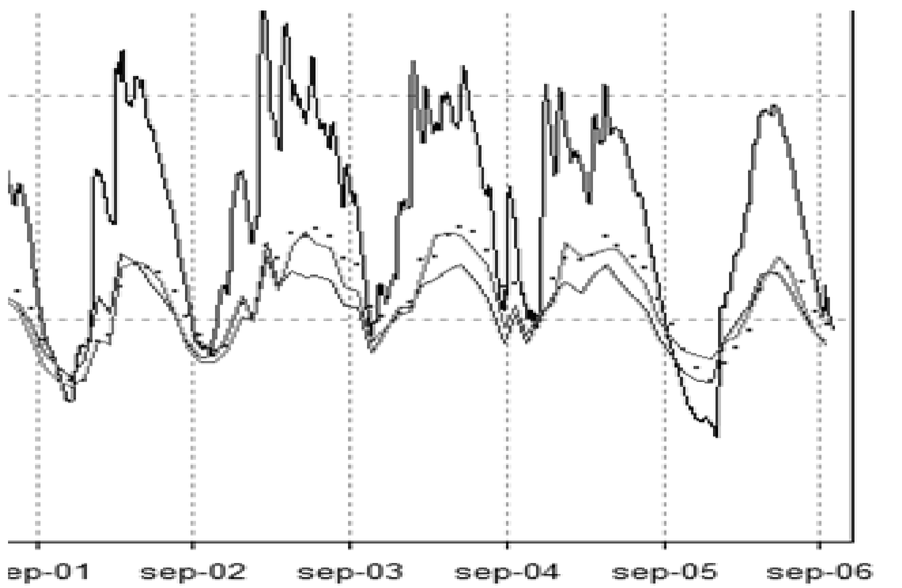

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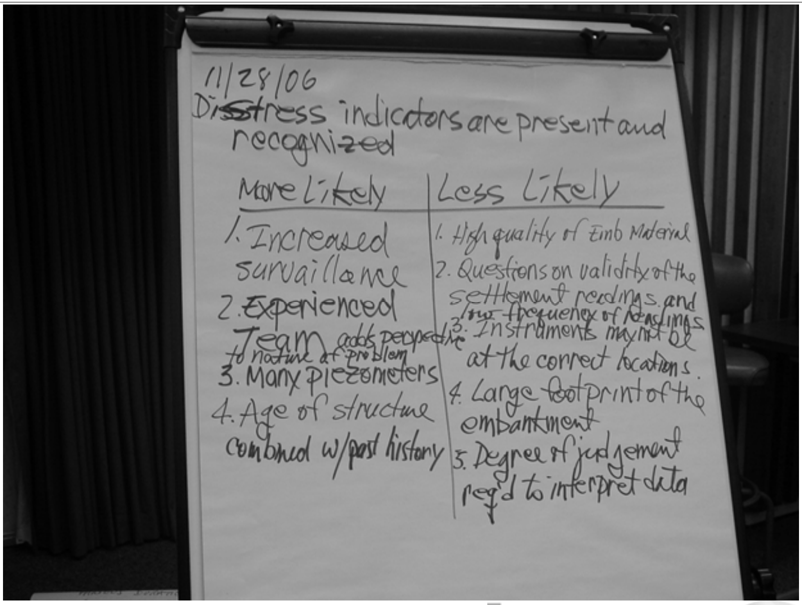
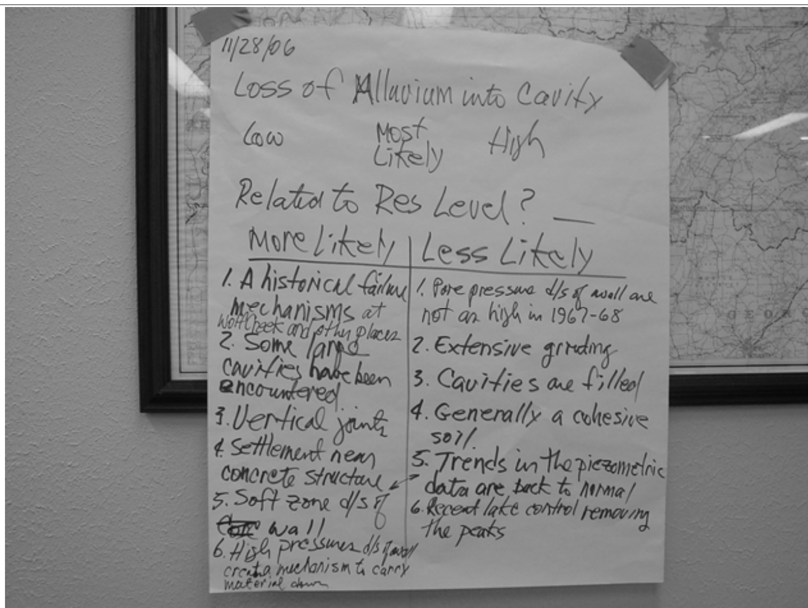


11/28/06
Distress indicators are present and recognized
More Likely
Less Likely
1. Increased survaillance
2. Experienced Team adds perspective to nature of problem
3. Many piezometers
4. Age of structure combined w/past history
1. High quality of Emb Material
2. Questions on validity of the settlement readings and low frequency of readings
3. Instruments may not be at the correct locations.
4. Large footprint of the embankment
5. Degree of judgement req'd to interpret data

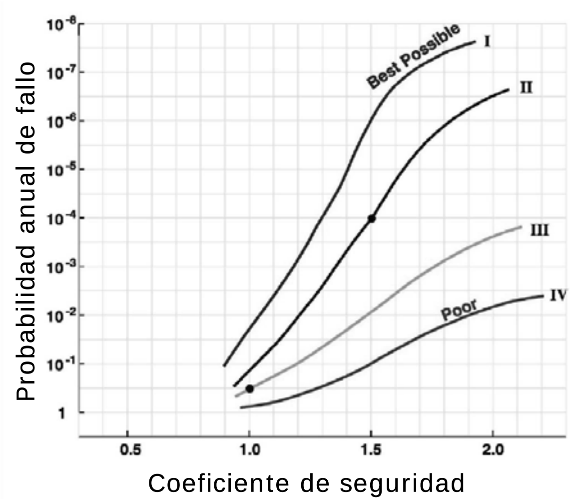


11/28/06
Loss of Alluvium into Cavity
Low
Most Likely
High
Related to Res Level?
More Likely
Less Likely
1. A historical failure mechanisms at Wolf Creek and other places
2. Some large cavities have been encountered
3. Vertical joints
4. Settlement near concrete structure
5. Soft zone d/s of wall
6. High pressures d/s of wall create a mechanism to carry material down
1. Pore pressure d/s of wall are not as high in 1967-68
2. Extensive grouting
3. Cavities are filled
4. Generally a cohesive soil.
5. Trends in the piezometric data are back to normal
6. Recent lake control removing the peaks

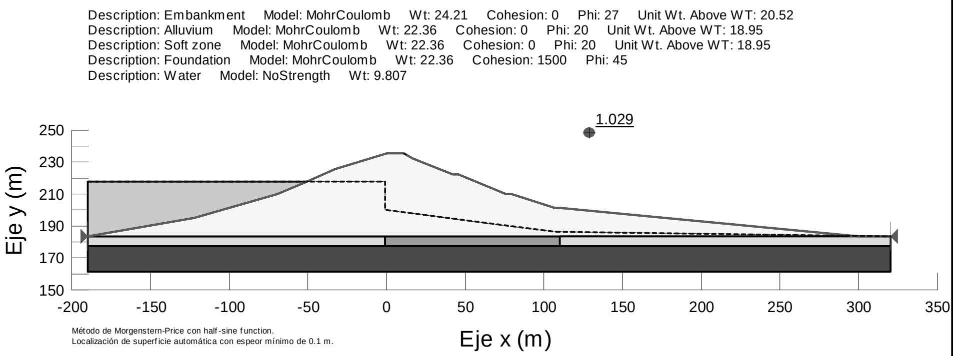
Numerical Responses and Ranges for 18 Probability Expressions (after Reagan, et. al., 1989)

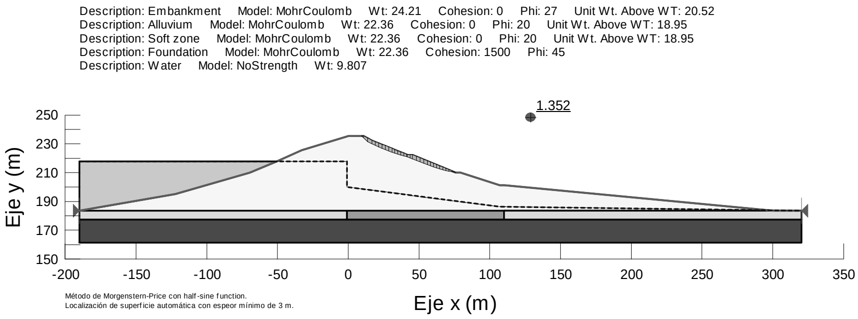
Expression	Single-number probability equivalent, % (median of responses)	Specified range, % (median upper and lower bounds)
Almost impossible	2	0 to 5
Very improbable	5	1 to 15
Very unlikely	10	2 to 15
Very low chance	10	5 to 15
Improbable	15	5 to 20
Unlikely	15	10 to 25
Low chance	20	10 to 20
Possible	40	40 to 70
Medium chance	50	40 to 60
Even chance	50	45 to 55
Problable	70	60 to 75
Likely	70	65 to 85
Very possible	80	70 to 87.5
Very probable	80	75 to 92
High chance	80	80 to 92
Very likely	85	75 to 90
Very high chance	90	85 to 99
Almost certain	90	90 to 99.5

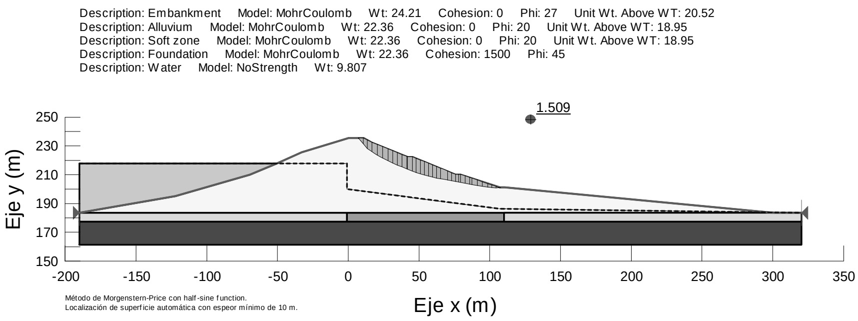
Median Estimates from Engineering Team								
Res 640			Res 680			Res 723		
L	ML	H	L	ML	H	L	ML	H
0,8	0,9	0,995	0,8	0,9	0,995	0,8	0,9	0,995
0,1	0,4	0,5	0,2	0,5	0,7	0,3	0,6	0,9
0,5	0,3	0,1	0,5	0,3	0,2	0,5	0,35	0,2
0,95	0,9	0,75	0,9	0,8	0,7	0,9	0,75	0,5
0,5	0,725	0,9	0,575	0,775	0,925	0,65	0,8	0,925
0,3	0,5	0,75	0,5	0,7	0,9	0,6	0,8	0,9
0,75	0,6	0,5	0,85	0,7	0,5	0,9	0,8	0,5
0,7	0,625	0,45	0,55	0,45	0,3	0,45	0,3	0,1
0,001	0,006	0,01	0,008	0,0125	0,065	0,0125	0,05	0,1
0,8	0,9	0,97	0,9	0,95	0,99	0,9	0,99	0,99
0,9	0,95	0,99	0,9	0,99	0,995	0,9	0,99	0,995
0,55	0,825	0,9	0,75	0,9	0,97	0,825	0,9	0,99



Fuente: F. Silva-Tula (2007)







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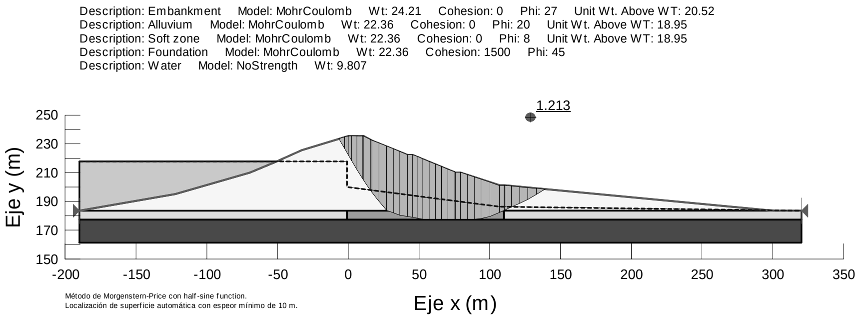

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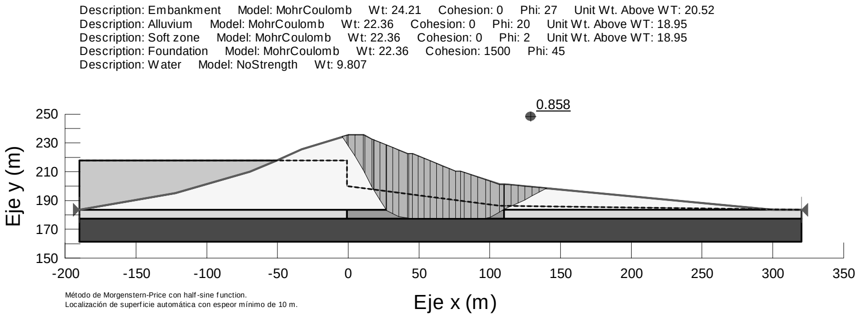

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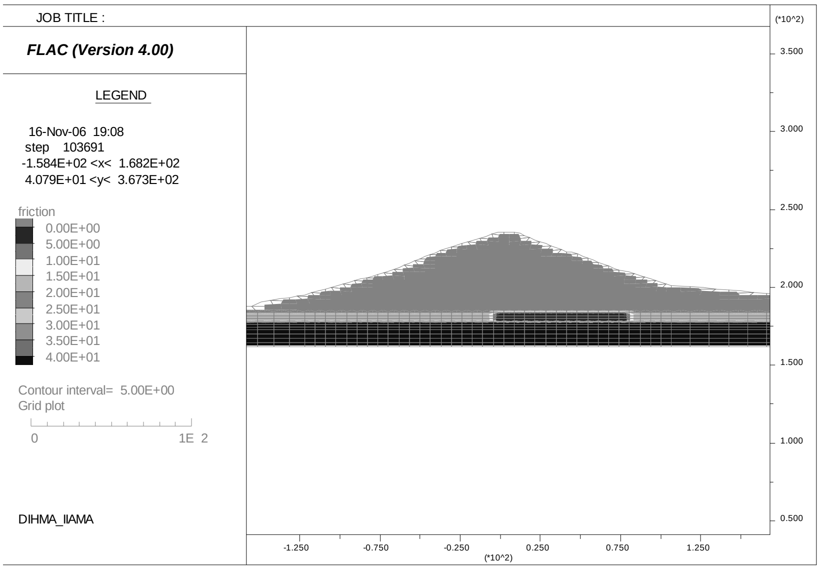
33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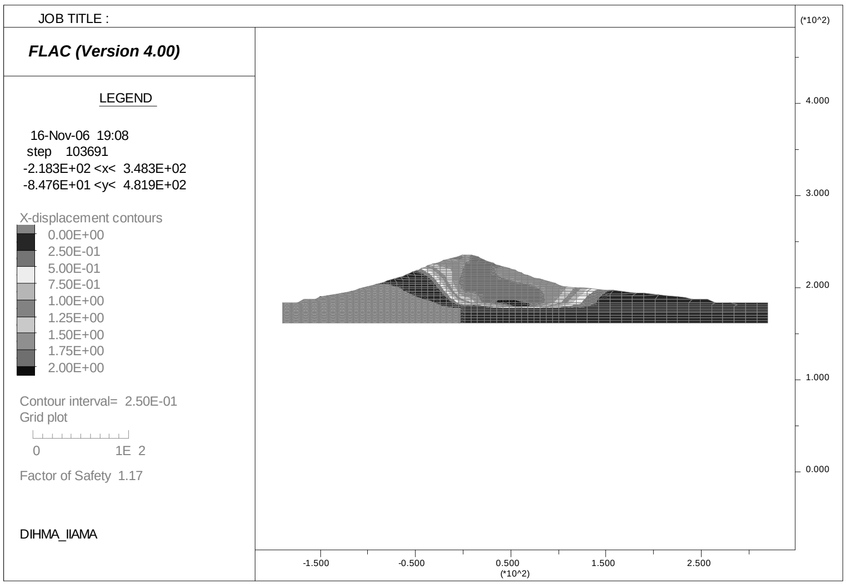
FLAC (Version 4.00)
LEGEND
16-Nov-06 19:08
step 103691
-1.584E+02 <x< 1.682E+02
4.079E+01 <y< 3.673E+02
friction
0.00E+00
5.00E+00
1.00E+01
1.50E+01
2.00E+01
2.50E+01
3.00E+01
3.50E+01
4.00E+01
Contour interval= 5.00E+00
Grid plot
0 1E 2
DIHMA_IIAMA
(*10^2)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
-1.250
-0.750
-0.250
0.250
0.750
1.250
(*10^2)

34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FLAC (Version 4.00)
LEGEND
16-Nov-06 19:08
step 103691
-2.183E+02 <x< 3.483E+02
-8.476E+01 <y< 4.819E+02
X-displacement contours
0.00E+00
2.50E-01
5.00E-01
7.50E-01
1.00E+00
1.25E+00
1.50E+00
1.75E+00
2.00E+00
Contour interval= 2.50E-01
Grid plot
0 1E 2
Factor of Safety 1.17
DIHMA_IIAMA
(*10^2)
4.000
3.000
2.000
1.000
0.000
-1.500
-0.500
0.500
1.500
2.500
(*10^2)

	Con pantalla			Sin pantalla		
	φ = 20º	φ = 8º	φ = 2º	φ = 20º	φ = 8º	φ = 2º
FLAC	1.41	1.41	1.18	1.41	1.37	1.04
SLOPE/W	-			1.03 / 1.35 / 1.51	1.21	0.86

Analysis of the elastic behavior of an arch-gravity dam after the first impounding

List of Participants:

Participant 1. Universidad Politecnica de Valencia (Spain)

Participant 2. Cesi Ricerca (Milan, Italy)

Participant 3. Coyne-et-Bellier

Participant 4. Faculty of Civil Engineering, Skopje, Republic of Macedonia.

Participant 5. Tokio Electric Power Service (Japan) and University of Colorado (USA).

1. INTRODUCTION
2. LA ACEÑA DAM FEATURES
3. OTHER GIVEN DATA
4. KNOWN BEHAVIOR
5. PART 0. NUMERICAL TOOL JUSTIFICATION
6. PART 1. CALCULATION OF DISPLACEMENTS RECORDED BY PEND. N.3
7. PART 2. ANALYSIS OF RECORDED DATA
8. PARTICIPANT’S CONCLUSSIONS
9. OVERALL CONCLUSSIONS

1. INTRODUCTION

Dam Safety in Spain has recently been updated by passing two new legal codes

- **Directriz 1995**, that has involved for all Large Dams:
  - ✓ Their Potential Risk Classification
  - ✓ For all those classified as A or B, the implementation of an Emergency Action Plan

- **Reglamento 1996**, that has involved for all public owned dams and those privately operated under license given later than 1st of April of 1996:
  - ✓ Implementation of Operating Procedures
  - ✓ Inspection and Annual Reports
  - ✓ Complete Safety Review (each five years for Dams Classified as A)

1. INTRODUCTION

Records obtained from dam instrumentation are crucial in order to interpret the structure behaviour and be able to assess its safety.

However, due to the uncertainties involved in the process of:

- ✓ Installing such instruments
- ✓ The way readings are collected
- ✓ The nature of the instruments and their conservation state,

Instrumentation records might not be as reliable as expected!!

1. INTRODUCTION

Instrumentation records can:

- ✓ be misunderstood
- ✓ lead to make the wrong decisions
- ✓ make dam engineers to develop some degree of skepticism about their importance

Numerical models can:

- ✓ be a helping tool but
- ✓ add some additional uncertainties if they are not carefully and rigorously used:
  - ➢ Construction data should be examined
  - ➢ Constitutive models properly chosen, etc.

1. INTRODUCTION

In summary:

- ✓ Combination of a good knowledge of the instruments
- ✓ An appropriate conservation of instrumentation and reading procedure
- ✓ A realistic data management program and the implementation of numerical models

are a very important tasks that have to be carefully undertaken due to all the involved uncertainties.

But also, the behaviour itself of the dam, is a source (some times the main one !!) of uncertainties.

2. LA ACEÑA DAM FEATURES

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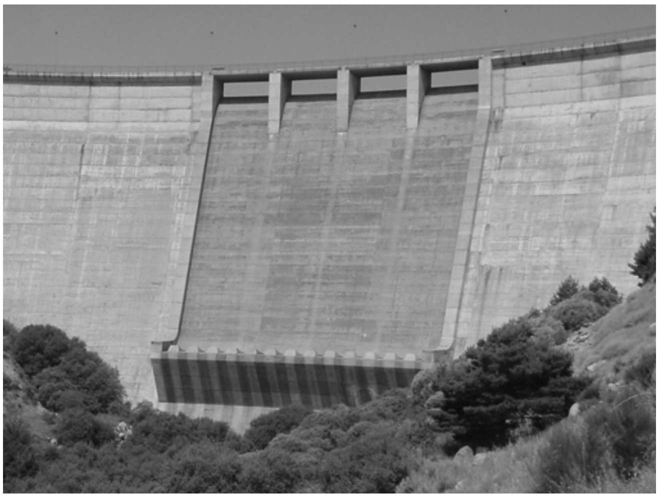
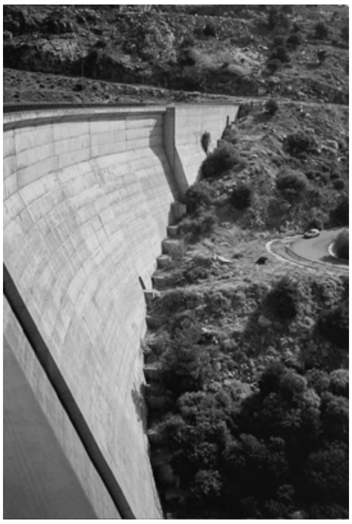


2. LA ACEÑA DAM FEATURES



2. LA ACEÑA DAM FEATURES

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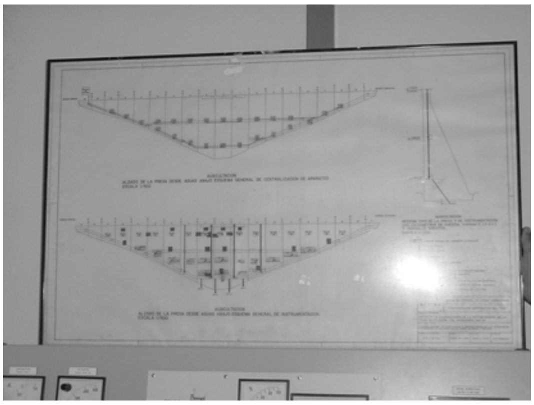
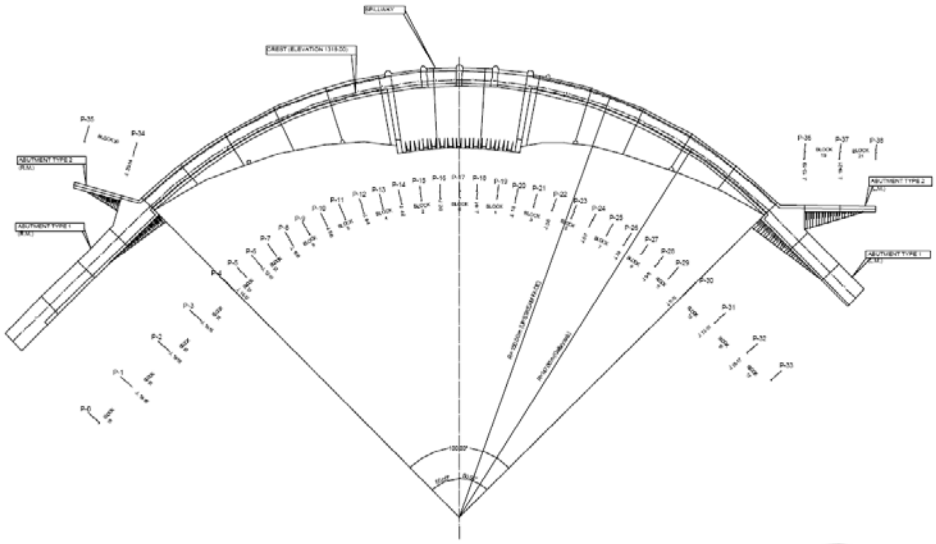
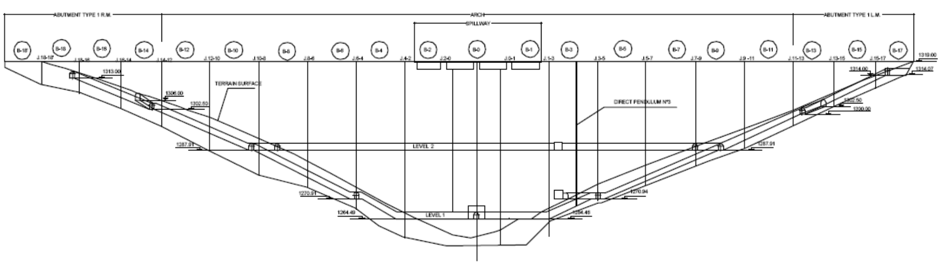


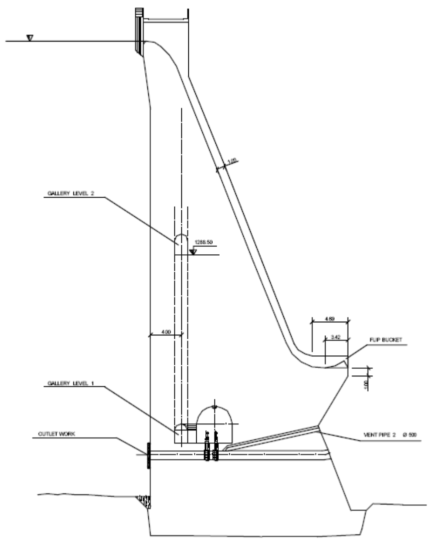
2. LA ACEÑA DAM FEATURES

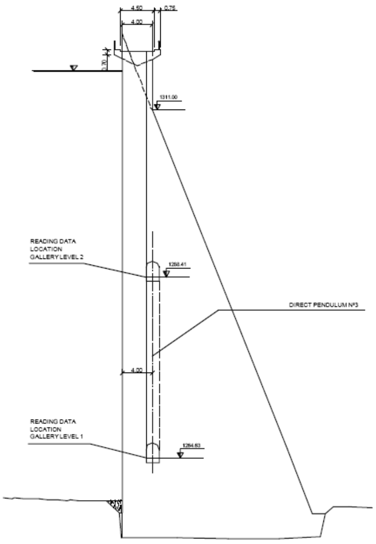


2. LA ACEÑA DAM FEATURES

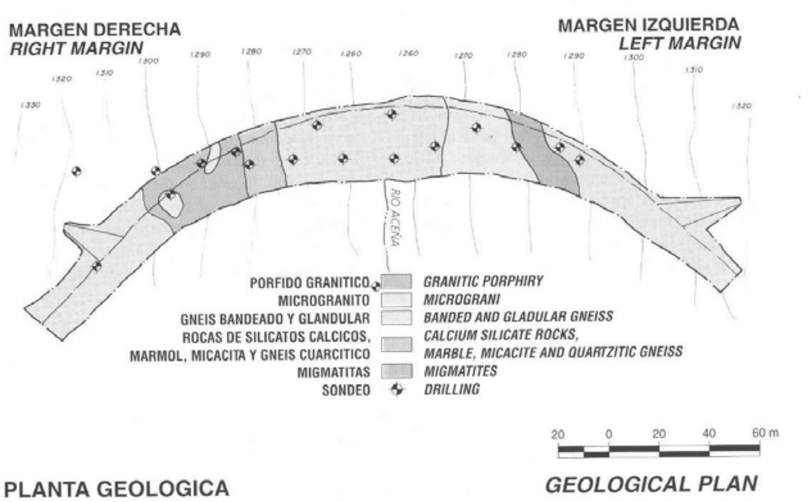


2. LA ACEÑA DAM FEATURES





3. OTHER GIVEN DATA



3. OTHER GIVEN DATA

Property	FOUNDATION	DAM BODY
Especific weight	22 kN / m^3	23.6 kN / m^3
E (Young modulus)	10000 Mpa	20000 Mpa
Poisson´s Ratio	0.2	0.2
Coef. of thermal exp. A	0	10^{-5} $^{o}C^{-1}$

Month	E	F	M	A	M	J	J	A	S	O	N	D
Temperature (ºC)	2.9	3.7	5.9	8.2	12.0	16.1	20.0	19.6	16.3	11.0	5.9	3.2

Note: joints were sealed in February of 1989

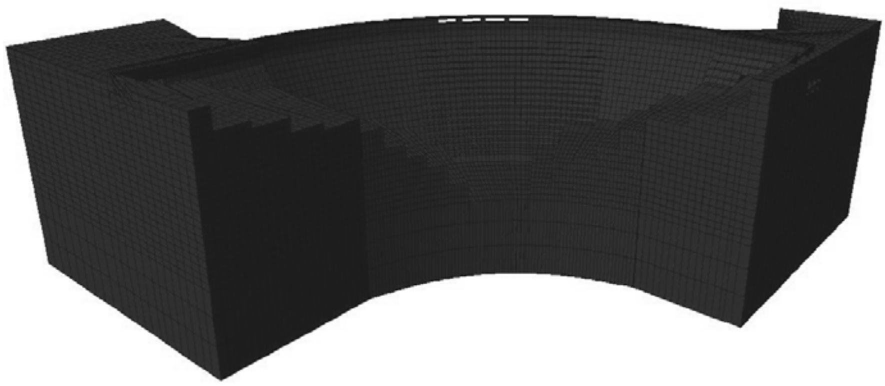
3. OTHER GIVEN DATA

	07/02/1990	26/04/1990	26/12/1990	31/01/1991	22/03/1991	04/05/1991
THERMOMETER	Empty reservoir	Water Level: 1280 masl	Water Level: 1293.6 masl	Water Level: 1296.5 masl	Water Level: 1311 masl	1316 (full reservoir)
B0/DOWNSTREAM/1269	8	9.2	8.5	7.4	8.4	9.4
B0/UPSTREAM/1269	5	6.2	7.2	5.8	6.5	7
B0/CENTER/1269	11.1	10.4	12.2	11.8	11.1	10.2
B0/DOWNSTREAM/1283	8	10.2	7.7	7.2	9.8	10
B0/UPSTREAM/1283	5.4	8.3	7.2	6.3	6.6	7.2
B0/CENTER/1283	13.7	11.6	14.6	13.9	12.7	10.8
B0/CENTER/1309	5.4	9.2	3.8	5.1	6.1	9
B1/DOWNSTREAM/1269	9.2	9.4				
B1/UPSTREAM/1269	4.2	7.2	6.1	5.4	6	6.6
B1/CENTER/1269			12.3	9.8	8.4	9.1
B1/DOWNSTREAM/1283	13.2	10.8	9.2	8.2	10	10.5
B1/UPSTREAM/1283						
B1/CENTER/1283			14.2	13	12.3	12.5
B1/CENTER/1309	4.1	7.7	6.3	3.1	5.3	8.3
B2/DOWNSTREAM/1269	6.8	9	6.6	5.9	9	9.1
B2/UPSTREAM/1269	5.6	8	7.5	6.5	6.7	7.1
B2/CENTER/1269	12.9	11.8	13.3	13.4	13	11.9
B2/DOWNSTREAM/1283	8.4	10.4	7.8	7.5	10	10.5
B2/UPSTREAM/1283	5.7		7.5	6.7	6.9	7.6
B2/CENTER/1283	14	12.1	15.3	14.4	12.8	11.5
B2/CENTER/1309	4.6	8.7	5.3	4.1	5.4	8.5
B3/DOWNSTREAM/1283	8.7	10.2	8.9	7.8	9.8	11.3
B3/UPSTREAM/1283						
B3/CENTER/1283	14.1	12.1	15.9	13.8	12.7	11
B3/CENTER/1309	3.8	7.8	3.9	2.8	5.3	8.3
B4/DOWNSTREAM/1283	7.8	9.7	6.2	5.9	10.4	10.5
B4/UPSTREAM/1283	5.8	8.9	7	6.4	7.1	7.9
B4/CENTER/1283	13.4	10.7	14.5	13.6	11.9	10
B4/CENTER/1309	3.8	7.7	2.7	2.4	5.5	8.2

3. OTHER GIVEN DATA

THERMOMETER	07/02/1990 Empty reservoir	26/04/1990 Water Level: 1280 masl	26/12/1990 Water Level: 1293.6 masl	31/01/1991 Water Level: 1296.5 masl	22/03/1991 Water Level: 1311 masl	04/05/1991 1316 (full reservoir)
B5/DOWNSTREAM/1283	9.6	11.3	9.6	9.2	11.4	12.1
B5/UPSTREAM/1283	5.9	8.5	8.1	7.1	7.3	8
B5/CENTER/1283	13.4	10.9	14.9	13.8	12	10.2
B5/CENTER/1309	5	8.6	6.2	4.7	5.8	9
B6/DOWNSTREAM/1283	7.7	9.7	7.4	6.9	6.5	10.5
B6/UPSTREAM/1283	5.8	8.2	8.2	6.9	9.7	6.9
B6/CENTER/1283	11.4	8.7	13.2	11.8	9.8	8
B6/CENTER/1309	4.1	8	3.8	6.3	5.7	8.5
B7/DOWNSTREAM/1283	11.2	11.8	12.7	11.1	10.4	11.4
B7/UPSTREAM/1283	6.7	7.4	8.7	7.2	6.8	7
B7/CENTER/1283	11.8	9.9	13.5	11.4	9.3	8.2
B7/CENTER/1309	4.9	8.9	5.8	4.4	5.9	9
B8/DOWNSTREAM/1283	6.4	7.3	6.2	5.4	7.5	8.9
B8/UPSTREAM/1283	8.7	7.2	8.7	7.3	7.5	7
B8/CENTER/1283	6	7.3	7.3	6.1	6.5	7.2
B8/CENTER/1309	4.5	8.5	4.2	3.8	6.1	8.7
B9/DOWNSTREAM/1291	8.5	10.2	9	8.3	9.9	10.8
B9/UPSTREAM/1291	8.4	7.5	9.7	8.3	7.5	7.2
B9/CENTER/1291	10.2	9.9	12.1	10.2	9.3	9.1
B9/CENTER/1309	4.1	7.5	4.4	3.6	5.6	9
B10/DOWNSTREAM/1293	5.2	7.2	4.3	3.7	7.3	8.3
B10/UPSTREAM/1293	8.3	6.7	10.8	7.8	6.4	5.9
B10/CENTER/1293	4.5	5.2	5.2	4.7	5.5	5.5

3. OTHER GIVEN DATA



4. KNOWN BEHAVIOR

a) First impounding (February 1990 to May 1991)

- Maximum displacement toward the abutments (tangential) was 3.75 mm, reached when the reservoir was at maximum normal operating level.

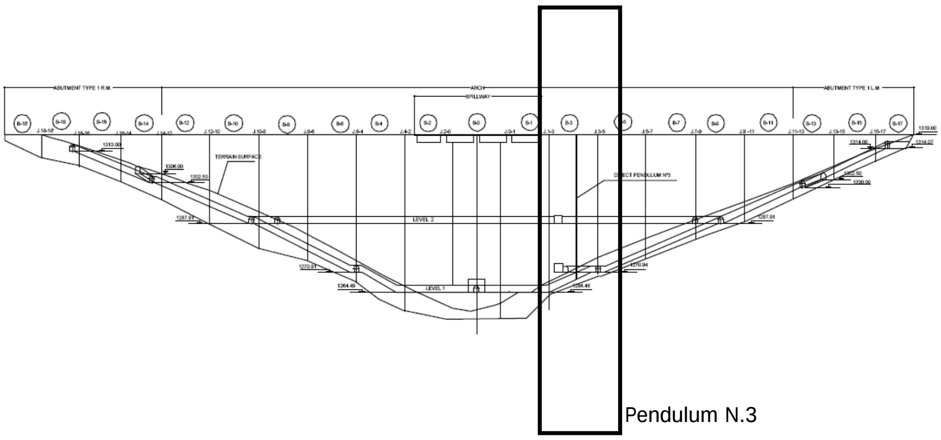
- Radial displacements (upstream-downstream) were in a range between 1.23 cm and 1.8 cm, with slight differences between blocks. Maximum joint movement recorded was 1.88 mm.

- Maximum seepage flow (40 l/min) also occurred for the maximum normal operating level. The maximum value for a single block was 1.7 l/min.

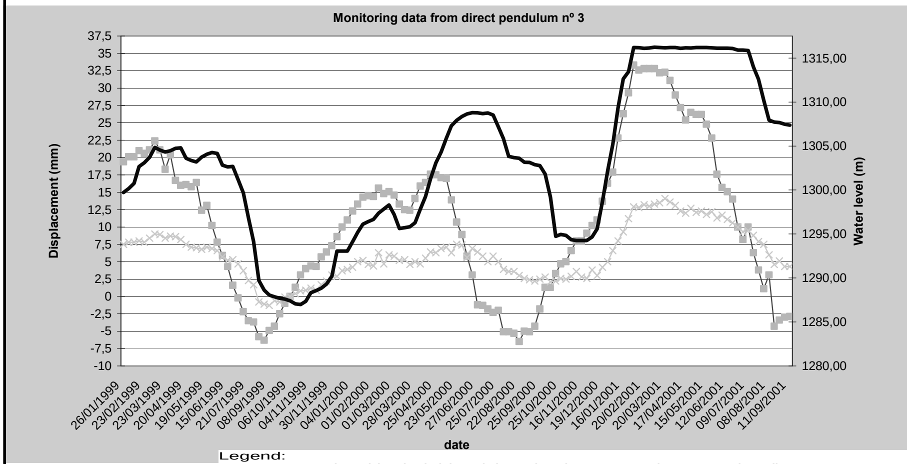
b) Movements after first impounding

- Movements recorded after first impounding by means of four plumblines revealed an apparently significant increase of the range of displacements (around 4 cm).

4. KNOWN BEHAVIOR



4. KNOWN BEHAVIOR



Legend:

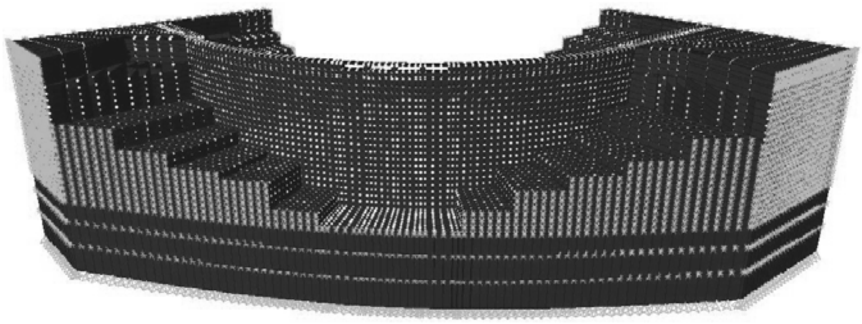
Water level in dark blue (elevation in meters above sea level)

Incremental horizontal displacements from lower gallery to the crest in green (displacement in millimetres; Possitive = Downstream direction)

Incremental horizontal displacements from lower to intermediate gallery in light blue (displacement in millimetres; Possitive = Downstream direction)

5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.1 Participant 1



SAP 2000. :

- 53038 joint
- 45740 SOLID elements

5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.1 Participant 1

Multiple Regression - desp
Multiple Regression Analysis

Dependent variable: disp1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	207864.0	77970.3	2.66595	0.0126
wlev	-318.952	119.139	-2.67714	0.0123
wlev^2	0.122366	0.0455113	2.6887	0.0119
Temp	-5.10044	9.92675	-0.513808	0.6114
Temp^2	0.739249	1.45244	0.508971	0.6148
Temp^3	-0.0555234	0.0852161	-0.65156	0.5200
Temp^4	0.00137341	0.00173033	0.793724	0.4340

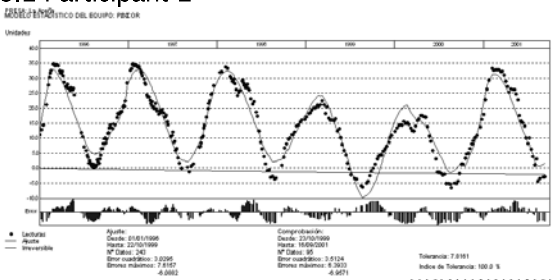
Analysis of Variance

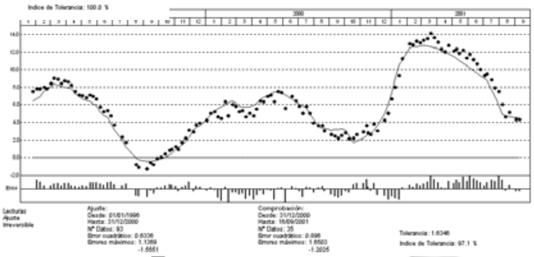
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	4076.64	6	679.441	24.72	0.0000
Residual	769.495	28	27.482		
Total (Corr.)	4846.14	34			

R-squared = 84.1215 percent
R-squared (adjusted for d.f.) = 80.719 percent
Standard Error of Est. = 5.24232
Mean absolute error = 3.3742
Durbin-Watson statistic = 0.978026 (P=0.0000)
Lag 1 residual autocorrelation = 0.505545

5. PART 0. NUMERICAL TOOL JUSTIFICATION

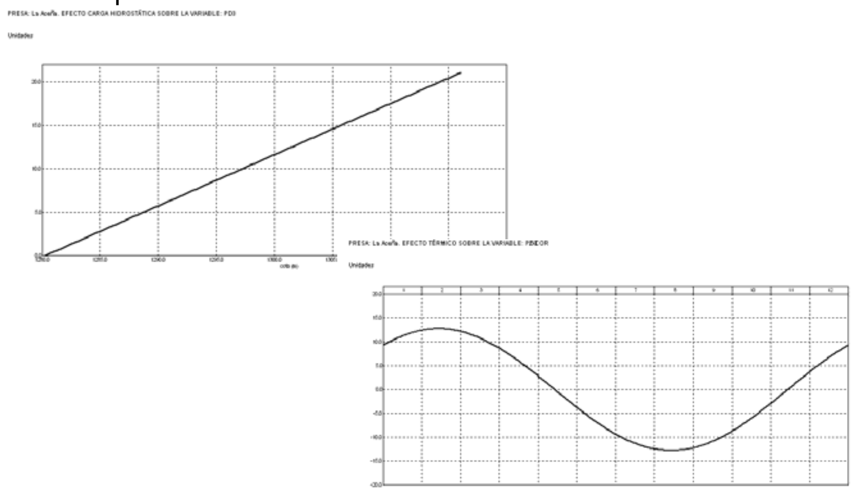
5.1 Participant 1





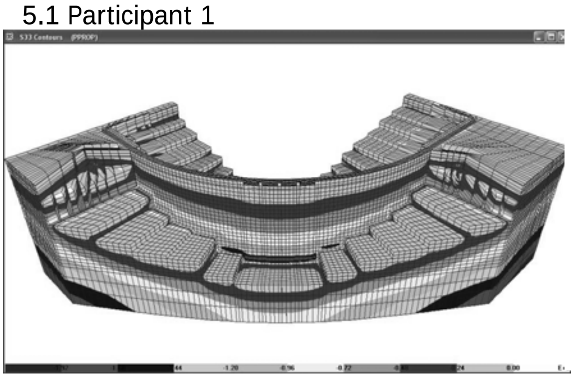
5. PART 0. NUMERICAL TOOL JUSTIFICATION

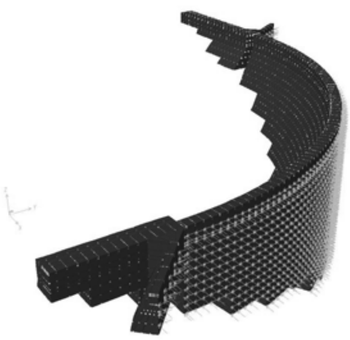
5.1 Participant 1



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.1 Participant 1





To analyze each case a thermal field has been created at the entire dam body, subjected to the following boundary conditions:

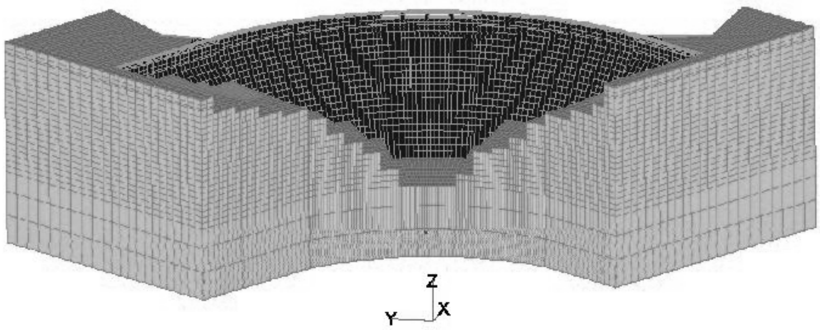
The wet face has a constant temperature of 4ºC.

The dry face and the head of the dam have the air temperature.

5. PART 0. NUMERICAL TOOL JUSTIFICATION

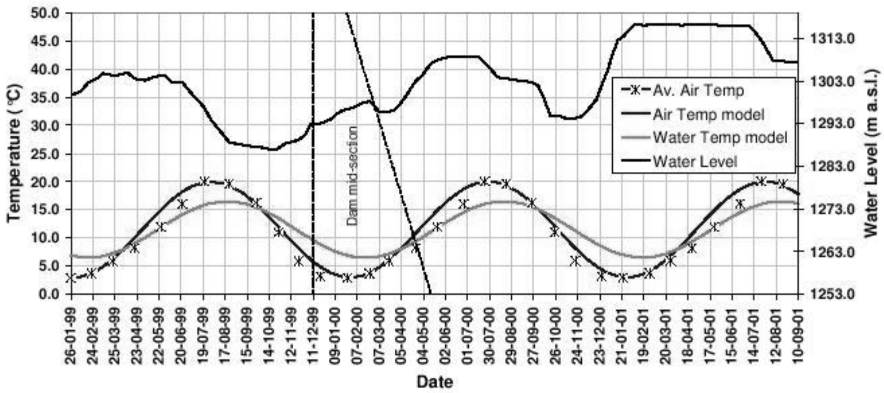
5.2 Participant 2

The authors, on the basis of the data provided by the formulators, used their in house developed FEM Code CANT-SD [2], to analyse the linear-elastic FEM model of La Aceña dam-foundation system. The mesh consists of 53038 nodes, 9328 linear brick elements for the dam block, 36413 linear brick elements for the rock foundation.



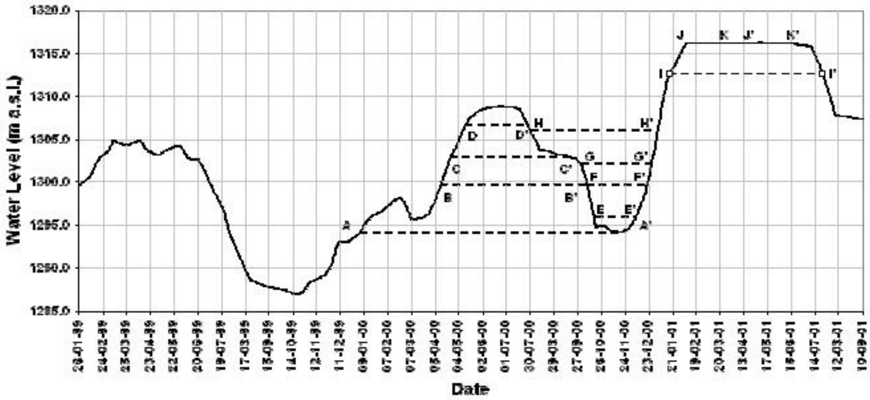
5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.2 Participant 2



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.2 Participant 2



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.2 Participant 2

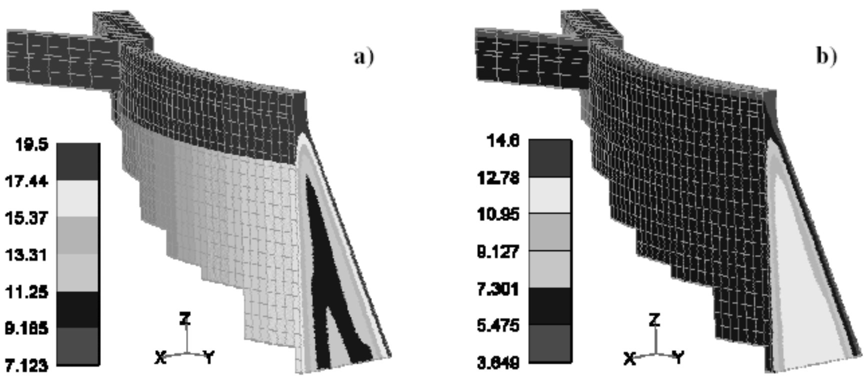


Fig. 4. Temperatures distributions: a) August 2000; b) February 2001

5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3

➢A file dedicated to COQEF was prepared with the nodes of the dam mesh. These nodes have been extracted from the file JOINTS.txt provided by the formulator.

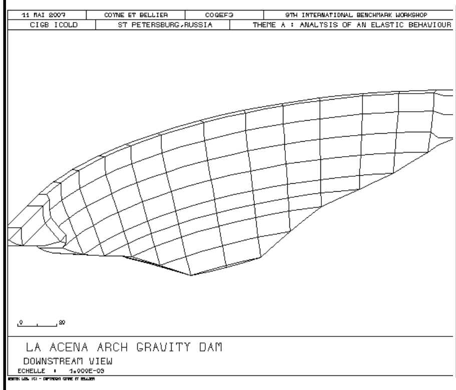
➢In order to get a reasonable mesh size, only 578 nodes were selected to build the dam model. There is only one material for all elements, namely the concrete. Nodes at the dam basis represent the interface foundation/dam body.

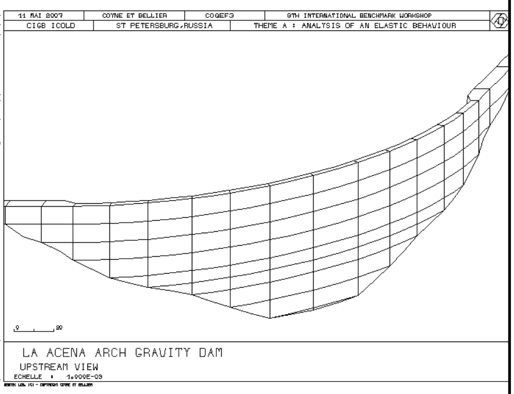
➢The dam mesh is built with 17 cantilevers and 9 arcs. The elements at the base of the dam are made up with triangular elements.

➢The flat base at the crown of the dam is also modelled with two small triangular elements.

5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3





5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3

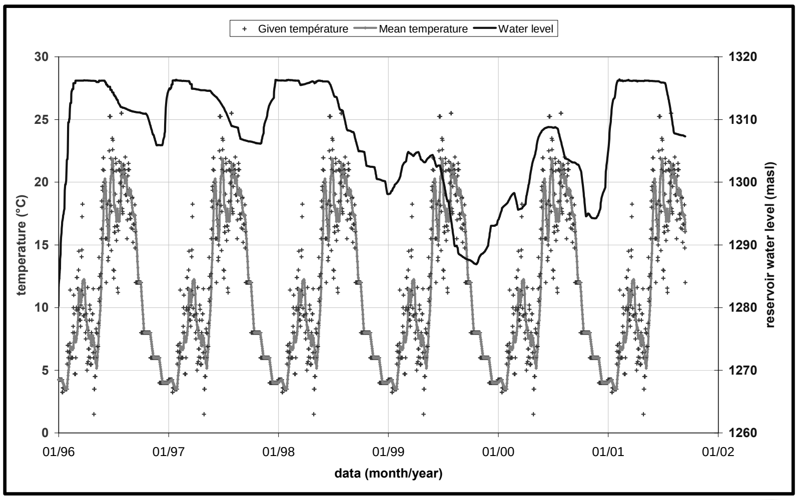
The thermal load was drastically simplified:

➢Variations of temperature in the dam body were considered linear from upstream to downstream, following Stucky's simplification.

➢The downstream and the upstream faces of the dam are faced with sinusoidal variations of temperature. These sinusoidal temperature distributions are calculated for each downstream and upstream node, taking into account their location (water, air) and elevation. The sinusoids have the same period but their amplitude varies according to their location and elevation.

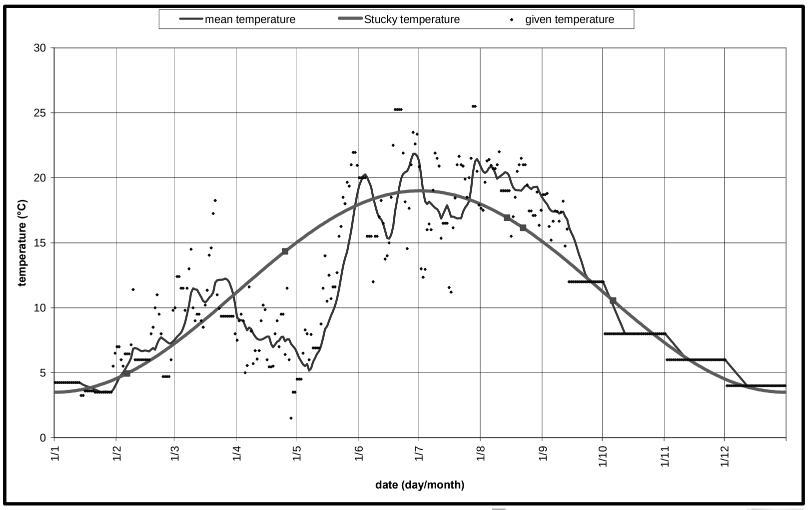
5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3



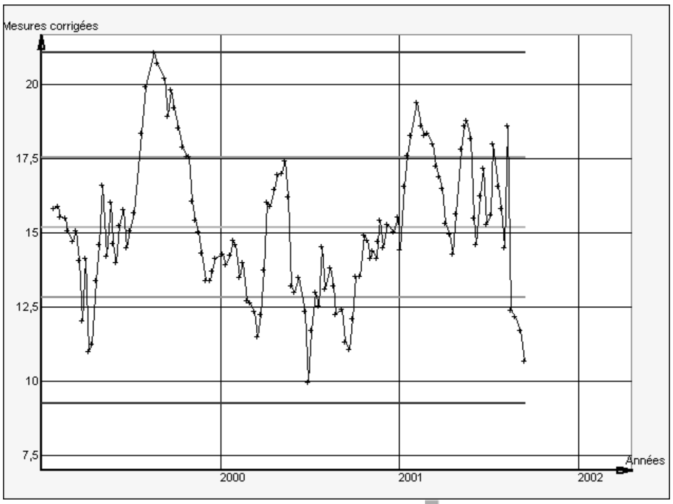
5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.3 Participant 3



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 4

➢The used computer software SOFiSTiK for stress-strain analyses, produced in Munich (Germany), is based on the finite element method.

➢It has a wide range of possibilities for simulation of dam behaviour and inclusion in the analyses of all necessary fenomena, important for real simulation of the dam behaviour, such as:

✓ an automatic discretization of the dam body taking into account the iregularities in the geometry of the dam base,

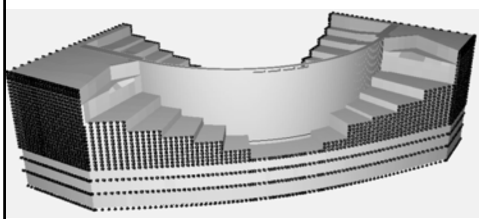
✓ application of different constitutive models for materials,

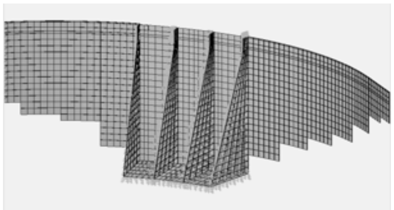
✓ simulation of the dam body construction and reservoir filling in increments, and so on.

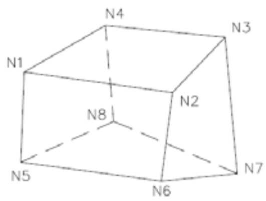
➢The program has rich possibilities for presentation of the output results. In our work, mainly plane graphical presentation was used, showing the output results in the main cross sections, as well as in longitudinal section.

5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 4

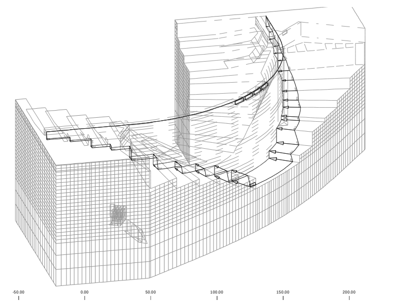


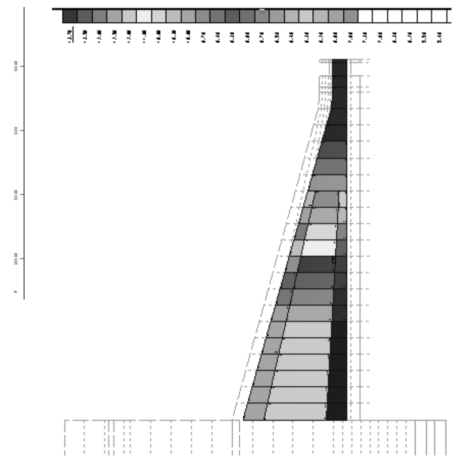




5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 4





5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 5

➢Analysis was performed by the computer code MERLIN (http://civil.colorado.edu/~saouma/Merlin) which has been in continuous development for over 12 years.

➢Merlin, probably one of the most sophisticated analytical tools for dam analysis, has numerous features essential for the modeling of dams. Amongst them: 2D-3D, static and dynamic, linear and nonlinear (numerous nonlinear constitutive models for fracture mechanics based discrete and smeared cracks for concrete and rock), fluid elements, automatically adjustable static and dynamic uplift pressures, sophisticated models for radiation damping, restart capabilities and ability to transfer static analysis reactions to nodal dynamic loads, possibility to incrementally modify the elastic properties, amongst others.

➢Such an analysis could not be possible without the support of a window-based preprocessor, KUMONOSU.

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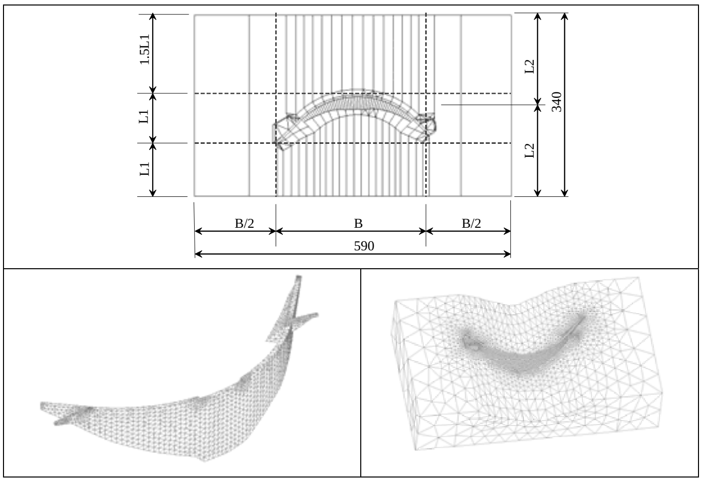
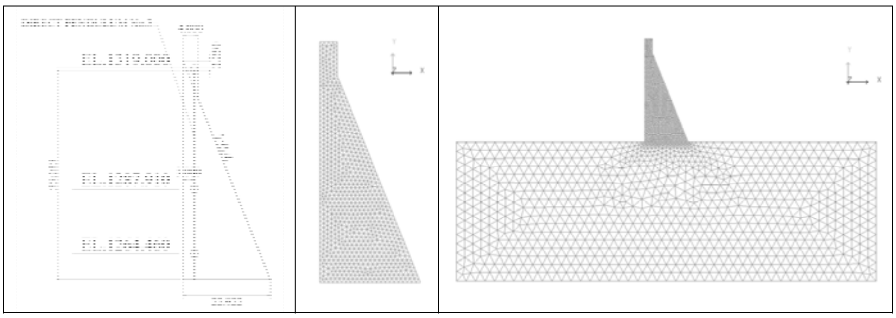
5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 5



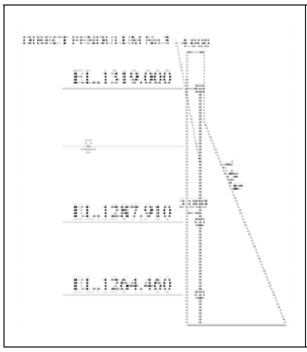
5. PART 0. NUMERICAL TOOL JUSTIFICATION

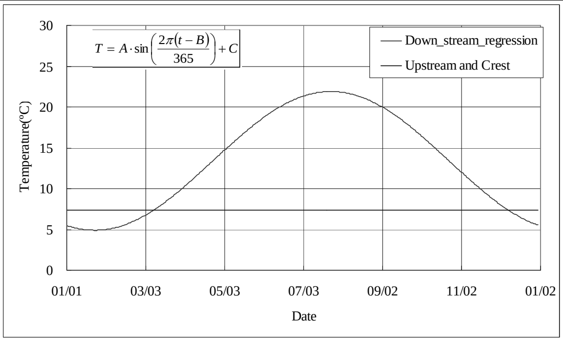
5.4 Participant 5



5. PART 0. NUMERICAL TOOL JUSTIFICATION

5.4 Participant 5





5. PART 0. NUMERICAL TOOL JUSTIFICATION

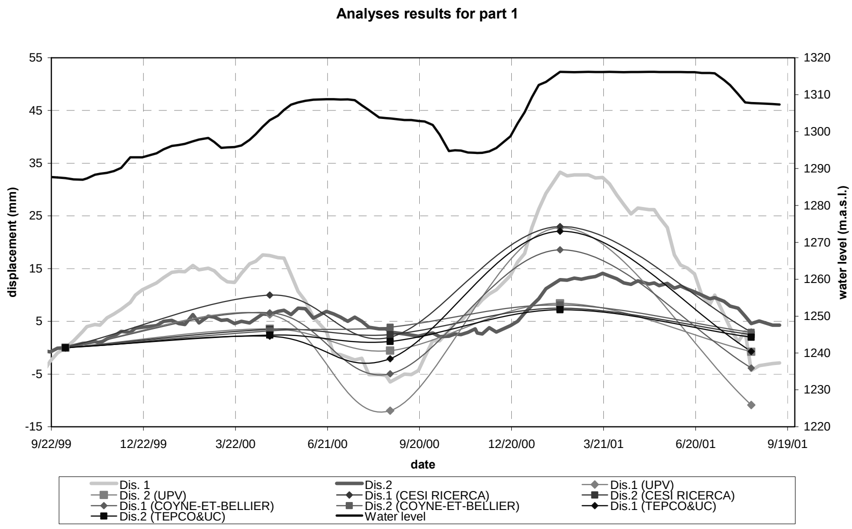
5.5 Summary

	CODE	DETERMINISTIC MODEL	STATISTICAL MODEL	TEMPERATURE	UPLIFT
PARTICIPANT 1 (UPV)	SAP 2000	3D. 53038 JOINTS	STAT GRAPHICS AUSMODEL	4º C- US SINUSOIDAL-DS LINEAR-VARIATION	YES
PARTICIPANT 2 (CESI)	CANT-SD	3D 53038 JOINTS	……..	SINUSOIDAL DIFFERENT RANGES WATER TEMP DELAY CONDUCTIVITY MOD.	NO
PARTICIPANT 3 (COYNE-ET-BELLIER)	COQ-EF	3D 578 NODES	HST/CONDOR	SINUSOIDAL STUCKY	……
PARTICIPANT 4 (SCOPJE)	SOFiSTiK	3D 56638 NODES INTERFACES	………	USING CONSTRUCTION RECORDS	……
PARTICIPANT 5 (TEPCO)	MERLIN	2D+3D 4113 NODES	………	7.4º C-US SINUSOIDAL-DS	YES

6. PART 1. CALCULATION OF DISPLACEMENTS RECORDED BY PEND. N.3

DATE	RECORDED		UPV		CESI RICERCA		COYNE-ET-BELLIER		FACULTY C.E. SKOPJE		TEPCO	
	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2
06/10/1999	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25/04/2000	17,50	6,30	6,30	3,61	10,00	3,50	6,63	3,18			2,20	2,40
22/08/2000	-6,50	3,00	-11,93	-0,53	2,00	2,50	-4,97	3,90			-2,10	1,20
06/02/2001	33,30	12,90	22,77	8,43	23,00	7,50	18,58	8,11			22,10	7,20
14/08/2001	-4,40	4,60	-10,85	-0,75	3,00	2,50	-3,85	2,92			-0,70	2,00

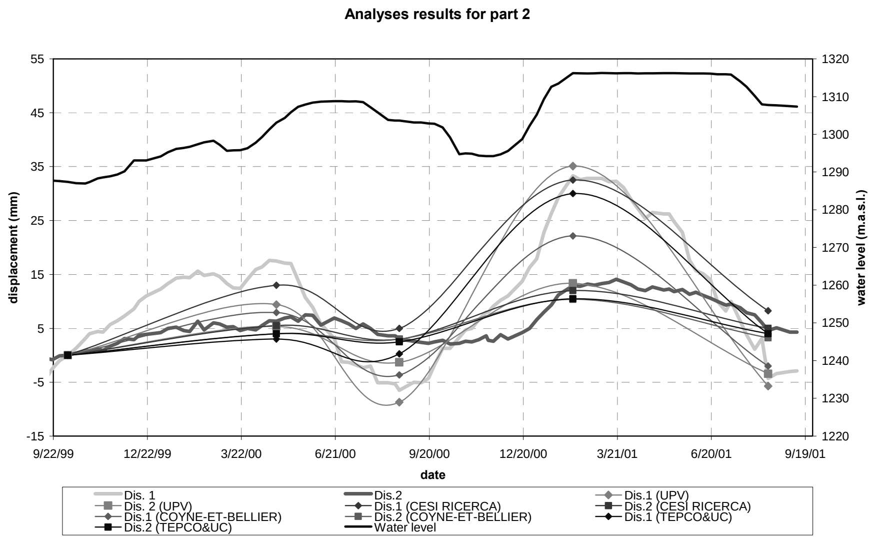
6. PART 1. CALCULATION OF DISPLACEMENTS RECORDED BY PEND. N.3



7. PART 2. ANALYSIS OF RECORDED DATA

DATE	RECORDED		UPV		CESI RICERCA		COYNE-ET-BELLIER		FACULTY C.E. SKOPJE		TEPCO	
	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2	dis1	dis2
06/10/1999	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25/04/2000	17,50	6,30	9,43	5,36	13,00	5,50	7,94	4,00			3,00	4,00
22/08/2000	-6,50	3,00	-8,70	-1,31	5,00	3,00	-3,65	2,99			0,25	2,50
06/02/2001	33,30	12,90	35,10	13,36	32,50	12,00	22,14	10,39			30,00	10,50
14/08/2001	-4,40	4,60	-5,72	-3,42	8,25	5,00	-1,99	3,24			4,00	4,00

7. PART 2. ANALYSIS OF RECORDED DATA



8. PARTICIPANT´S CONCLUSSIONS

UPV

Although the statistical analysis of the input data shows that 85% of the movement of the dam body can be explained by the joined action of water pressure and temperature, the analysis's results shows that there are another circumstances affecting the mechanical behaviour of the dam. The numerical model reproduces accurately the real movements of the dam body, but only when using the "best estimate" of probably unrealistic Young modulus.

CESI RICERCA

The main conclusion of the comparison indicates the need to properly include the joints behaviour in a future FEM model, which simulation might be gradually approached starting, for instance, from considering the central dam blocks free to move as independent cantilevers, to model the actual non-linear effects of the structural joints with proper FEM elements. The comparison of calculated and measured behaviour should include the joints relative displacements, if the relevant measurements are available. If not, the monitoring of them, in terms of opening, sliding and extension, is strongly recommended. Finally, in case the comparison still would not be acceptable, the assumptions made on the external temperatures models should be critically reviewed.

8. PARTICIPANT´S CONCLUSSIONS

COYNE-ET-BELLIER

According to the geological map given by the Formulator the most important part of the foundation of LA ACENA Dam is composed of banded and glandular gneiss. The Young modulus of the foundation (Er = 5 GPa) seems too small for this type of material, except if the foliation or fracturation of the foundation rock is high. A geological inspection of the foundation should validate or refute this assumption.

So the dam has a more flexible behaviour than the behaviour corresponding to the supposed material mechanical properties. The real amplitude of movements of this arch-gravity dam can be modelled only with an important increase of the dam flexibility. A non-linear phenomenon may appear in the behaviour of La ACENA dam and be responsible for this increase of flexibility.

The structural model completed the statistical method. It allowed the adjustment of material properties in order to characterize the increase of dam flexibility. This model allowed to explain the non-linear behaviour of LA ACENA dam but it can not be used alone to describe the non linear phenomenon, maybe due to the opening of joints under exceptional hydrostatic loads. A monitoring and a precise investigation into the displacements of joints are necessary to complete and to understand perfectly the non-linear response of LA ACENA arch-gravity dam. The return to the statistical method would be able to help the monitoring of these joints.

8. PARTICIPANT'S CONCLUSSIONS

FACULTY OF CIVIL ING., SKOPJE

Calibrating the previously done model, using some of the advanced features of SOFiSTiK software, it was possible to explain some of the results obtained by the measurements performed in the service period of 66 m high arch-gravity La Aceña Dam, in Spain.

But, to explain the complete behaviour, and to answer all questions, it is necessary to do very complex model, with simulation of the real construction procedure, introduction of all joints between concrete blocks with non-linear constitutive law, application of all loads with the real loading history, and, in the same time, calibrating the model using the measured data.

In our opinion, it is possible to fulfil these requirements, but this job requires much effort, and it is time consuming.

Despite the rapid progress of the computer techniques, to perform a three-dimensional stress-strain analysis of such a complex structure, as a dam is, it is not yet an easy task.

8. PARTICIPANT´S CONCLUSSIONS

TEPCO & UNIVERSITY OF COLORADO

2D analysis captured almost exactly the dam response except for the time period 2000/04 and 2000/10. There does not seem to be much arch action in this dam.
Results for the relative displacement from intermediate to lower gallery in 2D analysis point to a smaller elastic modulus.
Improved results could be obtained if we were provided with the exact history of the air temperature, the dam body temperature (including summer values), and more information regarding local radiation.

9. OVERALL CONCLUSIONS

Despite all different assumptions, load hypothesis, models, etc. almost all participants have identified:

1. Either dam body and/or foundation rock may be less stiff than expected
2. Temperatures can not be properly modelled with the available data, though they seem don´t either give a full explanation of the behavior in any realistic hypothesis.
3. Non-linear effects, particularly sliding in the joints, may be influencing the solution
4. Irrecoverable movements have not been identified