GENALE DAWA (GD3)
MULTI-PURPOSE
HYDROPOWER PROJECT
ETHIOPIA
Part 1: Ethiopia
Part 2: Hydropower In Ethiopia
Part 3: Genale Dawa (GD3) Scheme
Part 4: Dam Design & Construction
Part 5: Appurtenant Structures
Part 6: Summary
Part 7: Discussion
THE GREAT RIFT VALLEY
ARCHEOLOGY

THE BIRTHPLACE OF HUMANITY?
ROCK HEWN CHURCHES - BELA
THE BIRTH PLACE OF COFFEE

KAFFA
(SOUTH ETHIOPIA)
ECONOMY

One of the fastest growing economies in the World

Annual GDP growth has averaged around 10% for the past 10 years

Africa’s second most populous country. 50% under 18
MAIN ECONOMIC SECTORS

Agriculture  
Energy  
Construction  
Manufacturing  
Transport  
Telecommunications  
Tourism  
Minerals & Mining
Part 1: Ethiopia

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POWER DEVELOPMENT IN ETHIOPIA

Responsible Bodies

Government of the Federal Democratic Republic of Ethiopia
(Growth and Transformation Plan)

Ministry of Water, Irrigation and Electricity

Ethiopian Electric Power
REASONS FOR GROWTH IN ELECTRICITY DEMAND

High rate of urban development

High rate of industrial development

Rural electrification (Universal Electricity Access Program)

New railway developments

New large scale irrigation projects

Exportation of Electricity
## EXPORTATION OF ELECTRICITY

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<th>Country</th>
<th>Capacity (MW)</th>
<th>Start Date</th>
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<td>Sudan</td>
<td>1200</td>
<td>since 2012</td>
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<td>2000</td>
<td>2018/19</td>
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<td>Tanzania</td>
<td>400</td>
<td>2019/20</td>
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Possible future connections to Burundi, Egypt, Libya, Rwanda, Uganda, Yemen and beyond through proposed regional interconnectors.
EXPORTATION OF ELECTRICITY

East African Power Pool (EAPP)
CORRELATION BETWEEN GDP AND HYDROPOWER DEVELOPMENT
RENEWABLE ENERGY RESOURCES

- Hydropower: 45,000 MW
- Wind: 10,000 MW
- Geothermal: 5,000 MW
- Solar: 300 MW
- Waste to Energy: 500 MW
- Cogeneration (Biofuel): 600 MW

Ethiopia’s hydropower resources are second only to the Democratic Republic of Congo (DRC) throughout the whole of Africa.
HYDROPOWER DEVELOPMENT SINCE 1990

Total Installed Capacity (MW)

- Year: 1990 to 2016
- Total Installed Capacity: 0 MW to 4500 MW
### HYDROPOWER DEVELOPMENTS SINCE 2000

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<th>Installed Capacity (MW)</th>
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<td>300</td>
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<td>2012</td>
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<td>2016</td>
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<td>Genale Dawa (GD3)</td>
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<td>2018</td>
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<td>GERD</td>
<td>6000</td>
<td>2018</td>
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Lake Tana
HYDROPOWER PROJECTS IN ETHIOPIA

Tekeze

Double curvature concrete arch
188 m high
300 MW
Completed 2010
HYDROPOWER PROJECTS IN ETHIOPIA

Beles

Intake direct from Lake Tana
460 MW
Completed 2010
HYDROPOWER PROJECTS IN ETHIOPIA

Finchaa Amerti Neshe (FAN)

Earthfill
38m high
100 MW
Completed 2012
HYDROPOWER PROJECTS IN ETHIOPIA

Gilgel Gibe III

RCC
243 m high
1870 MW
Completed 2016
HYDROPOWER PROJECTS IN ETHIOPIA

Grand Ethiopian Renaissance Dam

RCC
175 m high
6450 MW
Under construction (2018)
Part 1: Ethiopia

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Part 7: Discussion
Located on Genale River
110 m high CFRD
Reservoir capacity 2,570 Mm$^3$
Reservoir area 98 km$^2$ / 8.4 Ha
254 MW
1,600 GWh/year
THE GENALE DAWA RIVER BASIN
ORGANISATIONAL STRUCTURE

Ethiopian Electric Power (EEP)

Main Contractor
CGGC

Employer’s Representative
MWH

Mid South Design Institute (MSDI)
Seli (TBM supply and operation)
Integrated Engineering
Acute Engineering

FIDIC ‘Silver Book’ for EPC/Turnkey Projects

EPC = Engineer Procure Construct
TIMELINE

2007 Aug  Feasibility Lahmeyer Consultants – August 2007
2009 Sep  Award to China Gezhouba Group Corporation (CGGC)
2011 Mar  Basic Design / Start on Site
2013 Jan  River Diverted
2013 Aug  Commencement of TBM drive
2014 Oct  Substantial completion of dam rockfill
2016 Oct  Completion of TBM drive
2017 Mar  Commence impounding
2017 Dec  Commence electricity generation
2018 Mar  Project completion
MAIN PROJECT FEATURES

110m HIGH CFRD

DIVERSION TUNNEL (plugged after start of impoundment)

GATED SPILLWAY (three radial gates)

MID LEVEL OUTLET (radial gate & vert. wheel gate)

INTAKE STRUCTURE (trash rake & vertical wheel gate)

HEADRACE TUNNEL (12.4km long of which 9km by TBM)

SURGE SHAFT (23 m diameter 120m high)

VERTICAL DROP SHAFT (188m high)

STEEL LINED PENSTOCK (various diameters)

U’GROUND P’HOUSE (three 84.7MW Francis Turbines)

TRANSFORMER CAVERN (immediately d/s of p’house cavern)

TAILRACE TUNNEL (820m long)

TAILRACE CHANNEL (480m long)
PROJECT IN PROFILE

TAILRACE
LENGTH: 1.52 km
DIAM: 6.1 m

HEADRACE
LENGTH: 12.4 km
DIAM: 8.1 m

POWER HOUSE
CAVERN: 60 x 20 x 40 m
POWER: 254 MW
TUNNEL BORING MACHINE
SURGE SHAFT

120m HIGH
23 m DIAMETER
SLIP-FORMED CONCRETE
POWER HOUSE
TAILRACE CHANNEL
Genale Dawa (GD3)

Part 1: Ethiopia
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DAM DESIGN

Feasibility Study\(^1\) Recommended Roller Compacted Concrete (RCC)

Contractor changed to Concrete Faced Rockfill Dam (CFRD)

\(^1\) Lahmeyer International, August 2007
DESIGN – DAM SITE LAYOUT

- Diversion
- Reservoir
- Mid-level Release Tunnel
- Spillway
- Downstream
RESERVOIR / DAM DETAILS

Reservoir
- Catchment area: 10,445 km²
- Reservoir area: 98 km²
- Mean Inflow: 92.6 m³/s
- Storage (Live / Dead): 2,570 / 2,310 Mm³
- Loss of live storage after 50 years: 2.1%
- Lifetime: > 1000 years

Dam
- Type: CFRD
- Geology / Rockfill material: Granite
- Height: 110 m
- Length: 450 m
- Fill volume: 3 Mm³
TYPICAL CFRD SECTION

1. Plinth

2. Grout Curtain

3. Rock Fill

4. Face Slab 1\((v):1.4(h)\)

5. Upstream Blanket

6. Crest Wall

Upstream

Downstream

1\((v):1.35(h)\)
EVOLUTION OF CFRD’s

Mid to late 1800s  Dumped rockfill with timber facing / steep slopes

1890’s            First use of concrete in 1890s (height < 25 m)

1920s-1960s       Dumped in high lifts and sluiced. Use of upstream rockfill zone. Dam heights 80m - 100m. Result in face slab cracking / high leakage. CFRD’s go out of fashion. . .

From late 60s      Rockfill placed in 1 - 2 metre lifts, watered and compacted. Reduction in particle size and improvements to plinth and face slab design = Improved performance. CFRDs popular again.

2010              Standard design formalised in ICOLD Bulletin 141.

Summarised from p.590 of Geotechnical Engineering of Dams, 2005, Taylor and Francis Group PLC
CONSTRUCTION – EARLY DAYS
Diversion system sized for 1 in 10 year flood event (551 m³/s)

Low consequence of overtopping of cofferdams

500 m long drill and blast tunnel

20 m long concrete plug to be installed upon completion
DIVERSION WORKS (JAN 2013)
PLINTH - DESIGN

Upstream

Plinth

Face Slab

Downstream
PLINTH – DESIGN

d = 500 mm / 800 mm
L = 4 m / 6m / 8 m
Hydraulic gradient ~ 14
Competent, groutable, non-erodible rock
PLINTH
PLINTH FOUNDATION PREPARATION
CURTAIN GROUTING

Layout of toe slab foundation consolidation grouting from X5' to X4
EMBANKMENT STABILITY

2D and 3D Dynamic Finite Element Analysis.

Scenarios:

1. Completion – dam constructed to crest
2. Normal water level
3. Highest flood water level
4. Lowest water level
5. Normal water level with earthquake

Fig. 4.4.2 The vertical displacement nephogram of the typical section at the time of completion (unit: cm)
GD3 dam site is located in an area of low seismic hazard (Hazard Class I).

Peak ground accelerations:

Maximum design earthquake (MDE): 0.12 g

Operating basis earthquake (OBE): 0.06 g
DESIGN – DAM SECTION

1B Rock Ballast
1A Clay Blanket

2A, 2B & 3A Fill Under Concrete Slab

3B General Rock Fill

3C Downstream Rock Fill
DESIGN – DAM SECTION

- 3B General Rock Fill
- 2A Filter Material
- 2B Cushion Material
- 3A Transition Material
MATERIALS

2A Filter < 40 mm
2B Cushion < 80 mm
3A Transition < 300 mm
3B General < 600 mm
3C General < 700 mm

2A Processed and blended
2B Processed and blended
3A Quarry direct / tunnelling
3B Quarry direct
3C Quarry direct
MATERIALS
QUARRY
CRUSHING, SCREENING AND BATCHING
PROCESSED MATERIALS

2A Blending

- **Gravel**
  - Diameter: 20~40mm

- **Sand**
  - Diameter: <5mm

- **Gravel**
  - Diameter: 5mm~20mm

Legend:
- **Material flow direction**
- **Equipment**
- **Tape machine**
- **Stockpile or material sti**
GENERAL ROCKFILL - CONSTRUCTION

- Blast at quarry
- Load (selectively)
- Transport / Unload
- Sluice / Water
- Spread
- Compact
- Test
- Repeat

• Abutment cleaning
• Control Layer thickness
• Control Segregation
• Test (prove density & grading)

EXCESSIVE / DIFFERENTIAL SETTLEMENT
DENSITY ASTM D5030 / GRADING
AND REPEAT . . .
3B/3C GENERAL ROCKFILL ZONES
3B/3C GENERAL ROCKFILL ZONES
DOWNSTREAM SLOPE
QUALITY CONCERNS . . .
QUARRY OPERATIONS

Secondary Blasting ?
ROCKFILL PROGRESS

Estimated Total Volume of Fill to El 1121 m = 3 M m³ (Doesn't include upstream blanket)
Tokwe-Mukosi dam wall breached (Pictures: David Coltart Facebook)
INSTRUMENTATION

- Piezometers in dam foundation
- Settlement Meters
- Horizontal Displacement Meters
- Abutment Strain Gauges
- Observation holes in abutments (seepage)
- Surface Monitoring Network
- Seepage flow measurement weir at D/S toe
- Res Water level and water temperature
- Weather station
- Seismic (right bank, crest, mid-berm and D/S)
ROCKFILL INSTRUMENTATION
ROCKFILL INSTRUMENTATION
FACE SLAB – DESIGN

8 m wide and 16 m wide panels

300 mm – 600 mm thick

2 layers of reinforcement
“These things always leak at the perimeter joint . . . It doesn’t matter what you do . . .” Anon
FACE SLAB PREPARATION
DAM DEFORMATION

Upstream face

Rock Fill
FACE SLAB PREPARATION
Mortar Cushions
FACE SLAB JOINTS
FACE SLAB CONSTRUCTION
FACE SLAB INSTRUMENTATION
FACE SLAB CONSTRUCTION
FACE SLAB CONSTRUCTION
FACE SLAB
CREST WALL CONSTRUCTION
TOP WATER-STOP
UPSTREAM BLANKET
Part 1: Ethiopia

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Longitudinal Section of spillway

WES Weir Detail Drawing

Notes:
1. The unit for dimension in the drawing is m.
SPILLWAY EXCAVATION
AERATION TOWERS
FLIP-BUCKET CONSTRUCTION
SPILLWAY CONSTRUCTION
SPILLWAY CONSTRUCTION
RELEASE TUNNEL DESIGN

- Gate-control shaft
- Flip bucket
- Open channel
- Free-flow tunnel
- Release model
SPILLWAY / RELEASE TUNNEL COMBINED
RIVER BED ‘PLUNGE’ MODEL
RELEASE TUNNEL INLET
Genale Dawa (GD3)

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### Rock Fill Gradation

#### Zone 3B

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<th>Grain Size (mm)</th>
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### Concrete Compressive Strength of dam Face Slab

- **(25MPa/90 days)**
- **Actual 28 day Compressive Strength test (MPa)**
- **Design Strength at 28 day (MPa)**
- **Actual 7 day Compressive strength test (MPa)**

<table>
<thead>
<tr>
<th>Date of Sample</th>
<th>Actual 28 day Compressive Strength test (MPa)</th>
<th>Design Strength at 28 day (MPa)</th>
<th>Actual 7 day Compressive strength test (MPa)</th>
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#### GD-3 PROJECT SITE LABORATORY

Test Record of Compressive Strength of Concrete

- **Location of Concrete Represented**: Plinth ypsum 10112-10125
- **Make Specimens Method**: ASTM C31
- **Lab No.**: ZC04
- **Test Method**: ASTM C39
- **Design Strength**: 21MPa
- **Cylinder No.**
- **Date of Casting**: 2013.03.02
- **Date of Testing**: 2013.03.30
- **Dimension of cube (cm)**: 15
- **Area (cm²)**: 225
- **Volume of Cylinder (cm³)**: 3375
- **Weight of Cylinder (kg)**: 8.107, 8.183, 8.162
- **Density of Concrete (kg/m³)**: 2402, 2425, 2418
- **Failure Load (KN)**: 753.25, 718.33, 721.84
- **Compressive Strength (Mpa)**: 33.5, 31.9, 32.1
- **Average Compressive strength (MPa)**: 32.5
- **Correct factor**: 0.8, 0.8, 0.8
- **Axial Compressive strength (Mpa)**: 26.0

**Remarks**

**Checked By**: [Signature]

**Tested By**: [Signature]
CHALLENGES . . .
COMPLETION (FROM UPSTREAM)
COMPLETION (DOWNSTREAM)
IMPOUNDING . . .
LIFE ON THE CAMP . . .
THE BEAUTIFUL GAME . . .
DINNER PARTIES ...
EASTER FUN RUN . . .