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DUSHANBE_RCC_FGU

ROLLER COMPACTED CONCRETE (RCC) DAMS IN TURKEY

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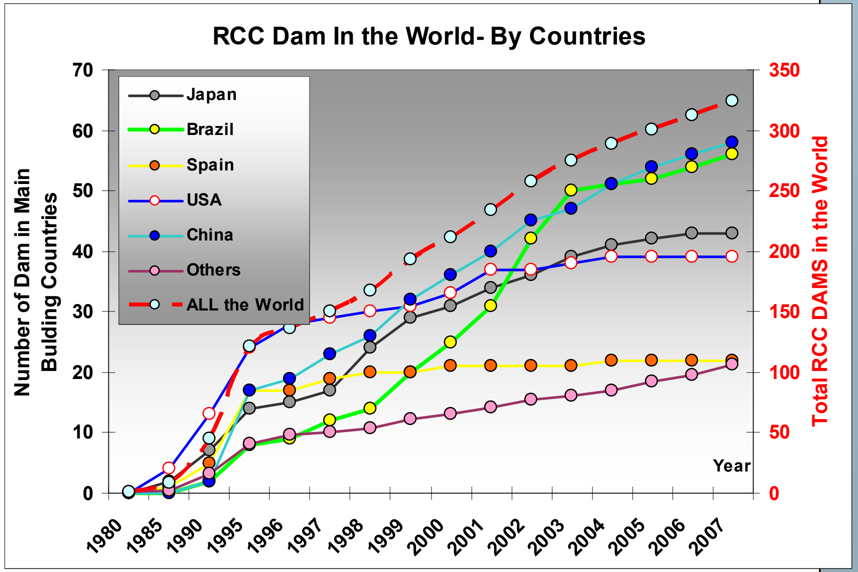
INTRODUCTION

Roller Compacted Concrete Dam (RCCD) is an innovative way of constructing the gravity dams.

Roller Compacted Concrete (RCC) has been developed in the last 30 years and became very efficient and economical construction material for mass concrete structures as compared with conventional concretes in gravity dams.



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RCC construction is based on simplicity:

It is a construction technique based on

making simple

but not making poorly and not having a chance of ignoring certain quality procedures.

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In the RCCD construction method,

- the fine and coarse aggregate, cement, pozzolanic material and other admixtures (if necessary) are mixed with water according to a mix design performed for the target strength requirements,
- transported to the dam site (by conveyors or by trucks),

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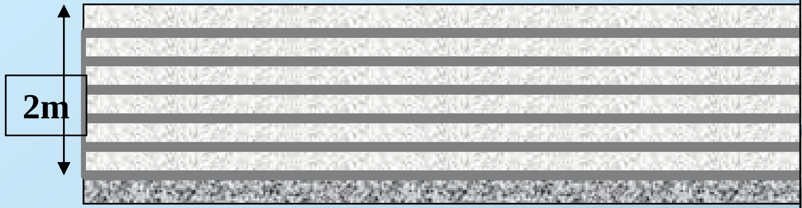
RCCD – TRADITIONAL METHOD

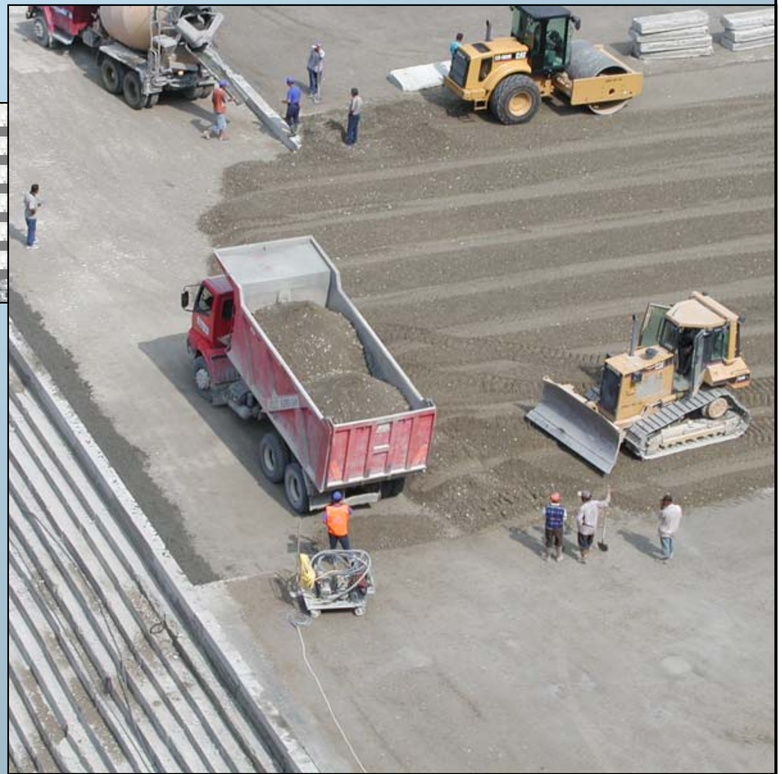
layers with h=0,33m



Base

RCC Layer

Bedding Mortar



- laid on in dry consistency (no slump) by using ordinary earthworks machinery usually in layers of 0.30 -0.35 m and
- compacted with vibrated cylinders in layers.

RCC Dam Design is a kind of art of “Materials of Construction Science”.

- Instead of designing the dam section for certain concrete classes, the method involves the geometrical design of the dam according to the stability and structural strength requirements;
- Evaluation of the related target strengths and performing RCC mix design in order to reach these strength values by using the local construction materials as much as possible.
- In the long term, the properties of hardened RCC will become similar to those of the conventional mass concrete if it is produced with convenient materials and following appropriate design and construction provisions.

Therefore, RCC can safely be used in mass concrete, large and thick foundations, continuous base floors, cofferdams, massive backfills and slope protection against overtopping in dams.

RCC dams have been applied increasingly in Turkey in the last 15 years in regard to the important advantages summarized below.

- RCC dam construction is **faster and simpler** as compared to other dam types,
- The **cost of RCC dams are much lower** than those of conventional concrete (CVC) dams, even than embankment dams,
- They are **safer than embankment dams**; economical seismic designs are possible in highly seismic earthquake regions and at locations close to active faults,
- They can be constructed **on relatively weaker rock foundations**. The elasticity modulus of the mixture can be adjusted according to the deformation characteristics of foundation rock,
- **Washing of the aggregate is not necessary** if the fine aggregate content smaller than 7.5 microns is lower than 10%,

- **Cementitious material content** is small in RCC mixtures.

The cementitious material content [Portland cement (C) + pozzolan/fly ash (P)] generally **varies between 50-300 kg/m3** based on the target strength requirements for design,

- Based on the cementitious material content, RCC can be classified as:

Hardfill - Low dosage I (C+P<100 kg/m3),

Medium dosage (100<C+P<150 kg/m3),

Rich mix - High dosage (C+P>150 kg/m3)

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- Casting by blocks or **cooling of the concrete are not necessary** to control the heat of hydration.
- **The continuity of the construction** is provided by successive dumping and compaction by cylinder,

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- The contraction joint spacings which are typically 12-15 m in conventional concrete dams may be **greater up to 35 m**,

Results of the Thermal Analyses.

Average monthly temperature data (C°)		Aggregate stockpile temperature (C°)	Concrete placement temperature (C°)	Peak concrete temperature (C°)	Estimated crack spacing (m)
Jan	8.5	14.1	11.5	24.5	411.4
Feb	9.9	12.8	11.9	24.9	320.0
March	11.7	13.7	13.5	26.5	190.6
April	16.2	14.9	16.9	29.9	99.8
May	21.2	17.9	21.2	34.2	62.1
June	26.0	21.3	25.5	38.5	45.1
July	28.8	24.5	28.5	41.5	38.1
Aug	28.2	26.4	28.7	41.7	37.6
Sept	24.1	26.0	25.8	38.8	44.4
Oct	18.3	23.2	21.0	34.0	63.2
Nov	13.8	19.3	16.7	29.7	101.9
Dec	10.5	16.3	13.5	26.5	187.7
Annual	18.1		30.0	43.0	35.2

The minimum crack spacing is determined as 35.2 m. However, due to the arrangements and construction sequences of various elements, the spacings between the contraction joints have been designed less than 30 m.

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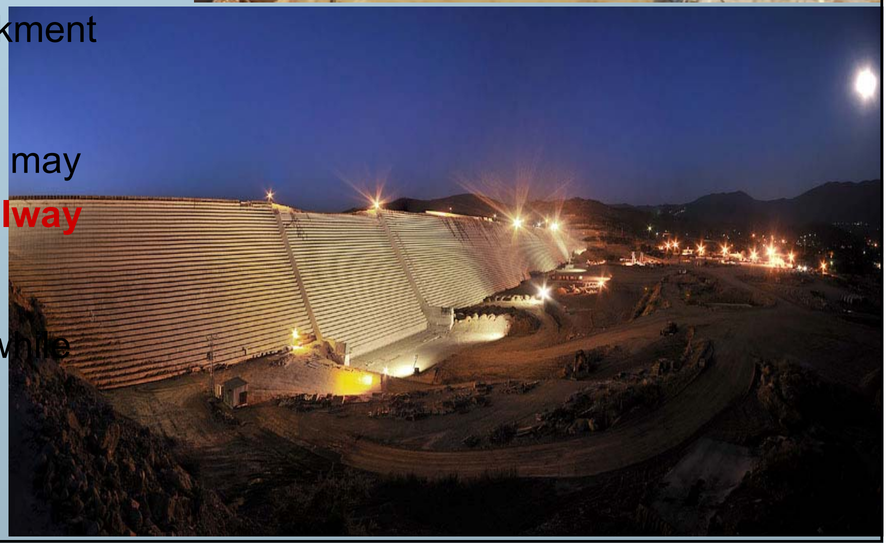
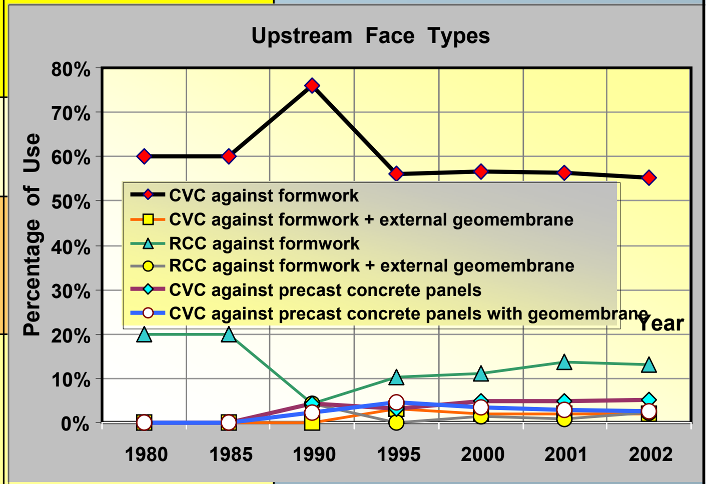
- **Formwork workmanship** is only necessary in upstream and downstream faces, and for some galleries
- **The spillway may be constructed on the dam body** and designed as controlled or uncontrolled according to downstream streambed conditions, therefore **spillway excavation** and **construction** which constitute an important cost in embankment dam projects **are not necessary**,
- **The dimensions of the stilling** basin may be reduced by making a **stepped spillway** for appropriate flow rates,
- **The water retention** may be started while dam construction is in progress.



FACES

FACE TYPE	PRESENT USE	PERFORMANCE AND USE	COUNTRIES OF MAJOR USE
CVC AGAINST FORMWORK	55%	TRADITIONAL AND WITHOUT USE HAS INCREASED	JAPAN, SOUTH AFRICA AND
RCC AGAINST FORMWORK	13%	ITS USE HAS DECREASED	
CVC AGAINST PRECAST CONCRETE PANELS	5%	ITS USE REMAINS CONSTANT	
RCC AGAINST FORMWORK + EXTERNAL GEOMEMBRANE	2%	ITS USE HAS INCREASED	
CVC AGAINST PRECAST CONCRETE PANELS WITH GEOMEMBRANE	3%	HAS BEEN USED ADDITIONALLY	USA



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FACES

CVC against Formwork and RCC poured at same time

Vibration of Grout Enriched RCC

External Geomembrane (Vandalizm!!!)

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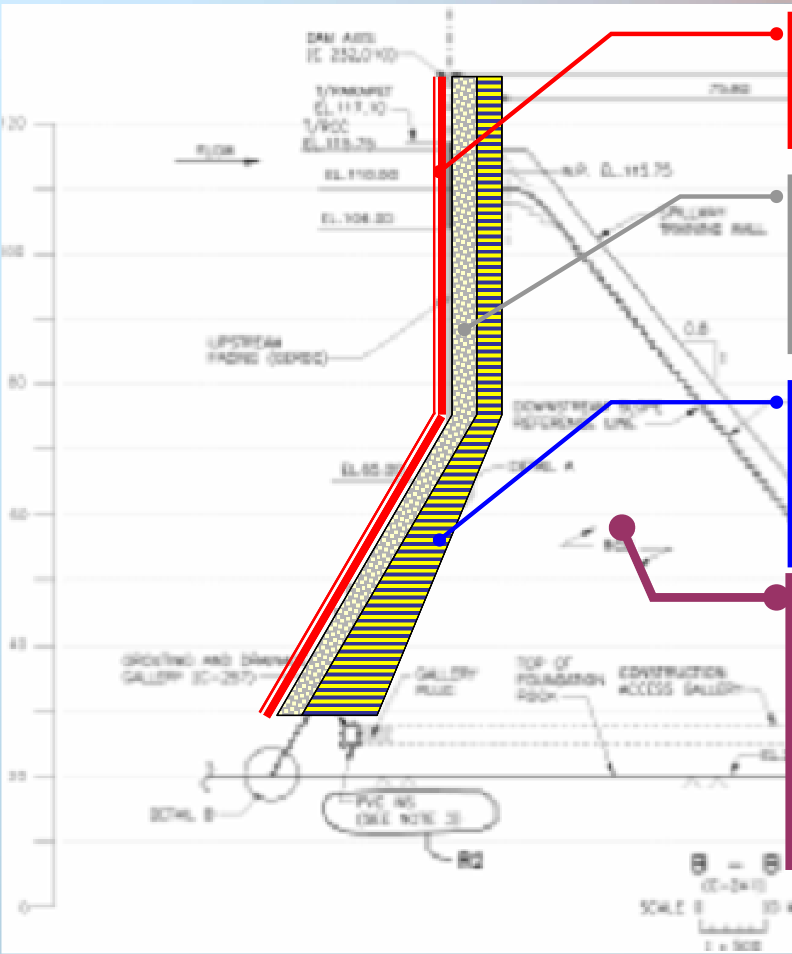

Pre- cast Concrete Element with PVC Membrane (2mm) Inside

CVC Concrete (≤ 200kg/m3) Placed at the same time as RCC Layers

Bedding mortar, between RCC Layers, for Cohesion and Tensile Resistance (Sbafety)

RCC Dam Body:

Cementitious Content JUST to support the Required Mechanical Properties Induced from the Stress Analysis

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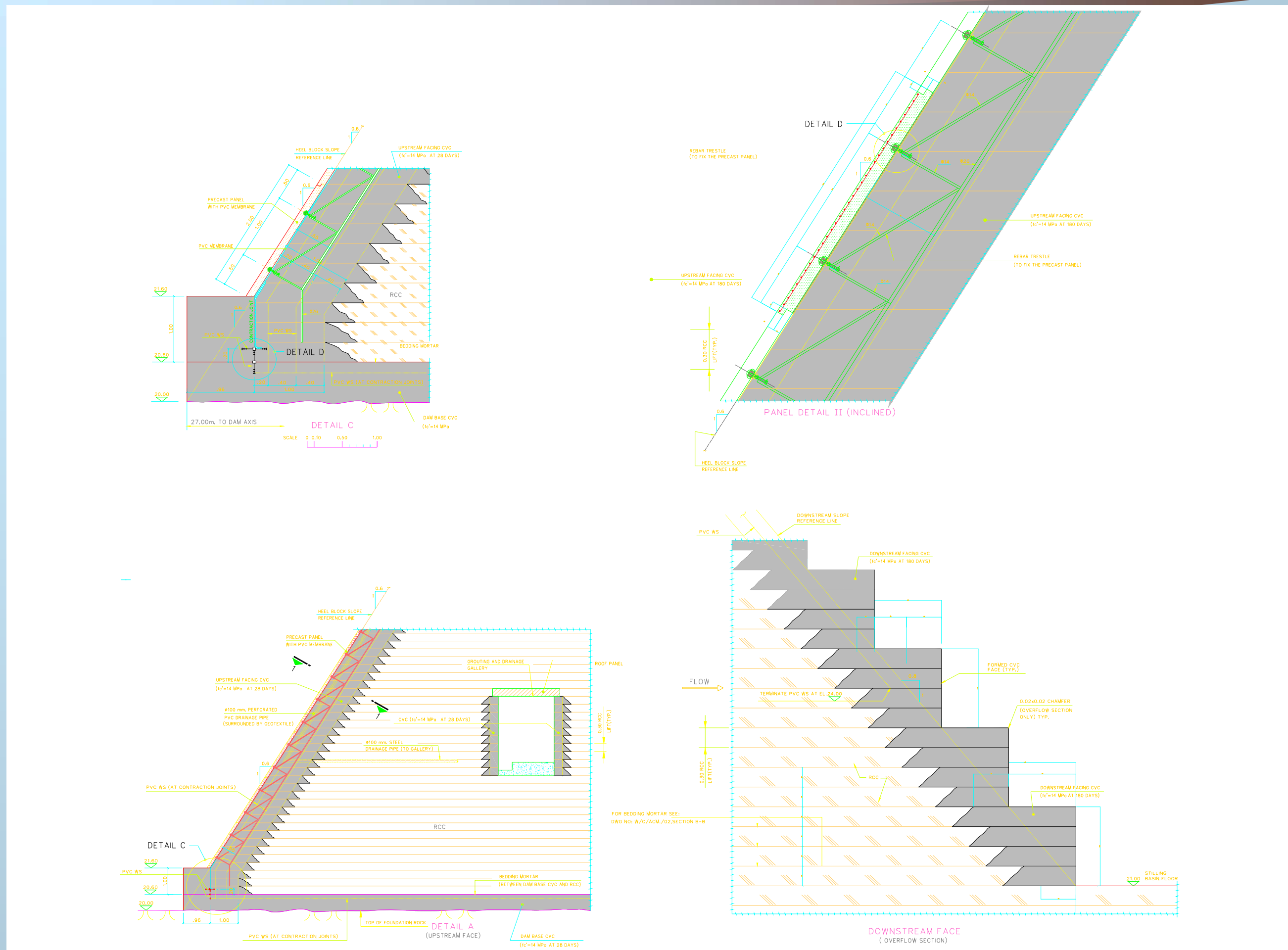

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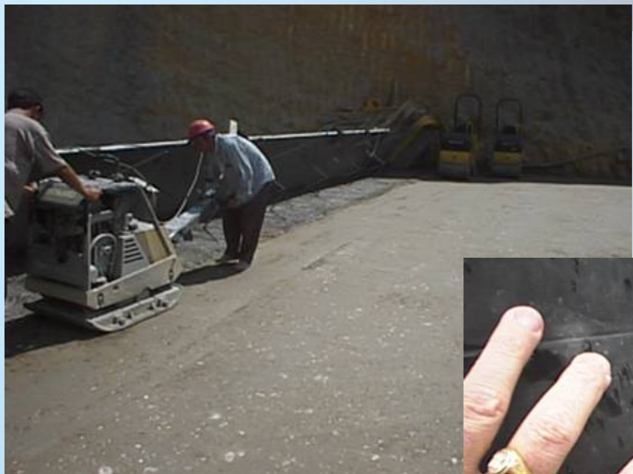

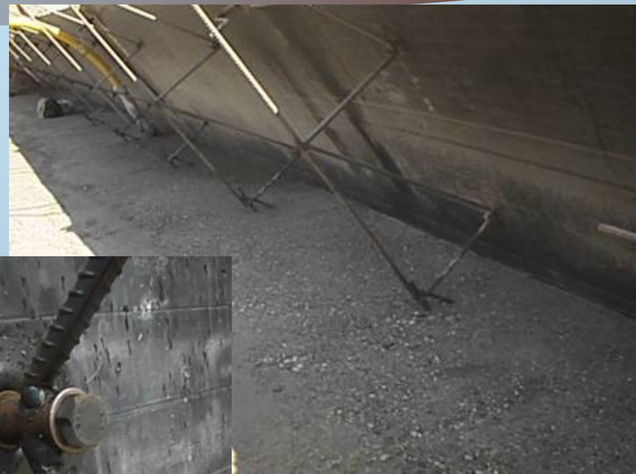

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STRUCTURAL DESIGN

- **Classical Gravity Analyses:**
  - To optimize the volume of the dam body.
    - Different upstream and downstream slopes.
- **Finite Element Analysis:**
  - To estimate the strength requirements of the RCC material.
    - Pseudo-static earthquake analyses,
    - Non-linear approach to simulate strain softening and stress redistribution.

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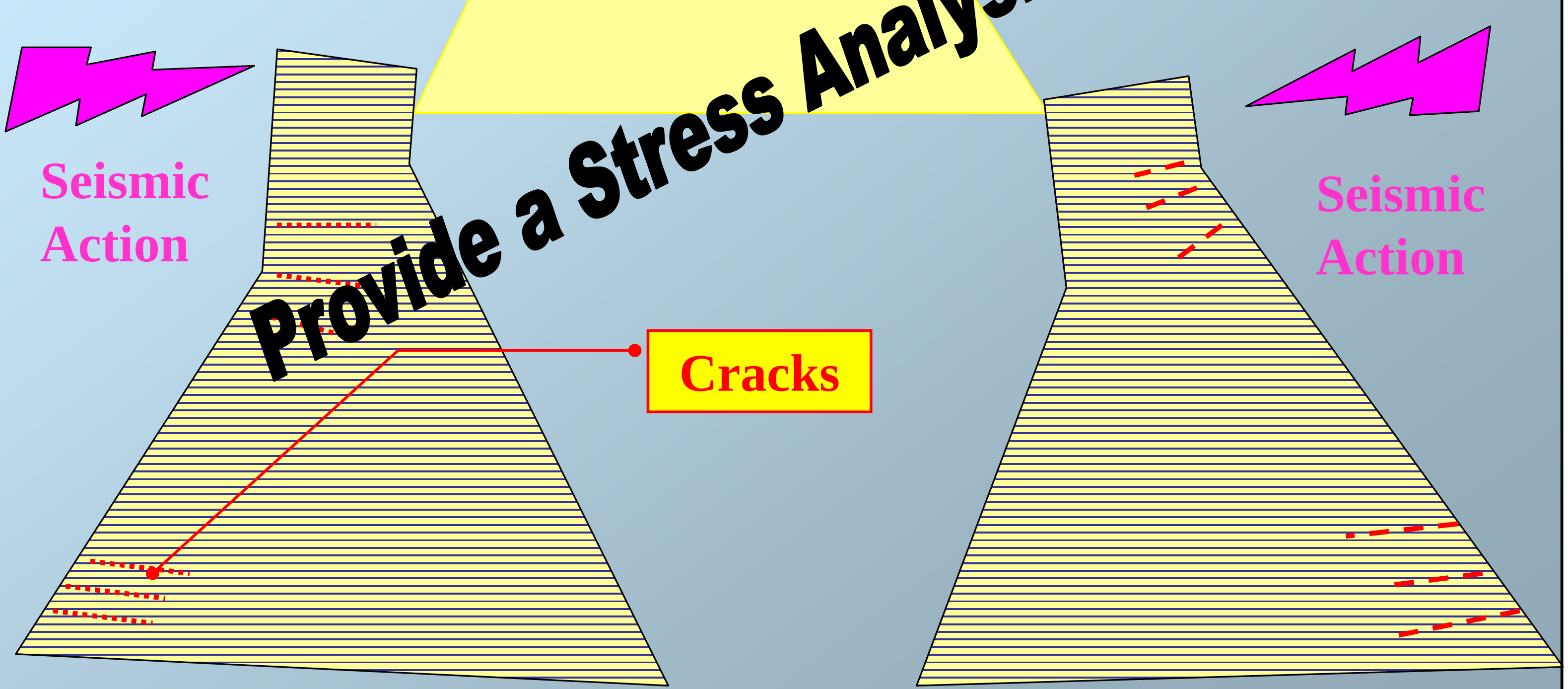
RCC dams are generally designed so that tensile stresses are not generated under normal conditions during the service life of the structure.

However, a specified level of tensile stress is allowed under unusual load conditions (such as earthquake loading). In these conditions, at the critical locations in terms of tensile stress (generally upstream face and downstream heel regions of the body.



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Results of the Stability Analyses (0.7 H : 1.0 V).

CLASSICAL GRAVITY ANALYSES

(Slope Optimization)

NO	UPSTREAM	DOWNSTREAM
1.	0.7 H : 1.0 V	0.7 H : 1.0 V
2.	0.6 H : 1.0 V	0.8 H : 1.0 V
3.	0.5 H : 1.0 V	0.9 H : 1.0 V
4.	0.4 H : 1.0 V	0.8 H : 1.0 V
5.	0.4 H : 1.0 V	0.9 H : 1.0 V
6.	0.4 H : 1.0 V	1.0 H : 1.0 V

Load case	SF overturn ing	SF sliding	Base pressure at toe (kPa)	Base pressure at heel (kPa)
End of construction	-	-	- 1681	- 1490
End of construction + EQ (OBE)	10. 04	2. 97	- 1198	- 1974
Service condition	2. 68	3. 86	- 1122	- 1312
Service condition + EQ (OBE)	2. 17	1. 40	- 638	- 1836
Service condition + EQ (MDE)	1. 97	1. 05	- 384	- 2111
Flood Case	2. 48	2. 90	- 1040	- 1440

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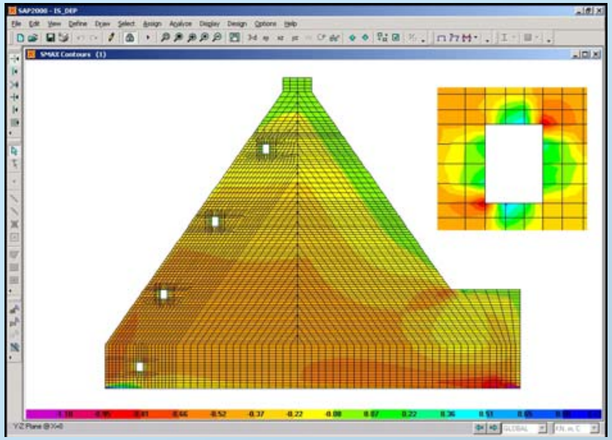
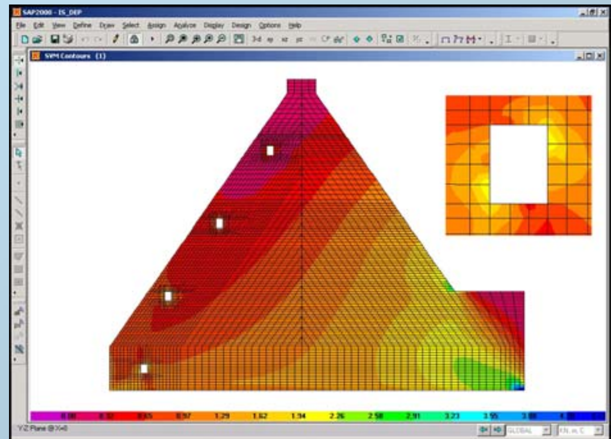
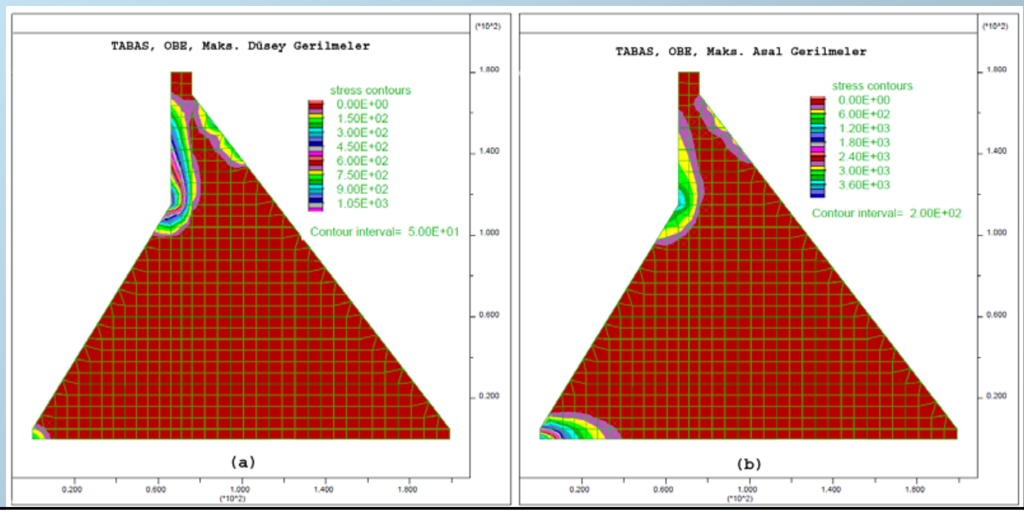
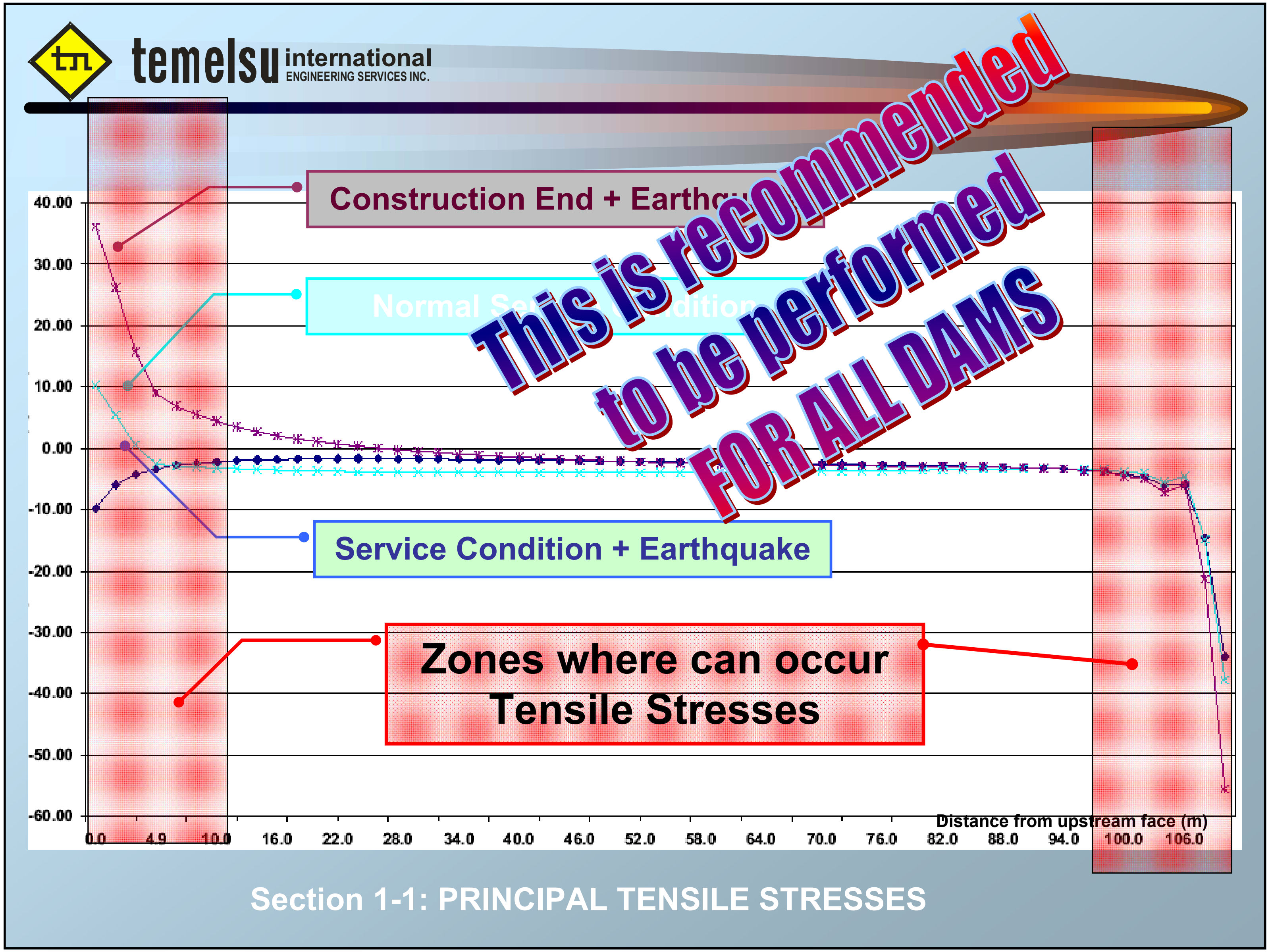
SERVICE CONDITION + OBE (a=0.2 g)







Hardfill type of dams with larger base dimensions are more economical especially in seismic regions of high ground accelerations and dam sites close to the active faults.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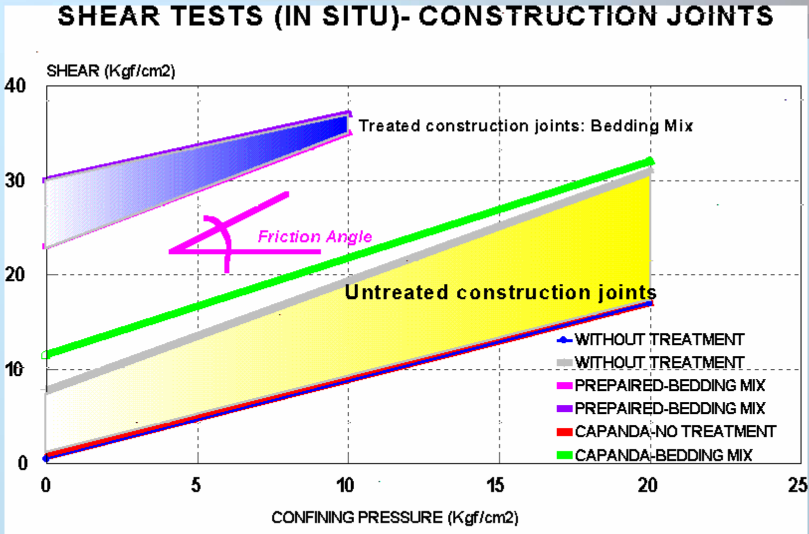
This is recommended to be performed FOR ALL DAMS
Construction End + Earthq
Service Condition + Earthquake
Zones where can occur Tensile Stresses
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
0.0
4.9
10.0
16.0
22.0
28.0
34.0
40.0
46.0
52.0
58.0
64.0
70.0
76.0
82.0
88.0
94.0
100.0
106.0
Distance from upstream face (m)
Section 1-1: PRINCIPAL TENSILE STRESSES



Joint improvement is applied by using high dosage cement mortar (bedding mortar) and the tensile and shear strength between the layers are increased.

In this way, fairly economical designs can be made **by zoning of the dam body according to the expected stresses** and using RCC mixtures of different strengths required for each zone.

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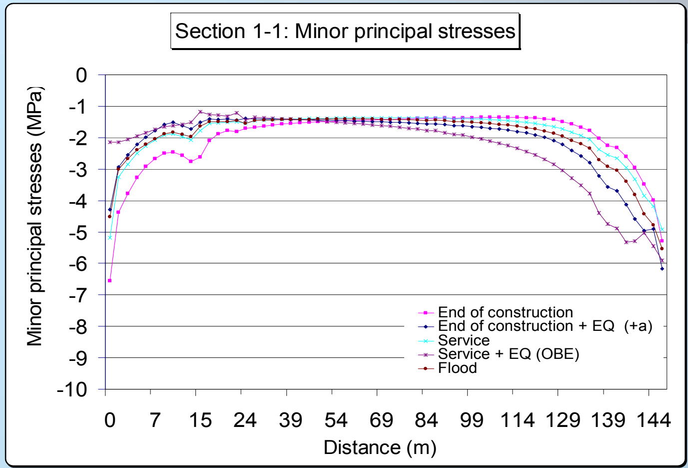

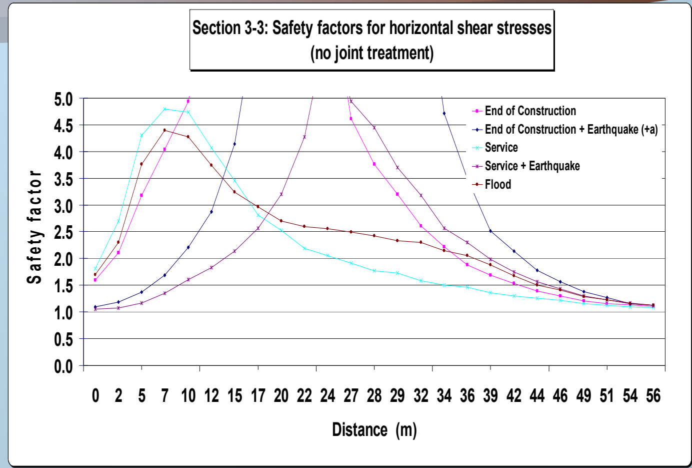

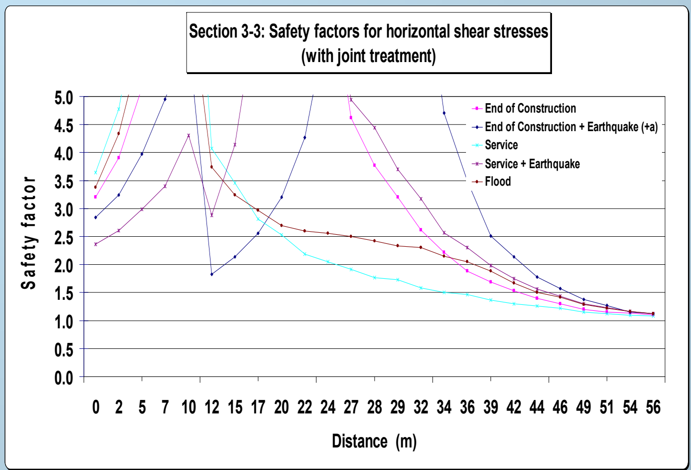

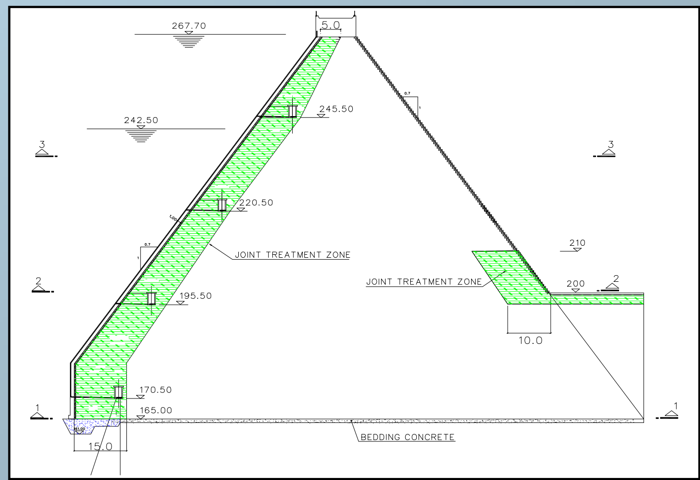

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MATERIAL PROPERTIES

THE STRENGTH REQUIREMENTS
in view of the analyses

Hardfill Mixture

Target Compressive Strength (180 d)

6.0 MPa

- **Cementitious material:**

  50 kg/m³ cement (OPC-42.5 type) + 20 kg/m³ fly ash

- **Three different well graded aggregate sizes for maximum density:**

  0-10 / 10-25 / 25-75 mm

Physical Properties

Material	Modulus of elasticity (kPa)	Unit weight (kN/m³)	Poisson ratio
Hardfill	1.0×10^7	24. 0	0. 22
Found. rock	5.0×10^6	23. 0	0. 20

Strength Properties

Material	180 d comp. Stren. (kPa)	180 d tens. stren. (kPa)	180 d cohes. stren. (kPa)	Inter. frict. angle (^{0})
Hardfill	6000	600	800	45
Bedding mortar	-	-	500	37
Found. rock	8000	800	200	25

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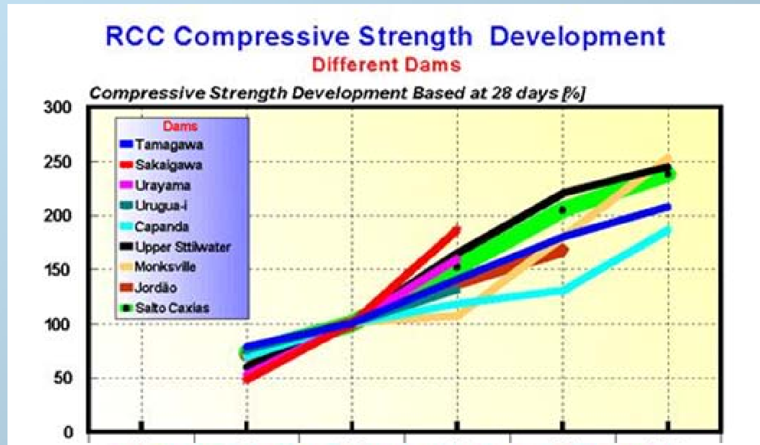
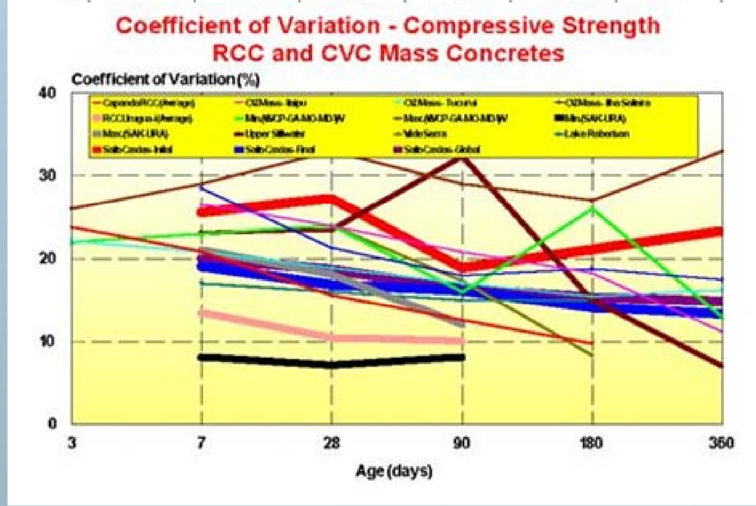
Quality Control Properties

- Standard Cylinders
  - Density
  - Compressive Strength;
  - Splitting Tensile Strength;
  - Modulus of Elasticity
- Drilled Core Specimens
  - Density
  - Compressive Strength;
  - Splitting Tensile Strength;
  - Modulus of Elasticity
  - Shear
- Statistical Analysis





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Details of 12 RCC dams designed and supervised by

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since 1987 in Saudi Arabia, Turkey and Jordan.

Majority of these dams have been constructed / or under construction in Turkey.

Characteristics of some of those RCC dams are presented below.

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RCC Dams Designed by TEMELSU since 1987

	Name of the Dam	Place	Construction Year	Maximum Height	Crest Width	Crest Length	Upstream Slope	Downstream Slope	Face
Constructed	Al Wehdah[(*)]	Jordan	2004-2007	96 m	7,20 m	480 m	Vertical 0,6H / 1V	0,8 H / 1V	Grout enriched RCC
Constructed	Beydağ	İzmir	2005 - 2009	95 m	9,80 m	800 m	0,25 H / 1V	0,8 H / 1V	PVC + Precast Panel
Constructed	Beyhan-1	Elazığ	2011 –Cont.	97 m	10 m	365 m	0,7 H / 1V	0,7 H / 1V	Concrete
Constructed	Cindere	Denizli	2002 - 2009	107 m	10 m	280 m	0,7 H / 1V	0,7 H / 1V	PVC + Precast Panel
Constructed	Damad	Saudi Arabia	2006 - 2009	52 m	5,4 m	600 m	Vertical	0,8 H / 1V	Concrete
Constructed	Güllübağ	Erzurum	2008 - 2012	71,5 m	10 m	92 m	Vertical	0,7 H / 1V	Concrete
Constructed	Köprü	Adana	2009 – Cont.	109 m	6 m	430 m	Vertical, 0,6 H / 1V	0,8 H / 1V	Concrete
Constructed	Menge	Adana	2009 - 2011	68 m	10 m	303 m	Vertical, 0,25 H / 1V	0,8 H / 1V	Concrete
Designed	Ergenli	İzmir	-	100,5 m	9 m	530 m	0,2 H / 1V	0,7 H / 1V	Concrete
Designed	Naras	Antalya	-	78 m	6,5 m	440 m	0,25 H / 1V	0,7 H / 1V	PVC + Precast Panel
Designed	Narlı	Muğla	-	99,5 m	10 m	275 m	Vertical, 0,6 H / 1V	0,8 H / 1V	PVC + Precast Panel
Designed	Pervari	Siirt	-	180 m	10 m	380 m	Vertical, 0,6 H / 1V	0,75 H / 1V	PVC + Precast Panel

(*) The final Design were performed by Harza - USA. Preparation of the detailed design and shop drawings for civil, electrical and hydro-mechanical works of RCC dam and appurtenant structures were completed in 2006 by Temelsu.

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Target Strengths, Cementitious Material Contents and Spillway Capacities of RCC Dams

	Name of the Dam	Place	Maximum Height	Roller Compacted <Concrete			Spillway		
				Design Strength	Cement	Puzolan	Type	Width	Design Discharge
Constructed	Al Wehdah (*)	Jordan	96 m	10 MPa	70 kg / m^3	30 kg / m^3	Ungated	250 m	7 600 m^3 / s
	Beydağ	İzmir	95 m	7 MPa	60 kg / m^3	30 kg / m^3	Ungated	70 m	735 m^3 / s
	Beyhan-1	Elazığ	97 m	15 MPa	65 kg / m^3	50 kg / m^3	Radial Gate	6 x 11,5 m	10 200 m^3 / s
	Cindere	Denizli	107 m	6 MPa	50 kg / m^3	20 kg / m^3	Radial Gate	4 x 10 m	3 620 m^3 / s
	Damad	Saudi Arabia	52 m	7 MPa	50 kg / m^3	30 kg / m^3	Ungated	209 m	4 800 m^3 / s
	Güllübağ	Erzurum	71,5 m	15 MPa	70 kg / m^3	70 kg / m^3	Radial Gate	3 x 11 m	4 465 m^3 / s
	Köprü	Adana	109 m	12 MPa	100 kg / m^3	50 kg / m^3	Ungated	125 m	5 170 m^3 / s
	Menge	Adana	68 m	10 MPa	70 kg / m^3	40 kg / m^3	Radial Gate	3 x 11 m	4 680 m^3 / s
Designed	Ergenli	İzmir	100,5 m	12 MPa	-	-	Ungated	30 m	300 m^3 / s
	Naras	Antalya	78 m	6 MPa	-	-	Ungated	80 m	900 m^3 / s
	Narlı	Muğla	99,5 m	15 MPa	-	-	Radial Gate	3 x 9 m	1 700 m^3 / s
	Pervari	Siirt	180 m	16 MPa	-	-	Radial Gate	3 x 10 m	2 670 m^3 / s

(*) The final Design were performed by Harza - USA. Preparation of the detailed design and shop drawings for civil, electrical and hydro-mechanical works of RCC dam and appurtenant structures were completed in 2006 by Temelsu.

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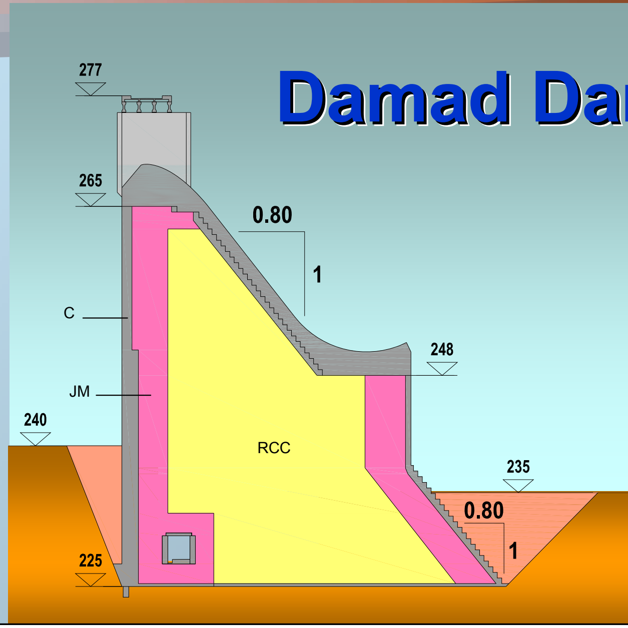
Damad Dam

The first RCC dam design by Temelsu in 1987 is the Damad Dam located in Jizan province of Saudi Arabia.

The detailed design has also been carried out by Temelsu in 2006 and construction is finished in 2010.



Damad Dam: *has a crest level of 277.00, foundation level of 225.00 and a height of 52.0 m.*

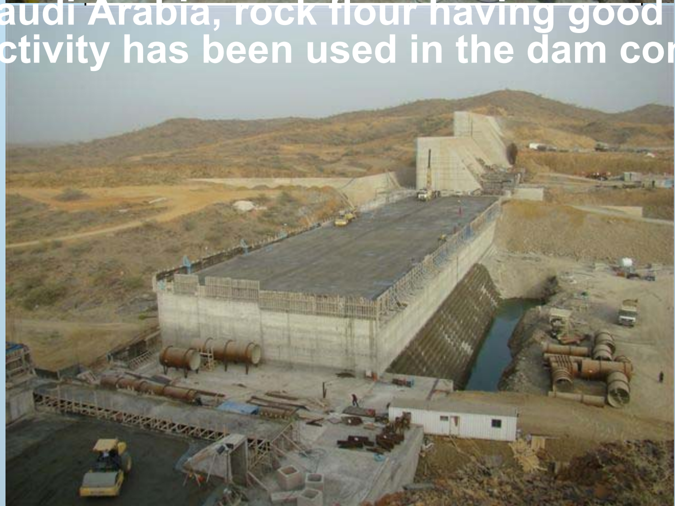
The un-gated spillway which consists of 14 chambers with a width of each 14.0 m has a sill level of 270.00; the reservoir volume at this level is 55.5 Million m3.

The RCC volume of the dam is 240 000 m3.

Materials Used During Construction

- Type I Portland Cement,
- Rock Flour

(As neither fly ash nor pozzolan are available in Saudi Arabia, rock flour having good pozzolanic activity has been used in the dam construction)



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CINDERE DAM AND H.P.P

THE FIRST HARDFILL DAM IN TURKEY

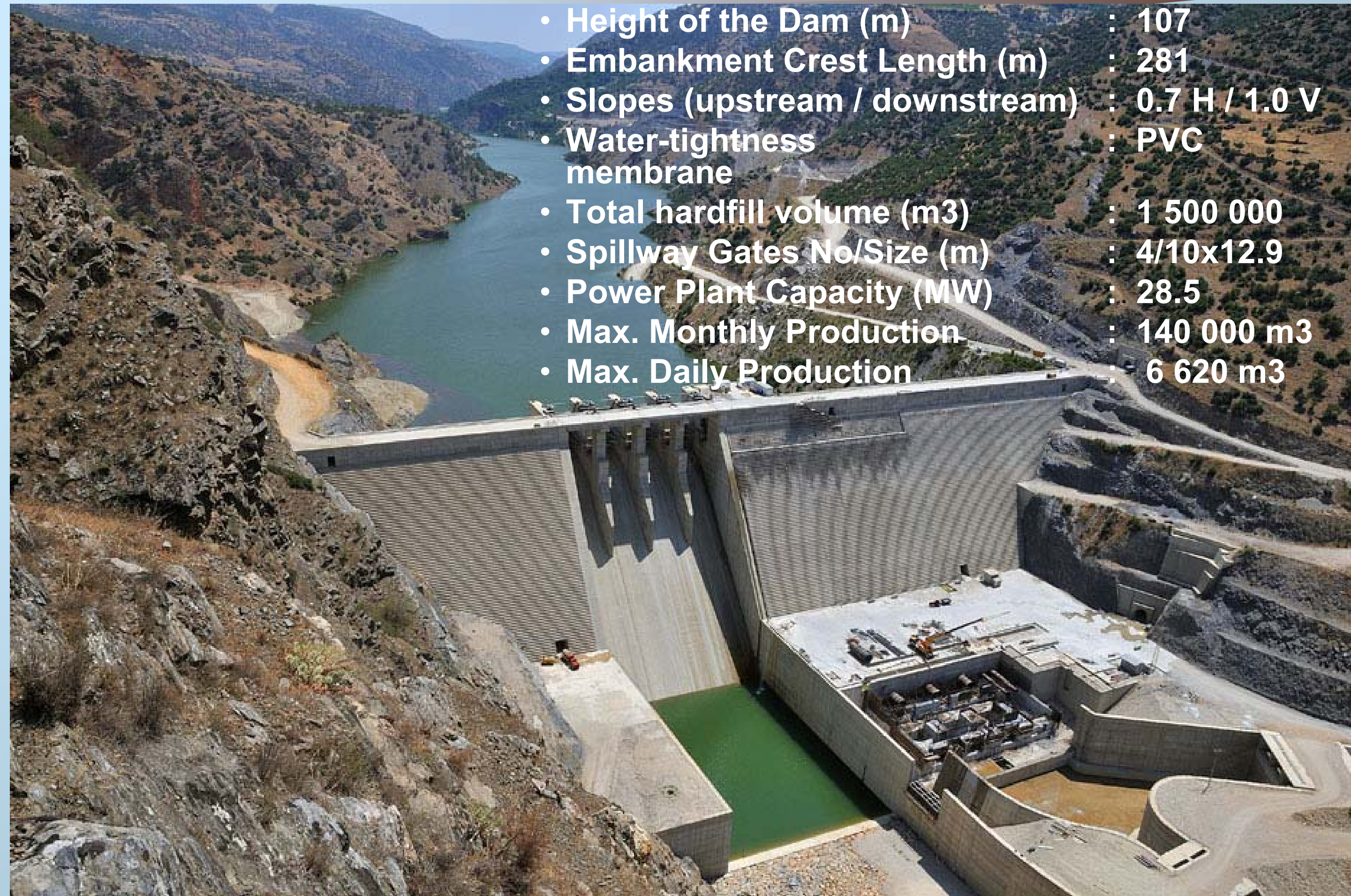
The first RCC application in Turkey is Çine Dam, whose construction has started in 1998.

The first Hardfill dam with low cementitious content (50 kg/m3 Portland cement + 20 kg/m3 fly ash = 70 kg/m3 cementitious content) in Turkey is Cindere Dam,

designed **by Temelsu International Engineering Services Inc**. in 2000.

CHARACTERISTICS OF THE CINDERE DAM

- Type : Face Symmetric Hardfill
- Height of the Dam (m) : 107
- Embankment Crest Length (m) : 281
- Slopes (upstream / downstream) : 0.7 H / 1.0 V
- Water-tightness membrane : PVC
- Total hardfill volume (m3) : 1 500 000
- Spillway Gates No/Size (m) : 4/10x12.9
- Power Plant Capacity (MW) : 28.5
- Max. Monthly Production : 140 000 m3
- Max. Daily Production : 6 620 m3



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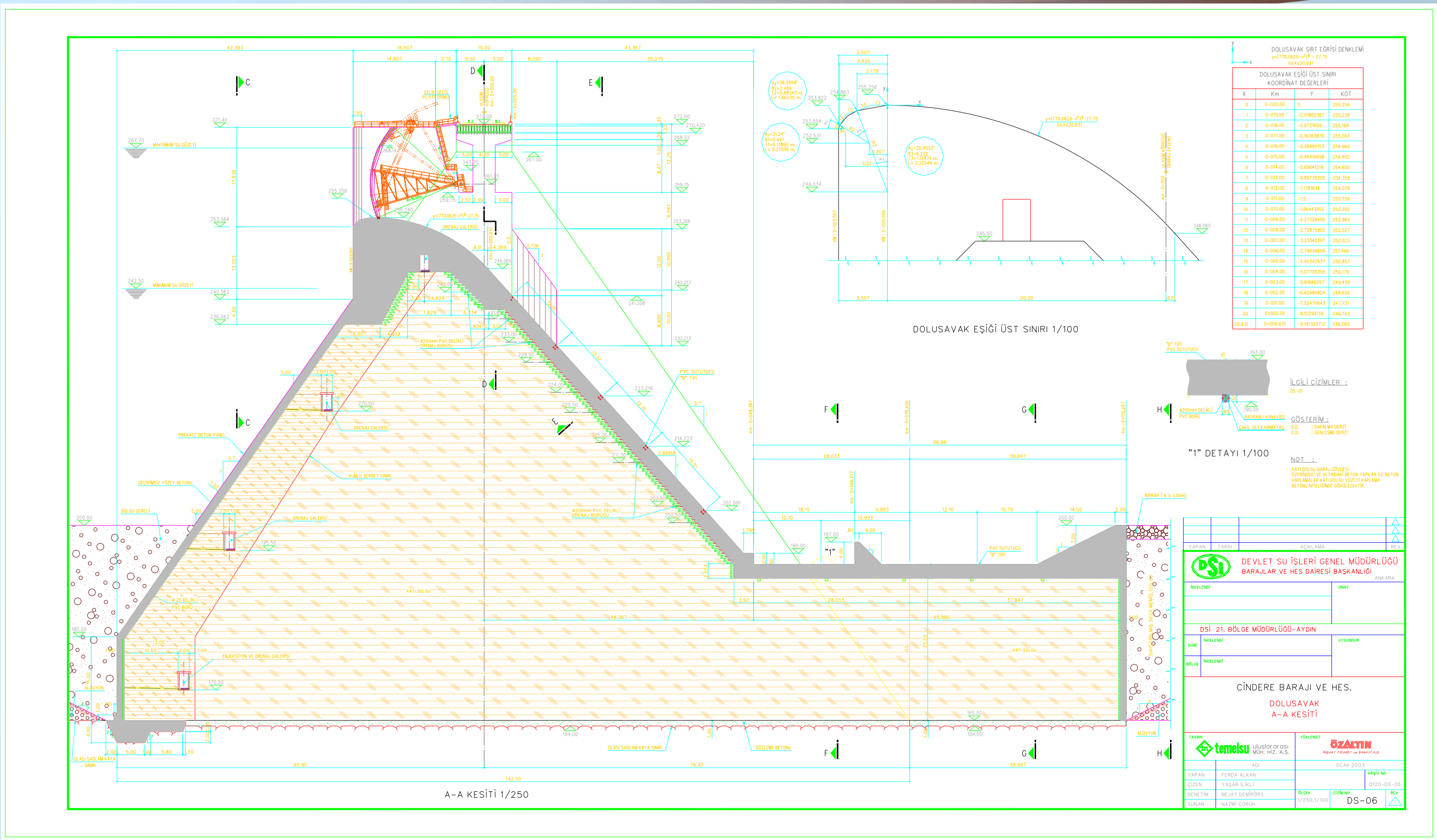

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ADVANTAGES OF F. S. HARDFILL DAMS

- High resistance to EQ excitations,
- Better stability against sliding,
- Low base pressure and less foundation settlement,
  - Gravity dam on weak foundations.
- Lower and more uniform stress distribution,
- Lower strength requirements:
  - Low cementitious content,
  - Low heat of hydration,
  - Less sensitive to volume changes,
  - No need for cooling.
- Low modulus of elastisity:
  - Flexible, better adaptation to foundation settlements.

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IMPERMEABLE UPSTREAM FACE

PVC membrane stuck on the inner side of precast concrete panels.

Advantages:

- **No seepage** through the cold joints and cracks,
- **Improves the stability** (reduces uplift pressure),
- Precast panels act as **formwork** and protect the impervious membrane,

IMPERMEABLE UPSTREAM FACE

- **Due to its flexibility:**
  - **The membrane is less influenced by dam settlement during construction and impounding of reservoir,**
  - **High resistance against earthquake,**
  - **Low sensitivity to volume changes of thermal or shrinkage origin.**

COST EFFECTIVE AND FAST.

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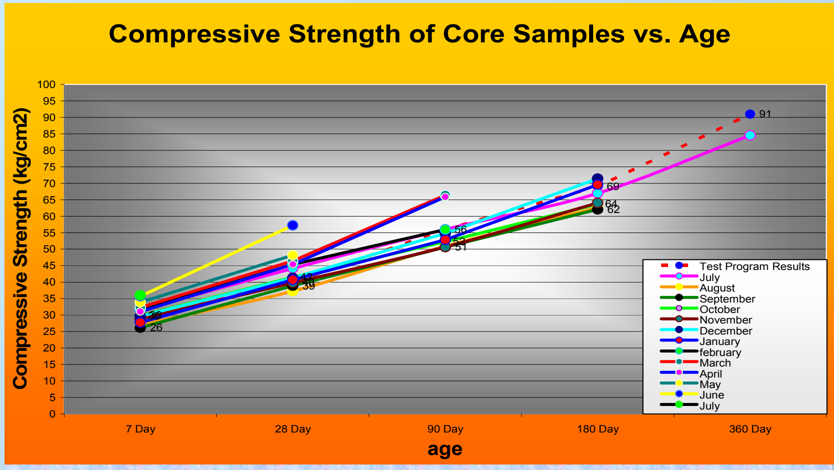
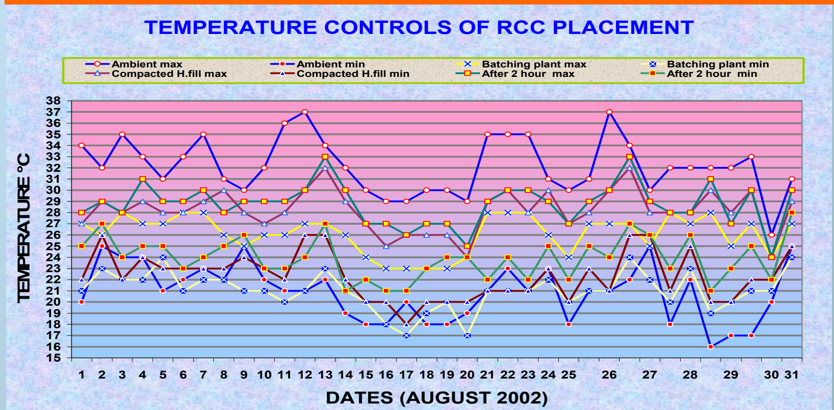
TEST RESULTS





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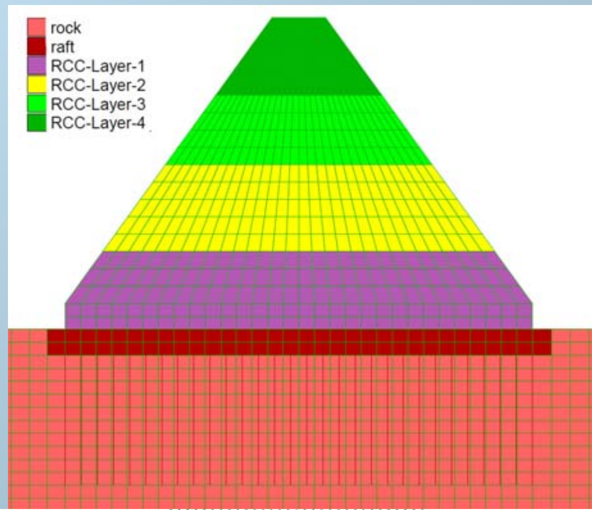
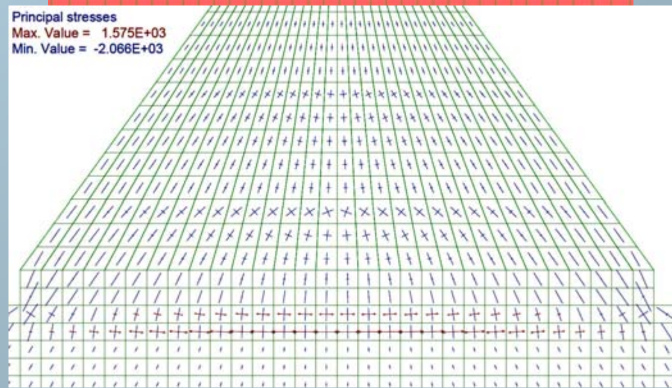
BEYHAN 2 DAM

- Because of high seismicity of the dam site, Beyhan-2 Dam, having the maximum height of 60 m, has been designed as a symmetrical faced RCC dam with slopes of 0.7H:1V.
- The geological studies have revealed that the deformation modulus of foundation has been estimated as E = 750 MPa, which is very small in terms of required stiffness for a RCC dam.
- It has been proposed to utilize a remediation system under the dam body, composed of a

rigid raft foundation resting on the improved rock with piles.

- Performed analyses have shown that a piled-raft system below the base of the dam may affectively be used to reduce excessive tensile stresses at the rock – RCC interface and also compensate the adverse effect of foundation settlements in case of a foundation rock with insufficient stiffness for a RCC dam.





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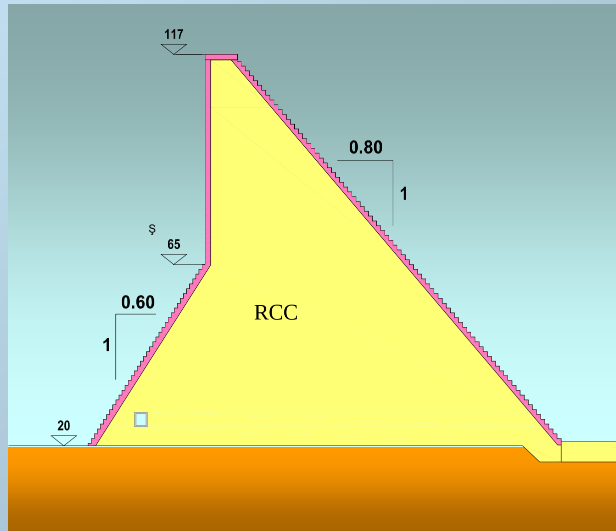
AL - WEHDAH DAM JORDAN



- ***<u>Al-Wehdah Dam:</u>*** *constructed in the north of Jordan on the Yarmouk River for irrigation and domestic water supply. It is a Roller Compacted Concrete (RCC) type dam with crest elevation 116.00 masl and 96 m height from foundation. The dam body consists of about 1.3 million cubic meters of RCC.*
- *Ungated spillway at El. 110.0 m is located over RCC dam body having an ogee 250.00 m long followed by a stepped chute channel. It has a maximum discharge capacity of 7600 m3/s corresponding to a maximum reservoir surcharge elevation 115.90 m asl during Probable Maximum Flood (PMF).*
- *The final Design and construction supervision works were performed by Harza - USA. Preparation of the detailed design and shop drawings for civil, electrical and hydro-mechanical works of RCC dam and appurtenant structures were completed in 2006 by Temelsu.*

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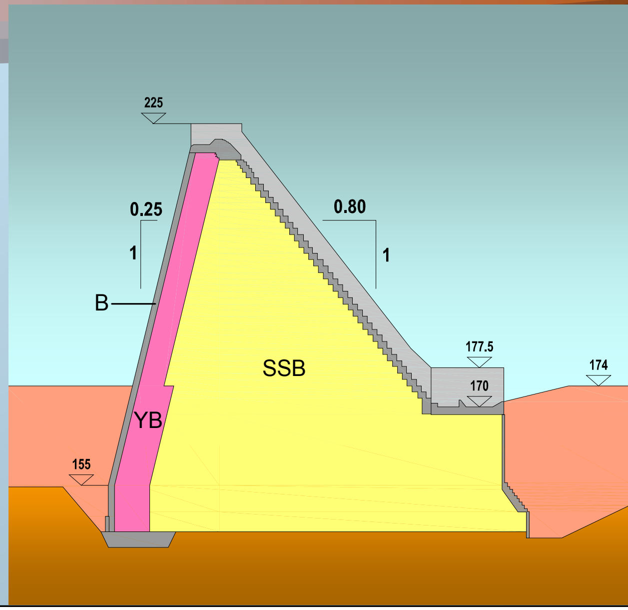
BEYDAG DAM
Turkey

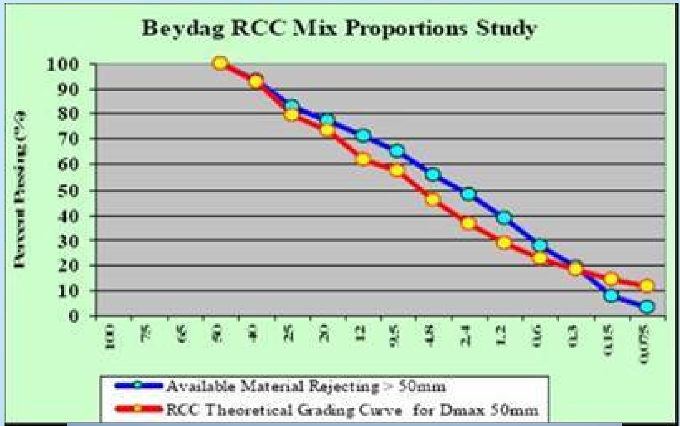


Beydag Dam is located on Küçük Menderes River for the irrigation of 10910 ha. agricultural area. Its height is 95.0 m above the foundation and 54.0 m above the thalweg. The embankment is originally designed as clay cored rockfill to impound 248.275 million m^3 of water. Later on, type of dam body was modified as RCC. The diversion tunnel 584.5 m long with an inner diameter of 5.00 m has a capacity of 151 m^3/sec.

The uncontrolled spillway on the right bank has a capacity of 1275 m^3/sec. Its ogee crested 60 m long weir is designed for a head of 4.75 m. Rectangular chute channel is 60.0 m long and 60 m wide at the beginning. It reaches a width of 40.0 before entering the stilling basin type energy dissipater.

RCC is produced with natural tuvenane aggregate.

Just ONE Grain Size Fraction- Less than 50mm



The Designer and/or Contractor must balance the potential cost savings in a reduction in number of stockpiles and separate handling and weighing facilities with the potential for increased variation in aggregate grading and its impact on uniformity of the RCC. The Figure shows an unique aggregate curve that is being used in Beydag RCC Dam in Turkey

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Beyhan 1 Dam and HPP

- Dam is constructed on Murat River (Eastern Anatolia region) for energy purpose.
- It has a drainage area of 25274 km2.
- The dam is RCC (roller compacted concrete) type with a crest length of 361.00 meter.
- Its height above foundation is 97.00 meter. The flow of Murat River is diverted through 3 tunnels with circular cross section which has an inner diameter of 9.50 meter.
- The probable maximum flood of 10528m3/s (QPMF) will pass through the spillway of 6 openings separated from each other by piers. Each opening is equipped with radial gates of 11.50 width and 15.20 meter height.
- The power plant consists of 3 units each with an installed capacity of 175.33 MW and a fourth small unit with an installed capacity of 24.00MW, thus totaling 550 MW to produce 1245.1 GWh annually.

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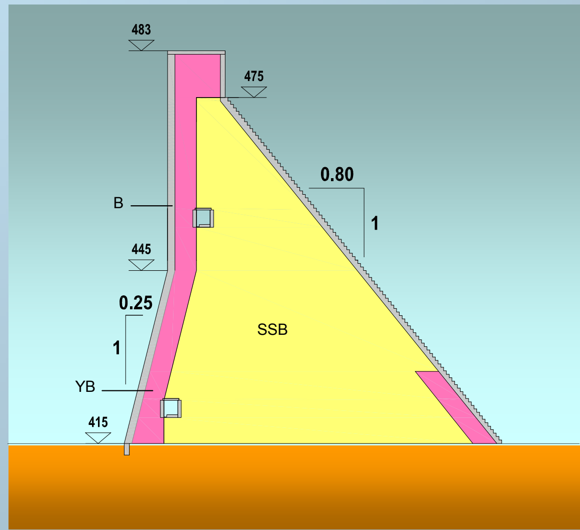
Menge Dam and HEPP Turkey



- ***Menge Dam*** *and HEPP is located on the Göksu River within the Adana province borders.*
- *It has a reservoir volume of 50 797 hm3. The RCC dam has concrete volume of 380 000 m3 with the crest length of 304 m. Its height above foundation is 68 m.*
- *The probable maximum flood of 4680 m3/sec will pass through the spillway of 3 openings separated from each other by piers. Each opening is equipped with radial gates of 11.00 m width and 15.4 m height.*
- *The power plant consists of 2 Francis type units each having installed capacity of 45.43 MW, total capacity is 90,85 to produce 203,14 GWh.*




Güllübağ Dam

Güllübağ Dam and Hydroelectric Power Plant: is located on Çoruh River (Eastern Anotolian region within the province of Erzurum) for energy purpose.

It has a drainage area of 5915 km2. The dam is RCC type with a crest length of 92.00 meter. Its height above foundation is 71.50 meter.

The spillway is on the RCC dam body. The probable maximum flood of 4464m3/s will pass through the spillway of 3 openings separated from each other by piers. Each opening is equipped with radial gates of 11.00 width and 14.80 meter height.

The power plant consists of 3 units with total installed capacity of 96 MW to produce 313.90 GWh annually.

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THANK YOU
VERY MUCH
for your kind attention

ISLAMIC DEVELOPMENT BANK GROUP
ANNUAL MEETING
Dushanbe, Tajikistan, 18 - 22 May 2013