International Symposium
Qualification of dynamic analyses of dams and their equipments
and of probabilistic assessment seismic hazard in Europe
31th August – 2nd September 2016 – Saint-Malo

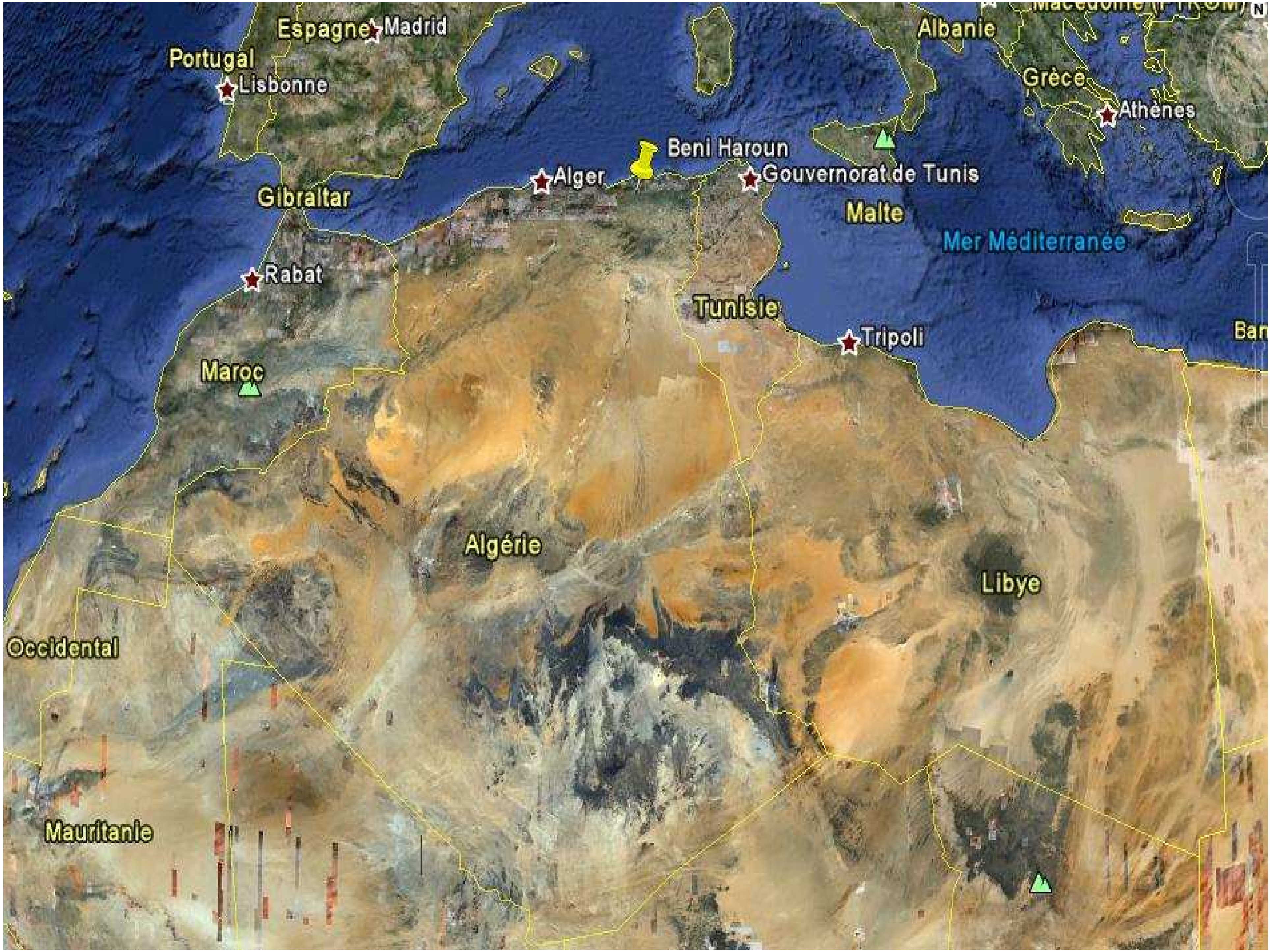
Patrick Lignier

Session :

SAFETY ASSESSMENT OF BENI-HAROUN DAM UNDER SEISMIC LOADING

SUMMARY

1.PRESENTATION OF BENI-HAROUN DAM



Espagne
Madrid
Portugal
Lisbonne
Albanie
Grèce
Athènes
Beni Haroun
Alger
Gouvernorat de Tunis
Gibraltar
Malte
Mer Méditerranée
Rabat
Tunisie
Tripoli
Maroc
Algérie
Libye
Occidental
Mauritanie

PRESENTATION OF BENI-HAROUN

- **RCC GRAVITY DAM**
  - Height : 118 m
  - Lenght : 710 m
  - Upstream slope : Vertical
  - Downstream slope : 0,8H/1V

- **Spillway**
  - Discharge 13 700 m^3/s
  - Free OGEE weir 114 m

- **Hydraulics level**
  - Full Supply level 200m
  - Maximum Water level 214, 8 m
  - Crest level 216,3 m

PRESENTATION OF BENI-HAROUN

- **MAIN DATES**
  - Works 1997 - 2003
  - Start of the impounding 2004
  - Additional grouting and drainage to control uplift 2005- 2011
  - Full supply level 2012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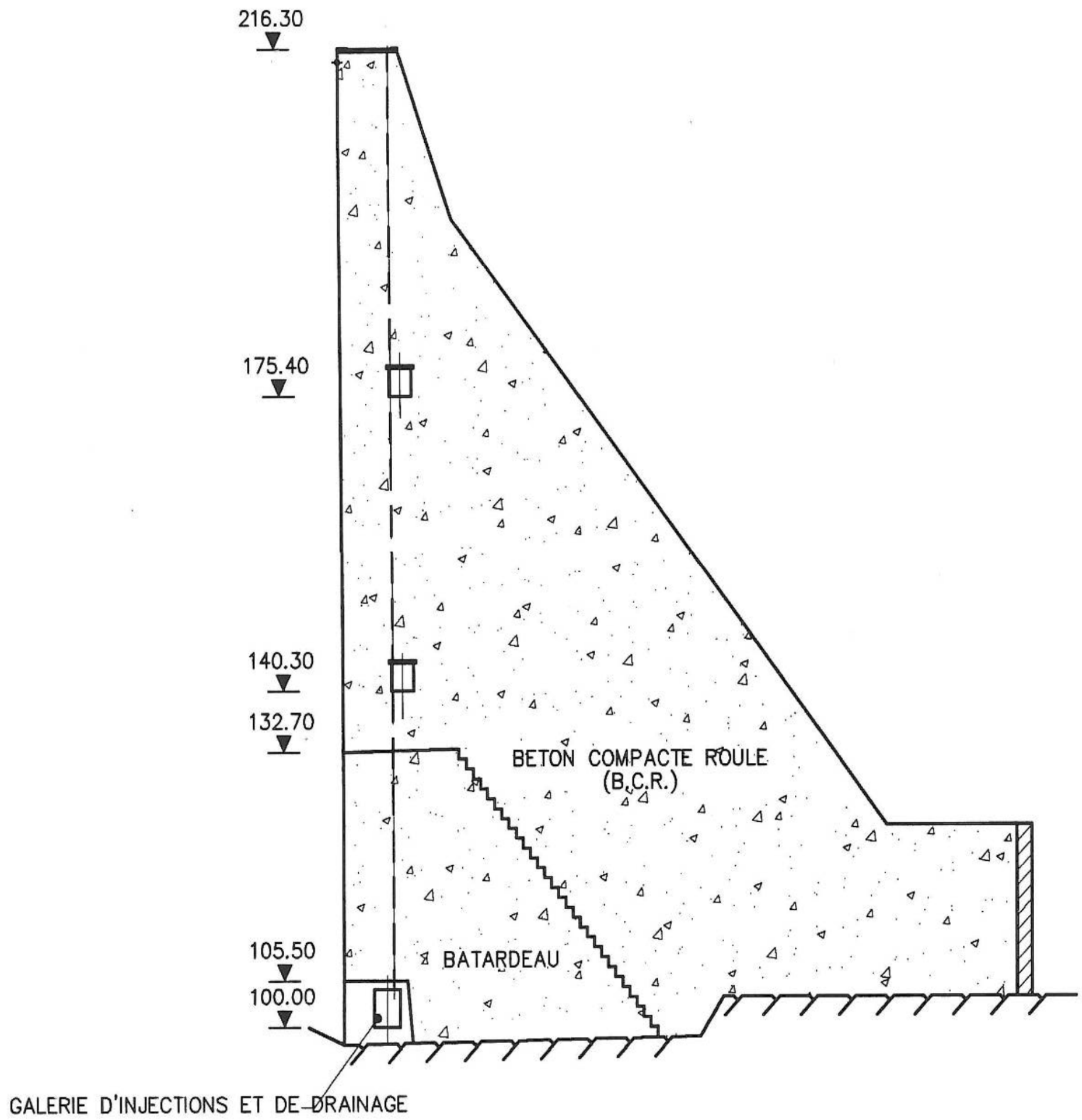
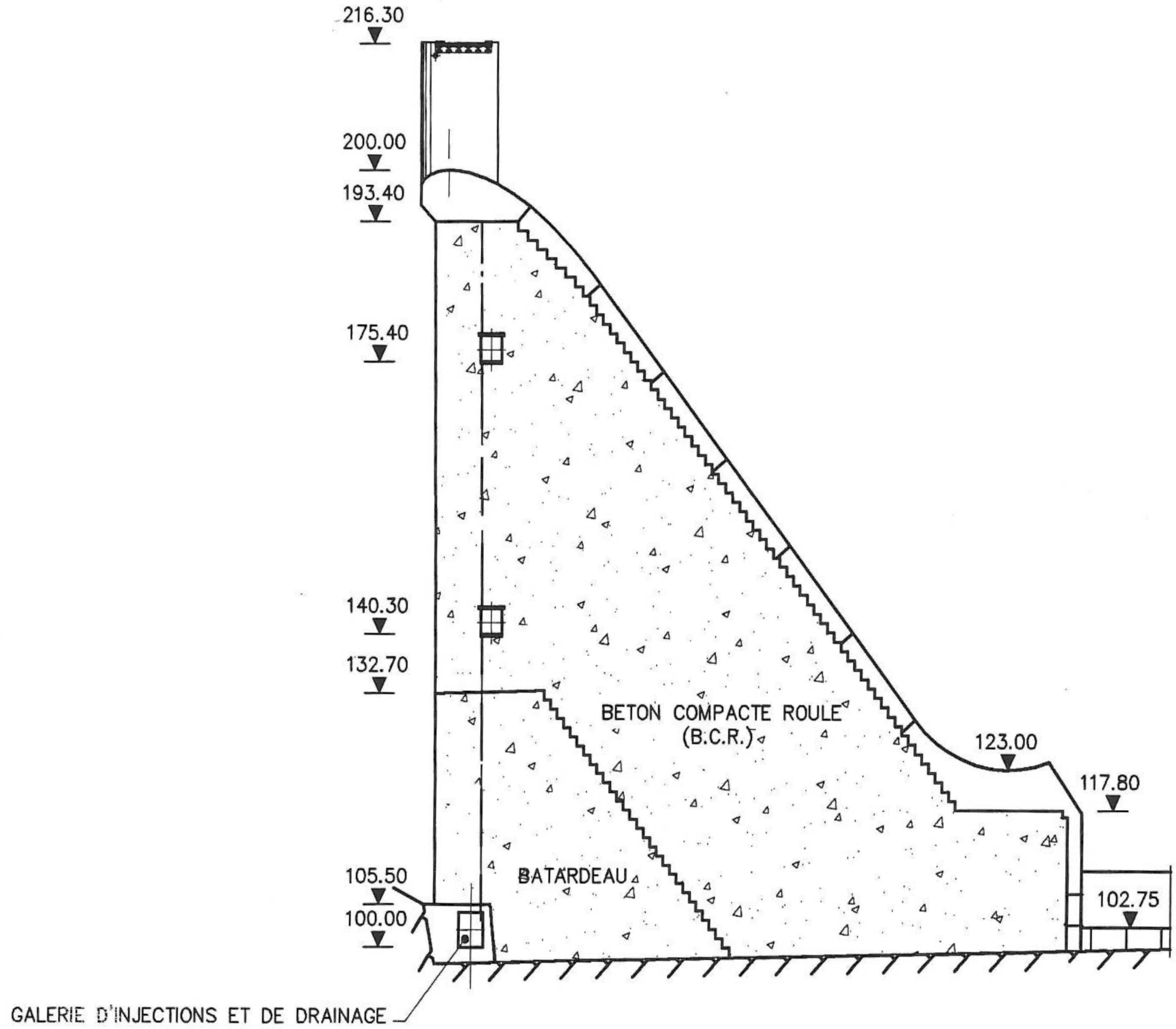


COUPE PLOT NON DEVERSANT

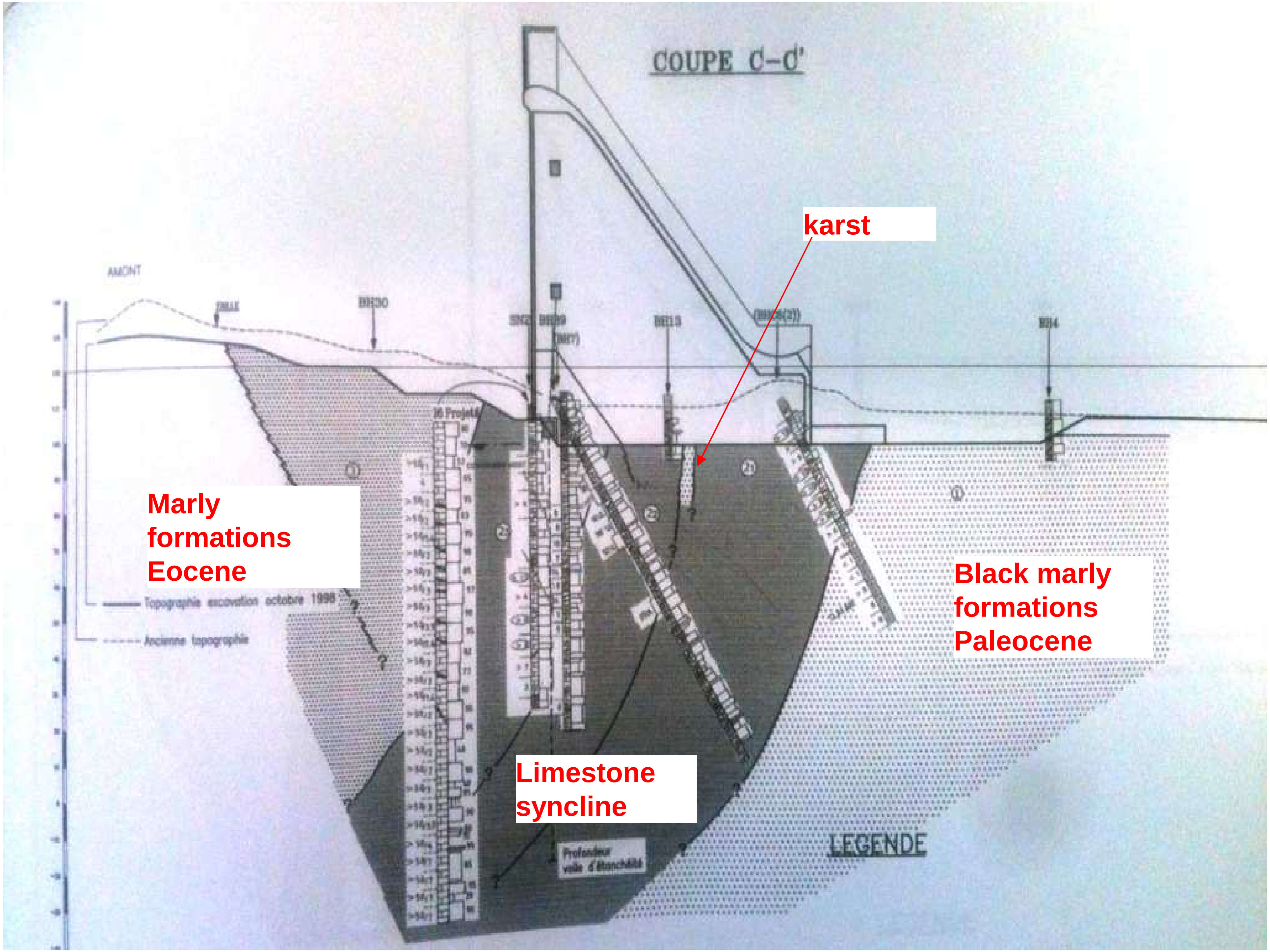


COUPE EVACUATEUR DE CRUES

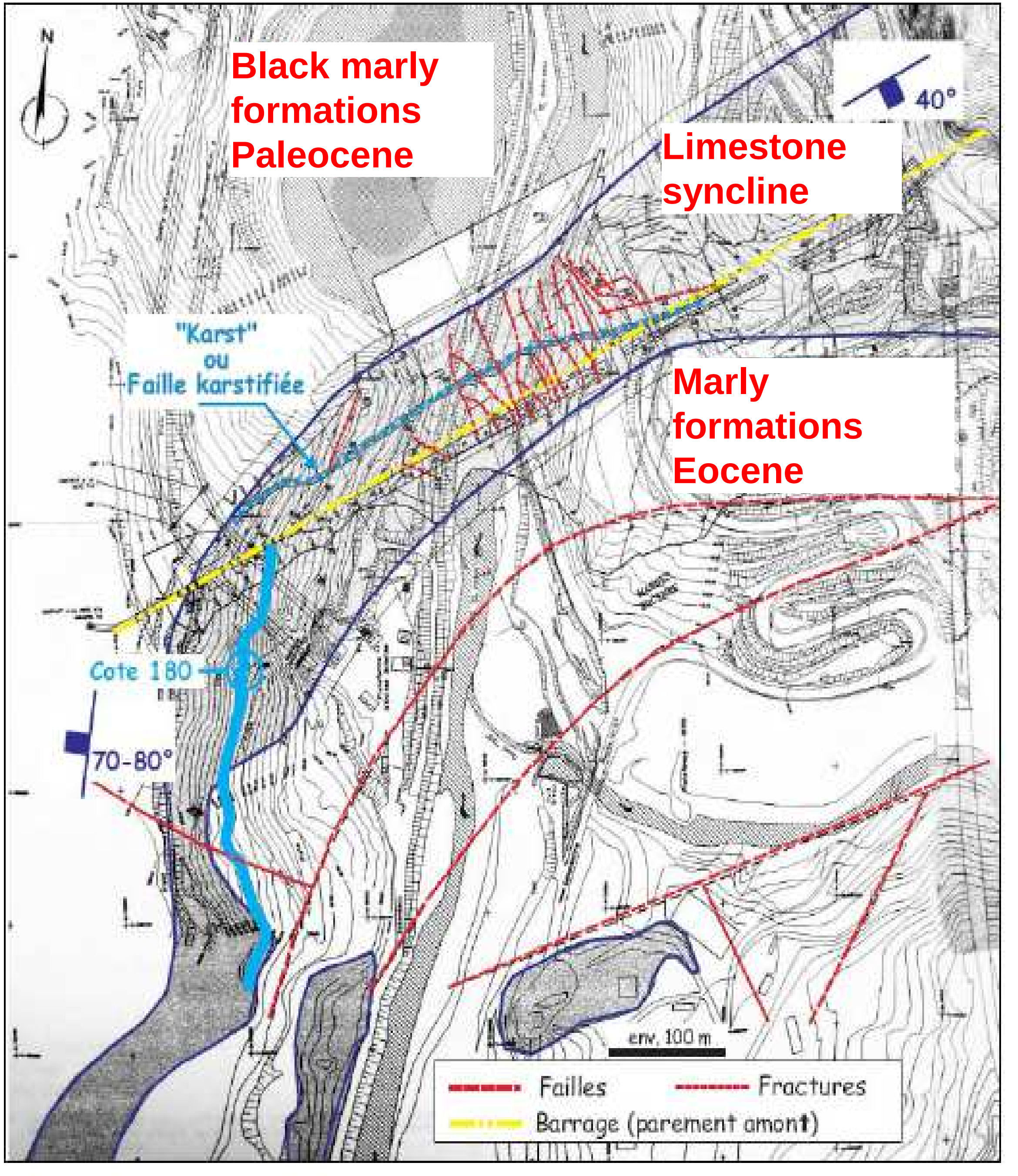
PRESENTATION OF BENI-HAROUN

- **REGIONAL GEOLOGY**
  - Complexe regional context
  - Displaced and superposed Nappe de charriage
  - Presence of karsts

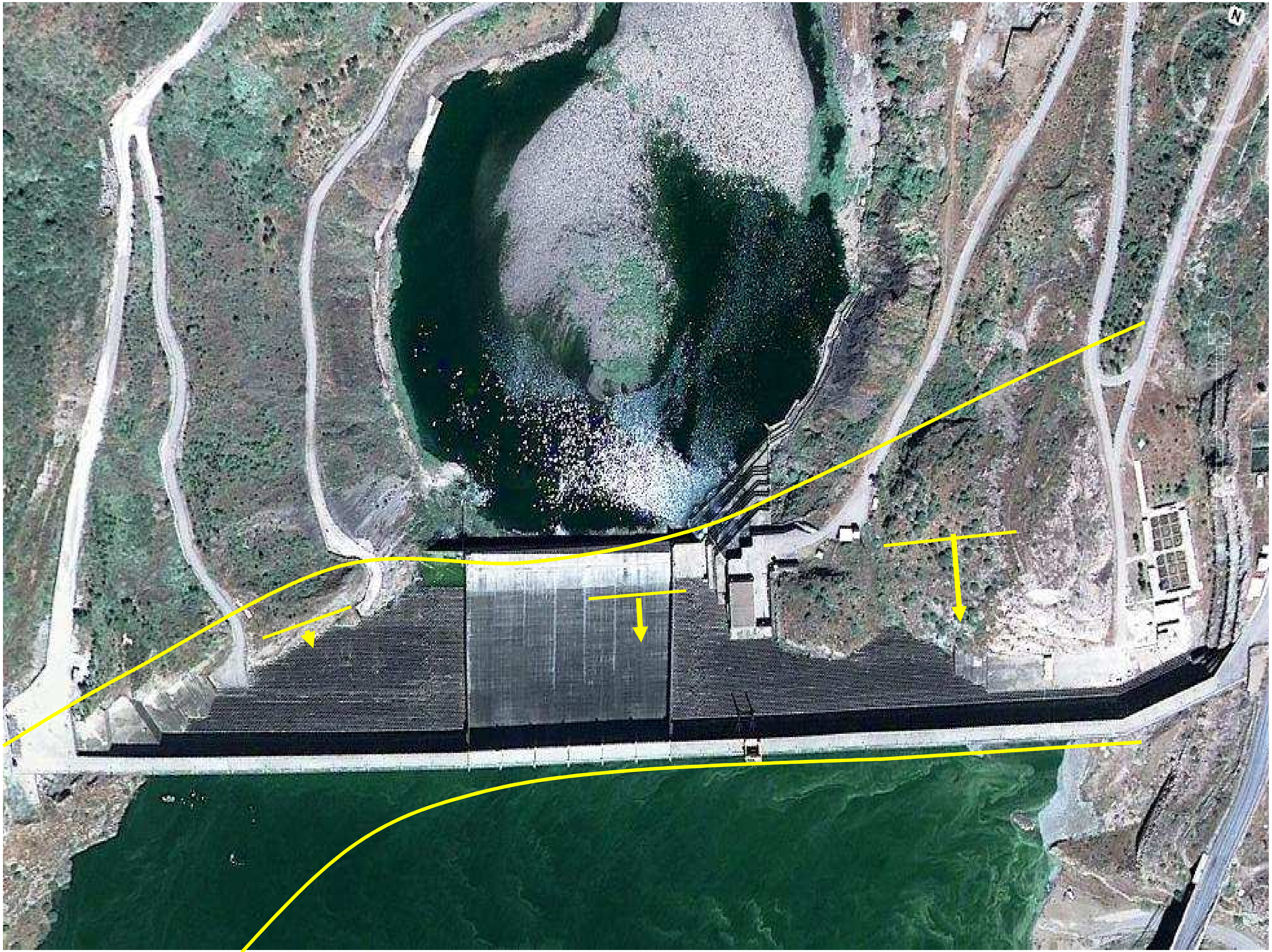
- **SITE GEOLOGY**
  - Upstream : Marly formations of Eocene age
  - Foundation : Syncline limestone marl (The southern flank of the syncline flushes in the reservoir about 300 m u/s from the dam)
  - Downstream : Black marly formation of Paleocene age



COUPE C-C'
karst
AMONT
Marly formations Eocene
Topographie excavation octobre 1998
Ancienne topographie
Black marly formations Paleocene
Limestone syncline
Profondeur voile d'étanchéité
LEGENDE



N
Black marly
formations
Paleocene
40°
Limestone
syncline
"Karst"
ou
Faille karstifiée
Marly
formations
Eocene
Cote 180
70-80°
env. 100 m
Failles
Fractures
Barrage (parement amont)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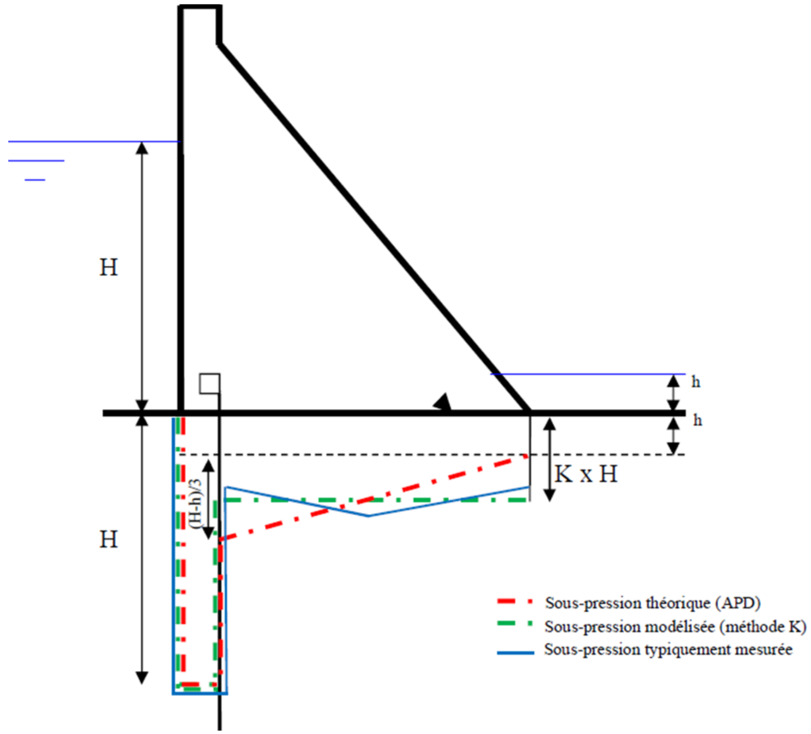
PRESENTATION OF BENI-HAROUN

- **MATERIAL CHARACTERISTICS - DAM**
  - Dynamic Young modulus 30 Gpa
  - Poisson ration 0,2
  - Density 2,35 t/m3
  - Cohesion 0
  - Friction angle 40°

- **MATERIAL CHARACTERISTICS - FOUNDATION**
  - Dynamic Young modulus 15 Gpa
  - Poisson ration 0, 33
  - Cohesion 0
  - Friction angle 45°

PRESENTATION OF BENI-HAROUN

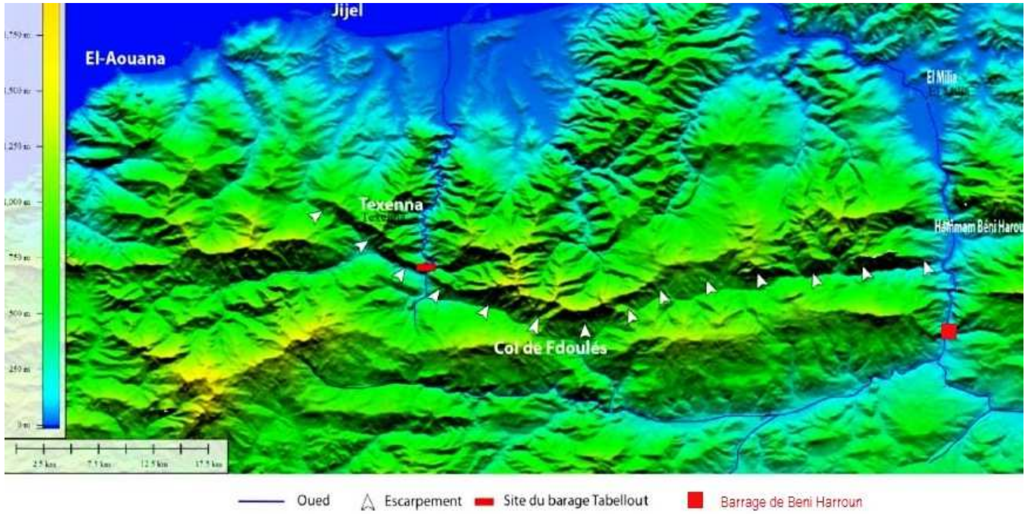
- **UPLIFT**



2.SEISMIC HAZARD

SEISMIC HAZARD

- **TABELLOUT DAM**
  - Discovery of active faults during the construction of Tabellout dam
  - Re-evaluation of the regional seismic hazard



SEISMIC HAZARD

- **BENI HAROUN DAM**

Earthquake	Return period [years]	PGA [g]	
		Old Values	New Values
Operating Basis Earthquake	200	0.17	0.25
	500	-	0.36
Safety Evaluation Earthquake	1 000	0.3	0.45
	10 000	-	0.69

SEISMIC HAZARD

- **Accelorogramms**
  - 8 accelerogramms records selected from Pacific Eartquake Engineering Research international data base which match with the Beni-Haroun site spectra
  - 3 near fields accelogramms and 4 far fields accelogramms
  - 1 local accelogramm (Boumerdes)

	Accelerogram	Year	Magnitude Mw
Near field	Loma Prieta	1989	6.93
	Cape Mendocino	1992	7.01
	Kobe	1995	6.9
Far field	Loma Prieta (Coyote Lake Dam)	1989	6.93
	Cape Mendocino (Loleta Fire Station)	1992	7.01
	Duzce (Mudurnu)	1999	7.14
	Cape Mendocino (Shelter Cove Airport)	1992	7.01
Local	Boumerdès	2003	6.8

3.PSEUDO-STATIC CALCULATIONS

PSEUDO-STATIC CALCULATIONS

LOADING	UPLIFT	SAFETY FACTOR
FSL	MEASURED	1.77
FSL + SBE	MEASURED	1.09
FSL + SEE	MEASURED	0.31
FSL	TRIANGULAR	1.34

4.SIMPLIFIED APPROACH

SIMPLIFIED APPROACH

- **TARDIEU SIMPLIFIED APPROACH - ASSUMPTIONS**
  - Dam is considered as a simple resonator (traingular prism) with two degrees of freedom (transaltion and bending parallel to the dam axis)
  - The height of the prism « H » is the height of the dam
  - The dam is founded on rigid rock
  - The effects of eathquake ban-to-bank hhorizpntal coponent is neglected

- **TARDIEU SIMPLIFIED APPROACH - RESULTS**
  - Empty reservoir N = 0,23 S/H N= 4,5 Hz
  - Full reservoir N = 0,17 S/H N = 3,3 Hz

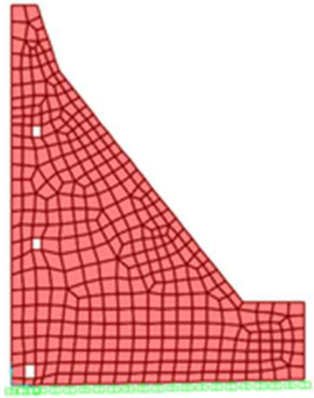
SIMPLIFIED APPROACH

- **CHOPRA SIMPLIFIED APPROACH**
  - Empty reservoir   N= 3,9 Hz
  - Full reservoir   N = 3,3 Hz

4.ELASTIC FINITE ELEMENTS MODELLING

2D ELASTIC FE MODELLING

- **MODEL : Rigid foundation**



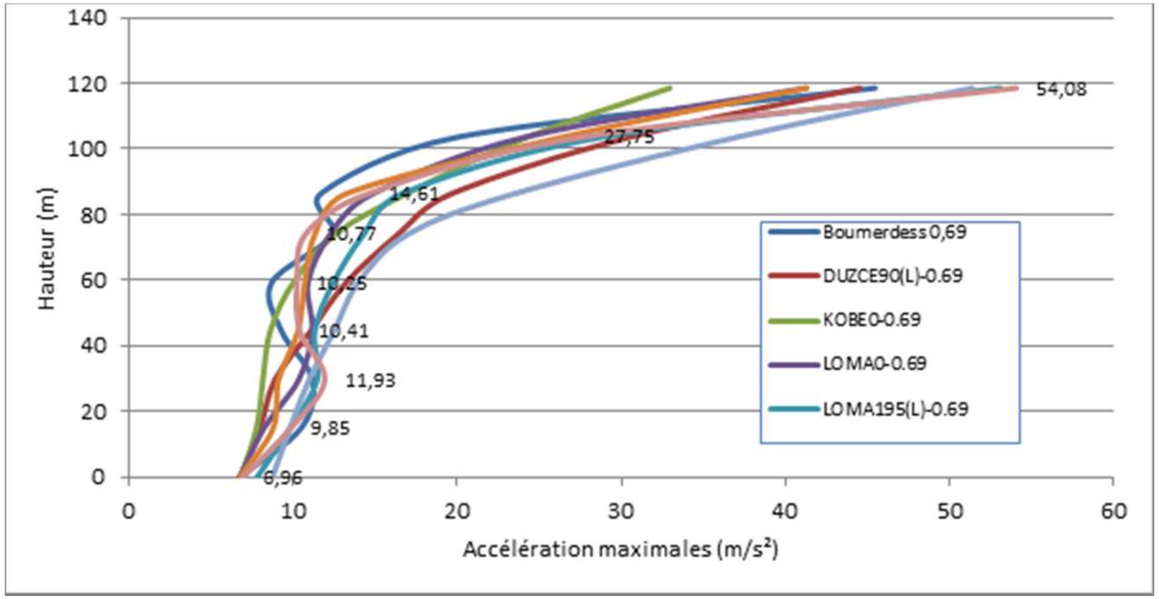
- **Assumptions**
  - Foundation : Massless
  - Damping (Dam & foundation) : 7% (OBE) – 10% (SEE)
  - Westergaard attached massed

2D ELASTIC FE MODELLING

- **Natural frequencies**

	Empty reservoir	Full reservoir
FE model 1	3.8	3.3
Tardieu	4.5	3.3
Chopra	3.9	3.3

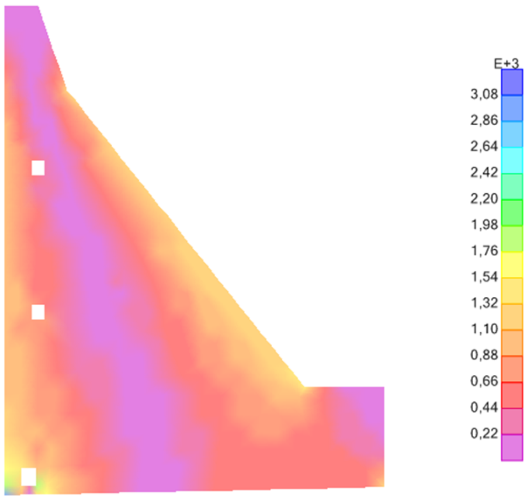
- **Acceleration evolution – Amplification ratio : 4 - 8**

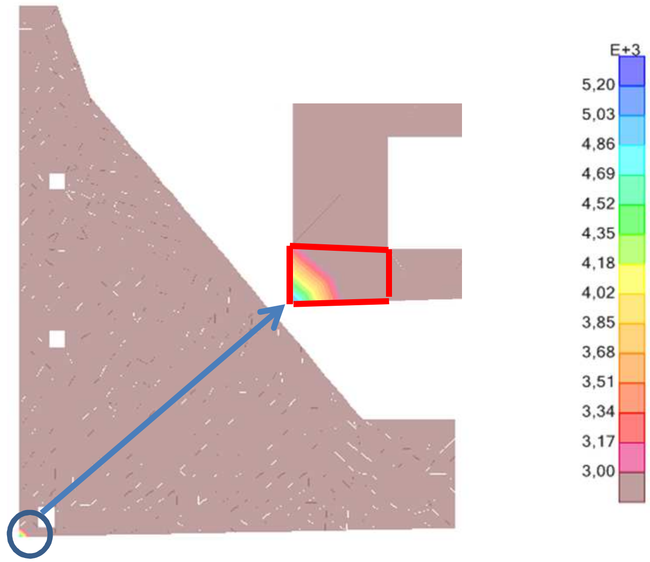


2D ELASTIC FE MODELLING

- **MAXIMUM STRESSES**

  - Compressive stresses 6 MPa
  - Tensile stresses 4 Mpa

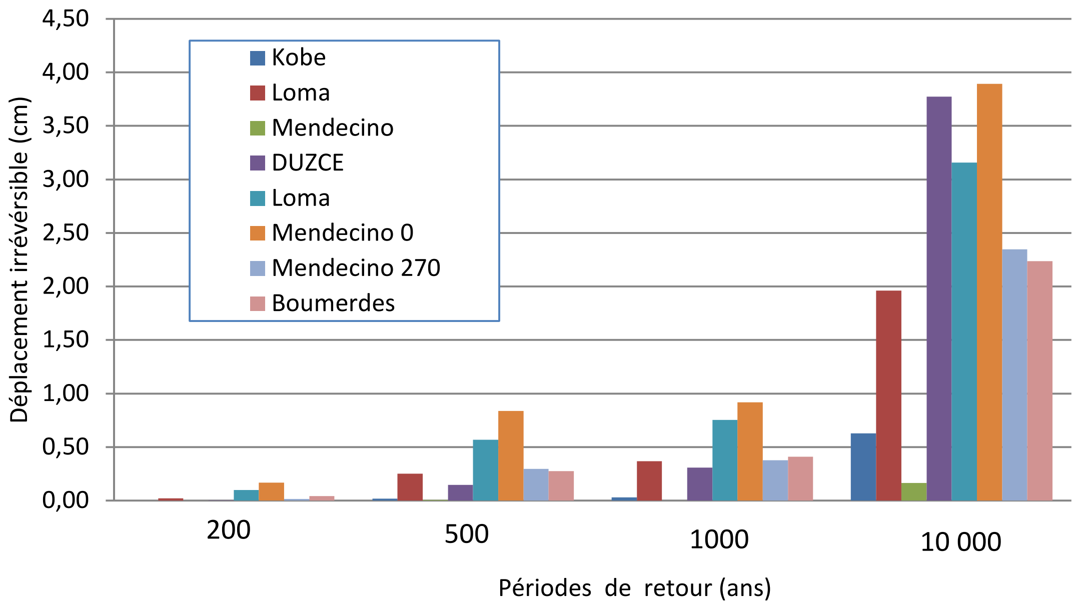




5.IRREVESIBLE DISPLACEMENTS

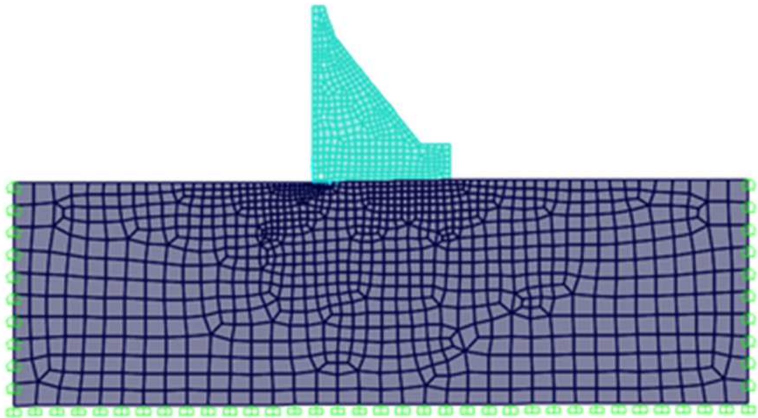
IRREVERSIBLE DISPLACEMENTS

- **NEWMARK'S APPROACH – IRREVERSIBLE DISPLACEMENTS**
  - O.B.E 0 – 2 mm
  - S.E.E 5 – 40 mm



IRREVERSIBLE DISPLACEMENTS

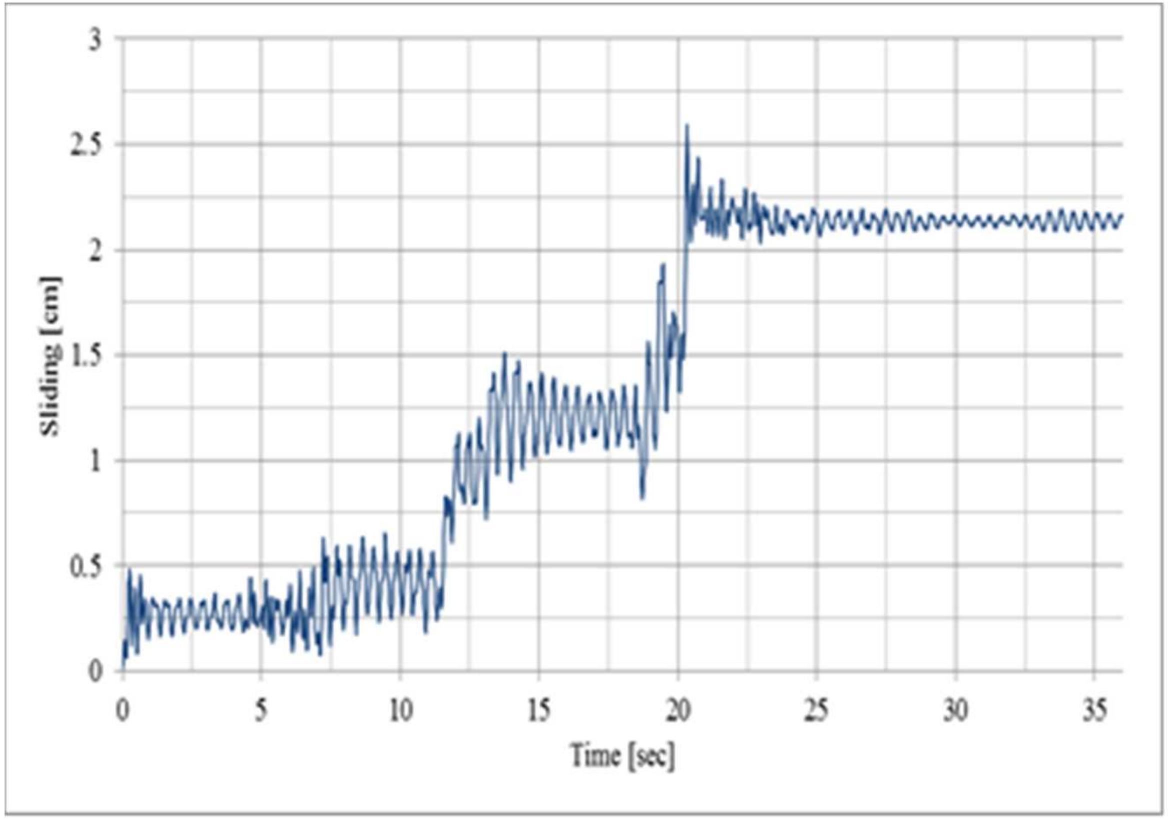
- **NON LINEAR MODELLING – 2 D EF CALCULATIONS**



- **Assumptions**
  - Foundation : Massless
  - Damping (Dam & foundation) : 10% (SEE)
  - Westergaard attached massed
  - Contact friction behaviour law at hte interface between dan body and foundation (c=0 , φ =45°)

IRREVERSIBLE DISPLACEMENTS

- **NON LINEAR MODELLING – 2 D EF CALCULATIONS**
  - Accelegramm : MENDOCINO « Shelter Cove Airport «
  - Irreversible displacement : 21 mm (Peak 25 mm)



6.ESTIMATION OF POST SEISM UPLIFT

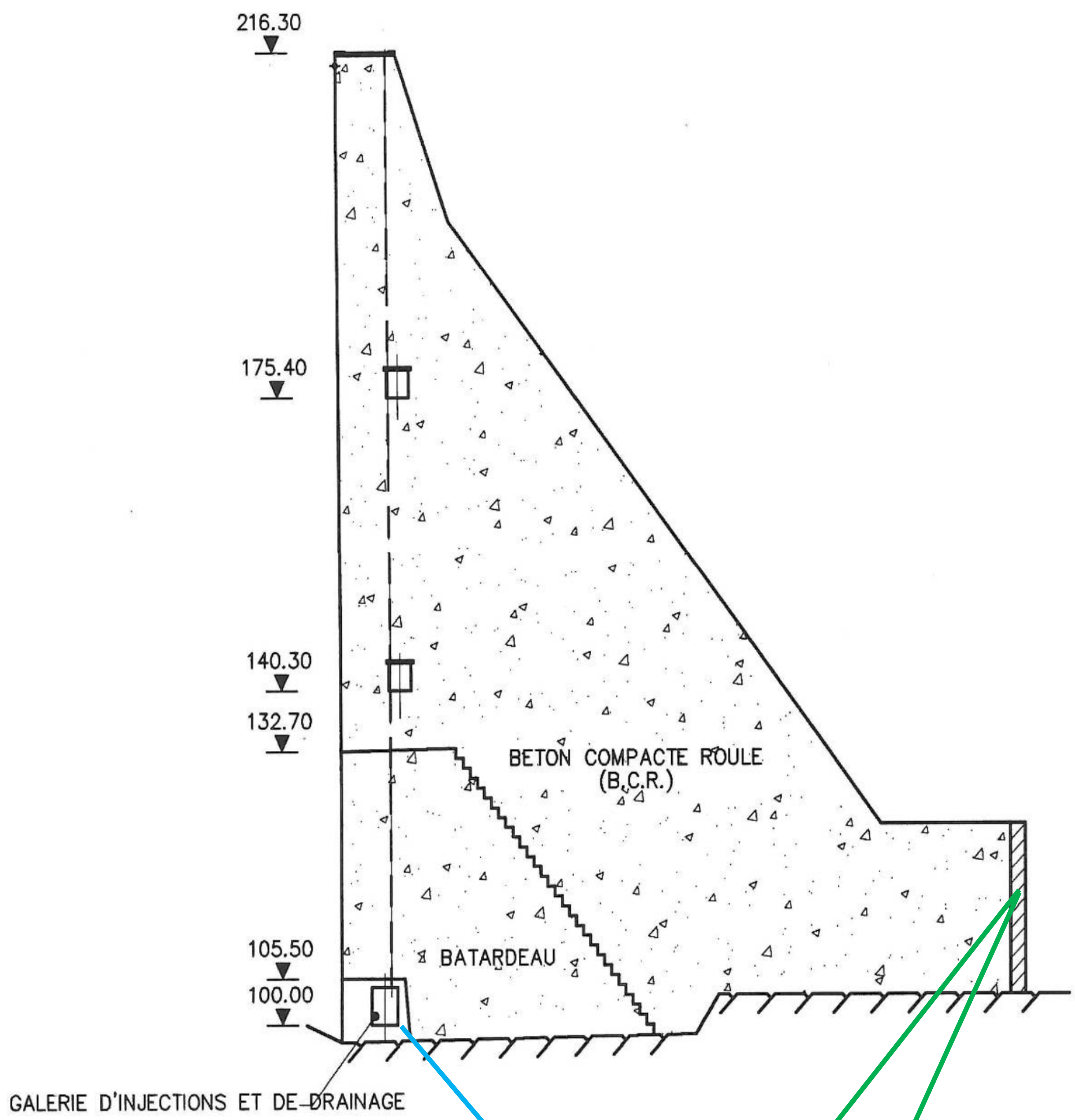
ESTIMATION OF POST SEISM UPLIFT

- **TWO ASSUMPTIONS CAN BE MADE**
  - The movement occurs in the plane of contact between the concrete and the rock foundation (one crack)
  - The movement affects a certain thickness of the rock foundation (several cracks)

ESTIMATION OF POST SEISM UPLIFT

- **Estimation of the drain seepage in one crack at the contact dam/foundation**
    - Crack opening e : 15% of sliding due to dilatancy
    - Flow velocity (turbulent very rough flow regime) v = $V = (4\sqrt{\varepsilon g}\ln(\frac{1.9}{R_r}))\sqrt{J_r}$
    - Drain discharge : Q = 6 . v . e

Irreversible displacement	40 mm	21 mm
e (mm)	6	4
V (m/s)	4,8	3,5
U/S drain : Q (l/s)	170	65
D/S drain : Q (l/s)	60	22



COUPE PLOT NON DEVERSANT

ESTIMATION OF POST SEISM UPLIFT

- **Estimation of the drain seepage located in several cracks within the rock foundation**
  - Number of cracks : 10
  - Crack opening e: 15% of sliding due to dilatancy
  - Equivalent permeability (Maini & Hocking) K = e3 . F. g/(12 Vc . B. C)

Irreversible displacement	40 mm	21 mm
e (mm)	0,6	0,3
K (m/s)	2,7 10^{-5}	3,9 10^{-6}
Q l/s	24	3

  - The drains are not saturated.

7.CONCLUSION

CONCLUSION

- RE-EVALUATION OF THE DYNAMIC BEHVIOUR OF BENI-HAROUN DAM
- FIRSTLY, SIMPLIFIED METHODS TO IDENTIFY THE FREQUENCIES OF THE DAM
- SECONDLY, A FE 2D MODEL TO ASSESSMENT THE ACCELERATION AND STRESSES EVOLUTION
- THIRDLY, NEWMARK'S APPROACH AND A FE 2D NON LINEAR MODEL TO ESTIATE THEIRREVERSIBLE DISPLCAMENTS
- FINALY, ESTIMATION OF THE INCREASE OF DRAIN DISCHARGE AND CAPACITY OF THE DRAINAGE SYSTEM TO CONTROL THE UPLIFT POST SEISM

THANK YOU FOR YOUR ATTENTION