APPENDIX G-3

Draft Report of Physical Hydraulic Model Test (by HRI)

Field Investigation Report

Field Investigation at Dairut Group of Regulators for Physical Model Studies

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Aug .63/2015

Report No.

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Field Measurements at Dairut Group of Regulators for Physical Model Studies

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CLIENT:	The Reservoirs and Grand Barrages Sector "RGBS"
TITLE:	**Field Investigation at Dairut Group of Regulators for Physical Model Studies**

ABSTRACT:

Dairut group regulators "DGR" is located on El-Ibrahemiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages.

This group of regulators was constructed in 1872 to play a vital role of delivering about 9.6 billion m3/year of irrigation water to all beneficiary area of about 1.43 million feddans through El-Ibrahemia main canal. "DGR" branches at El-Ibrahimia main canal at Dairut into seven main canals, namely El-Ibrahimia canal, Bahr-Yusef canal, Sahelyia canal, El-Diroutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal. The Bahr-Yousef canal is the largest canal in capacity among the seven canals. Its length extends as long as 312 km downstream of "DGR" and there are four regulators along the canal, namely El-Lahoun regulator, Mazoura regulator, Sakoula regulator and Dahab regulator. Those regulators have been rehabilitated by Japan's Grant Aid since 1995.

One important point should be raised concerning the existing "DGR" which is that Dairut Group of Regulators was constructed in 1872 and can be considered as the oldest active regulator in Egypt, and the their weirs cannot function well due to their age. For this reason rehabilitation of such hydraulic construction should be urgently implemented. It is expected that the impacts of the rehabilitation of the "DGR" should be significant considering the vast beneficiary area and very long canal networks. Therefore, rehabilitation of "DGR" was quite urgent for seeking effective use of the limited water resources and due to limited facilities as well as high cost operation and maintenance.

Based on such an understanding, the Government of Egypt "GOE" requested informally to the Government of Japan "GOJ" for the Japanese Official Development Assistance by Yen-Loan. Accordingly, Japan International Cooperation Agency "JICA" dispatched the study team for the preparatory survey for the rehabilitation and improvement of Dairut Group of Regulators "DGR".

Therefore, in order to increase agricultural production and to keep sustainability of agricultural industry in the Upper Egypt region the main objectives of the conducted study were defined as the following 4 subjects:

1. To formulate the rehabilitation plan for Dairut Group of Regulators "DGR";
2. To formulate the improving water distribution plan for the entire operation and maintenance of "DGR" and other regulators that are located along the main canals;
3. To evaluate the present situation and the rehabilitation plan of the existing minor structures based on the result of the inventory survey carried out by the Ministry of Water Resources and Irrigation "MWRI"; and
4. To carry out technology transfer to the implementation agency through the study period on the above mentioned subjects.

The current investigation is being carried out referring to letter No. 1379/156 dated on the 8th day of May 2014 from the Reservoirs and Grand Barrages Sector "RGBS" of the Ministry of Water Resources and Irrigation "MWRI" which requested "HRI" to prepare for a technical and financial proposal to carry out hydraulic physical model for testing a new alternative for Dairut Group Regulators "DGR". The focal objective of the proposed testing program is to adopt the best alignment and hydraulic design for the new barrages group components which fulfills the new emerged flow morphology regime through El-Ibrahimiya canal after the construction of the new Assuit barrages. Flow capacity and velocity distribution upstream and downstream each of the new group components would be physically tested and investigated.

This report presents the results of the field investigations, which were carried out by HRI during June 2015 (from 25/6/2015 till 1/7/2015).

REFERENCES:

VER	ORIGINATOR	DATE	REMARKS	REVIEW	APPROVED BY
	Eng. Ahmed M.Lotfy	8/07/2015		Dr. Ahmed Amin	Prof. Khaled Rammadan

PROJECT IDENTIFICATION:		63 /2015						
KEYWORDS:		Bathymetry, flow velocity, discharge, water levels, hydrographic survey						
CONTENTS:	TEXT PAGES		TABLES		FIGURES		APPENDICES	
STATUS:	☐ PRELIMINARY		☐ DRAFT		☒ FINAL			

Contents

To figure

1 Introduction

Dairut group regulators "DGR" is located on El-Ibrahemiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages.

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This report presents the results of the field investigations, which were carried out by HRI during June 2015 (from 25/6/2015 till 1/7/2015).

2 Field Measurements

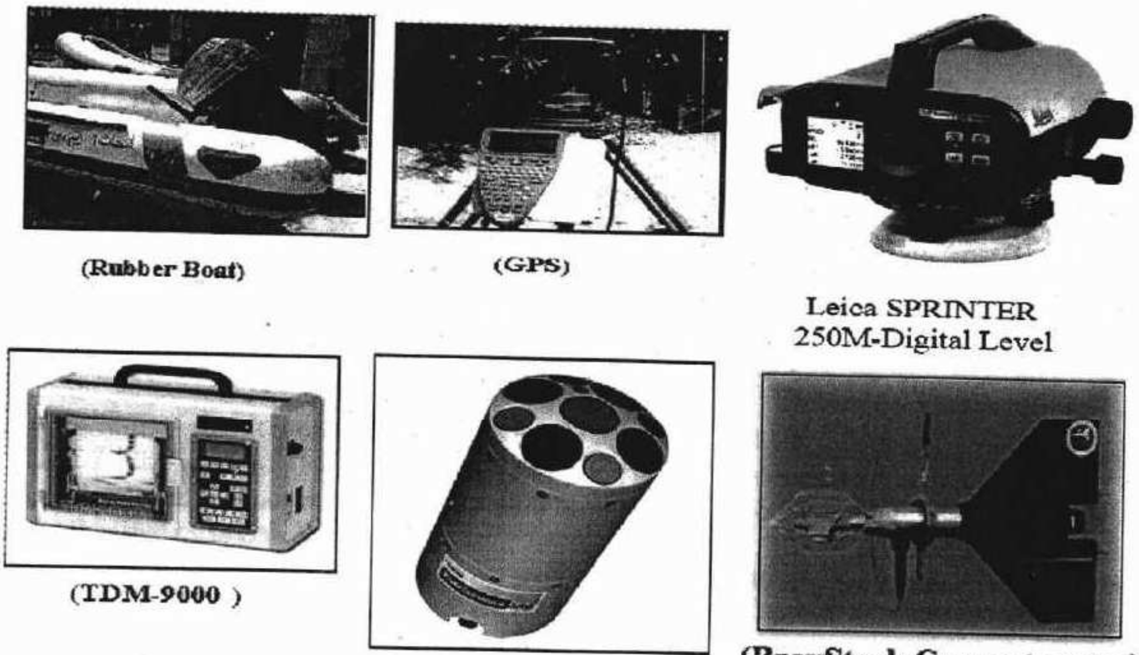
The field measurements were carried out by the specialist "HRI" team from 24/6/2015 till 2/7/2015 to document the latest topographic and hydrologic conditions upstream and downstream Dairut group of regulators "DGR" which can be used to construct and conduct the required model studies. The measurements included topographic, bathymetric and hydrometric measurements along the branched seven canals downstream "DGR" and the located part of El-Ibrahmia canal upstream of "DGR". The survey was done at the project site using advanced survey equipments. The following sections present summary of the equipments and the methodology used in the survey. While appendix "A" presents the used equipments in more details.

2.1 Equipments

The equipment and instruments that used during field investigation are as follows:

- Surveying boat, (Rubber Boat),
- Four Geographical Positioning System (GPS) unites, (Leica and Trimble),
- Digital Levelling instruments (Leica-Sprinter 250M),
- Echo sounder units, (TAMAYA TDM-9000),
- ADCP (Acoustic Doppler Current Profile)
- Bray-Stock Current meters

Some photos for the used instruments are shown in Figure (1), while detailed description of those instruments is provided in appendix (A) at the end of the current report.



(Rubber Boat) (GPS) Leica SPRINTER 250M-Digital Level

(TDM-9000) ADCP (BrayStock Current meter)

Figure (1): Some of the Used Field Instruments

2.2 Methodology

A- Horizontal and Vertical Control

A-1 Horizontal control

In order to determine the horizontal control, the Differential Geographical Positioning System (DGPS) was used to measure the global coordinate of the site. All site coordinates were measured using WGS 84 System.

A-2 Vertical control

Bahr Youssef gauge was used as a reference for all of the measured levels.

B- Topographic and Bathymetric Survey

- The topographic survey covered the located upstream and downstream branches at Dairut group of regulators. The topographic survey covered the eight branched canals of total distance of 6400 m according to the following:
  - 1.28 km of El-Ibrahimia canal upstream of Dairut group of regulators.
  - 1.07 km of Bahr youssef canal downstream of Dairut group of regulators.
  - 0.58 km of Badrman canal downstream Dairut group of regulators.
  - 0.55 km of El-Dairotiah canal downstream of Dairut group of regulators.
  - 1.23 km of El-Ibrahemia canal downstream of Dairut group of regulators.
  - 0.59 km of El-Sahelia canal downstream of Dairut group of regulators.
  - 0.50 km of Dalgawy canal downstream of Dairut group of regulators.
  - 0.60 km of Abou Gabal canal downstream of Dairut group of regulators.
- Shown in (figure 1). The topographic survey was carried out using a hand held units of the GPS. The location of the all land facilities, (roads, structures... etc), were surveyed and attached to the contour maps.
- Bathymetric survey of the canals within the project area (Dairut group of regulators), was carried out by Sounding using Echo sounder that installed on a rubber boat, (for water depth measurements), attached to a GPS unit , (for position measurements).
- The surveyed area was carried out by surveying cross sections perpendicular to the flow direction,
- The distance between the developed cross sections was ranged between 25-50 m.
- Intensive bathymetric survey around the existing structures within the surveyed area (groins, islands..etc) was implemented.
- The measured data is used to develop a contour map using SURFUR software.
- The facilities within the surveyed area were identified in the contour maps
- The developed contour map was produced with UTM coordinate system and 0.5 m contour step and finalized by the AUTOCAD software
- The developed contour map and the measured cross-sections are shown in the attached Compact Disc.

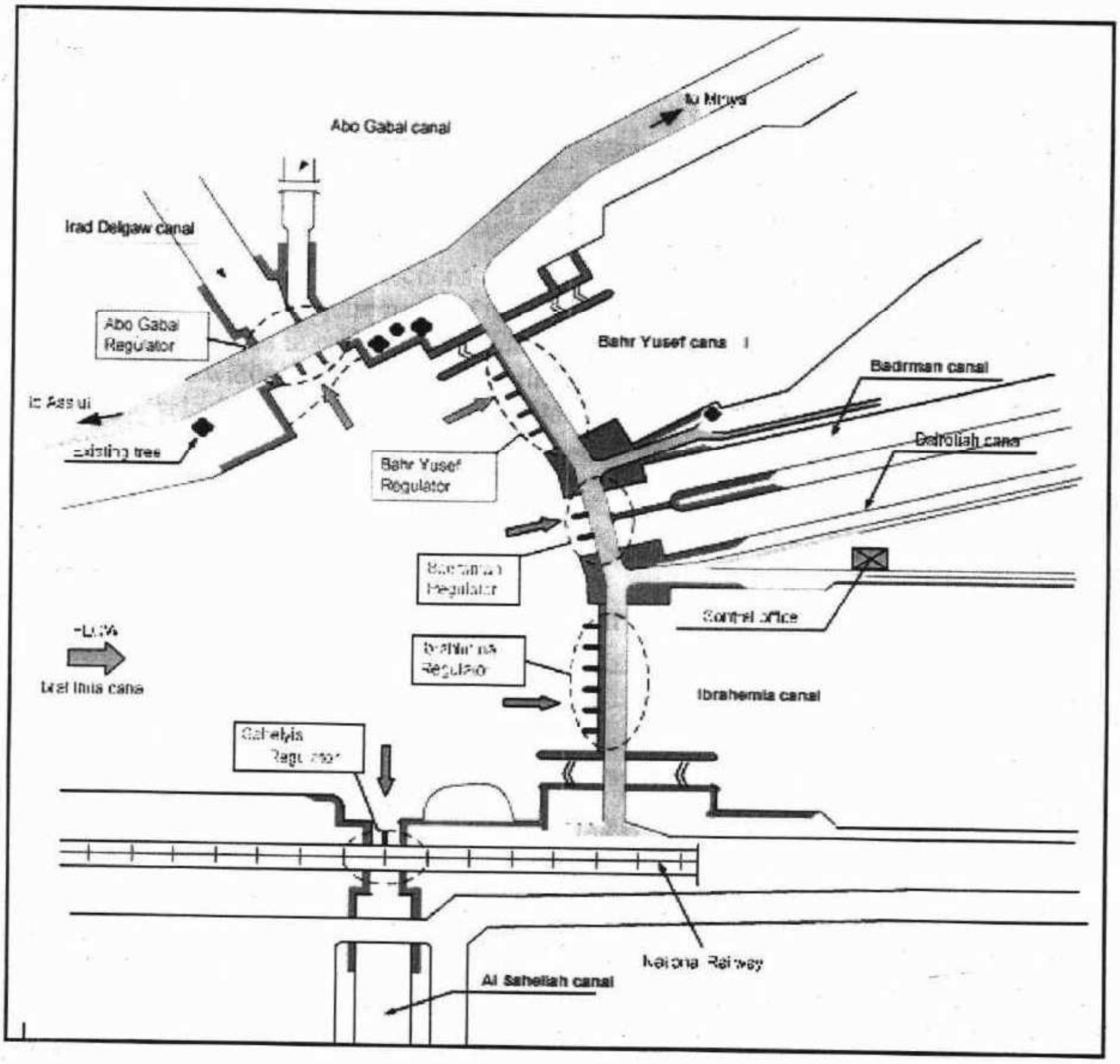


Figure (1): layout of the surveyed area

C- Hydrometric Survey

ADCP and Pray-stock current meters were used for measuring the velocity distributions for 8 cross sections at 30/6/2015 covering the surveyed area.

- Velocity measurements were carried out at ten distributed cross-sections along the surveyed eight branched canals.
- The locations of the cross-sections are shown in Figure 2. These cross sections were selected based on the requirements of the model calibration.
- Number of verticals in each cross section ranged between 5 to 7 vertical, depending on the shape and the width of the each cross section.
- The flow velocity was measured at the middle point for each vertical due to small depth of each cross section.
- Table (1), shows the computed discharges at the selected cross-sections based on the velocity measurements.
- Figures from (3) to (10) show the velocity distribution at the selected cross-sections.
  Q = flow discharge in m^3/s
  WL = Water Level with respect to the mean sea level, (+MSL).

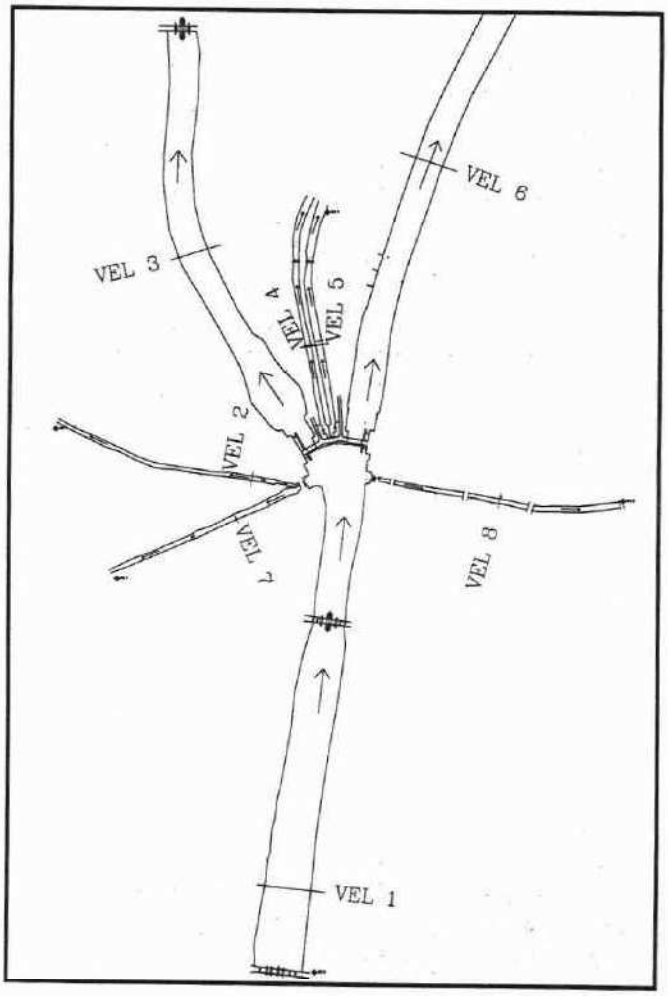


Figure (2): locations of velocity measurements cross-sections

TABLE (1): COMPUTED DISCHARGE AT THE SELECTED CROSS-SECTIONS

Location	Canal	Q (m^3/s)	WL (m)		Left Bank (m)		Right Bank (m)	
			U.S	D.S	E	N	E	N
Vel.1	U.S. Dairut	355.76	46.02	----	283754	3049185.9	283863.2	3049174.2
Vel.2	Abo Gabal	6.21		45.7	283715.6	3050160.7	283717.3	3050171
Vel.3	Bahr Youssef	169.8		45.80	283538.8	3050692.7	283607	3050715.1
Vel.4	Badrman	5.97		45.79	283842.5	3050484.7	283854.4	3050486.6
Vel.5	El-Dairotiah	9.01		45.68	283863.5	3050495.5	283879.7	3050498.1
Vel.6	El-Ibrahemia	155.575		45.88	284100.2	3050940.1	284169.4	3050918
Vel.7	Dalgawy	2.67		44.80	283680.5	3050067.3	283674	3050079.8
Vel.8	El-Saheliah	3.9		45.75	284306.9	3050123	284304.6	3050112.6

Print

Discharge Measurement Summary

Date Measured: Tuesday, June 30, 2015

Site Information

Site Name: up stream dairot
Station Number
Location

Measurement Information

Party
Boat/Motor
Meas. Number

System Information

System Type	RS-M9
Serial Number	4821
Firmware Version	3.80
Software Version	3.8

System Setup

Transducer Depth (m)	0.20
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	110.211
Area (m2)	456.792
Mean Speed (m/s)	0.779
Total Q (m3/s)	355.766
Maximum Measured Depth	4.711
Maximum Measured Speed	1.519

Measurement Results

1	-	6:12:08	0:01:58	26.7	104.53	104.21	110.211	456.792	0.886	0.779	0.73	0.36	33.16	277.48	44.04	355.766	--	78.0
			Mean	26.7	104.53	104.21	110.211	456.792	0.886	0.779	0.73	0.36	33.16	277.48	44.04	355.766	0.000	78.0
			Std Dev	0.0	0.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:01:58
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Comments

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Compass Calibration

Figure (3): Results summery of cross-section (1)

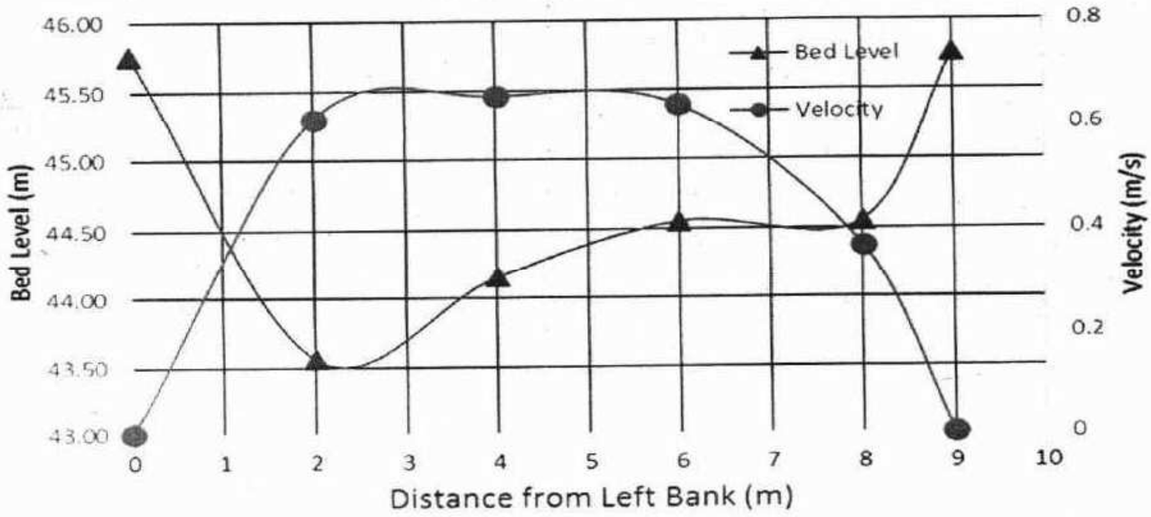

Figure (4): Velocity distribution at cross-section (2)

Print

Discharge Measurement Summary

Date Measured: Tuesday, June 30, 2015

Site Information

Site Name	bahr youssef
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	4821
Firmware Version	3.80
Software Version	3.8

System Setup

Transducer Depth (m)	0.23
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	64.226
Area (m2)	239.880
Mean Speed (m/s)	0.708
Total Q (m3/s)	169.828
Maximum Measured Depth	4.415
Maximum Measured Speed	1.325

Measurement Results

1	L	8:20:14 AM	0:01:25	27.5	60.26	59.23	64.226	239.880	0.709	0.708	1.90	0.06	18.18	128.94	20.75	169.828	--	75.9
			Mean	27.5	60.26	59.23	64.226	239.880	0.709	0.708	1.90	0.06	18.18	128.94	20.75	169.828	0.000	75.9
			Std Dev	0.0	0.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:01:25

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Comments

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Compass Calibration

Error from calibration: 0.00 deg
Mean Magnitude: 0.00
Pitch: 0/0
Roll: 0/0

System Test

System Test: PASS

Figure (5): Results summery of cross-section (3)

Discharge Measurement Summary

Print

Date Measured: Tuesday, June 30, 2015

Site Information

Site Name	badraman
Station Number	
Location	

Measurement Information

Party
Boat/Motor
Meas. Number

System Information

System Type	RS-M9
Serial Number	4821
Firmware Version	3.80
Software Version	3.8

System Setup

Transducer Depth (m)	0.18
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	10.397
Area (m2)	18.675
Mean Speed (m/s)	0.320
Total Q (m3/s)	5.979
Maximum Measured Depth	2.712
Maximum Measured Speed	0.585

Measurement Results

1	R	9:08:12 AM	0:00:36	27.1	7.66	7.40	10.397	18.675	0.213	0.320	0.03	0.28	0.86	3.98	0.84	5.979	--	66.6
			Mean	27.1	7.66	7.40	10.397	18.675	0.213	0.320	0.03	0.28	0.86	3.98	0.84	5.979	0.000	66.6
			Std Dev	0.0	0.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:00:36

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Comments

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Compass Calibration

Error from calibration: 0.00 deg
Mean Magnitude: 0.00
Pitch: 0/0
Roll: 0/0

System Test

System Test: PASS

Figure (6): Results summery of cross-section (4)

Discharge Measurement Summary

Print

Date Measured: Tuesday, June 30, 2015

Site Information

Site Name	dairotia
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	4821
Firmware Version	3.80
Software Version	3.8

System Setup

Transducer Depth (m)	0.22
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	14.708
Area (m2)	27.687
Mean Speed (m/s)	0.326
Total Q (m3/s)	9.012
Maximum Measured Depth	2.756
Maximum Measured Speed	0.658

Measurement Results

1	R	9:27:21 AM	0:01:02	27.0	11.04	10.71	14.708	27.687	0.178	0.326	0.09	0.37	1.41	5.91	1.24	9.012	--	65.6
			Mean	27.0	11.04	10.71	14.708	27.687	0.178	0.326	0.09	0.37	1.41	5.91	1.24	9.012	0.000	65.6
			Std Dev	0.0	0.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:01:02

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Comments

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Compass Calibration

Error from calibration: 0.00 deg
Mean Magnitude: 0.00
Pitch: 0/0
Roll: 0/0

System Test

System Test: PASS

Figure (7): Results summery of cross-section (5)

Print

Discharge Measurement Summary

Date Measured: Tuesday, June 30, 2015

Site Information

Site Name	ibrahemia
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	4821
Firmware Version	3.80
Software Version	3.8

System Setup

Transducer Depth (m)	0.22
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	62.381
Area (m2)	210.828
Mean Speed (m/s)	0.738
Total Q (m3/s)	155.575
Maximum Measured Depth	4.471
Maximum Measured Speed	1.192

Measurement Results

1	-	10:40:27 AM	0:01:10	26.9	55.70	54.38	62.381	210.828	0.796	0.738	2.07	0.00	16.10	116.66	20.74	155.575	--	75.0
			Mean	26.9	55.70	54.38	62.381	210.828	0.796	0.738	2.07	0.00	16.10	116.66	20.74	155.575	0.000	75.0
			Std Dev	0.0	0.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:01:10

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Comments

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Compass Calibration

Error from calibration: 0.00 deg
Mean Magnitude: 0.00
Pitch: 0/0
Roll: 0/0

System Test

System Test: PASS

Figure (8): Results summery of cross-section (6)

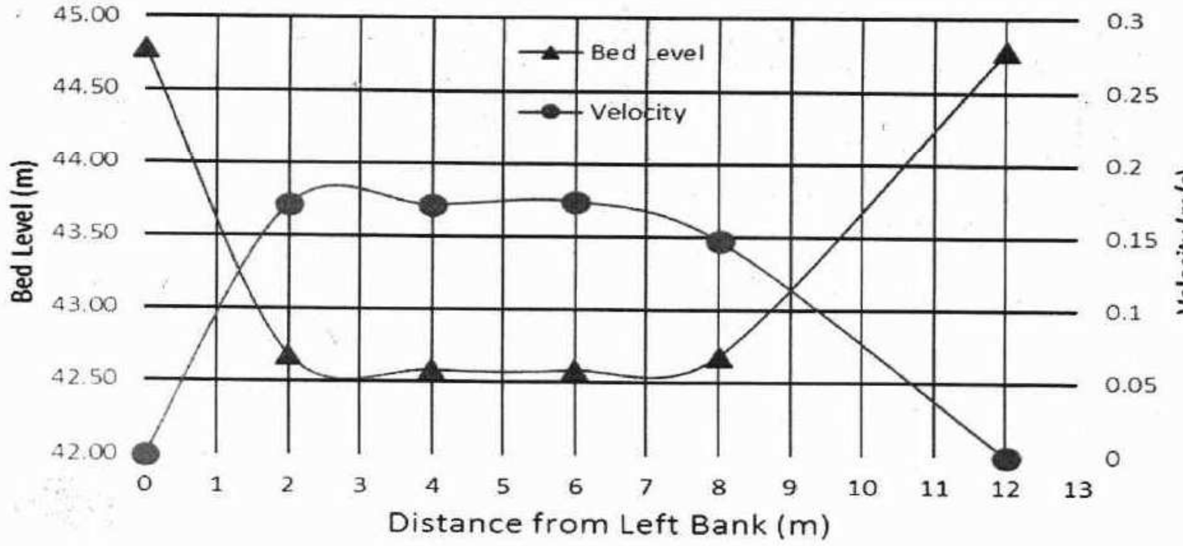


Figure (9): Velocity distribution at cross-section (7)

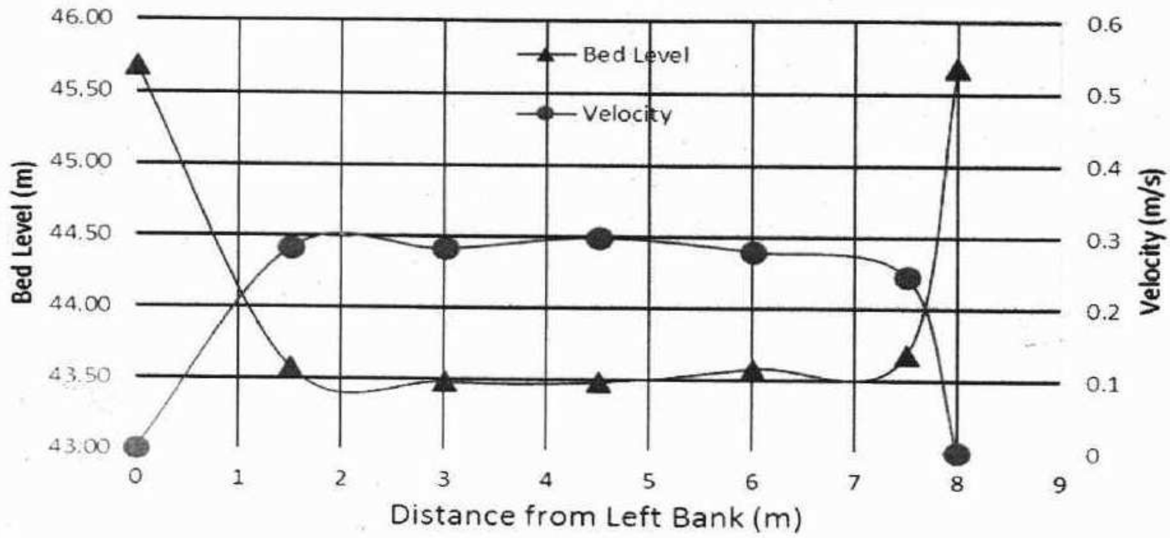


Figure (10): Velocity distribution at cross-section (8)

TABLE (2): VELOCITY DISTRIBUTION AT VEL.2

Dist. (m)	Depth (m)	Point Depth (m)	R/50 sec		R_{avg}/sec	Point Vel. (m/s)	Discharge (m3/s)
			R1	R2			
0	0.00	0.00	0.00	0.00	0.00	0.00	0.67
2	2.20	1.10	115	112	2.27	0.61	2.41
4	1.60	0.80	121	122	2.43	0.66	1.81
6	1.20	0.60	117	119	2.36	0.64	1.21
8	1.20	0.60	66	69	1.35	0.37	0.11
9.0	0.00	0.00	0.00	0.00	0.00	0.00	0

TABLE (3): VELOCITY DISTRIBUTION AT VEL.7

Dist. (m)	Depth (m)	Point Depth (m)	R/50 sec		R_{avg}/sec	Point Vel. (m/s)	Discharge (m3/s)
			R1	R2			
0	0.00	0.00	0.00	0.00	0.00	0.00	0.18
2	2.10	1.05	30	31	0.61	0.17	0.74
4	2.20	1.10	30	31	0.61	0.17	0.76
6	2.20	1.10	30	32	0.62	0.17	0.69
8	2.10	1.05	24	28	0.52	0.15	0.31
12.0	0.00	0.00	0.00	0.00	0.00	0.00	0

TABLE (4): VELOCITY DISTRIBUTION AT VEL.8

Dist. (m)	Depth (m)	Point Depth (m)	R/50 sec		R_{avg}/sec	Point Vel. (m/s)	Discharge (m3/s)
			R1	R2			
0	0.00	0.00	0.00	0.00	0.00	0.00	0.22
2	2.10	1.05	51	52	1.03	0.28	0.91
3	2.20	1.10	51	52	1.03	0.28	0.96
5	2.20	1.10	52	57	1.09	0.30	0.93
6	2.10	1.05	53	49	1.02	0.28	0.81
8	2.00	1.00	47	42	0.89	0.25	0.06
8.0	0.00	0.00	0.00	0.00	0.00	0.00	0

Appendix A

Surveying equipments
BATHYMETRIC SURVEY INSTRUMENTS

- **GEOGRAPHICAL POSITIONING SYSTEM (GPS)**

Manufacturer : LEICA, Swiz
Model : GPS 1200 and Viva
Number of units: 4 units
Accuracy
Rapid static (phase)
Static mode after initialization
Horizontal: 5 mm + 0.5 ppm (rms)
Vertical: 10 mm + 0.5 ppm (rms)
Kinematic (phase)
Moving mode after initialization
Horizontal: 10 mm + 1 ppm (rms)
Vertical: 20 mm + 1 ppm (rms)

- **ACOUSTIC DOPPLER CURRENT PROFILE (ADCP)**


ADCP

Profiling Range — Distance 0.06 to 5m 0.06 to 40m
Profiling Range1 — Velocity ±20 m/s ±20 m/s
Velocity1 — Accuracy ±0.25% of measured velocity
±0.2cm/s ±0.25% of measured velocity
±0.2cm/s
Velocity — Resolution 0.001 m/s 0.001 m/s
Number of Cells Up to 128 Up to 128
Cell Size 0.02 to 0.5m 0.02 to 4m
Transducer Configuration Five (5) Transducers Nine (9) Transducers
4-beam 3.0 MHz
Janus 25° Slant Angle Dual 4-beam 3.0 MHz/1.0 MHz
Janus 25° Slant Angle
1.0 MHz Vertical Beam Echosounder 0.5 MHz Vertical Beam Echosounder
Depth — Range 0.20 to 15 m 0.20 to 80m
Depth — Accuracy 1% 1%
Depth — Resolution 0.001 m 0.001 m
Discharge Measurement Range — Bottom-Track 0.3 to 5m 0.3 to 40m
Discharge Measurement Range — RTK GPS 0.3 to 15 m 0.3 to 80 m
Discharge Measurement — Computations Internal Internal

<u>LEVELING INSTRUMENT</u>

Manufacturer : LEICA, Swiz
Model : Sprinter 250M-Digital Level
Number of units: 1 unit
<u>Specifications`</u>

Technical Data Sprinter 250m

- Height accuracies
  - Electronic measurement with Sprinter barcode staff: 1.0/0.7 mm
  - Optical measurement: 2.5mm
- Distance Accuracy: 10 mm for D ≤ 10 m and for D > 10 m
- Full Range: 2 -100 m
- Single and Tracking measuring modes
- Compensator: Magnet damped pendulum
- Telescope: Magnification 24x
- Environmental Standards: IP55
- Power Type: AA Batteries
- Full Weight:
- Data Storage of up to 1000 points.

- **TAMAYA TDM-9000 ECHO SOUNDER**

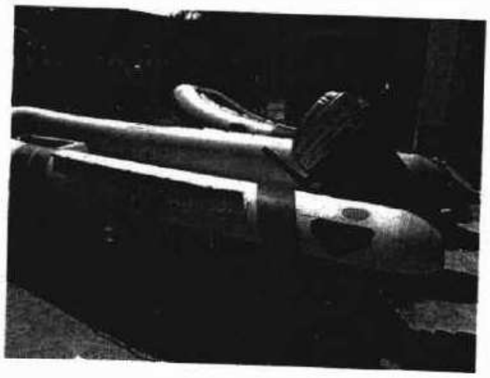
Manufacturer : TAMAYA TECHNICS INC., JAPAN.
Model : TDM-9000
Number of units : 1 unit
Measurement Range : 0.65m-50m (1/100), 0.65m-100m (1/200)

Accuracy : ±2cm±water depth x 1/1000
Transducer Frequency : 200KHz±3KHz
Direction Angle of Transducer: Half value half angle, about 3 °

- **BOATS USED FOR BATHYMETRIC SURVEYS:**

1) Fiber Rubber boats

Different boats will be used in the bathymetric survey with capacity up to 7 persons, and 55 HP outboard motors.



The dimensions of the big boats are:

Length : 4.7 m
Width : 1.9 m
Draft : 0.25 m
Capacity: 0.7 ton
Motor : 55HP

The dimensions of the small boat are:

Length : 3.96 m
Width : 1.68 m
Draft : 0.20 m
Capacity: 0.5 ton
Motor : 40HP

Progress Report 2

Physical Model Study of Dairut Group of Regulators

Progress Report No. 2

Model Design and Construction

Author

Dr. Ahmed Fahmy Ahmed

Director

Prof. Khaled Ramadan

Sep. 2015

HRI- 79/2015

HRI

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Eng. Eman Mahmoud El-Sherbiny	Research Assistance

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ABBREVIATIONS

No.	Symbol	Abbreviations
1	DGR	Dairut Group of Regulators
2	ADCP	Acoustic Doppler Current Profile
3	D.S.	Downstream
4	GOE	The Government of Egypt
5	HAD	High Aswan Dam
6	HRI	Hydraulics Research Institute
7	JICA	Japan International Cooperation Agency
8	Max.	Maximum
9	Min.	Minimum
10	MWRI	Ministry of Water Resources and Irrigation
11	OAD	Old Aswan Dam
12	RGBS	Reservoirs and Grand Barrages Sector
13	R_e	Reynolds Number
14	U.S.	Upstream
15	WDS	Water Distribution Sector
16	WSL	Water surface level

LIST OF SYMBOLS

Symbol	Definition	Unit
A	**Cross section area**	**[m^2]**
B	**River bed width**	**[m]**
Fr	**Froud number**	**[-]**
g	**Acceleration due to gravity**	**[m / s2]**
h	**Flow depth**	**[m]**
Fr	**Froud Number**	**[-]**
n_L	**Length scale ratio**	**[-]**
P	**Canal top width**	**[m]**
Q	**Flow discharge**	**[m^3 / s]**
R_e	**Reynolds number**	**[-]**
V	**Flow velocity**	**[m / s]**
μ	**Fluid viscosity**	
ρ	**Fluid density**	**[kg/m^3]**
ρs	**Particle density**	**[kg/m^3]**
Δρ	**Density difference**	**[kg/m^3]**
Δ	**Relative density**	**[-]**
υ	**Kinematics viscosity**	**[m^2 / s]**

ABSTRACT

Dairut group regulators "DGR" is located on El-Ibrahimiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages. This group of regulators was constructed in 1872 to play a vital role of delivering about 9.6 billion m^3/year of irrigation water to all beneficiary area of about 1.43 millions feddans through El- Ibrahimia main canal. "DGR" branches at El-Ibrahimia main canal at Dairut into seven main canals, namely El-Ibrahimia canal, Bahr-Yusef canal, Sahelyia canal, El-Diroutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal. The Bahr-Yousef canal is the largest canal in capacity among the seven canals. Its length extends as long as 312 km downstream of "DGR" and there are four regulators along the canal, namely El-Lahoun regulator, Mazoura regulator, Sakoula regulator and Dahab regulator. Those regulators have been rehabilitated by Japan's Grant Aid since 1995.

One important point should be raised concerning the existing "DGR" which is that Dairut Group of Regulators was constructed in 1872 and can be considered as the oldest active regulator in Egypt, and the their weirs cannot function well due to their age. For this reason rehabilitation of such hydraulic construction should be urgently implemented. It is expected that the impacts of the rehabilitation of the "DGR" should be significant considering the vast beneficiary area and very long canal networks. Therefore, rehabilitation of "DGR" was quite urgent for seeking effective use of the limited water resources and due to limited facilities as well as high cost operation and maintenance.

Based on such an understanding, the Government of Egypt "GOE" requested informally to the Government of Japan "GOJ" for the Japanese Official Development Assistance by Yen-Loan. Accordingly, Japan International Cooperation Agency "JICA" dispatched the study team for the preparatory survey for the rehabilitation and improvement of Dairut Group of Regulators "DGR". Therefore, in order to increase agricultural production and to keep sustainability of agricultural industry in the Upper Egypt region the main objectives of the conducted study were defined as the following:

1. To formulate the rehabilitation plan for Dairut Group of Regulators "DGR";
2. To formulate the improving water distribution plan for the entire operation and maintenance of "DGR" and other regulators that are located along the main canals;
3. To evaluate the present situation and the rehabilitation plan of the existing minor structures based on the result of the inventory survey carried out by the Ministry of Water Resources and Irrigation "MWRI"; and
4. To carry out technology transfer to the implementation agency through the study period on the above mentioned subjects.

To fulfill the above mentioned objectives, a three dimensional physical model study would be carried out in the Hydraulics Research Institute "HRI" which is the main concern of the present reports.

1. INTRODUCTION

The current investigation is being carried out referring to letter No. 1379/156 dated on the 8th day of May 2014 from the Reservoirs and Grand Barrages Sector "RGBS" of the Ministry of Water Resources and Irrigation "MWRI" which requested "HRI" to prepare for a technical and financial proposal to carry out hydraulic physical model for testing a new alternative for Dairut Group Regulators "DGR". The focal objective of the proposed testing program is to adopt the best alignment and hydraulic design for the new barrages group components which fulfills the new emerged flow morphology regime through El-Ibrahimiya canal after the construction of the new Assuit barrages. Flow capacity and velocity distribution upstream and downstream each of the new group components would be physically tested and investigated.

To achieve the above mentioned study objectives, several field and laboratory activities would be carried out which can be summarized as follows:

1. Topographic, bathymetric survey and field measurements would be conducted to cover about 6.5 km which comprises the branched canals downstream Dairut Group of Regulators "DGR" and main El-Ibrahimia canal upstream "DGR". Field measurements should involve every needed details to construct and calibrate the physical model.

2. Data collection for different hydrological information for passing flow discharges and the corresponding water surface levels for each of the seven branched canals. These would be summarized and analyzed for the case of existing conditions for the maximum and minimum flow discharges. Also the detailed dimensions of the existing barrages and head regulators at "DGR" would be collected to be simulated in the model.

3. Using the collected field data and the hydrological information for the maximum and minimum passing flow discharges through each of the modeled "DGR" branches to design and construct the model to simulate the existing condition in the prototype.

4. The model would be then calibrated according to the recent field measurements at the existing flow conditions in the prototype during the field survey period. Then the flow condition through each of the branched canals would be investigated at the two cases of the minimum and maximum flow discharges.

5. The proposed design for the new "DGR" would be then assembled in the workshop and affixed at 140 m downstream the existing situation then flow pattern through each of the 4 branched canals would be investigated. The entering flow currents for the 3 upstream branches would be also investigated in the model and some engineering works for there entrance could be recommended.

The first report was released by "HRI" in August 2015 which was mainly focused on the field measurements for conducting the model study. While the present report (the second one) would be directed to cover the prototype conditions, laboratory set up, model design and construction.

Historical hydrological features of each branched canals at the cases of maximum and minimum flow discharges during the existing conditions and that expected after the construction of the new Assuit barrages would be provided. This, in other words, means that the current report would concentrate on the detailed preparation for model design and testing under the following sections:

- Dairut group of regulators "DGR"
- Hydrological condition
- Prototype conditions
- Similarity rules
- Model construction
- Discharge measurements
- Testing plane

2. DAIRUT GROUP OF REGULATORS "DGR"

Dairut group of regulators "DGR" was constructed in 1872 on El-Ibrahimiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages as illustrated in Figure (1).

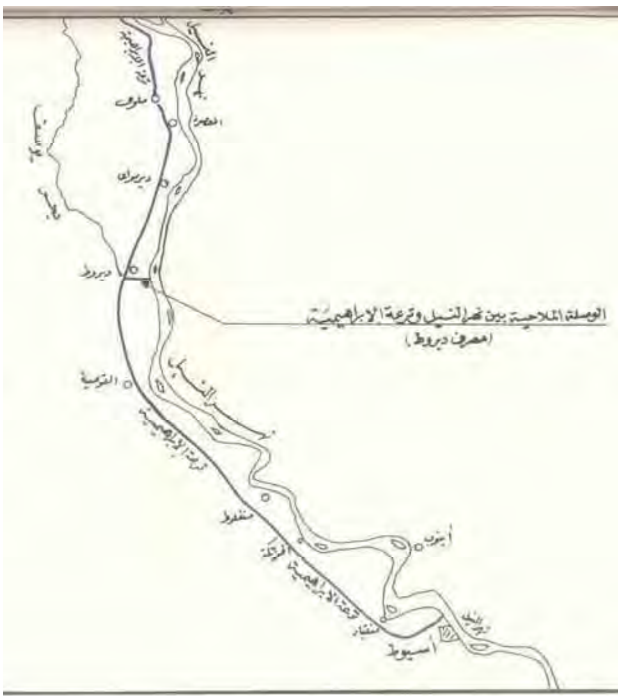


Figure (1): Location of Dairut Group of Regulators "DGR"

Each of the existing group of regulators and the new proposed group would be described in the following two sub-sections:

2.1. The Existing "DGR"

The existing "DGR" is mainly located on El-Ibrahimia main canal which branched downstream of "DGR" – as shown in Figure (2) and Photo (1) - into seven canals, namely El-Ibrahimia canal, Bahr-Yusef canal, Sahelyia canal, El-Dairutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal. While Table (1) illustrates the current formation of "DGR" which is mainly consist of five main head regulators. This because each of the two branches of Irad Delgaw and Abou Gabal canals and two branches of Badraman and Dairutia canals are branched downstream only one head regulator as shown in Figure (2) and Photo (1).

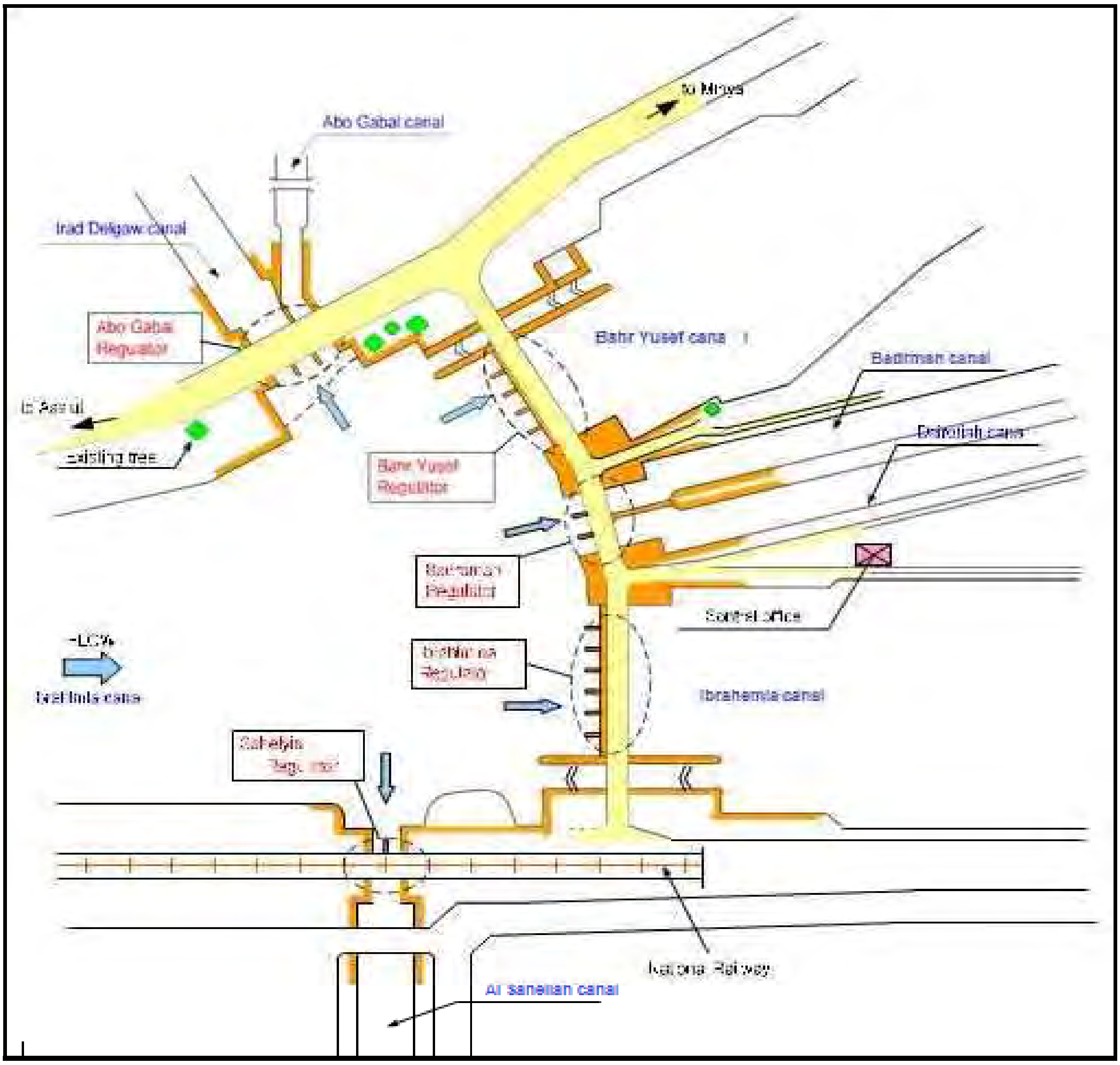


Figure (2): Main Branch Canals Downstream of "DGR"

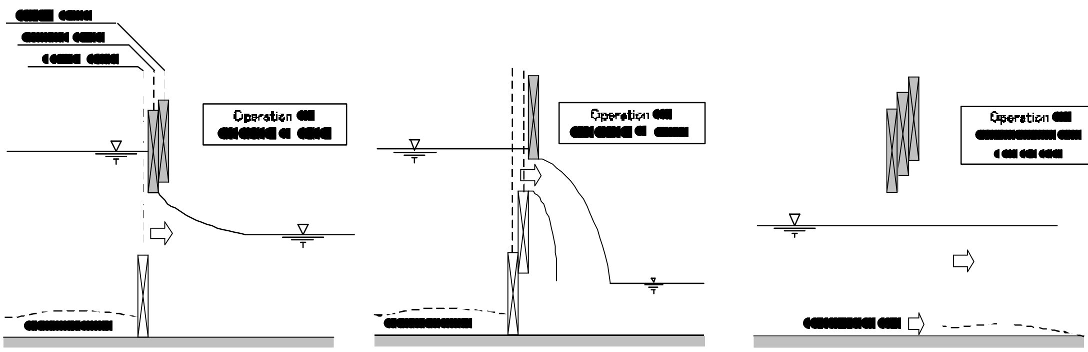
Photo (1): layout of the Existing Dairut Group of Regulators

Table (1): Current Formation of Dairut Group of Regulators

Name of canal at DGR	Regulator unit	Dimensions of the regulator unit	
		Structural	Gates
Bahr Yusef	No. of gates	5 vents	3m width x 5 vents
	Pier	4 units & width 1.80~2.25m	Total height 7.5 m
	Mid. apron	L=43.25m, thickness 3m	3 leaves of gate
	Foundation	Limestone partially concrete	Bottom elevation (39.50) m
	Lock	width 8.5m	Operational high water level (46.00) m
Badraman & Dirotiah	No. of gates	2 vents (1 vent closed)	3m wide x 2 vents total height 7.5m
	Pier	2 units & width 1.80~2.25m	3 leaves of gate
	Mid. apron	L=38.65m,	Bottom elevation (39.30) m
	Foundation	limestone, t=unknown	Operational high water level (46.00)m
Ibrahimia	No. of gates	7 vents	3m width x 7 vents
	Pier	6 units & width 1.80~2.25m	Total height 7.5 m
	Mid. apron	L=39.70m, thickness 3m	3 leaves of gate
	Foundation	limestone partially concrete	Bottom elevation (39.81) m
	Lock	width 8.5m	Operational high water level (46.00) m
Sahelyia (right bank)	No. of gates	2 vents	3m wide x 2 vents total height 5.5 m
	Pier	1 unit & width 1.80~2.25m	1 leaves of gate
	Mid. apron	L=18.90m,	Bottom elevation (41.80) m
	Foundation	limestone, t=unknown	Operational high water level (46.00) m
Abo Gabal & Irad Delgaw (left bank)	No. of gates	3 vents	3m wide x 3 vents total height 5.5 m
	Pier	2 units & width 1.80~2.25m	1 leaves of gate
	Mid. apron	L=28.60m,	Bottom elevation (42.00) m
	Foundation	limestone, t=unknown	Operational high water level (46.00) m

The above general description is taken from the conducted Japan International Cooperation Agency "JICA" study for the preparatory survey for the rehabilitation and improvement of Dairut Group of Regulators "DGR". However, as some more details of the existing "DGR" are still needed to be simulated in the model, engineering drawings of the existing "DGR" at the Reservoirs and Grand Barrages Sector "RGBS" were utilized. Flow discharge and the corresponding water surface level upstream of each regulator is controlled using the three leaf gates that fixed at downstream side of every vent as illustrated in Figure (3). This reveals the following:

- Case (1) which used to be applied at the ordinary and regular flow discharges. The discharge in this case is controlled by using upper and middle gates while the upstream gate is lowered on the floor as shown in Figure (3-a).
- Case (2) which used to be applied at the passing low flow discharges. The discharge in this case is controlled by using upper gate while the two upstream gates (the lower and middle gates) are lowered to raise the upstream water surface level as shown in Figure (3-b).
- Case (3) which used to be applied at the case of maintenance work to flush deposited sedimentation. The discharge in this case is passing without any control by lifting the three leaf gates above the existing water surface level as shown in Figure (3-c).



Case (1) **Case (2)** **Case (3)**

Figure (3): Operation of the Three Leaf Gates

The current operation gates of the existing "DGR" are listed in Table (2).

Table (2): Current Status of the Gates of the "DGR"

Regulator Name	No. from left bank	Upper Gate	Mid. Gate	Lower Gate	Remarks
Ibrahimia Reg.	No. 1	o	o	o	
	No. 2~6	o	o	×	without chain
	No.7	o	o	o	
Bhar Yusef Reg.	No.1~5	o	o	o	
Badraman Reg.	No.1~2	o	o	o	
Abo Gabal Reg.	No.1~3	o			
Sahelyia Reg.	No.1~2	o			

2.2. THE PROPOSED NEW "DGR"

According to the preparatory study that carried out by "JICA" for the rehabilitation and improvement of Dairut Group of Regulators "DGR", three alternatives were presented which are shown in Photo (2). The first one is rehabilitating the existing "DGR" which would be very costly and the repaired regulators would not be used for more than 40 years. The other two alternatives are constructing new "DGR" just upstream or at about 140 m downstream of the existing one. Comparative study for the three alternatives revealed that construction of new "DGR" at about 140 m downstream the existing one would be the best. The detailed designs of the proposed new "DGR" are shown in Figure (4) and listed in Tables (3, 4, 5, and 6). In this case, the over-flow type gate was recommended for the new "DGR" as shown in Figure (5).

Photo (2): The Three Alternative Designs for the New "DGR"

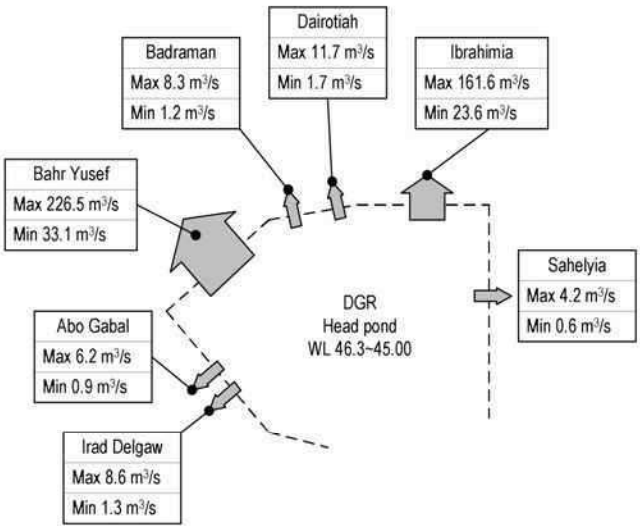


Figure (4): Proposed Flow Diversion of the New "DGR"

Table (3): Hydrological Conditions of the New "DGR"

Regulator		Max. U/S W.L. (m)	Min. D/S W.L. (m)	Passing Discharge (m3/s)	
				Max.	Min.
Bahr Yusef		(46.30)	(43.00)	226.5	33.1
Ibrahimia		(46.30)	(43.00)	161.6	23.6
Badraman	Badraman canal	(46.30)	Single-leaf Gate	8.3	1.2
	Diroutiah canal	(46.30)	Single-leaf Gate	11.7	1.7
Abo Gabal	Abo Gabal canal	(46.30)	Single-leaf Gate	6.2	0.9
	Irad Delgaw canal	(46.30)	Single-leaf Gate	8.6	1.3
Sahelyia		(46.30)	Single-leaf Gate	4.2	0.6

Table (4): Basic Design of the New "DGR"

Regulator		Gate type	Number of vets and width
Bahr Yusef		Double-leaf Gate	8m x 4vents
Ibrahimia		Double-leaf Gate	8m x 3vents
Badraman	Badraman canal	4m x 1vent	4m x 1vent
	Diroutiah canal	4m x 1vent	4m x 1vent
Abo Gabal	Abo Gabal canal	4m x 1vent	4m x 1vent
	Irad Delgaw canal	4m x 1vent	4m x 1vent
Sahelyia		4m x 1vent	4m x 1vent

Table (5): Proposed Main Dimensions for the New "DGR"

Regulators	Pile length	Length of cutoff	Thickness of	Length of apron	Length of bed
Bahr-Yusef	Prefabricate con. Pile (500mm) L=7m/pcs.	L=14.5m/pcs.(U.S) L=13.0m/pcs.(M. D) L=	Max. 2.5m Min 0.6m	L= 6.0m(U.S) L=17.5m(M.D) L=24.0m(D.S)	L=50.0m
Ibrahimia	Prefabricate con. pile (500mm) L=7m/pcs.	L=14.5m/pcs.(U.S) L=13.0m/pcs.(M. D) L= 2.0m/pcs.(D.S)	Max 2.5m Min 0.6m	L= 6.0m(U.S) L=17.5m(M.D) L=24.0m(D.S)	L=50.0m
Badraman	Prefabricate con. pile (500mm) L=11m/pcs.	L=10.5m/pcs.(U.S) L= 9.0m/pcs.(M.D)	Max 2.5m Min 0.6m	L= 4.5m(U.S) L=15.2m(M.D) L=16.0m(D.S)	L=20.0m
AboGabal	Prefabricate con. pile (500mm) L=11m/pcs.	L= 2.0m/pcs.(M.D)	Max 2.7m Min 0.7m	L= 9.0m L=15.0m	Riprap stone works
Sahelyia	Prefabricate con. pile (500mm) L=11m/pcs.	L= 2.0m/pcs.(M.D)	Max 2.7m Min 0.7m	L=9.0m L=7.0m	Riprap stone works

Table (6): Proposed Main Elevations of the new "DGR"

Regulators	Top of pier	Bed level of gate	Maintenance bridge
Bahr Yusef	**EL47.5 (same as existing)**	**EL40.0 (0.5m higher than the existing**	**EL50.0 (same as existing)**
Ibrahimia	**EL47.5 (same as existing)**	**EL40.0 (0.5m higher than the existing**	**EL50.0 (same as existing)**
Badraman	**EL47.5 (same as existing)**	**EL43.5 ((0.5m higher than the existing**	**EL50.0 (same as existing)**
Abo Gabal	**EL47.5 (same as existing)**	**EL44.0 (0.5m higher than the existing**	**EL50.0 (same as existing)**
Sahelyia	**EL47.5 (same as existing)**	**EL44.0 (0.5m higher than the existing**	**EL50.0 (same as existing)**

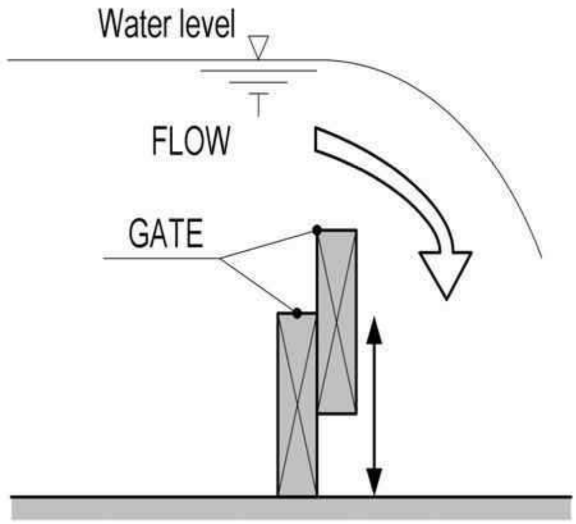


Figure (5): Selected Over-flow Type Gate for New "DGR"

3. HYDROLOGICAL CONDITIONS

The hydrological study for the modeled reach would be very essential for running the model at different flow discharges and the corresponding water surface levels. According to the carried out investigation by "JICA", some common hydrological information were recorded. The monthly discharge volume for the past 10 years individually downstream El-Ibrahimia head regulators at Dairut were recorded as listed in Table (7). Also the annual average discharge volume for the past 10 years individually downstream Bahar Yusef and El-Ibrahimia head regulators at Dairut were worked out as 4820 million m^3 and 4069 million m^3 respectively as listed in Table (8). This makes the ratio between the entering flow discharge through Bahar Yusef and that of El- Ibrahimia 47.23 % and 39.92% out of seven main canals at Dairut Group of Regulators "DGR". This means that 87.15 % of the annual average discharges (equivalent to 8889 million m^3) are flowing through the two main branched canals at Dairut and only 12.85 % (equivalent to 1310 million m^3) are flowing through the five rests branched canals.

Table (7): Monthly Discharge Records at Ibrahimia Dairut

Year	Monthly discharge (million m^3)												Average
	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
1999	274	303	408	411	431	540	522	526	409	***	352	327	***
2000	104	327	346	356	381	455	472	451	365	341	311	273	4.182
2001	128	301	332	331	350	441	460	449	369	359	300	264	4.084
2002	142	274	315	334	350	436	451	442	353	312	293	263	3.965
2003	81	290	302	302	331	430	445	438	335	314	292	261	3.821
2004	124	270	289	409	332	418	433	432	342	305	291	262	3.907
2005	87	275	303	307	329	423	448	444	354	305	286	243	3.804
2006	74	253	324	318	345	442	460	420	378	327	299	263	3.903
2007	151	281	340	382	403	448	475	485	412	397	379	301	4.454
2008	117	318	373	403	422	465	491	479	405	392	334	301	4.500
Average	128	289	333	355	367	450	466	457	372	339	314	276	4.069

Table (8): Annual Discharge Records at "DGR"

No.	Year	Annual passing discharge (million m^3)				
		Ibrahimia Intake	Bahar Yousef		Ibrahimia at Dairut	
			Discharge	Percent (%)	Discharge	Percent (%)
1	1999	10,381	4,759	45.84 %	***	***
2	2000	10,132	4,690	46.29 %	4,182	41.28 %
3	2001	10,206	4,752	46.56 %	4,084	40.02 %
4	2002	9,877	4,640	46.98 %	3,965	40.14 %
5	2003	9,695	4,608	47.53 %	3,821	39.41 %
6	2004	9,892	4,722	47.74 %	3,907	39.50 %
7	2005	9,907	4,735	47.79 %	3,804	38.40 %
8	2006	10,127	4,967	49.05 %	3,903	38.54 %
9	2007	10,784	5,050	46.83 %	4,454	41.30 %
10	2008	11,065	5,281	47.73 %	4,500	40.67 %
Average		10,207	4,820	47.23 %	4,069	39.92 %

This information as well as the other existing hydrological data for "DGR" operation were utilized to work out Table (9) for different branched canals at "DGR".

Table (9): Existing hydrological Records at "DGR"

No.	Flow case	Maximum flow discharge				Minimum flow discharge			
	Branched canal	Passing flow		Water level (m)		Passing flow		Water level (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S	(mm^3/day)	(m^3/s)	U/S	D/S
1	Bahr-Yusef canal	19.57	226.50	46.30	NL	2.86	33.11	NL	NL
2	Badraman canal	0.717	8.30	46.30	NL	0.104	1.20	NL	NL
3	Diroutiah canal	1.019	11.70	46.30	NL	0.147	1.70	NL	NL
4	Ibrahimia canal	13.964	161.62	46.30	NL	2.042	23.63	NL	NL
5	Sahelyia canal	0.363	4.20	46.30	NL	0.052	0.60	NL	NL
6	Irad Delgaw canal	0.743	8.60	46.30	NL	0.112	1.30	NL	NL
7	Abo Gabal canal	0.536	6.20	46.30	NL	0.078	0.90	NL	NL

NL in the above table means Not Available. On the other hand, base on the existing commend of the served area and the quota, the daily flow discharge distribution downstream of "DGR" was worked out as listed in Table (10). This data were reported in "JICA" study according to the agreement of Water Distribution Sector "WDS" in (2002) for the flow discharge distribution downstream of El-Ibrabimia canal.

Table (10): Design Discharge Based on the Quota at "DGR"

No.	Canal	Served Area (Fed)	Design discharge		Ratio (%)
			Min. (m^3/s)	Max. (m^3/s)	
1	Ibrahimia canal	576,700	23.63	161.62	36.84%
2	Bahr-Yusef canal	808,000	33.11	226.50	51.63%
3	Sahelyia canal	15,100	0.60	4.20	0.96%
4	Diroutiah canal	41,800	1.70	11.70	2.67%
5	Badraman canal	29,700	1.20	8.30	1.90%
6	Abo Gabal canal	22,000	0.90	6.20	1.41%
7	Irad Delgaw canal	30,800	1.30	8.60	1.97%
8	Direct intake(Upstream of DGR)	41,000	1.70	11.50	2.62%
Total		1,565,100	64.14	438.62	100%

However, such study should be related to the actual maximum and minimum capacities of El-Ibrahimia canal upstream the "DGR" which used to be distributed through the branched canals in the downstream. This in other words means that the overall some of the maximum and minimum capacities of the downstream branched canals would be more and less than the actual prototype values in El-Ibrahimia canal upstream of "DGR" respectively. Therefore in order to deal with such case in realistic way as well as to imitate the real hydrological prototype conditions, the maximum and minimum flow discharge through El-Ibrahimia canal upstream Dairut group of regulators "DGR" and the corresponding water surface level, an assured hydrological study was worked out

The maximum and minimum flow discharge and water surface level through El-Ibrahimia canal upstream Dairut group of regulators "DGR" during the last ten years from 2005 to 2014 were determined as listed in Table (11) and Figure (6). Those data were utilized to deduce the overall maximum and minimum annual flow discharge during the last ten years as listed in Table (12). As the flow discharge in Table (12) corresponding to the entering flow to El-Ibrahimia canal from the Nile River upstream the new Assuit barrages, the recorded data in Table (12) was corrected as follows.

Table (11): Hydrological Data of El-Ibrahimia Canal Upstream "DGR"

No.	Year	Water Level U.S. Dairut (m)		Discharge at Assuit (m m^3/day)	
		Max.	Min.	Max.	Min.
1	2005	46.00	42.40	39.500	2.000
2	2006	46.20	43.60	41.000	1.500
3	2007	46.50	42.80	41.800	2.000
4	2008	46.20	42.30	41.000	1.000
5	2009	46.16	43.60	37.500	2.000
6	2010	45.92	43.40	36.700	1.800
7	2011	45.98	43.50	37.800	1.000
8	2012	45.98	43.30	37.900	1.800
9	2013	46.10	43.15	38.300	0.850
10	2014	45.98	42.60	38.800	2.000

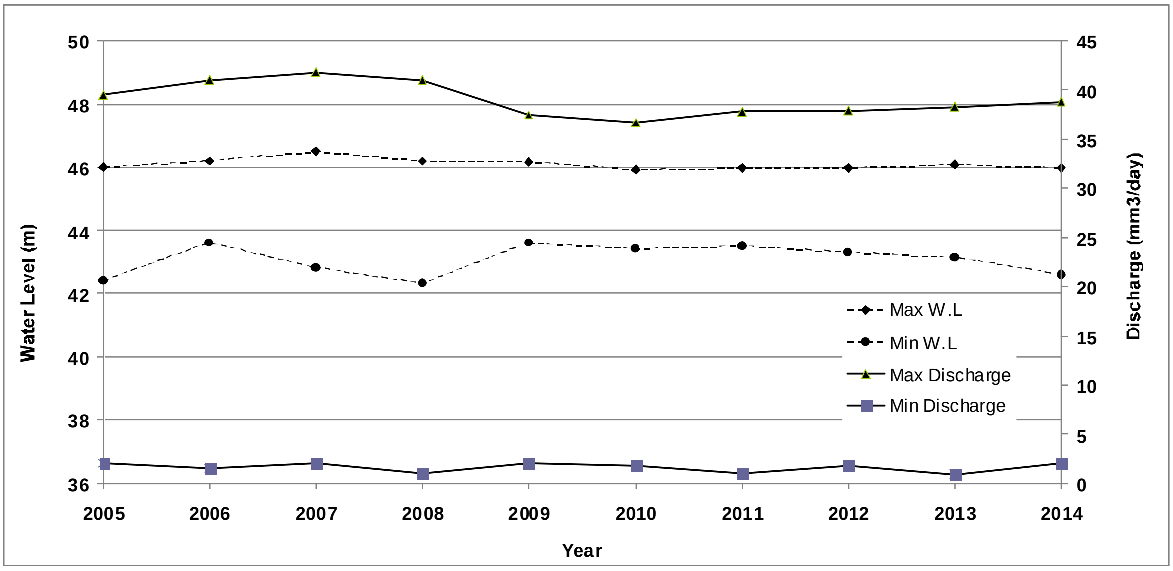


Figure (6): Historical Hydrological Records U.S. "DGR"

Table (12): Maximum and Minimum Annual Records Upstream "DGR"

Case No.	Flow case	Discharge at Assuit (mm^3/day)	Date	Upstream level U.S. Dairut (m)	Date
1	Minimum flow upstream "DGR"	0.850	7/1/2013	42.30	22/1/2008
2	Maximum flow upstream "DGR"	41.80	8/6/2007	46.50	6/10/2007

- The maximum flow discharge downstream El-Ibrahimia head regulator during the last ten years is 41.80 m m^3/day which was recorded in 8/6/2007
- The minimum flow discharge downstream El-Ibrahimia head regulator during the last ten years is 0.850 m m^3/day which was recorded in 7/1/2013
- Bearing in mind a lag time of one day to reach upstream "DGR" at 60.600 km downstream El-Ibrahmia head regulator at Assuit during maximum discharges and two days during minimum discharges, therefore the maximum and minimum flow discharges upstream Dairut occurred on 9/6/2007 and 9/1/2013 respectively.
- According to the attainable daily records of the flow discharges and the corresponding water surface level at the above two dates, the existing flow distribution and the corresponding upstream and downstream water surface levels for each branched canals could be worked out.
- However, as the attainable records for the two selected dates were limited to the existing water surface levels downstream each branched canal and only the flow discharge through Bahr Yussef and El-Ibrahimia canals, the reported flow ratio distribution by "JICA" study in Table (10) was used to produce the required flow discharge as listed in Tables (13 and 14).
- In this case the actual flow discharge though El-Ibrahimia and Bahr Ussef canals on 9/6/2007 (at the case of maximum discharge) which are equivalent to 15.447 and 17.662 mm^3/day were considered to represent 36.84% and 51.63% of total upstream discharge at Dairut respectively. While on 9/1/2013 (at the case of minimum discharge) which are equivalent to 0.180 and 1.600 mm^3/day were considered to represent 36.84% and 51.63% of total upstream discharge at Dairut respectively.

Table (13): Hydrological Records at Maximum Discharge (9/6/2007)

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	**Bahr-Yusef canal**	**17.662**	**204.42**	**46.00**	**45.60**
2	**Badraman canal**	**0.711**	**8.23**		**45.85**
3	**Diroutiah canal**	**1.000**	**11.574**		**45.85**
4	**El-Ibrahimia D/S "DGR"**	**15.447**	**178.78**		**45.15**
5	**Sahelyia canal**	**0.359**	**4.16**		**45.85**
6	**Irad Delgaw canal**	**0.737**	**8.53**		**45.00**
7	**Abo Gabal canal**	**0.528**	**6.11**		**45.85**
8	**El-Ibrahimia U/S "DGR"**	**36.444**	**421.81**		**-**

Table (14): Hydrological Records at Minimum Discharge (9/1/2013)

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	**Bahr-Yusef canal**	**1.600**	**18.52**	**43.35**	**42.55**
2	**Badraman canal**	**0.038**	**0.44**		***
3	**Diroutiah canal**	**0.054**	**0.63**		***
4	**El-Ibrahimia D/S "DGR"**	**0.180**	**2.08**		**41.55**
5	**Sahelyia canal**	**0.019**	**0.22**		***
6	**Irad Delgaw canal**	**0.040**	**0.46**		***
7	**Abo Gabal canal**	**0.028**	**0.32**		***
8	**El-Ibrahimia U/S "DGR"**	**1.959**	**22.67**		**-**

4. PROTOTYPE CONDITION

The model would be constructed according to the conducted field measurements that were recently carried out by "HRI" survey staff on June 2015. The measurements included topographic, bathymetric and hydrometric measurements along the seven branched canals downstream "DGR" and the located reach of El-Ibrahmia canal upstream of "DGR". Also, the field survey included velocity measurements and collecting some bed samples. The survey was done at the project site using advanced survey equipments. Summary of the conducted topographic and bathymetric field measurements are listed in Table (15).

Table (15): Conducted Survey and Field Measurements

No.	Branch name	Symbol	Survey Length (m)	Velocity profiles		Bed samples	
				No.	Location (m)	No.	Location (m)
1	El-Ibrahimia U.S. "DGR"	AA	1280	1	AA1080	3	AA1080
2	Irad Delgaw canal	BB	500	1	BB215		
3	Abo Gabal canal	CC	600	1	CC130		
4	Bahr-Yusef canal	DD	1075	2	DD250 DD500	3	DD540
5	Badraman canal	EE	580	1	EE230		
6	Diroutiah canal	FF	550	1	FF230		
7	Ibrahimia canal	GG	1230	2	GG250 GG500	2	GG690
8	Sahelyia canal	HH	590	1	HH325		
Total Survey activities			6405	10		8	

The attainable results from the field measurements can be presented as follows:

4.1. Bathymetric Measurements

Figure (7) illustrates the applied sounding technique during field measurements of all branched canals which was carried out in such a way as to cover major parts of the surveyed branches. The recorded data for the sounded depths were converted into levels which were utilized with there locations to create a contour map for each branch. This contour map comprises the lines which have the same levels for every 0.5 m along each surveyed canals as shown in Figure (8).

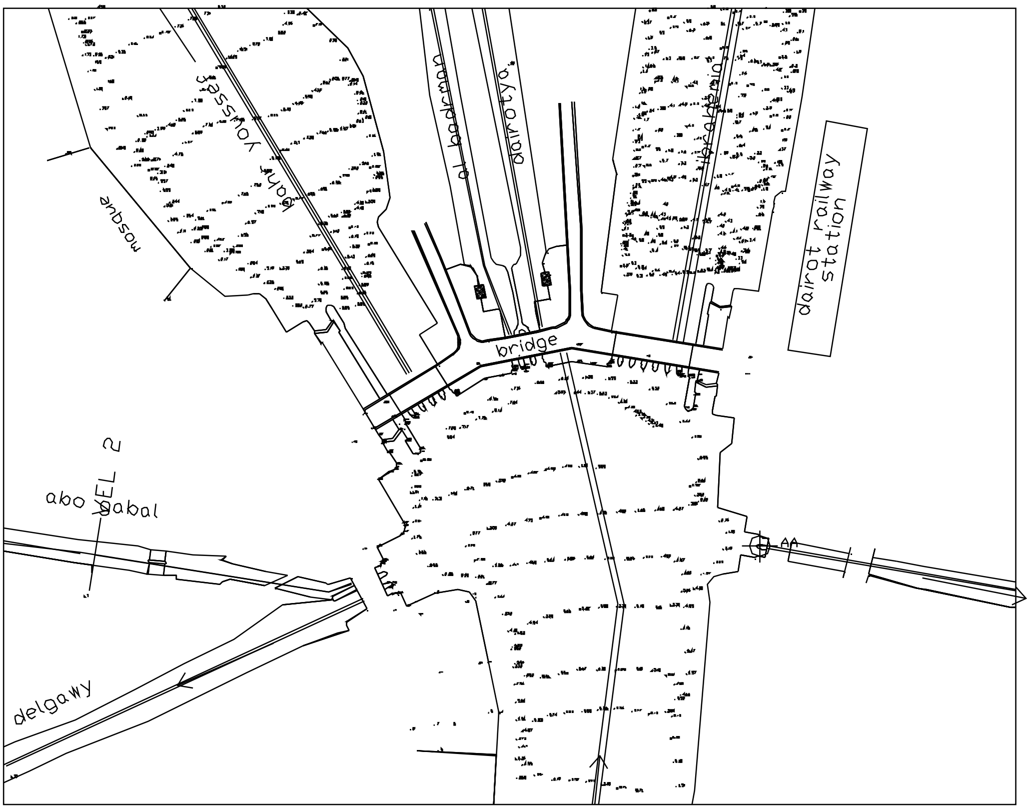


Figure (7): Applied Sounding Technique during Field Measurements

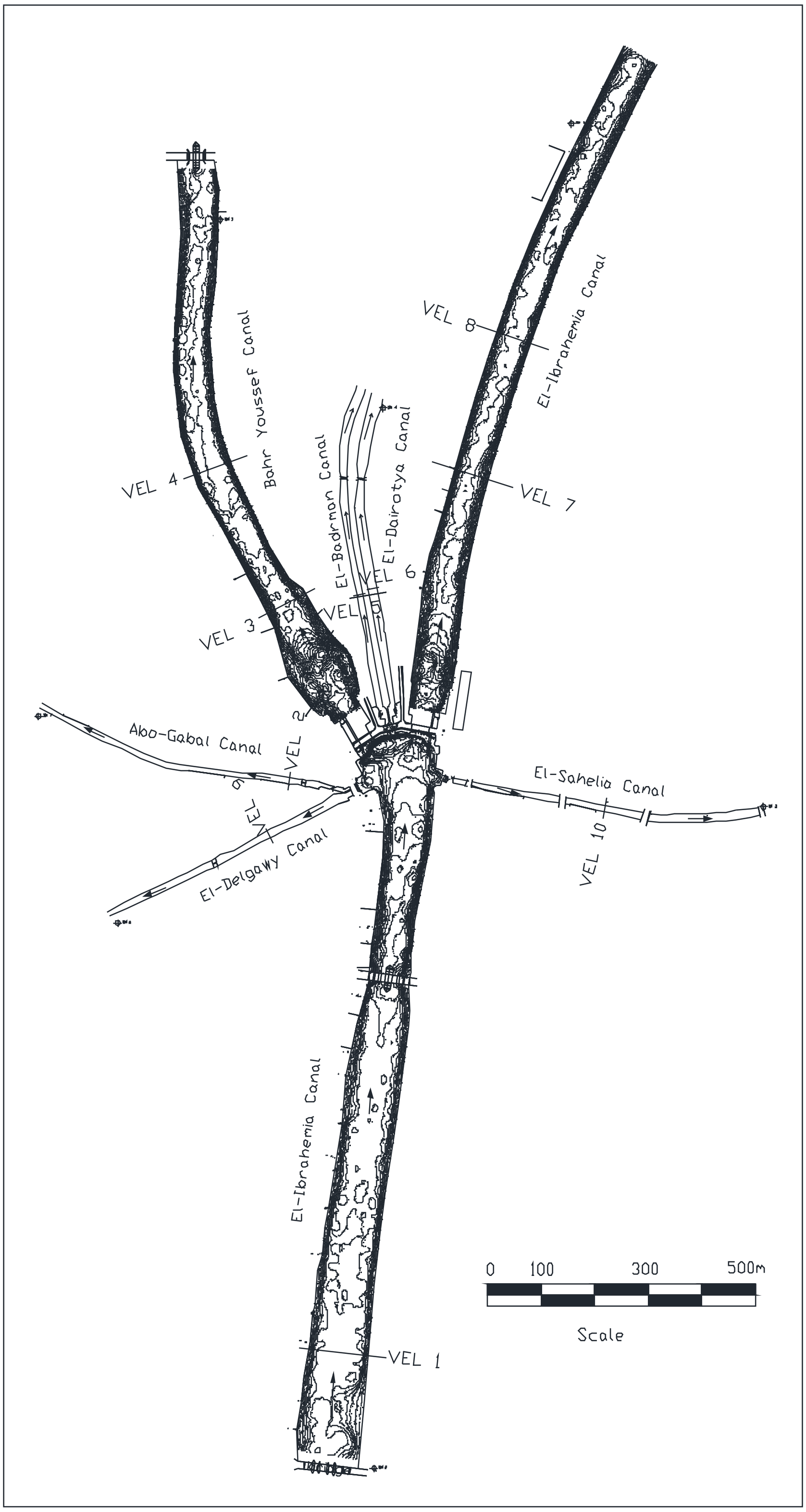


Figure (8): General Layout of the Surveyed Canals

4.2. Velocity Measurements

Applying each of the Acoustic Doppler Current Profile "ADCP" and Pray-Stock current meters, the velocity distribution was measured along 10 cross sections through the seven branched canals and El-Ibraheemia main canal upstream "DGR". Location and number of the measured velocity profiles for each branched canal are shown in Figure (9) and listed in Table (15) while Figures (from 10 to 19) illustrate the measured mid-depth velocity distribution and bed profiles for each branched canal.

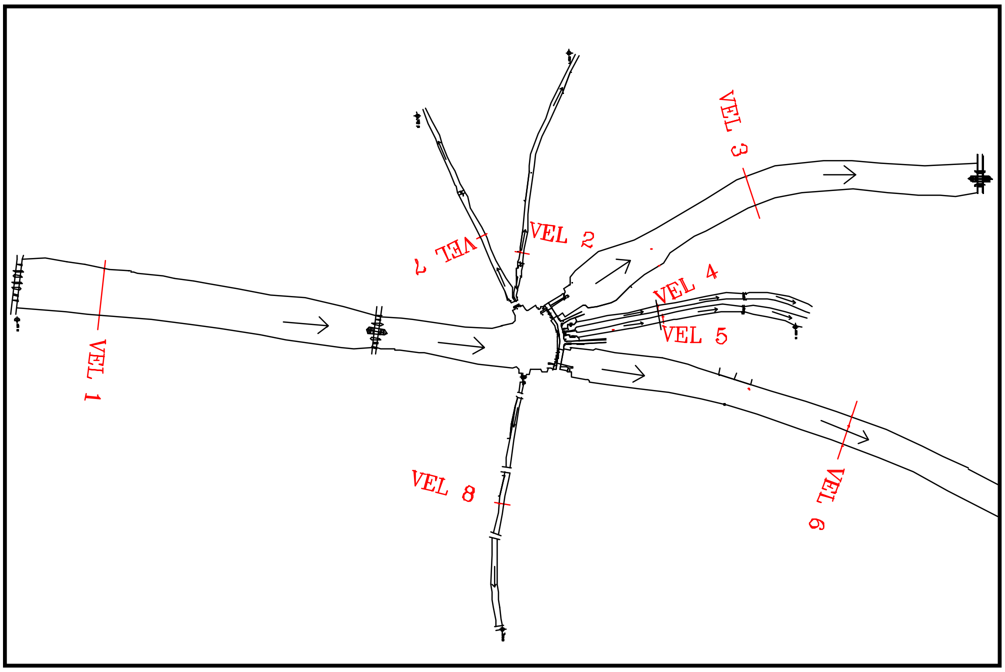


Figure (9): Locations of the measured velocity Distribution

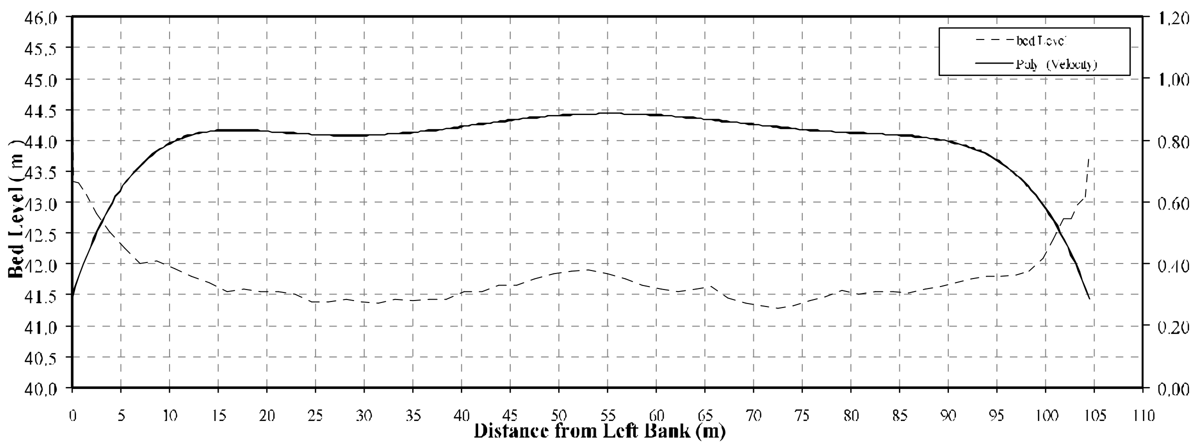


Figure (10): Velocity Distribution at El-Ibrahimia Main Canal

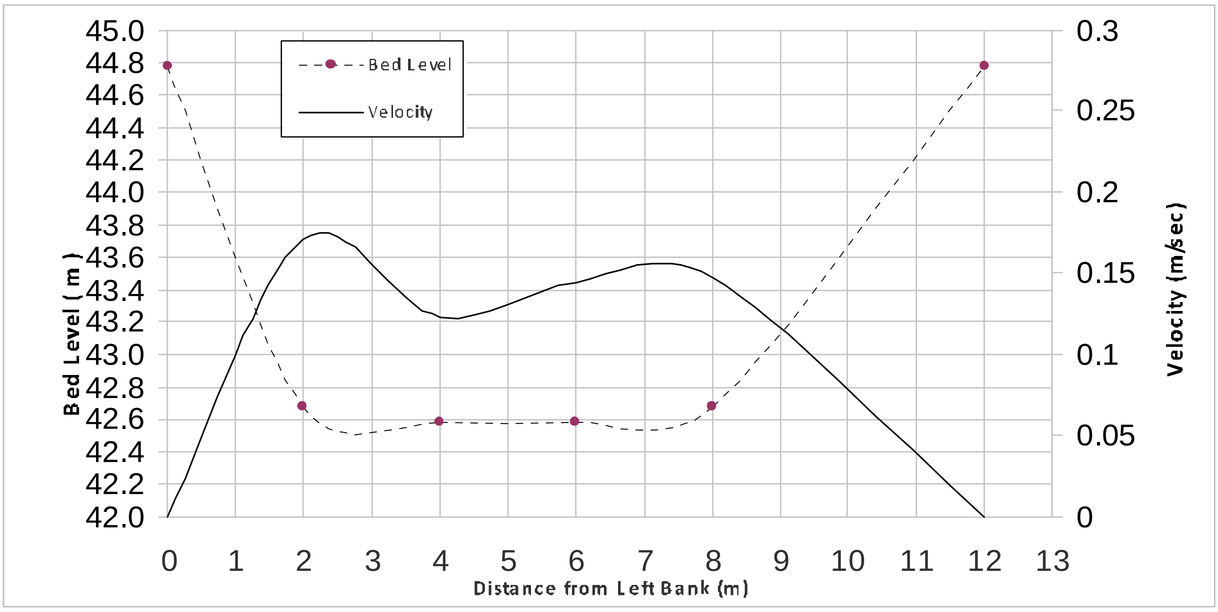


Figure (11): Velocity Distribution at Irad Delgaw Canal

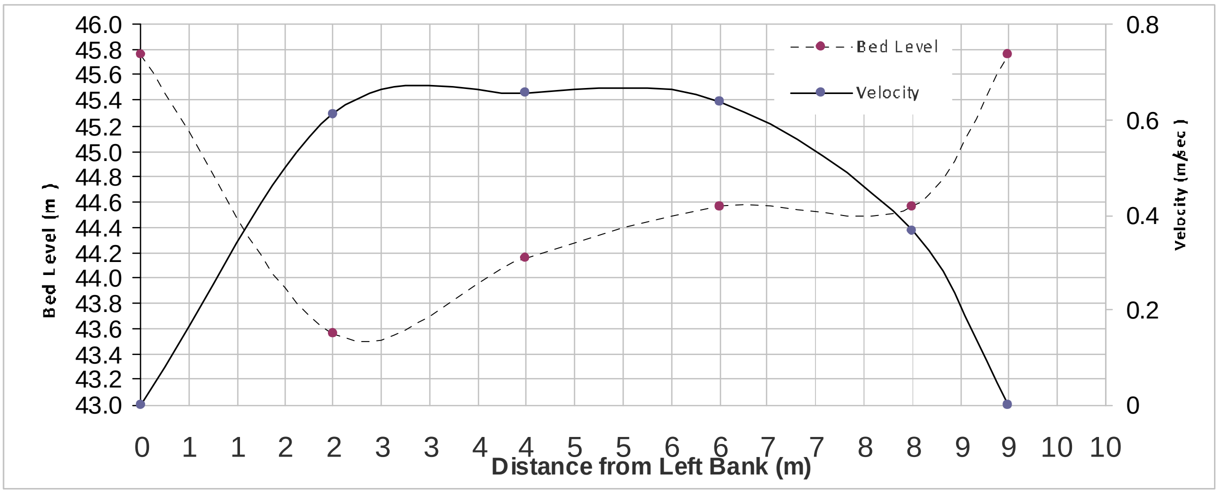


Figure (12): Velocity Distribution at Abou Gabal Canal

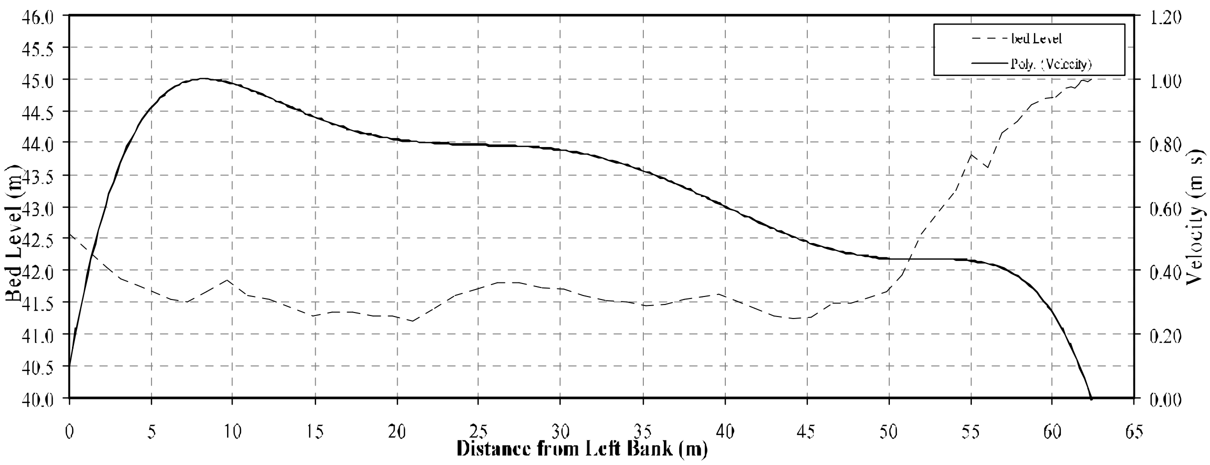


Figure (13): Velocity Distribution Upstream of Bahr Ussef Canal

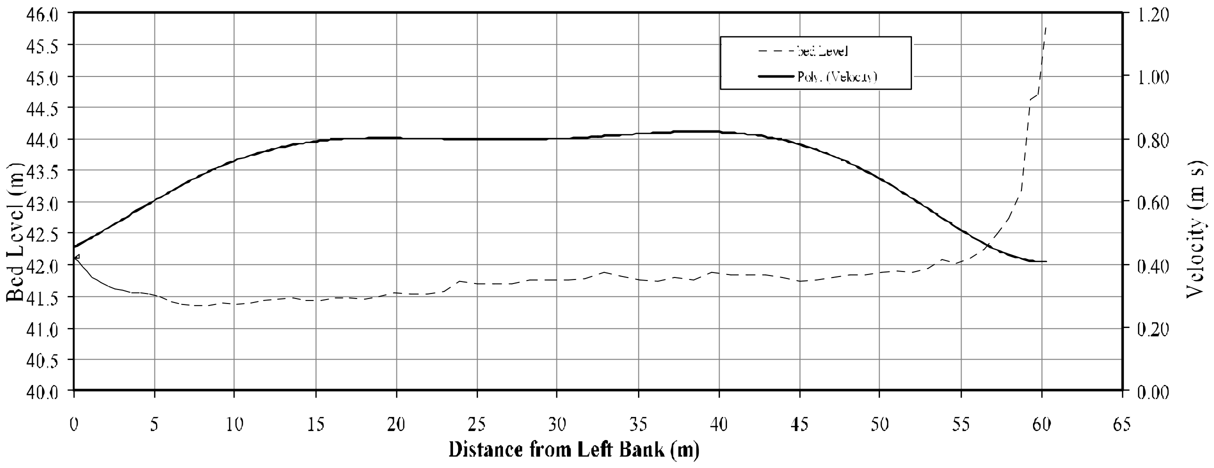


Figure (14): Velocity Distribution Downstream of Bahr Ussef Canal

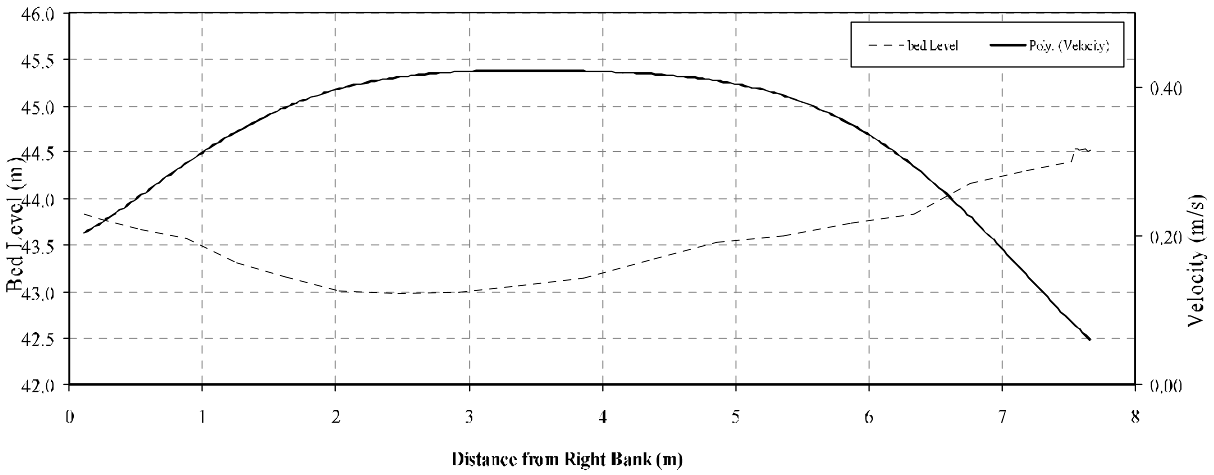


Figure (15): Velocity Distribution at Badraman Canal

Figure (16): Velocity Distribution at El-Dairutia Canal

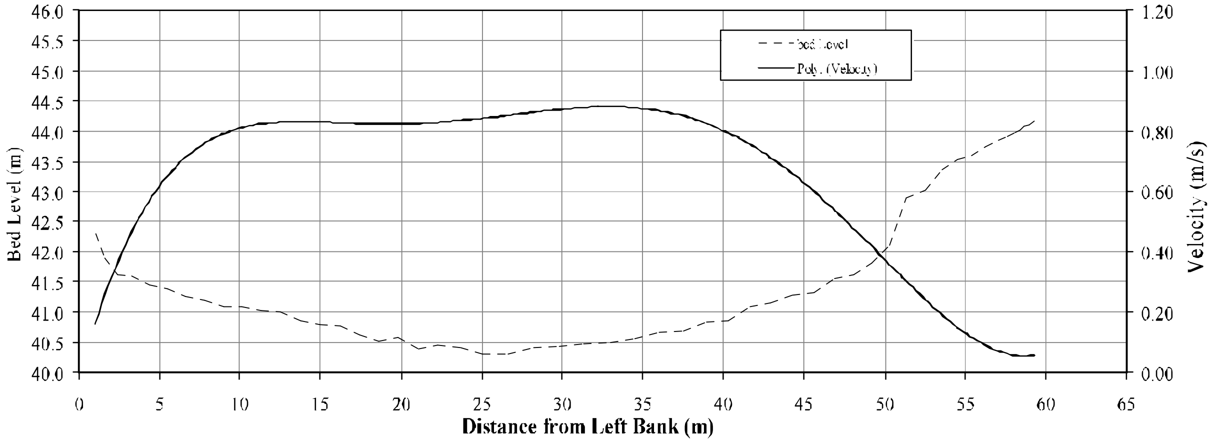


Figure (17): Velocity Distribution Upstream of El-Ibrahimia Canal

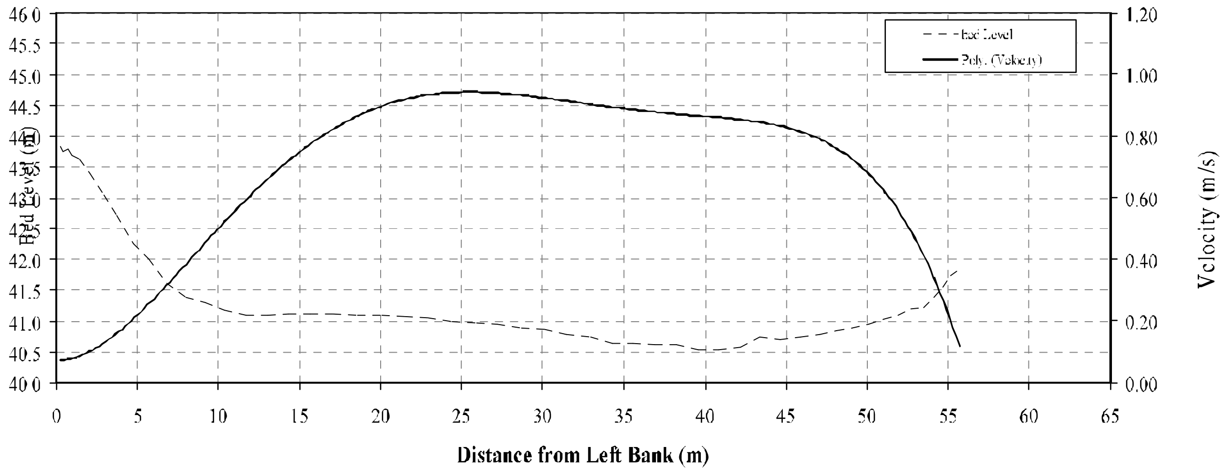


Figure (18): Velocity Distribution Downstream of El-Ibrahimia Canal

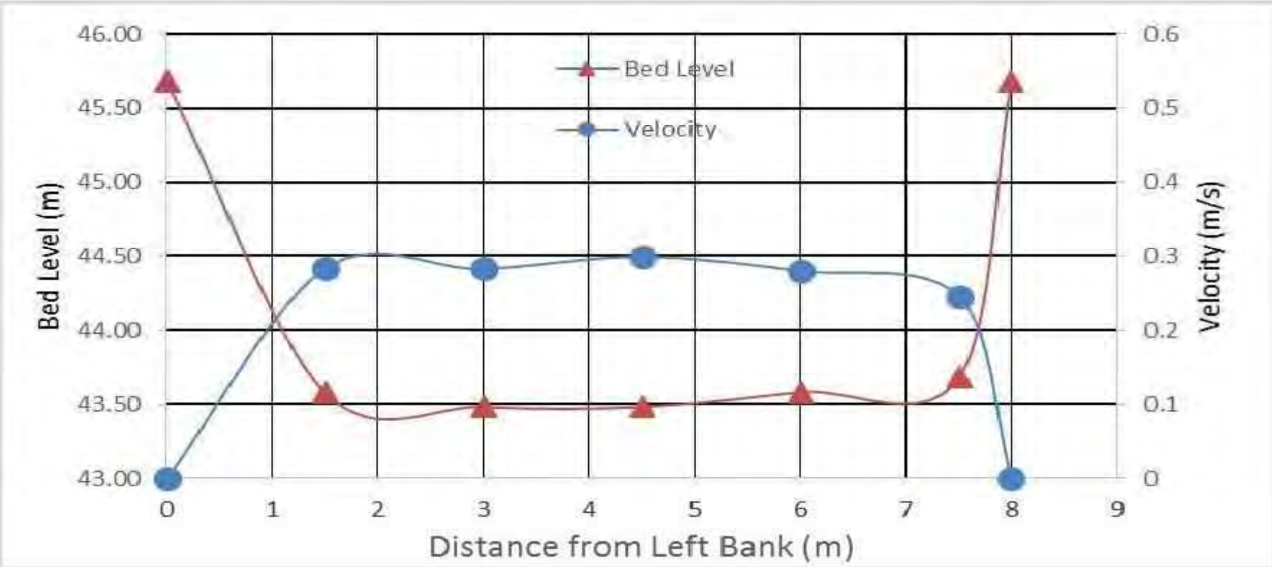


Figure (19): Velocity Distribution at El-Sahelia Canal

4.3. Bed Materials Analysis

As listed in Table (15) for the field measurements, eight bed material samples were collected by using Van Veen Grab sampler. Three bed samples were collected from each of Bahr Yusseff and El-Ibrahemia main canals while only two samples were collected from El-Ibrahimia canal downstream of "DGR". Those samples were utilized to form a representative sample for each of the three mentioned canals which were analyzed in the "HRI" soil laboratory. The analysis results for each of El-Ibrahimia main canal, El-Ibrahimia canal downstream of "DGR" and Bahr Yssef canal are listed in Tables (16, 17 and 18) respectively. While Figures (20, 21 and 22) illustrate the resulted grain size distribution curve for each of the three mentioned canals respectively. Moreover, characteristics of the representative gradation curve for every bed materials are provided.

Table (16): Soil Analysis Results for El- Ibrahimia Main Canal

Sieve diameter(mm)	1.4	1.0	0.85	0.5	0.355	0.212	0.15	0.075	0.063	0.0
Retain weight(grm)	14.74	1.82	1.95	29.55	166.15	391.31	1.66	0.43	0.15	0.32
Finer weight (grm)	593.34	591.52	589.57	560.02	393.87	2.56	0.9	0.47	0.32	0.0
Finer percent (%)	97.58	97.28	96.96	92.1	64.77	0.42	0.15	0.08	0.05	0.0

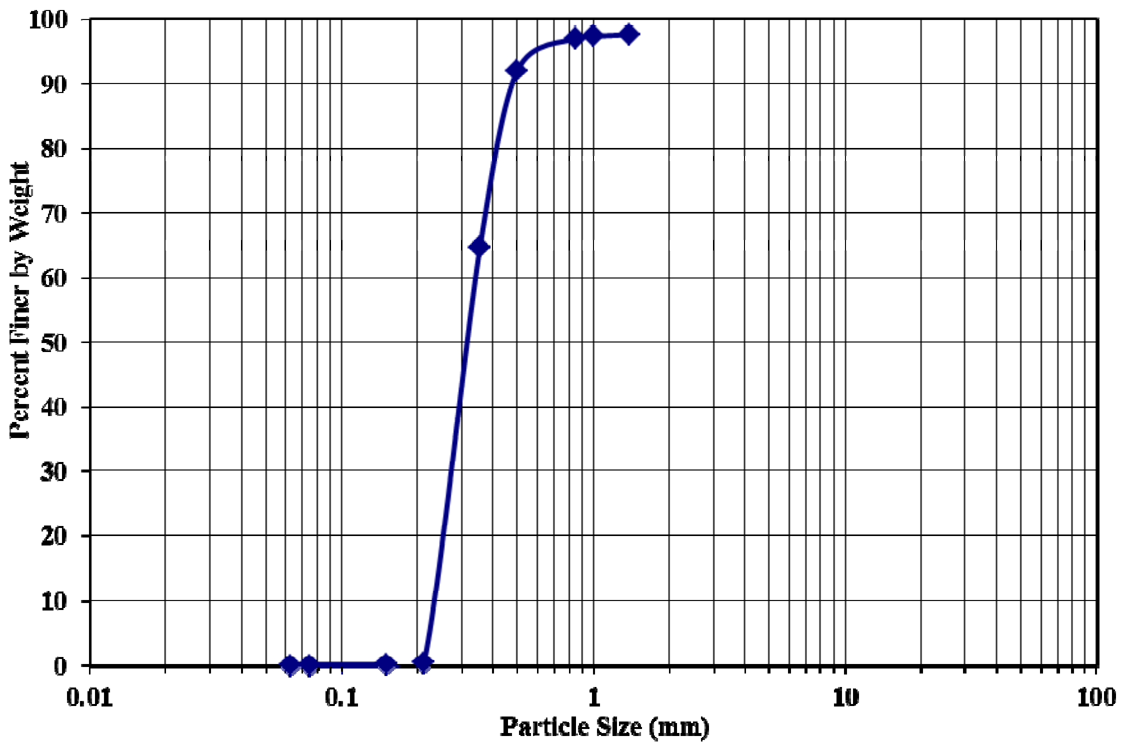


Figure (20): Grain Size Distribution Curve for El- Ibrahimia Main Canal

Characteristics of the Grading Curve

- Total sample weight = 608.08 (grm)
- D_{95} = 0.687 mm D_{90} = 0.487 mm D_{84} = 0.452 mm
- D_{75} = 0.404 mm D_{65} = 0.356 mm D_{60} = 0.342 mm
- D_{50} = 0.315 mm D_{40} = 0.291 mm D_{35} = 0.280 mm
- D_{30} = 0.269 mm D_{25} = 0.258 mm D_{16} = 0.240 mm
- D_{10} = 0.229 mm D_{5} = 0.220 mm
- D_{84}/D_{50} = 1.432
- D_{50}/D_{16} = 1.313
- Geometric Mean Diameter = 0.315 mm
- Geometric Standard Deviation = 1.371
- Uniformity Coefficient = 1.493
- Sorting Coefficient = 0.800
- Curvature Coefficient = 0.923
- Mean Diameter = 0.339 mm

Table (17): Soil Analysis Results for Ibrahimia canal D.S. "DGR"

Sieve diameter(mm)	1.4	1.0	0.85	0.5	0.355	0.212	0.15	0.075	0.063	0.0
Retain weight(grm)	80.82	0.18	0.1	0.5	1.72	46.62	4.83	2.22	0.12	0.19
Finer weight (grm)	56.48	56.3	56.2	55.7	53.98	7.36	2.53	0.31	0.19	0.0
Finer percent (%)	41.14	41.01	40.93	40.57	39.32	5.36	1.84	0.23	0.14	0.0

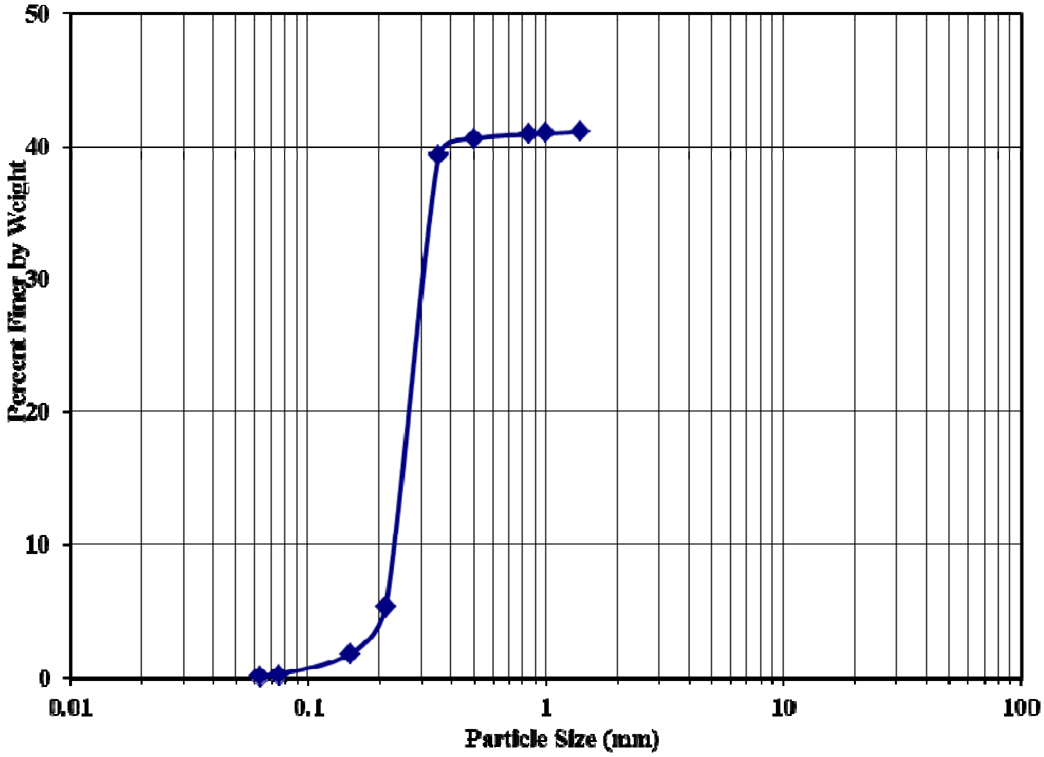


Figure (21): Grain Size Distribution Curve for Ibrahimia Canal D.S. "DGR"

Characteristics of the Grading Curve

- Total sample weight = 137.3 (grm)
- D_{95} = 0.188 mm D_{90} = 0.227 mm D_{84} = 0.283 mm
- D_{75} = 0.396 mm D_{65} = 0.575 mm D_{60} = 0.693 mm
- D_{50} = 1.006 mm D_{40} = 0.428 mm D_{35} = 0.332 mm
- D_{30} = 0.308 mm D_{25} = 0.286 mm D_{16} = 0.249 mm
- D_{10} = 0.227 mm D_5 = 0.205 mm
- D_{84}/D_{50} = 0.282
- D_{50}/D_{16} = 4.038
- Geometric Mean Diameter = 1.006 mm
- Geometric Standard Deviation = 1.066
- Uniformity Coefficient = 3.047
- Sorting Coefficient = 0.849
- Curvature Coefficient = 0.602
- Mean Diameter = 0.115 mm

Table (18): Soil Analysis Results for Bahr Youssef Canal

Sieve diameter(mm)	1.4	1.0	0.85	0.5	0.355	0.212	0.15	0.075	0.063	0.0
Retain weight(grm)	4.6	0.96	1.06	16.42	41.74	153.63	3.1	0.53	0.03	0.2
Finer weight (grm)	217.67	216.71	215.65	199.23	157.49	3.86	0.76	0.23	0.2	0.0
Finer percent (%)	97.93	97.5	97.02	89.63	70.86	1.74	0.34	0.1	0.09	0.0

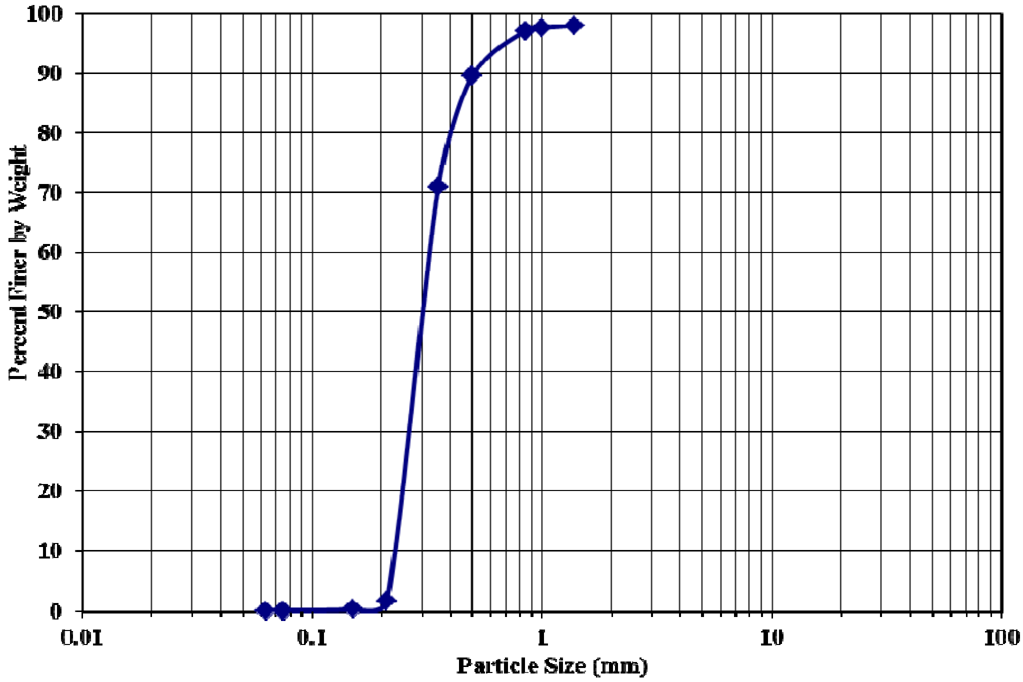


Figure (22): Grain Size Distribution Curve for Bahr Youssef Canal

Characteristics of the Grading Curve

- Total sample weight = 222.27 (grms)
- D_{95} = 0.735 mm D_{90} = 0.513 mm D_{84} = 0.451 mm
- D_{75} = 0.383 mm D_{65} = 0.340 mm D_{60} = 0.327 mm
- D_{50} = 0.304 mm D_{40} = 0.282 mm D_{35} = 0.272 mm
- D_{30} = 0.262 mm D_{25} = 0.252 mm D_{16} = 0.236 mm
- D_{10} = 0.225 mm D_{5} = 0.217 mm
- D_{84}/D_{50} = 1.485
- D_{50}/D_{16} = 1.289
- Geometric Mean Diameter = 0.304 mm
- Geometric Standard Deviation = 1.383
- Uniformity Coefficient = 1.452
- Sorting Coefficient = 0.812
- Curvature Coefficient = 0.928
- Mean Diameter = 0.339 mm

The above results showed that the geometric mean diameter for the representative bed materials for each of El-Ibrahimia main canal upstream "DGR" and Bahr Usseff canal are almost similar of sandy soil of 0.3 mm. While the geometric mean diameter of El-Ibrahimia canal downstream of "DGR" is much larger and equals to 1.006 mm. This can be lead to conclude that El-Ibrahimia canal downstream of "DGR" is subjected to a degree of general degradation much more than that in the other two canals.

5. SIMILARITY RULES

For accurate and correct reproduction of any important hydraulic phenomena in a hydraulic model, a number of requirements must be fulfilled when determining the model scales which can be worked out as follows:

5.1. Geometrical Similarity

Geometrical similarity in the model is achieved when all geometric dimensions of length, width, and depth in the prototype, exhibit a constant ratio to the corresponding dimensions in the model. Considering that n_m is the ratio between any geometrical dimension in the prototype and that in the model. This can be written as the scale ratio for such geometrical dimension is $n_m = m_p / m_m$. Therefore, the following three scale ratio conditions can be deduced:

Length scale ratio $= n_L$
Area scale ratio $= (n_L)^2$
Volume scale ratio $= (n_L)^3$

In this case, models which have one scale ratio for all geometrical dimensions are called undistorted models, while models which have unequal horizontal and vertical scale ratios are called distorted models. Therefore considering that n_L is the length scale ratio and n_h is the depth scale ratio, undistorted model when ($n_L = n_h$) and distorted model when $n_L \neq n_h$

5.2. Kinematic Similarity

Kinematic similarity can be fulfilled when time-dependent events that proceeded in the model occurred in a way such that corresponding time intervals in nature and the model would show a constant ratio. Considering that n_t is the time scale ratio and n_v is the velocity scale ratio, the velocity scale ratio can be deduced as:

$n_t = n_L / n_v$

5.3. Dynamic Similarity

Dynamic similarity implies that corresponding forces in nature and in model must show a constant ratio. These ratios can be derived from the relations between the acting forces in the flow field. The relevant forces in case of free surface flow with density difference are inertia, gravitation, buoyancy, and viscous forces. These force ratios are the Froude Number *(F_r)* which is the ratio of inertia to gravitation forces and can be specified as:

$$Fr = \frac{V}{\sqrt{gh}}$$

And the Reynolds Number *(R_e)* which is the ration of inertia to viscous forces and can be written as .

$$Re = VR/\nu$$

Where V is the velocity (m/s), g is the gravitational acceleration (m/s^2), h is the characteristic depth (m), ρ is the density (kg/m^3), Δρ is the density difference (kg/m^3), R is the hydraulic radius (m) and N is the kinematic viscosity (m^2/s). From the condition that the scale of the Froude Number in both nature and model should be equal, the velocity scale ratio can be determined from which the other scale ratios can be derived as follows:

Velocity scale ratio = $n_v = (n_h)^{0.5}$

Discharge scale ratio = $n_q = n_L\, n_h\, n_v = n_L\, (n_h)^{1.5}$

Time scale ratio = $n_t = n_L / n_v = n_L / (n_h)^{0.5}$

Since the kinematic viscosity in the model and prototype is generally at the same order, the condition that Reynolds Number is equal for both prototype and model in combination with the velocity scale determined as above can not be fulfilled. However in practice the nature of the turbulent transport dose not depend upon the Reynolds Number as long as it exceeds a certain critical value for open channels in the model which is as follows:

$$Re_c \geq 2000$$

While the critical Reynolds Number for jets discharging into ambient water has been experimentally determined to be

$$Re_c \geq 750$$

In order to check Reynolds Number in the small branched canals in the prototype and in the model, the measured hydrological functions for Abou Gabal canal – which are shown in Figure (23) – were utilized to determine the Reynolds Number along that canal and the corresponding value in the model as listed in Table (19).

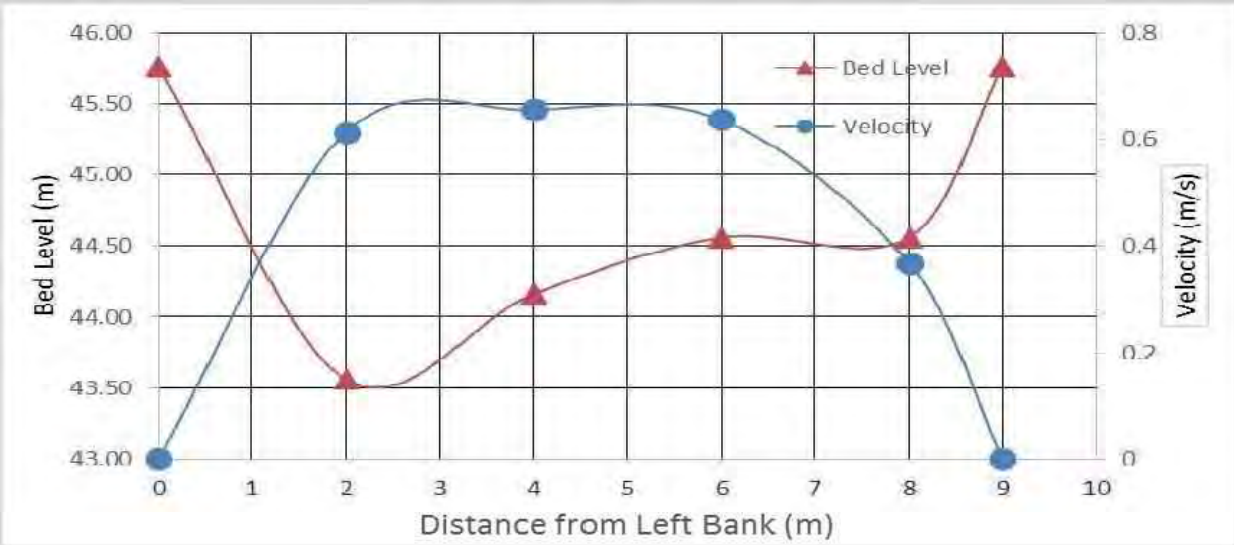


Figure (23): Velocity Distribution in Abou Gabal Canal

Table (19): Re Calculations in Abou Gabal Canal

No.	Hydraulic term	Prototype	Model
1	Top width |P| (m)	9.0	0.36
2	Average Depth |H| (m)	1.25	0.05
3	Cross section area |A| (m^2)	11.25	0.018
4	Passing discharge |Q| (m^3/s)	6.21	1.987 l/s
5	Average Velocity |V| (m/s)	0.552	0.110
6	Kinematic viscosity | υ | (m^2/s)	10^{-6}	10^{-6}
7	Reynolds Number |Re| (-)	690000	5520

The above results revealed that the Reynolds Number in the small branched canals downstream of the existing "DGR" either in the prototype and model can be considered turbulent flow. As undistorted geometric scale of 1:25 was selected for model construction which revealed the listed scale ratios in Table (20) for the other hydraulic components:

Table (20): Applied Scale Rations in the Model

No.	Quantity	Scale	Ratio
1	Depth scale ratio	$n_h = h_p/h_m$	25
2	Length scale ratio	$n_l = l_p/l_m$	25
3	Area scale ratio	$n_a = n_l^2$	625
4	Velocity scale ratio	$n_v = n_h^{1/2}$	5.0
5	Discharge scale ratio	$n_Q = n_l^{2.5}$	3125
6	Time scale ratio	$n_t = n_l^{1/2}$	5.0

6. MODEL CONSTRUCTION

An appropriate open air area in the northern experimental hall of "HRI" of about 46 m length and 24 m width (about 830 m^2) was assigned to construct the required model. The model area was deliberately selected not only to guarantee high flow discharges and other experimental requirements, but also to secure adequate lengths for the downstream branched canals when testing the new proposed "DGR". The model was constructed to simulate appropriate reaches of the 7 branched canals downstream "DGR" and the main El-Ibrahima canal upstream of "DGR". The model would be a fixed bed undistorted scale of equal horizontal and vertical construction scale of 1 to 25. Details of measured lengths and cross sections for each of eight modeled canals are listed in Tables (21 and 22) while Figure (24) shows general lay out and arrangement of different parts of the constructed model. In this Figure the outlet of the modeled branches for each of Irad Delgaw canal, Abo Gabal canal, Badraman canal, El-Dairutia canal and El-Sahelyia canal was called as E1, E2, E4, E5 and E7 respectively. While the outlet of the modeled branches for Bahr Yssef canal and El-Ibrahimia canal downstream of "DGR" was called E3 and E6 respectively. The model consists of three main components; the entrance, the modeled reach, and the outlet. Full description of the abovementioned model components are as follows:

Table (21): Simulated Canal Lengths in the Model

No.	Canal name	Prototype condition (m)				Modeled length (m)
		Survey length (m)		Cross sections		
		Measured	Modeled	Measured	Modeled	
1	Bahr-Yusef canal	1075	620	34	18	24.80
2	Badraman canal	580	225	12	8	9.00
3	Diroutiah canal	550	245	12	8	9.80
4	Ibrahimia canal	1230	600	40	18	24.00
5	Sahelyia canal	590	410	15	83	16.40
6	Irad Delgaw canal	500	410	19	8	16.40
7	Abo Gabal canal	600	175	16	7	7.00
8	Ibrahimia Main canal	1280	650	40	20	26.00
Total Length (m)		6405	3335		90	133.40

Table (22): Simulated Cross Sections in the Model

No.	Canal name	Symbol	Measured Sections	Modeled sections	
				From	To
1	Ibrahimia Main canal	AA	20	AA20	AA41
2	Irad Delgaw canal	BB	8	BB1	BB8
3	Abo Gabal canal	CC	7	CC1	CC7
4	Bahr-Yusef canal	DD	18	DD1	DD18
5	Badraman canal	EE	8	EE1	EE8
6	Diroutiah canal	FF	8	FF1	FF8
7	Ibrahimia canal	GG	18	GG1	GG18
8	Sahelyia canal	HH	3	HH1	HH3
Total Length (m)			90		

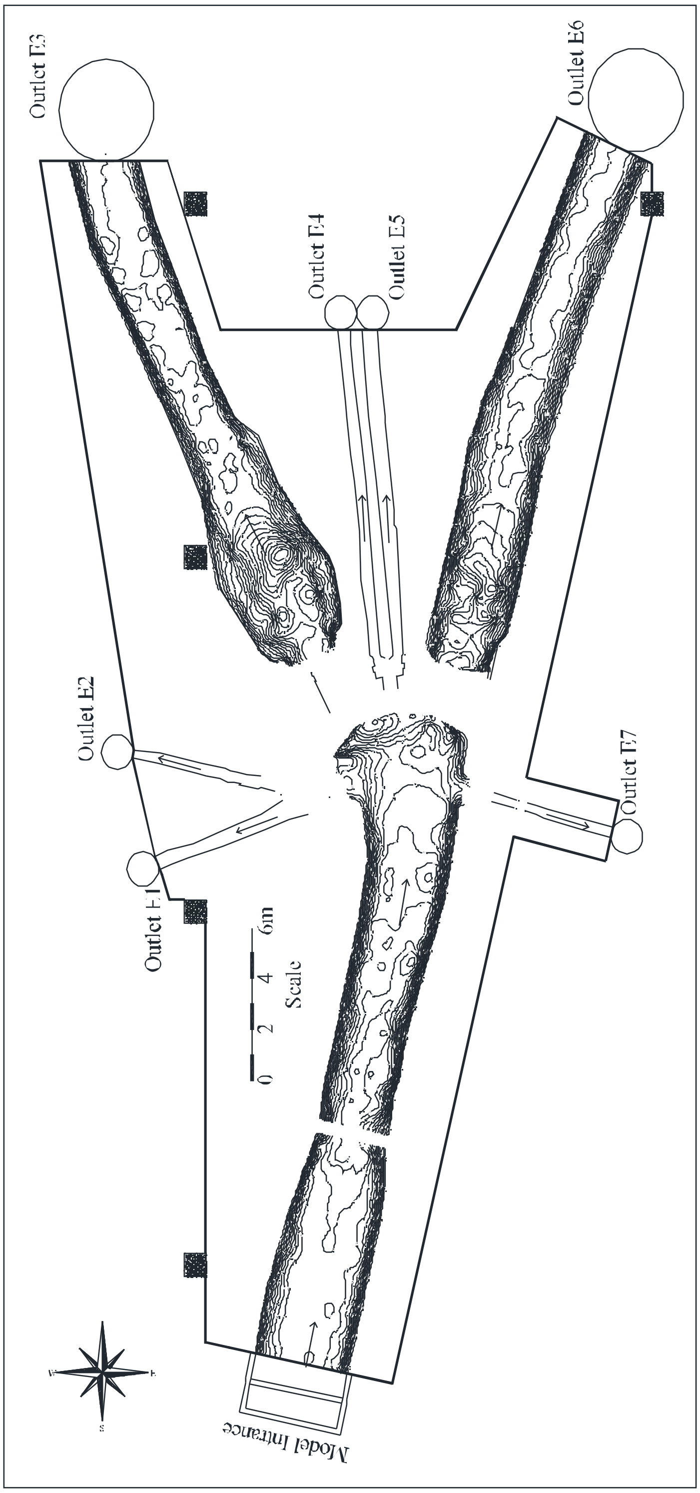


Figure (24): General Layout of the Modelled Reach

6.1. Model Entrance

The model entrance – as illustrated in Figure (25) would be made of 0.15 m thickness bricks wall covered with 0.02 m cement mortar mixed with chemical isolated materials to prevent seepage from the model. The model entrance consists of two compartments. The upstream one is 1.0 m length which is made to receive the delivered pumped water from the underground reservoir. While the downstream compartment is mainly constructed to convey the delivered water from the upstream compartment straightforwardly to the simulated model reach. The downstream compartment also provided with pieces of wood to distribute the entering water flow through the model in such a way as to simulate the prototype condition.

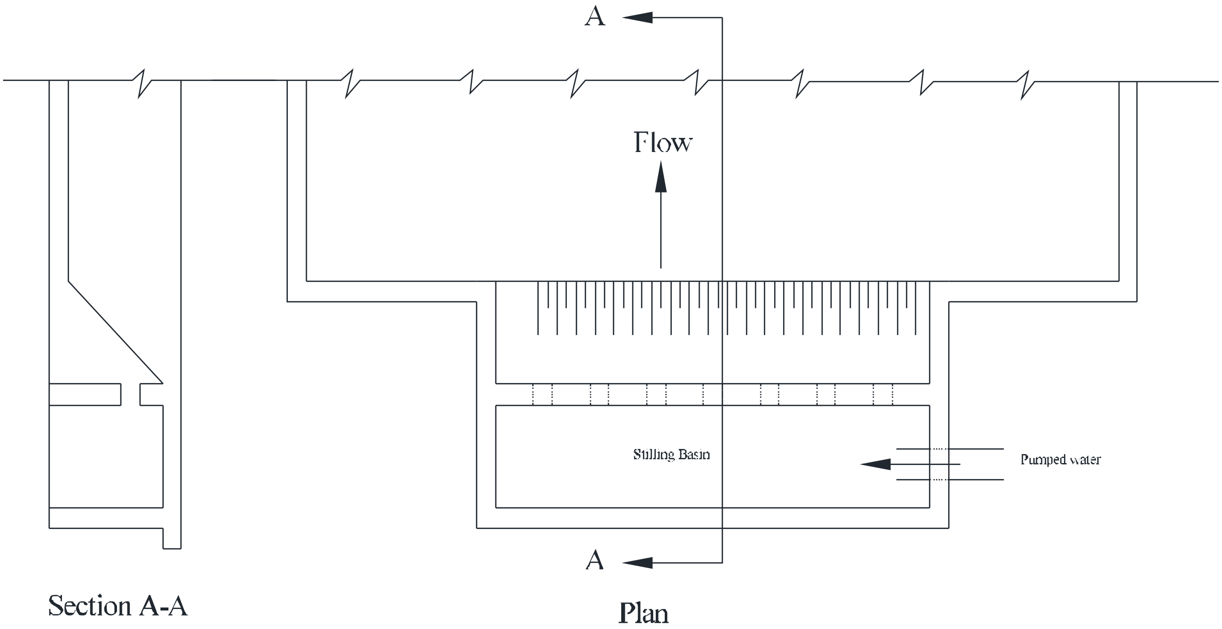


Figure (25): Model Entrance

6.2. Modelled reach

The modeled reach is the main study component which simulates the 7 branched canals downstream of "DHR" and part of the main El-Ibrahimia canal upstream of "DGR". Those branches would be constructed in levels and locations in such a way as to simulate the prototype condition and according to the latest field and bathymetric measurements which were carried out by "HRI" survey team. Those components were constructed of about 0.07 m thick layer of plane concrete which poured in location and levels in the same configurations according to that in the prototype. The measured cross section in the prototype were scaled and allocated according to their orientation, location and levels as shown in Figure (26). Then the reach between each successive two cross sections were filled with plane mortar. The modeled regulators which simulate the existing "DGR" were constructed of woods in the "HRI" workshop of the same undistorted model scale of 1 to 25. Level of the constructed reach was previously determined in the hydraulic laboratory in such a way as to provide the necessary water levels upstream each of the installed sharp crested weirs and the tailgates as shown in Figure (27).

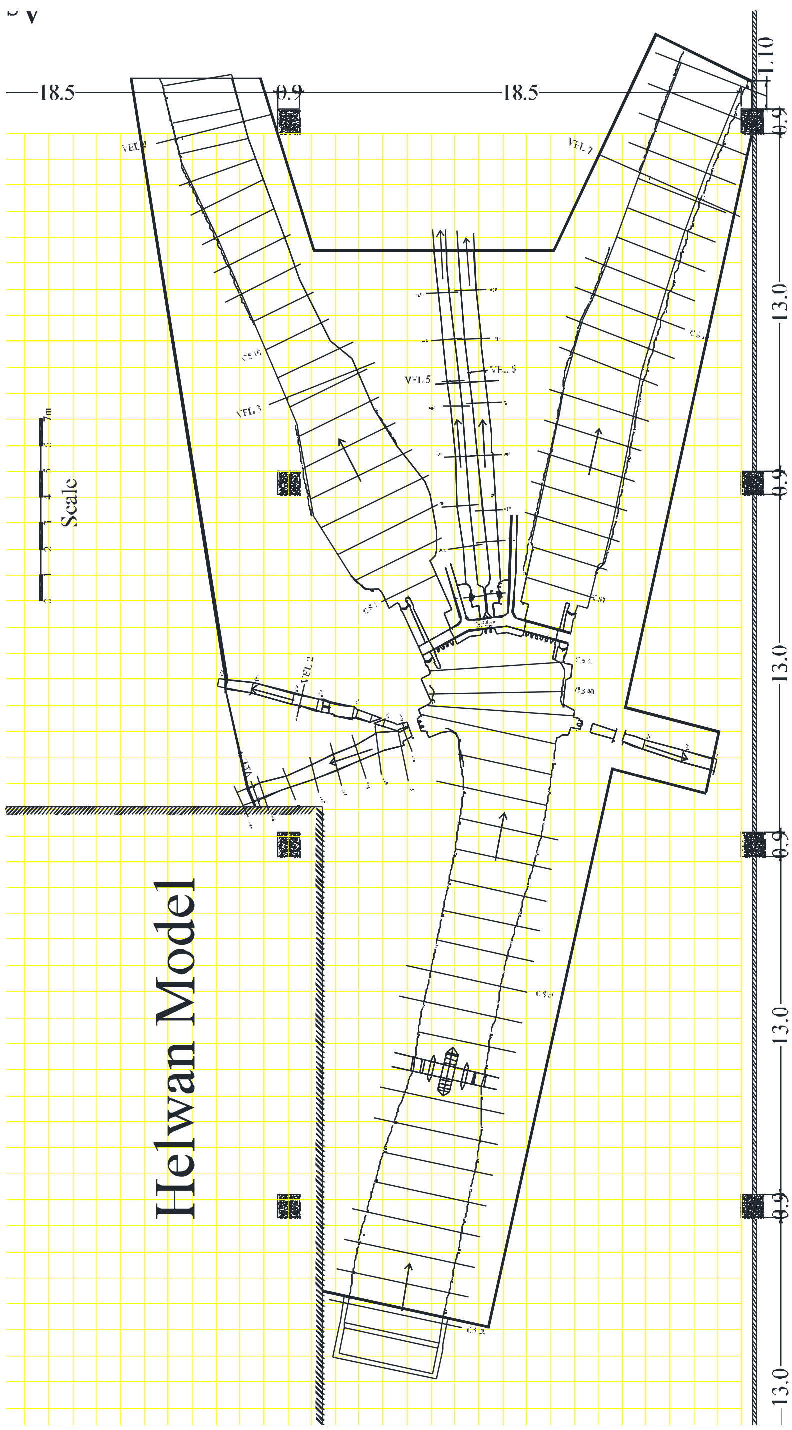


Figure (26): Simulated Cross Sections in the Model

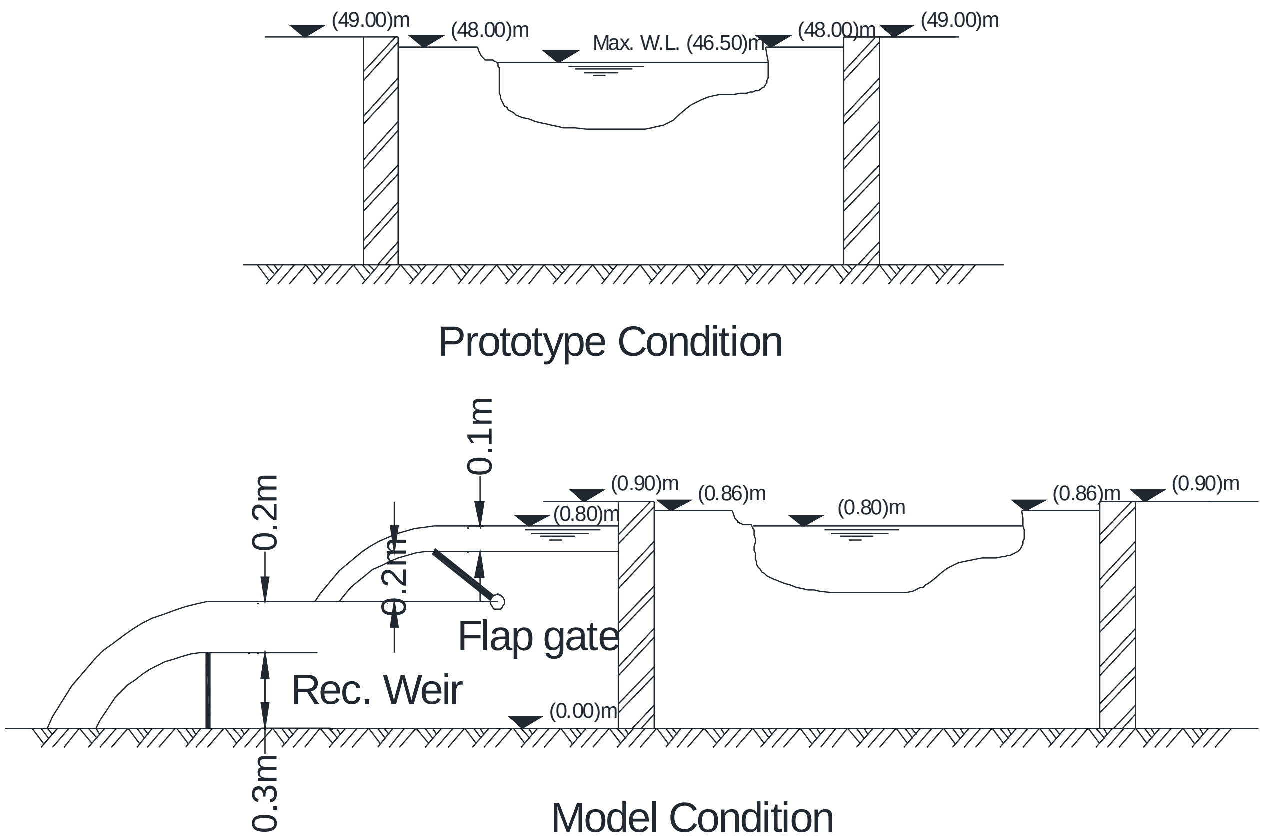


Figure (27): Model Levelling Arrangement

6.3. Model Outlets

The principal function of the model exit is to maintain water surface level through each modeled branch canales in such a way as to reproduce all the hydraulical and hydrological conditions in the prototype, then to divert the passing flow discharge to the outlet sharp crested weir. For this reason the model exit consists of the tailgate and the approach channel. The tailgate is used to adjust the water surface level in the model which was made of 5mm rectangular steel plate and hinged from bottom which can be easily rotated around the lower hinge to adjust the upstream water surface level through each modeled branch. This tailgate type was used at the exit end of the two modeled reaches of El-Ibrahimia and Bahr Ussef canals. While in case of the other small branched canals another vertical and simple tail gates were utilized.

The outlet of the modeled branches for each of El-Sahelyia canal, El-Dairutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal was provided and equipped with a sharp crested weir of 30 cm height and 20 cm width as shown in Figure (28). While two flap tailgates of about 4.0 m long were affixed at the downstream end of the modeled parts of Bahr Yussef canal and El-Ibrahimia canal downstream of "DGR" as shown in Photo (3). While two sharp crested weirs of 30 cm height and 50 cm width each was used at the modeled outlet of El-Ibrahimia and Bahr-Yusef canals. The model feeding system consists of an electric centrifugal pump of 10 inch diameter and a suction pipe connected to the sump. Water was pumped from the underground reservoir and delivered to the model entrance through the delivery pipeline.

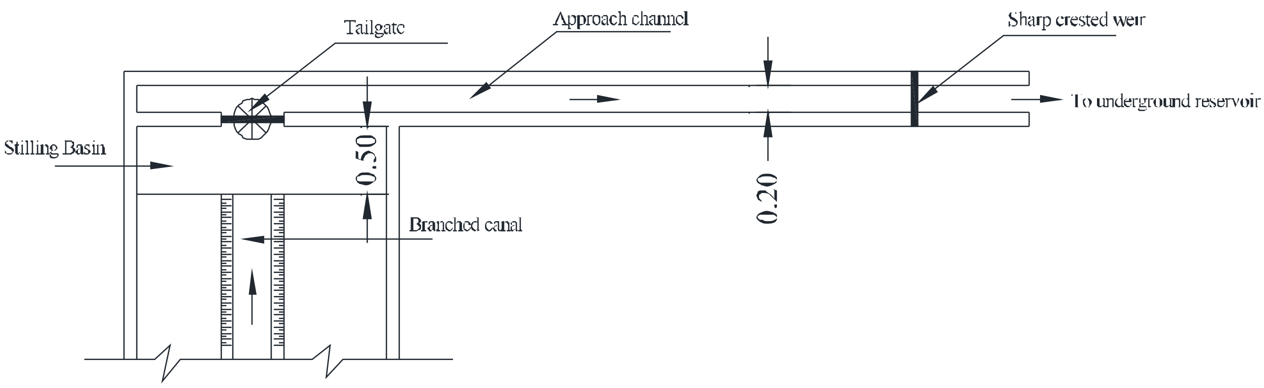


Figure (28): Model Outlets E1, E2, E4, E5 and E7

Photo (3): Model Outlet Type for E3 and E6

7. DISCHARGE MEASUREMENTS

Two flow discharge measurement techniques were applied during the testing period. The first one was on the feeding system through the delivering pipes from the underground feeding reservoir to the upstream inlet of the model and the second one is the outlet flow rate over 7 sharp crested weirs that were affixed at the downstream end of each branched canal in the model. The evolutions of the inflow discharges were carried out by measuring the inflow rates to the upstream reservoir, while the outlet flow was determined by using the variation in the flow water levels over the sharp crested weir which is consequently diverted to corresponding out flow rates downstream of the model. For this reason, the measuring flow discharges in the model can be classified into inflow and outflow as follows:

7.1. The Inflow Measuring

In order to measure the inflow discharge through pipes to the upstream reservoir, the Ultrasonic Flow Meter (Flexim Flow meter) is used which uses the transit time difference principle. Transient-time ultrasonic meters, also known as 'time-of-travel' meters, measure the difference in travel time between pulses transmitted in the direction of flow and pulses transmitted against the flow. The two transducers are mounted opposite to each other along the pipe. Both transducers serve alternately as transmitter and receiver. The upstream transducer transmits a pulse, which is detected by the downstream transducer, giving a 'transmit-time' in the direction of flow. The downstream transducer will then transmit a pulse, which is detected by the upstream transducer (acting as a receiver), to give a 'transmit-time' against the flow. The difference between the upstream and downstream transit times can be correlated to flow rate through the meter. With this in mind, the following specifications were fulfilled:

- The allowed flow velocity is ranged between 0.01 m/s and 25.0 m/s
- The measuring accuracy is ranged between ±1.6 % of reading ±0.01 m/s (standard)
- The pipe diameter range is from 10.0 mm to 12.00 m

The ultrasonic flow meter was utilized to measure the variation in input flow rate discharge to the upstream model inlet which is shown in Photo (4) of 20 inch delivery pipe diameter. Calibration of such instrument was carried out by comparing the attainable measurements with the corresponding electromagnetic flow meter readings which is traceable to international standards.

Photo (4): Fixed Ultrasonic Flow Meter around Feeding Pipe

7.2. The Outflow Measuring

The present section would be elaborated for recording the variation in the passing discharges out of the model over the sharp crested weir to precisely determine the corresponding prototype discharges. Two steps would be involved in the present section which is recording the existing steady the water level over the sharp crested weir then determining the corresponding flow rate due to the measured flow head. This was carried out according to Swiss Specifications which are published for approach channel of 100 cm width (b) and 40 cm weir height (s) as follows::

$$\mu_1 = 0.615\left(1+\frac{1}{h+1.6}\right)\left[1+0.5\left(\frac{h}{h+s}\right)^2\right] \qquad (1)$$

For h and s in mm

$$\mu_2 = \left(.06035+0.0813\frac{h_e}{s}\right)\frac{h_e}{h}\sqrt{\frac{h_e}{h}} \quad \text{(Rehbock)} \qquad (2)$$

h_e = h+0.0011 m; b, s, h and he in meters (3)

$$\mu_m = \tfrac{1}{2}(\mu_1 + \mu_2) \qquad (5)$$

$$Q = \frac{2}{3}\,\mu_m\, b h \sqrt{2\,gh} \qquad (6)$$

On the other hand, as the passing flow discharge through the modeled small branches upstream of "DGR" would be very diminutive with respect to that through Bahr Yussef and El-Ibrahimia canals at Dairut, approach channels of 0.2 m width were utilized. The outlet of the modeled branches for each of El-Sahelyia canal, El-Diroutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal was provided equipped with a sharp crested weir of 30 cm height and 20 cm width. While two sharp crested weirs of 30 cm height and 50 cm width each was used at the modeled outlet of El-Ibrahimia and Bahr-Yusef canals. Apply the above equations, the passing flow discharges in litters per second were calculated for every 5 mm height step as listed in Table (23) and shown in Figure (29) for sharp crested weir of 1 m, 0.50 m and 0.20 m approach channel width respectively.

Table (23): Passing Discharge for Various Flow Heads

Head [H] (mm)	Discharge (l/s) over weir			Head [H] (mm)	Discharge (l/s) over weir		
	1 m	0.5 m	0.2 m		1 m	0.5 m	0.2 m
10	2.033	1.017	0.407	120	78.599	39.299	15.720
15	3.602	1.801	0.720	125	83.685	41.842	16.737
20	5.444	2.722	1.089	130	88.889	44.445	17.778
25	7.528	3.764	1.506	135	94.211	47.106	18.842
30	9.828	4.914	1.966	140	99.649	49.825	19.930
35	12.330	6.165	2.466	145	105.203	52.601	21.041
40	15.020	7.510	3.004	150	110.870	55.435	22.174
45	17.888	8.944	3.578	155	116.649	58.325	23.330
50	20.925	10.463	4.185	160	122.541	61.270	24.508
55	24.125	12.062	4.825	165	128.543	64.272	25.709
60	27.481	13.741	5.496	170	134.656	67.328	26.931
65	30.989	15.495	6.198	175	140.877	70.439	28.175
70	34.644	17.322	6.929	180	147.207	73.603	29.441
75	38.442	19.221	7.688	185	153.644	76.822	30.729
80	42.380	21.190	8.476	190	160.188	80.094	32.038
85	46.455	23.227	9.291	195	166.838	83.419	33.368
90	50.663	25.332	10.133	200	173.593	86.797	34.719
95	55.003	27.501	11.001	205	180.453	90.227	36.091
100	59.472	29.736	11.894	210	187.417	93.709	37.483
105	64.068	32.034	12.814	215	194.484	97.242	38.897
110	68.788	34.394	13.758	220	201.654	100.827	40.331
115	73.633	36.816	14.727				

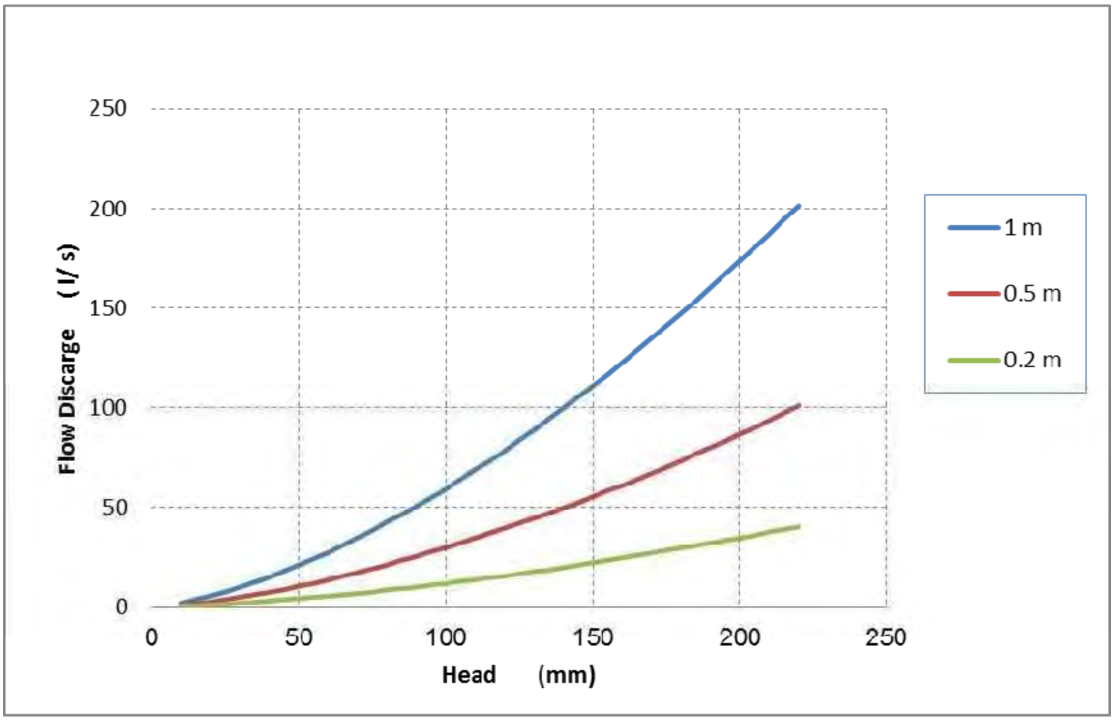


Figure (29): Calibration Chart for Sharp Plated Weir

8. TESTING PLAN

As the model would be constructed, the following experimental stages would be carried out:

8.1. Calibration Phase

This stage would be firstly carried out to check the simulation between the model and prototype as well as to assure model performance and validity by using the attainable results from the recently carried out field survey measurements. The measured flow discharge through each branched canal and the corresponding water surface level downstream the existing "DGR" are listed in Table (24). It is clear from Table (24) that the total flow discharge through the seven branched canals equals 353.14 m^3/s while the measured flow discharge through the main El-Ibrahimia canal upstream "DGR" is 355.76 m^3/s. However, such difference between the two discharges which equals 2.62 m^3/s only would be accepted as it equivalent to 0.74% of the entering flow discharge.

Table (24): Hydrological Condition during Calibration

No.	Canal name	Discharge		Water level (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	Bahr-Yusef canal	14.67	169.80	46.02	45.80
2	Badraman canal	0.52	5.97		45.79
3	Diroutiah canal	0.78	9.01		45.68
4	Ibrahimia canal D/S "DGR"	13.44	155.58		45.88
5	Sahelyia canal	0.34	3.90		45.75
6	Irad Delgaw canal	0.23	2.67		44.80
7	Abo Gabal canal	0.54	6.21		45.70
8	Ibrahimia canal U/S "DGR"	30.74	355.76		-

The equivalent model flow discharge through El-Ibrahimia main canal upstream of "DGR" as well as that through the seven branched canals downstream of "DGR" as well as the corresponding water surface level were worked out and adjusted in the model as listed in Table (25). Those values were calculated according to the selected model scale of 1 to 25 in the vertical and horizontal directions and according to the above mentioned simulation rules. As the flow discharge and the corresponding water surface level through each branch would be adjusted, the existing distribution for the flow velocity profile would be measured and compared with that acquired from the prototype.

Table (25): Model Discharges during Calibration

No.	Canal	Prototype discharge		Model discharge (l/s)
		(mm^3/day)	(m^3/s)	
1	Bahr-Yusef canal	14.67	169.80	54.34
2	Badraman canal	0.52	5.97	1.91
3	Diroutiah canal	0.78	9.01	2.88
4	El-Ibrahimia D/S "DGR"	13.44	155.58	49.79
5	Sahelyia canal	0.34	3.90	1.25
6	Irad Delgaw canal	0.23	2.67	0.85
7	Abo Gabal canal	0.54	6.21	1.99
8	El-Ibrahimia U/S "DGR"	30.74	355.76	113.84

8.2. Existing Prototype Conditions

This stage would be carried out in such a way as to record the existing flow conditions along the modeled reach upstream and downstream "DGR" before constructing the new "DGR" at the downstream in case of maximum and minimum flow discharges. As the model was calibrated against the field measurements of the prototype data, the two selected hydrological cases for the maximum and minimum flow conditions – which are listed in Tables (26 and 27) respectively - would be successively tested in the model. For each of the two flow conditions, several velocity profiles along each branched canal would be measured and the existing turbulent waves downstream the existing "DGR" could be recorded as well as the distribution of the flow current along the simulated canals.

Table (26): Existing Hydrological Records at Maximum Discharge

No.	Canal name	Discharge		WSL	
		Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	Bahr-Yusef canal	204.42	65.41	46.00	45.60
2	Badraman canal	8.23	2.63		45.85
3	Diroutiah canal	11.574	3.70		45.85
4	El-Ibrahimia D/S "DGR"	178.78	57.21		45.15
5	Sahelyia canal	4.16	1.33		45.85
6	Irad Delgaw canal	8.53	2.73		45.00
7	Abo Gabal canal	6.11	1.96		45.85
8	El-Ibrahimia U/S "DGR"	421.81	134.98		-

Table (27): Existing Hydrological Records at Minimum Discharge

No.	Canal name	Discharge		WSL	
		Prototype (m^3/s)	Model (l/s)	U/S(m)	D/S (m)
1	Bahr-Yusef canal	18.52	5.93	43.35	42.55
2	Badraman canal	0.44	0.14		***
3	Diroutiah canal	0.63	0.20		***
4	El-Ibrahimia D/S "DGR"	2.08	0.67		41.55
5	Sahelyia canal	0.22	0.07		***
6	Irad Delgaw canal	0.46	0.15		***
7	Abo Gabal canal	0.32	0.10		***
8	El-Ibrahimia U/S "DGR"	22.67	7.25		-

8.3. Testing the New "DGR"

The recommended design for the new Dairut Group of Regulators "DGR" would be then assembled according to proposed design by "JICA" which was previously detailed in this report. This would be affixed according to the recommended location, orientation and levels. Several model measurements for flow velocity distributions and flow currents upstream and downstream the new "DGR" would be justified for maximum and minimum flow discharges.

9. MODEL INSTRUMENTATION

In order to smooth the progress of the experimental work in the model as well as to fulfill the required accuracy, several advanced instruments would be utilized which can be illustrated as follows:

9.1. Ultra-sonic Flow-meter

To determine the flow discharge into the model with high accurately, an ultrasonic flow-meter is used. As shown in plate (9996) which would be installed on the one 10 inch-diameter feeding pipe. This flow meter read the water flow rate with an accuracy of $\pm$ 1%.

9.2. Electro-Magnetic Current meter

The flow velocity distribution in different branched canals would be measured in the model using an Electro-Magnetic current meter type E.M.S. Plate (7), which was manufactured by Delft Hydraulics of the Netherlands. The device was connected to a mean value meter to show the average velocity within a selected time period.

Point Gauges

To monitor and follow the water surface levels along each of branched canals downstream of "DHR" in the model, one point gauge with side stilling wells would be installed at an appropriate distance downstream the modeled "DGR". Also, another point gauge would be employed to measure water surface elevations along the main El-Ibrahimia canal upstream of "DGR". These point gauges can read the model water surface level with accurately up to $\pm$ 0.1 mm in the model which equivalent to $\pm$ 0.25 cm in the prototype.

Piezometer Tubes

In order to measure the pressure distribution on the horizontal apron, twelve cells 2 m apart (prototype scale) were fixed at the centerline of the apron surface. These cells are connected to twelve glass water manometers fixed on a vertical board to directly determine the pressure head above the inclined and horizontal apron Plate (9).

Video and Photo - Camera

Video and Photo cameras documentations are essential in such hydraulic study to record flow patterns for different flow cases and to monitor the stability of downstream rip-rap zones Plate (10).

Photos (from 5 to 19) illustrat some steps for model construction

Photo No. (5)

Photo No. (6)

Photo No. (7)

Photo No. (8)

Photo No. (9)

Photo No. (10)

Photo No. (11)

Photo No. (12)

Photo No. (13)

Photo No. (14)

Photo No. (15)

Photo No. (16)

Photo No. (17)

Photo No. (18)

Photo No. (19)

Progress Report 3

Physical Model Study of Dairut Group of Regulators

Progress Report No. 3

Model Set-up and Calibration

Authors

Prof. Ahmed Fahmy Ahmed

Dr. Mohamed Mohamed Abdel-Lateef

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ABSTRACT

Dairut group regulators "DGR" is located on El-Ibrahimiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages. This group of regulators was constructed in 1872 to play a vital role of delivering about 9.6 billion m^3/year of irrigation water to all beneficiary area of about 1.43 millions feddans through El- Ibrahimia main canal. "DGR" branches at El-Ibrahimia main canal at Dairut into seven main canals, namely El-Ibrahimia canal, Bahr-Yusef canal, Sahelyia canal, El-Diroutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal. The Bahr-Yousef canal is the largest canal in capacity among the seven canals. Its length extends as long as 312 km downstream of "DGR" and there are four regulators along the canal, namely El-Lahoun regulator, Mazoura regulator, Sakoula regulator and Dahab regulator. Those regulators have been rehabilitated by Japan's Grant Aid since 1995.

One important point should be raised concerning the existing "DGR" which is that Dairut Group of Regulators was constructed in 1872 and can be considered as the oldest active regulator in Egypt, and the their weirs cannot function well due to their age. For this reason rehabilitation of such hydraulic construction should be urgently implemented. It is expected that the impacts of the rehabilitation of the "DGR" should be significant considering the vast beneficiary area and very long canal networks. Therefore, rehabilitation of "DGR" was quite urgent for seeking effective use of the limited water resources and due to limited facilities as well as high cost operation and maintenance.

Based on such an understanding, the Government of Egypt "GOE" requested informally to the Government of Japan "GOJ" for the Japanese Official Development Assistance by Yen-Loan. Accordingly, Japan International Cooperation Agency "JICA" dispatched the study team for the preparatory survey for the rehabilitation and improvement of Dairut Group of Regulators "DGR". Therefore, in order to increase agricultural production and to keep sustainability of agricultural industry in the Upper Egypt region the main objectives of the conducted study were defined as the following:

1. To formulate the rehabilitation plan for Dairut Group of Regulators "DGR";
2. To formulate the improving water distribution plan for the entire operation and maintenance of "DGR" and other regulators that are located along the main canals;
3. To evaluate the present situation and the rehabilitation plan of the existing minor structures based on the result of the inventory survey carried out by the Ministry of Water Resources and Irrigation "MWRI"; and
4. To carry out technology transfer to the implementation agency through the study period on the above mentioned subjects.

To fulfill the above mentioned objectives, a three dimensional physical model study would be carried out in the Hydraulics Research Institute "HRI" which is the main concern of the present reports.

1. INTRODUCTION

The current investigation is being carried out referring to letter No. 1379/156 dated on the 8th day of May 2014 from the Reservoirs and Grand Barrages Sector "RGBS" of the Ministry of Water Resources and Irrigation "MWRI" which requested "HRI" to prepare for a technical and financial proposal to carry out hydraulic physical model for testing a new alternative for Dairut Group Regulators "DGR". The focal objective of the proposed testing program is to adopt the best alignment and hydraulic design for the new barrages group components which fulfills the new emerged flow morphology regime through El-Ibrahimiya canal after the construction of the new Assuit barrages. Flow capacity and velocity distribution upstream and downstream each of the new group components would be physically tested and investigated.

To achieve the above mentioned study objectives, several field and laboratory activities were carried out which can be summarized as follows:

1. Topographic, bathymetric survey and field measurements were conducted to cover about 6.5 km which comprises the branched canals downstream Dairut Group of Regulators "DGR" and main El-Ibrahimia canal upstream "DGR". Field measurements involved every needed detail to construct and calibrate the physical model. Accordingly the first report was released by "HRI" in August 2015 which was mainly focused on the field measurements for conducting the model study.
2. Different hydrological information for passing flow discharges and the corresponding water surface levels for each of the seven branched canals was collected. These data were summarized and analyzed for the case of existing conditions as well as for the maximum and minimum flow discharges. Also the detailed dimensions of the existing barrages and head regulators at "DGR" were collected to be simulated in the model.
3. The second progress report entitled "Model Design and Construction" was raised on September 2015 in which the prototype condition, the hydrological and hydraulic properties of the existing and the new proposed "DGR" were comprised.
4. Several hydrological details of the passing flow discharges and the corresponding water surface levels for different branched canals downstream of "DGR" as well as general description of the model construction and design similarity rules were also comprised within the second progress report.

The current report (the third one) would be directed to cover all details of the model set-up and the calibration results under the following sections:

- Model description
- Modeled hydraulic structures
- Discharge measuring
- Simulated flow conditions
- Model operation
- Calibration results

Description of different branched canals concerning the carried out measurements and the corresponding hydraulic properties as well as the attainable results would be provided and arrangement in this report following clock wise direction.

2. MODEL DESCRIPTION

The model was constructed according to the conducted field measurements that were recently carried out by "HRI" survey staff on June 2015. The measurements included topographic, bathymetric and hydrometric measurements along the seven branched canals downstream "DGR" and the located reach of El-Ibrahmia canal upstream of "DGR". Also, the field survey included velocity measurements and collecting some bed samples. The survey was done at the project site using advanced survey equipments. General layout of the contour map for the surveyed branches is illustrated in Figure (1) while summary of the conducted topographic and bathymetric field measurements are listed in Table (1).

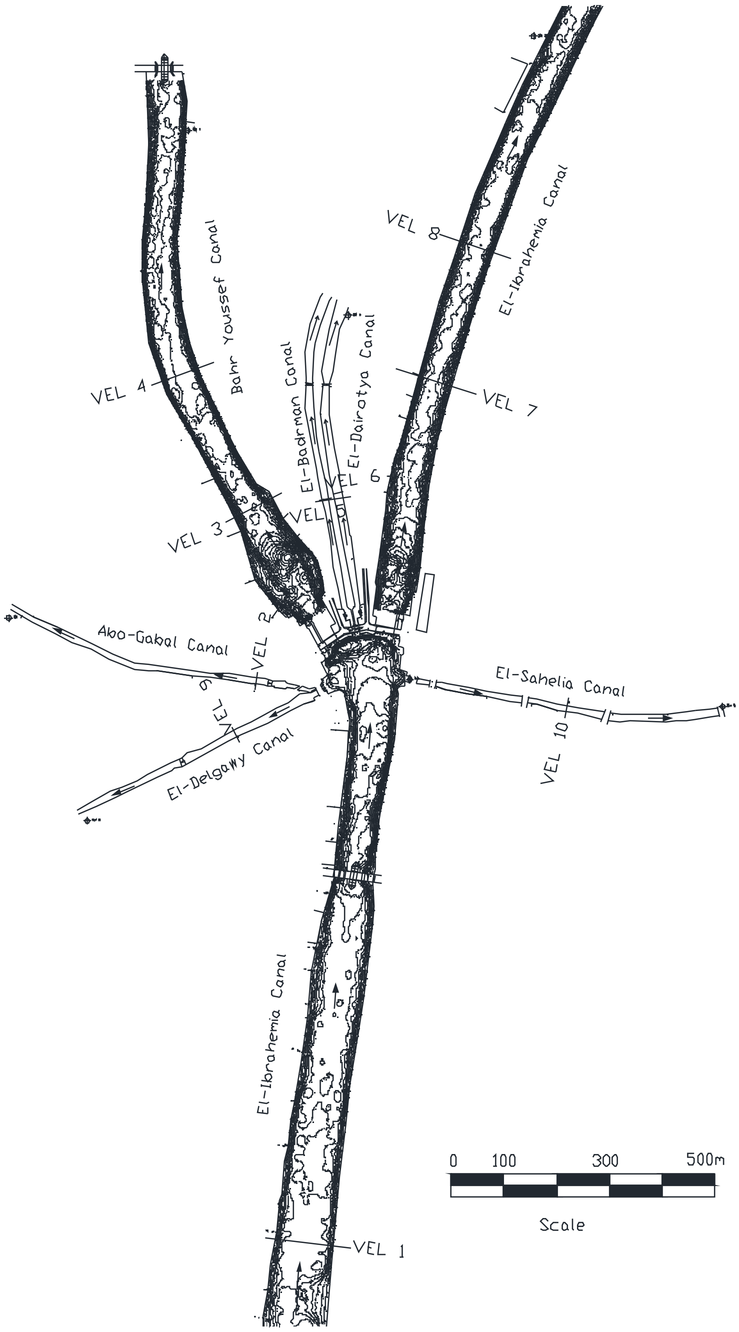


Figure (1): General Layout of the Surveyed Canals

Table (1): Conducted Survey and Field Measurements

No.	Branch name	Symbol	Survey Length (m)	Velocity profiles		Bed samples	
				No.	Location (m)	No.	Location (m)
1	El-Ibrahimia U.S. "DGR"	AA	1280	1	AA1080	3	AA1080
2	Irad Delgaw canal	BB	500	1	BB215		
3	Abo Gabal canal	CC	600	1	CC130		
4	Bahr-Yusef canal	DD	1075	2	DD250 DD500	3	DD540
5	Badraman canal	EE	580	1	EE230		
6	Diroutiah canal	FF	550	1	FF230		
7	Ibrahimia canal	GG	1230	2	GG250 GG500	2	GG690
8	Sahelyia canal	HH	590	1	HH325		
Total Survey activities			6405	10		8	

The model was constructed in open air area within the northern experimental hall of "HRI" of about 46 m length and 24 m average width to cover about 910 m^2. This area was deliberately selected not only to guarantee high flow discharges and other experimental requirements, but also to secure adequate lengths for the downstream branched canals when testing the new proposed "DGR". The model was constructed to simulate appropriate reaches of the 7 branched canals downstream "DGR" and the main El-Ibrahima canal upstream of "DGR". The model would be a fixed bed undistorted scale of equal horizontal and vertical construction scale of 1 to 25. Details of measured lengths and cross sections for each of eight modeled canals are listed in Tables (2 and 3) while Figure (2) and Photos (1 and 2) show general lay out and general view of the model. The model consists of three main components; the entrance, the modeled reach, and the outlet. Full description of the abovementioned model components are as follows:

Table (2): Simulated Canal Lengths in the Model

No.	Canal name	Prototype condition (m)				Modeled length (m)
		Survey length (m)		Cross sections		
		Measured	Modeled	Measured	Modeled	
1	Bahr-Yusef canal	1075	577	34	18	23
2	Badraman canal	580	353	12	7	14
3	Diroutiah canal	550	351	12	7	14
4	Ibrahimia canal	1230	563	40	18	23
5	Sahelyia canal	590	112	15	2	4
6	Irad Delgaw canal	500	221	19	9	9
7	Abo Gabal canal	600	205	16	7	8
8	Ibrahimia Main canal	1280	652	40	20	26
Total Length (m)		6405	3032		88	121

Table (3): Simulated Cross Sections in the Model

No.	Canal name	Symbol	Measured Sections	Modeled sections	
				From	To
1	Ibrahimia Main canal	AA	20	AA20	AA41
2	Irad Delgaw canal	BB	8	BB1	BB8
3	Abo Gabal canal	CC	7	CC1	CC7
4	Bahr-Yusef canal	DD	18	DD1	DD18
5	Badraman canal	EE	8	EE1	EE8
6	Diroutiah canal	FF	8	FF1	FF8
7	Ibrahimia canal	GG	18	GG1	GG18
8	Sahelyia canal	HH	3	HH1	HH3
Total Length (m)			90		

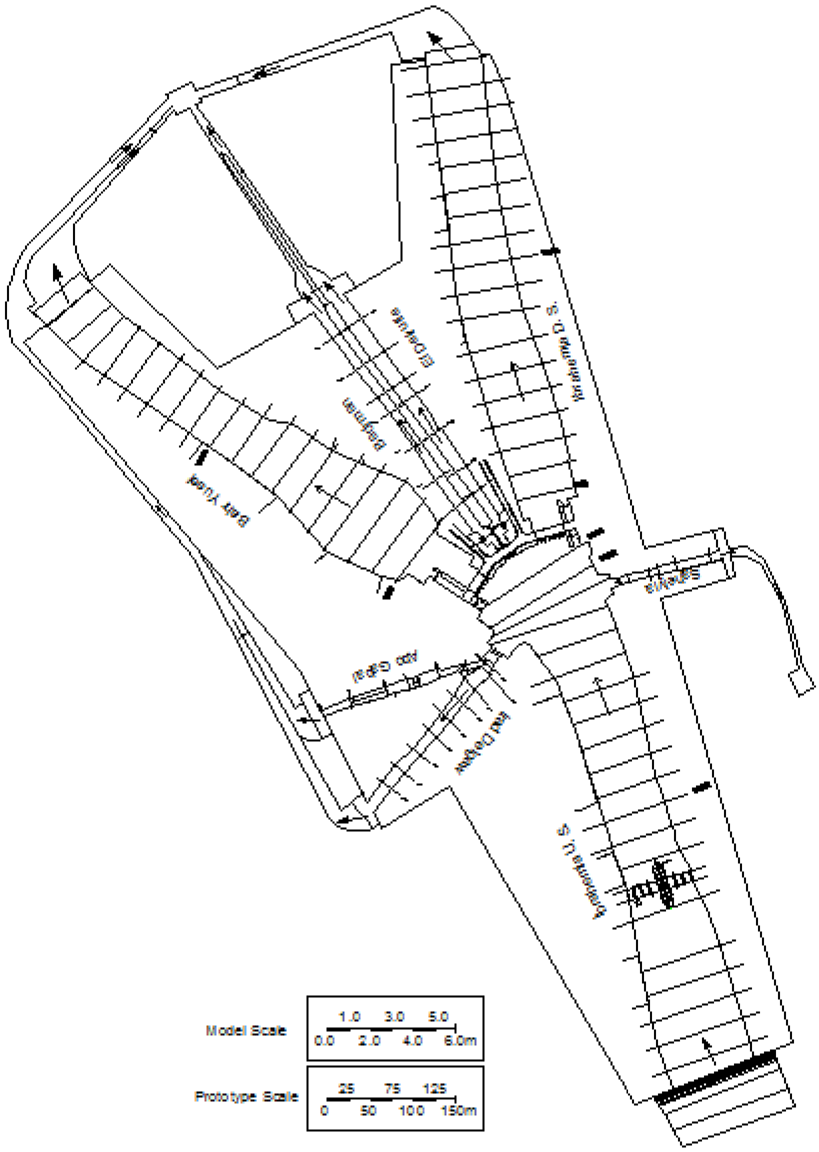


Figure (2): General Layout of the Model

Photo (1): General Model Photo Looking Downstream

Photo (2): General Model Photo Looking Upstream

2.1. Model Entrance

The model entrance – as illustrated in Figure (3) and Photos (3 and 4) was made of 0.18 m thickness bricks wall covered with 0.02 m cement mortar at both sides mixed with chemical isolated materials to prevent seepage. The entrance is 6.0 m width, 3.30 m long and consists of three successive divisions one meter long each. The upstream one is constructed of 2.0 m high closed walls to receive the delivered pump water from the underground reservoir to the model. While the following division is one meter height and mainly constructed to convey the delivered water from the upstream compartment straightforwardly to the simulated model reach through a unfilled wall. The third downstream division is opened to guide the flow discharge to the modelled reach through an access ramp as shown in Figure (3). The third division is provided with a frame of pieces of wood to distribute the entering water flow through the entire model cross section in such a way as to simulate the prototype condition.

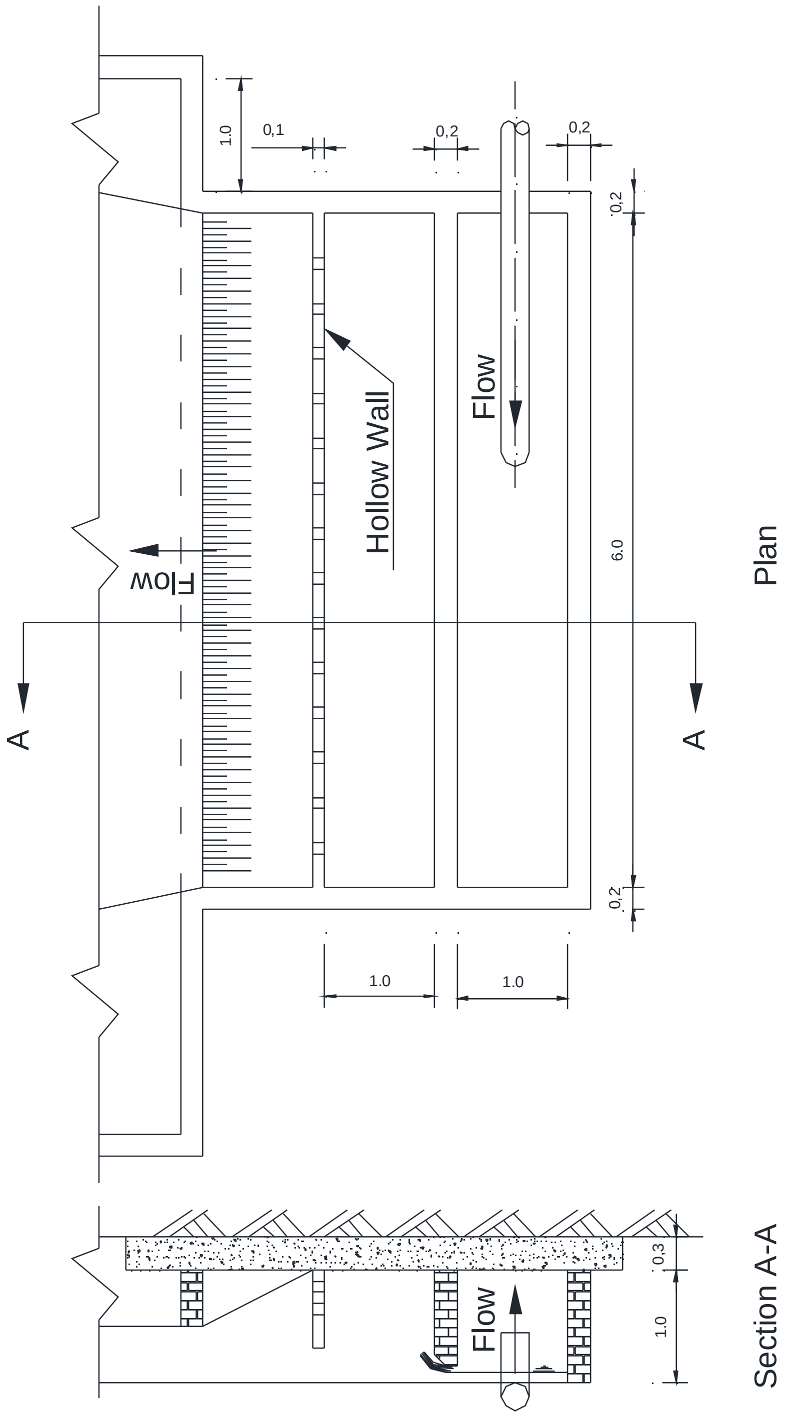


Figure (3): Model Entrance Design

Photo (3): Model Entrance Construction

Photo (4): Model Entrance after Construction

2.2. Modelled Reach

The modeled reach is the main study model element which simulates the 7 branched canals downstream of "DHR" and part of the main El-Ibrahimia canal upstream of "DGR". Those branches were shaped according to the existing configurations, levels and locations in equal horizontal and vertical construction scale of 1 to 25 which were constructed of about 0.07 m thick layer of plane concrete. The modeled reach was formed in such a way as to imitate the prototype condition and according to the latest field and bathymetric measurements which were carried out by "HRI" survey team. To guarantee high accuracy, the measured cross section in the prototype were scaled down and allocated according to their orientation, location and levels in the prototype. Then the separation between each successive two cross sections were filled up and shaped with plane mortar. The modeled regulators which simulate the existing "DGR" were constructed in the "HRI" workshop following the same undistorted model scale of 1 to 25. Level of the constructed reach was previously determined in the hydraulic laboratory in such a way as to provide the necessary water levels upstream each of the installed sharp crested weirs and the tailgates.

In order to monitor and follow the water surface levels along the model in El-Ibrahimia canal upstream "DGR" and along the seven branched canals downstream "DGR", eight point gauges were installed along those branches as shown in Figure (4). Each point gauge was affixed on a vertical 10 inch diameter side well which was in term connected to the bed of one branch through 10 mm diameter plastic tube. Therefore, the point gauges can measure water surface levels along the whale length of the model and read accurately up to ± 0.1 mm. with height accuracy of 0.1 mm. The point gauge locations were previously assigned to be downstream of the proposed location for the new "DGR" and in such a way as to avoid the back water curve upstream the installed end tail gate downstream each of the seven branched canals.

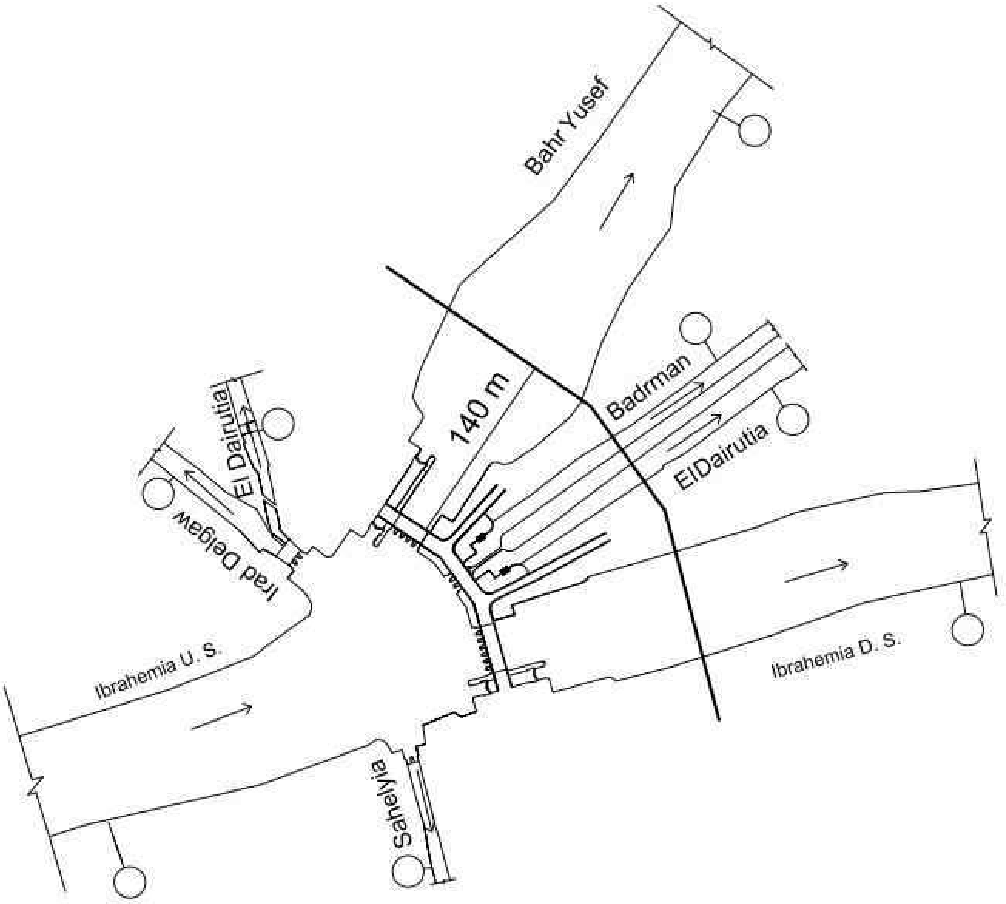


Figure (4): Installed Point Gauges along the Model

2.3. Model Outlets

The principal function of the model outlets is to maintain water surface level through each modeled branch canales in such a way as to reproduce all the existing hydraulic and hydrology conditions in the prototype, then leading the passing flow discharge to the outlet sharp crested weir. For this reason the model exit consists of the tailgate and the approach channel. The tailgate is used to adjust the water surface level in the upstream which was made of 5mm rectangular steel plate and hinged from bottom and can be easily rotated around the lower hinge to adjust the upstream water surface level through each modeled branch. This tailgate type was used at the exit end of the two modeled reaches of El-Ibrahimia and Bahr Yussef canals. While in case of the other small branched canals another vertical and simple tail gates were utilized.

The outlet of the modeled branches for each of El-Sahelyia canal, El-Dairutia canal, Badraman canal, Abo Gabal canal and Irad Delgaw canal was provided and equipped with a sharp crested weir of 30 cm height and 20 cm width as shown in Figure (5) and Photos (5, 6, and 7). While two flap tailgates of about 4.0 m long were affixed at the downstream end of the modeled parts of Bahr Yussef canal and El-Ibrahimia canal downstream of "DGR" as shown in Photos (8 and 9). While two sharp crested weirs of 30 cm height and 50 cm width each was used at the modeled outlet of El-Ibrahimia and Bahr-Yusef canals. The model feeding system consists of an electric centrifugal pump of 10 inch diameter and a suction pipe connected to the sump. Water was pumped from the underground reservoir and delivered to the model entrance through the delivery pipeline.

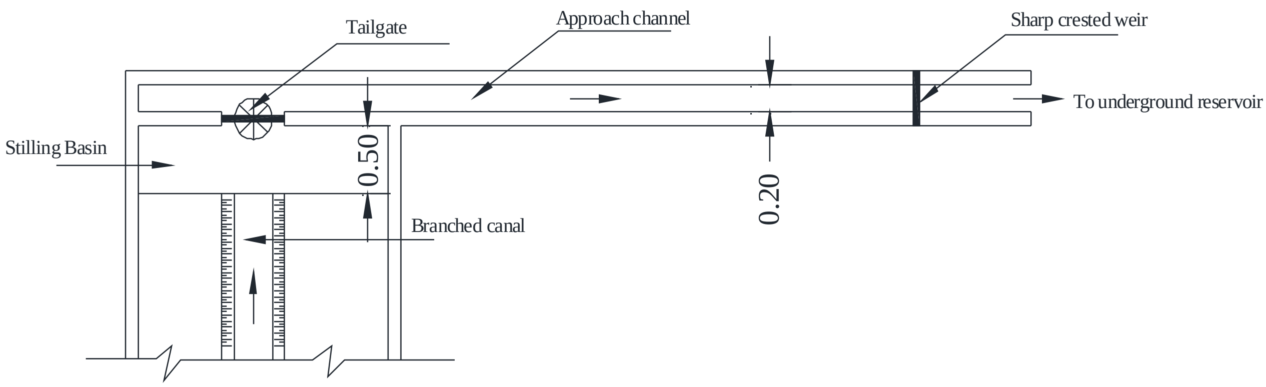


Figure (5): Model End Tail Gate for Small Branches

Photo (5): Sharp Crested Weirs for Irad Delgaw and Abou Gabal Canals

Photo (6): End Tail Gate of Badraman and Daytutiah Canals

Photo (7): Sharp Crested Weirs of Badraman and Daytutiah Canals

Photo (8): Mounted End Tail Gate for Bahr-Yussef Canal

Photo (9): Mounted End Tail Gate for El-Ibrahimia Canal

3. MODELED HYDRAULIC STRUCTURES

The existing Dairut group of regulators "DGR" was constructed in 1872 on El-Ibrahimiya canal at km 60.600 downstream of El-Ibrahemiya head barrages which is branched from the west Nile River bank at km 544.450 downstream of Old Aswan Dam "OAD" and about 400 m upstream the existing Assiut barrages. Those regulators are mainly constructed to feed seven downstream canals, namely from west to east; Irad Delgaw canal, Abo Gabal canal, Bahr-Yusef canal, Badraman canal, El-Dairutia canal, El-Ibrahimia canal, and El- Sahelyia canal. This group of regulators comprises only five main head regulators. This because each of the two branches of Irad Delgaw and Abou Gabal canals and two branches of Badraman canal and Dairutia canals are branched downstream only one head regulator as shown in Figure (6) and Photo (10), and listed in Table (4).

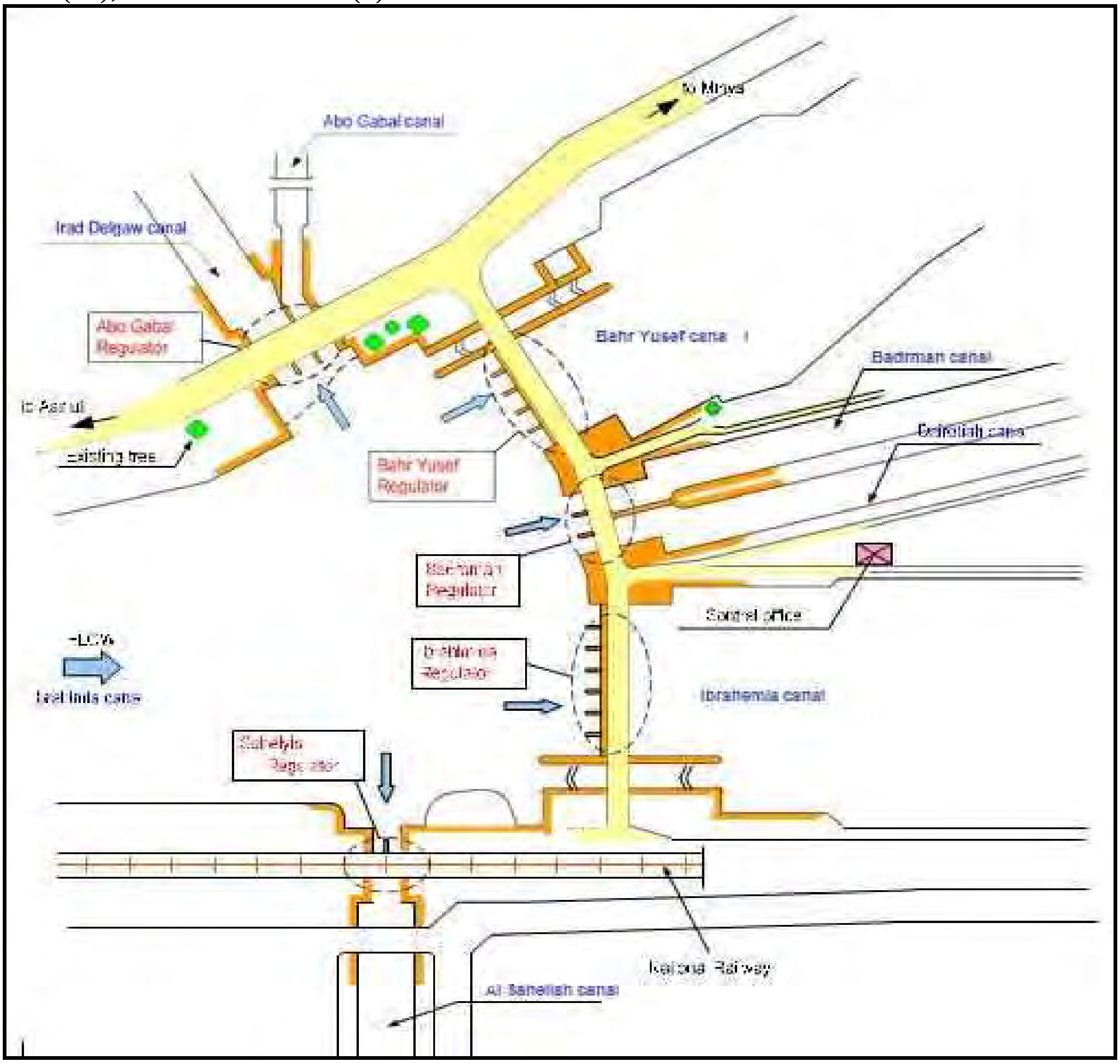


Figure (6): Main Branch Canals Downstream of "DGR"

Photo (10): layout of the Existing Dairut Group of Regulators

Table (4): Current Formation of Dairut Group of Regulators

Name of canal at DGR	Regulator unit	Dimensions of the regulator unit	
		Structural	Gates
Bahr Yusef	No. of gates	5 vents	3m width x 5 vents
	Pier	4 units & width 1.80~2.25m	Total height 7.5 m
	Mid. Apron	L=43.25m, thickness 3m	3 leaves of gate
	Foundation	Limestone partially concrete	Bottom elevation (39.50) m
	Lock	width 8.5m	Operational high water level (46.00) m
Badraman & Dirotiah	No. of gates	2 vents (1 vent closed)	3m wide x 2 vents total height 7.5m
	Pier	2 units & width 1.80~2.25m	3 leaves of gate
	Mid. apron	L=38.65m,	Bottom elevation (39.30) m
	Foundation	limestone, t=unknown	Operational high water level (46.00)m
Ibrahimia	No. of gates	7 vents	3m width x 7 vents
	Pier	6 units & width 1.80~2.25m	Total height 7.5 m
	Mid. apron	L=39.70m, thickness 3m	3 leaves of gate
	Foundation	limestone partially concrete	Bottom elevation (39.81) m
	Lock	width 8.5m	Operational high water level (46.00) m
Sahelyia (right bank)	No. of gates	2 vents	3m wide x 2 vents total height 5.5 m
	Pier	1 unit & width 1.80~2.25m	1 leaves of gate
	Mid. apron	L=18.90m,	Bottom elevation (41.80) m
	Foundation	limestone, t=unknown	Operational high water level (46.00) m
Abo Gabal & Irad Delgaw (left bank)	No. of gates	3 vents	3m wide x 3 vents total height 5.5 m
	Pier	2 units & width 1.80~2.25m	1 leaves of gate
	Mid. apron	L=28.60m,	Bottom elevation (42.00) m
	Foundation	limestone, t=unknown	Operational high water level (46.00) m

On the other hand, three more bridges are installed within the study reach which are located on Abo Gabal canal, El- Sahelyia canal and El-Korashia bridge at Km 60.100 on El-Ibrahimia canal at km 60.100 upstream of "DGR". Those mounted hydraulic structures in the model can be illustrated as follows:

3.1. Head Regulators

In order to assemble the modeled regulators, the conducted Japan International Cooperation Agency "JICA" report for the preparatory survey for the rehabilitation and improvement of Dairut Group of Regulators "DGR" were utilized and some more details of the engineering drawings were obtained from the Reservoirs and Grand Barrages Sector "RGBS". Moreover some particular details and pictures were recorded for each structure by "HRI" survey group to support and help model simulation. Those references were utilized to work out all detailed dimensions and features of the modeled hydraulic structures. According to "JICA" report, "DGR" consists of five head regulators comprise 19 continuous arch structural vents made by bricks. This is one of the typical models of river structures, and was the most advanced technology at the time when reinforced concrete was not popular yet. The width of each vent is three meters. The assembled piers to construct the five head regulators in the model are shown in Figures (from 7 to 9).

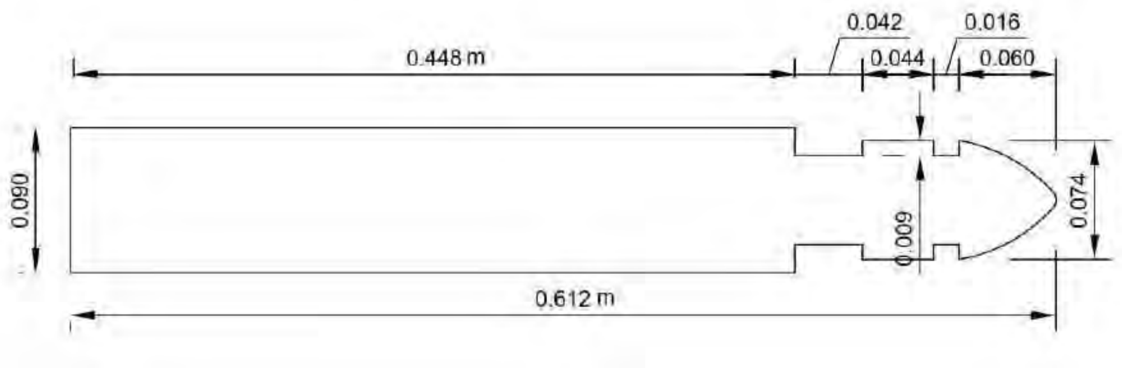


Fig. (7): Simulated Piers for Bahr Yusef, Ibrahimia, Badrman and Dirotiah Regulators

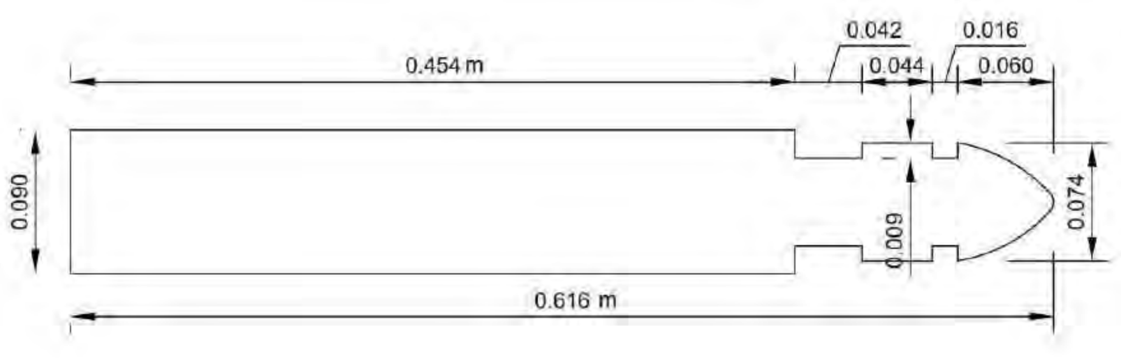


Figure (8): Simulated Piers for Abo Gabal and Irad Delgaw Head Regulators

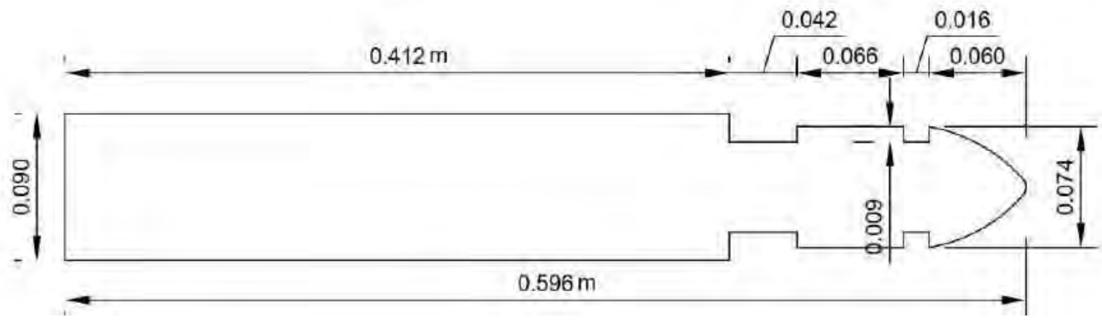


Figure (9): Simulated Piers for El-Sahelyia Head Regulators

The modeled two head regulators for the two branched canals of Badraman and El-Dairutia, and El- Sahelyia canal were completely erected and assembled of a special type of timber in "HRI" workshop. While each pier of the other three head regulators were shaped of reinforced concrete by using wooden form work as shown in Photos (10 and 11).

Photo (10): Forming Modeled Piers

Photo (11): Shaped Reinforced Concrete Piers

Those piers and attached lock chambers were then placed according to their levels and locations to assemble each of the three modeled head regulators as shown in Photos (12 and 13). Also Photos (from 14 to 18) show each of the five mounted "DGR" head regulators.

Photo (12): Mounting El-Ibrahimia Head Regulator

Photo (13): Mounted Dairut Group of Regulators

Photo (14): Mounted Irad Delgaw Head Regulator

Photo (15): Mounted Bahr Yussef Head Regulator

Photo (16): Mounted Badraman-Dayrutia Head Regulator

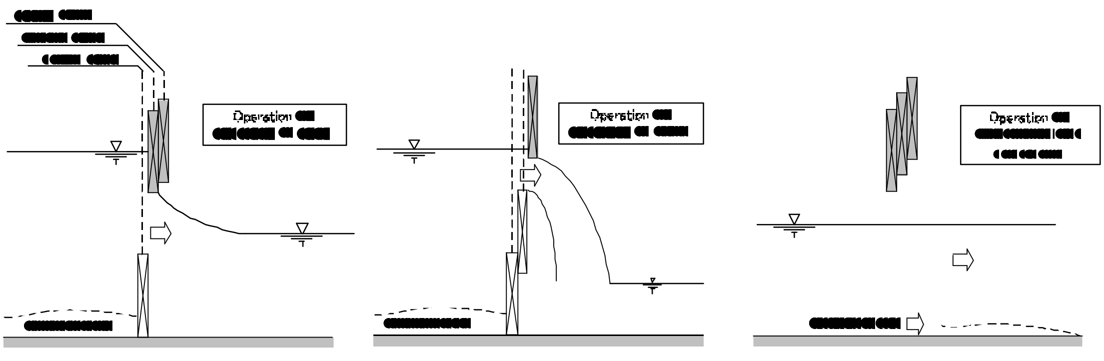
Photo (17): Mounted El-Ibrahimia Head Regulator

Photo (18): Mounted El-Saheliah Head Regulator

3.2. Leaf Gates

Each vent of the three head regulators of Bahr Yusef, Badraman, and El-Ibrahimia head regulators, have three gates with upper, middle and lower gates of 7.5 m high. The gutter of each gate is made of cast metal and divided into three rows. Flow discharge and the corresponding water surface level upstream each of the three regulator is controlled using the three leaf gates that fixed at downstream side of every vent as illustrated in Figure (10). This reveals the following:

- Case (1) which used to be applied at the ordinary and regular flow discharges. The discharge in this case is controlled by using upper and middle gates while the upstream gate is lowered on the floor as shown in Figure (10-a).
- Case (2) which used to be applied at the passing low flow discharges. The discharge in this case is controlled by using upper gate while the two upstream gates (the lower and middle gates) are lowered to raise the upstream water surface level as in Figure (10-b).
- Case (3) which used to be applied at the case of maintenance work to flush deposited sedimentation. The discharge in this case is passing without any control by lifting the three leaf gates above the existing water surface level as shown in Figure (10-c).



Case (1) **Case (2)** **Case (3)**

Figure (10): Operation of the Three Leaf Gates

On the other side, each vent of El-Sahelyia head regulator and Abo Gabal head regulator consists of one life gate with 5.5 m height. The current operation gates of the existing "DGR" are listed in Table (5). Those gates were assembled by using a special type of wood to control the entering water discharge downstream each of the seven assembled head regulator.

Table (5): Current Status of the Gates of the "DGR"

Regulator Name	No. from left Bank	Upper Gate	Mid. Gate	Lower Gate	Remarks
Ibrahimia Reg.	No. 1	0	0	0	
	No. 2 to 6	0	0	̊X	without chain
	No.7	0	0	0	
Bhar Yusef Reg.	No. 1to 5	0	0	0	
Badraman Reg.	No. 1 to 2	0	0	0	
Abo Gabal Reg.	No. 1to 3	0			
El-Sahelia	No. 1 to 2	0			

3.3. Bridges

The mounted three bridges within the modeled reach were scaled and assembled according to the model scale on Abo Gabal canal, El- Sahelyia canal, and El-Ibrahimia canal upstream of "DGR". Although each of the two constructed bridges on Abo Gabal canal, and El- Sahelyia canal are simple constructions, the existing bridge on El-Ibrahimia canal upstream of "DGR" is rather dense. This bridge consists of seven combined piers; each comprises 20 square piles of 0.4 m side long, while a middle circular pier comprises 28 square piles 0.4 m side long (which equal to 1.6 cm in the model). In order to protect the bridge against navigation units a main wooden fender was constructed around the middle circular pier which is supported on 26 circular piles 0.3 m diameter each (which equal to 1.2 cm in the model) as shown in Photos (19 and 20). While the two sided piers were partially protected from upstream and downstream directions by four elements of wooden finders. Each element was supported on 3 circular piles 0.3 m diameter each (which equal to 1.2 cm in the model) as shown in Photos (19 and 20) and Figure (11).

Photo (19): El-Korashia Bridge Construction

Photo (20): Mounted El-Korashia Bridge

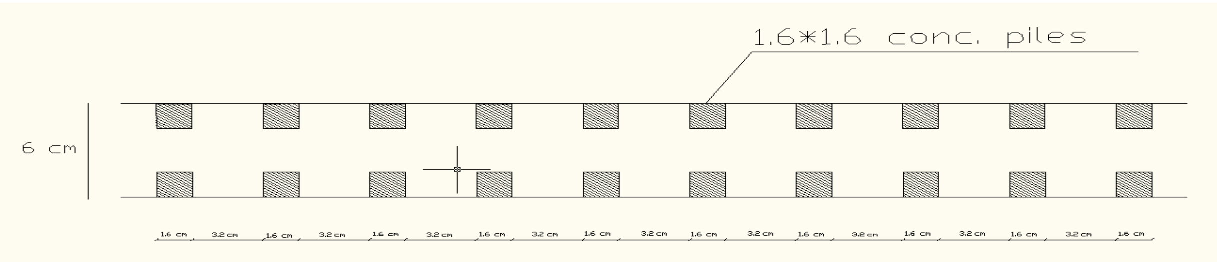


Figure (11): Shaped Piers of El-Korashia Bridge

4. DISCHARGE MEASURING

The model was constructed on a large underground reservoir to work as a feeding and drainage basin at the same time which can be assigned as a recalculated feeding system. The capacity of the underground reservoir was completely sufficient to feed the model with more than the maximum required flow discharge. Two electric centrifugal pumps of 10 and 6 inch diameters pipe lines with capacity of 150 and 60 l/s respectively were utilized. The required flow discharge in the model is pumped from the underground reservoir via either of the two provided pumps and delivered to the upstream room of the model entrance. While the spelt flow discharges downstream each of the seven installed sharp crested weirs is directed back to the underground reservoir.

Two flow discharge measuring techniques were applied during testing program in the model. The first one is used on the two delivery pipe lines which are pumping water from the underground feeding reservoir to the upstream model entrance. While the second one is measuring the outlet flow rate over 7 sharp crested weirs that are affixed at the downstream end of each branched canal in the model. The outlet flow was determined by using the variation in the flow water levels over the sharp crested weir which is consequently diverted to corresponding out flow rates for each branched canal in the model. For this reason, the measuring flow discharges in the model can be classified into inflow and outflow as follows:

4.1. The Inflow Measuring

To determine the flow discharge into the model accurately, two flow-meters were employed. As shown in Photo (21), an Electro-Magnetic flow-meter type E.M.S. was installed on 10 inch pipeline diameter of the major electric feeding pump. The flow-meters can be used to measures the passing flow rate with $\pm$ 1% accuracy.

Photo (21): The Electro-Magnetic Flow-Meter

Also one portable Ultrasonic (Flexim) flow meter was affixed on the 6 inch pipeline diameter of the assisting feeding pump to be used for small discharges as shown in Photos (22 and 23). This flow meter uses the transit time difference principle to measure the difference in travel time between pulses transmitted in the direction of flow and pulses transmitted against the flow. The difference between the upstream and downstream transit times can be correlated to flow rate through the meter. With this in mind, the following specifications were fulfilled:

- The allowed flow velocity is ranged between 0.01 m/s and 25.0 m/s
- The measuring accuracy is ranged between ±1.6 % of reading ±0.01 m/s (standard)
- The pipe diameter range is from 10.0 mm to 12.00 m

Photo (22): Fixed Ultrasonic Flow Meter around Feeding Pipe

Plate (23): Ultra-Sonic Flow-meter Gauge

4.2. The Outflow Measuring

The present section would be elaborated to record the variation in the passing flow discharges out of the model over the sharp crested weir to precisely determine the corresponding prototype discharges. Two steps would be involved in the present section which is recording the existing steady water level over the sharp crested weir then determining the corresponding flow rate due to the measured flow head. The Swiss Specifications that were published for approach channel of 100 cm width and 40 cm weir height was utilized. To determine the passing flow over any sharp crested weir, the following formula was applied:

$$Q = \frac{2}{3}\mu..B.\sqrt{2g}.H^{1.5}$$

Where,

Q = Discharge (m3/s)

μ =Discharge coefficient =0.64

B =Weir length (m)

G =gravity acceleration (m^2/s)

H =Weir head (distance between the weir crest and u/s water level) (m)

Reading over weir crest=70cm

On the other hand, as the passing flow discharge through the small modeled branches upstream of "DGR" would be very diminutive with respect to that through Bahr Yussef canal and El-Ibrahimia canal at Dairut, sharp plated weirs of 0.2 m width were utilized at the outlet of the small branched canals. While the outlet of the modeled branches for each of Irad Delgaw canal, Abo Gabal canal, Badraman canal, El-Dairutia canal, and El- Sahelyia canal was equipped with a sharp crested weir of 30 cm height and 20 cm width. While two sharp crested weirs of 30 cm height and 50 cm width each was used at the modeled outlet of Bahr-Yusef canal and El-Ibrahimia canal.

The published equations to determine the passing flow discharges in litters per second were applied for every one mm height step for sharp crested weir of 0.3 m height and for 0.20 m and 0.50 m approach channel width respectively as listed in Tables (6 and 7) and shown in Figure (12).

Table (6): Passing Discharge for Sharp Plated Weir of 0.2m Width

Head (H) (mm)	Flow Discharge in (L/s) for each one mm step									
	0	1	2	3	4	5	6	7	8	9
0		0.025	0.052	0.083	0.119	0.159	0.202	0.249	0.299	0.351
10	0.407	0.465	0.525	0.588	0.653	0.721	0.790	0.862	0.936	1.012
20	1.090	1.170	1.251	1.335	1.420	1.507	1.596	1.687	1.779	1.873
30	1.969	2.066	2.165	2.265	2.367	2.470	2.575	2.682	2.790	2.899
40	3.010	3.123	3.237	3.352	3.468	3.586	3.706	3.826	3.949	4.072
50	4.197	4.323	4.450	4.579	4.709	4.840	4.973	5.106	5.242	5.378
60	5.515	5.654	5.794	5.936	6.078	6.222	6.367	6.513	6.660	6.808
70	6.958	7.109	7.261	7.414	7.568	7.723	7.880	8.038	8.197	8.357
80	8.518	8.680	8.843	9.008	9.173	9.340	9.508	9.676	9.846	10.017
90	10.190	10.363	10.537	10.712	10.889	11.066	11.245	11.424	11.605	11.787
100	11.970	12.153	12.338	12.524	12.711	12.899	13.088	13.278	13.469	13.661
110	13.854	14.048	14.243	14.440	14.637	14.835	15.034	15.234	15.435	15.637
120	15.841	16.045	16.250	16.456	16.663	16.871	17.080	17.290	17.501	17.713
130	17.926	18.140	18.355	18.571	18.788	19.006	19.225	19.444	19.665	19.887
140	20.109	20.333	20.557	20.783	21.009	21.237	21.465	21.694	21.924	22.155
150	22.387	22.620	22.854	23.089	23.325	23.562	23.799	24.038	24.277	24.518
160	24.759	25.001	25.245	25.489	25.734	25.980	26.226	26.474	26.723	26.972
170	27.223	27.474	27.727	27.980	28.234	28.489	28.745	29.002	29.259	29.518
180	29.777	30.038	30.299	30.561	30.824	31.088	31.353	31.618	31.885	32.153
190	32.421	32.690	32.960	33.231	33.503	33.776	34.049	34.324	34.599	34.876
200	35.153	35.431	35.709	35.989	36.270	36.551	36.834	37.117	37.401	37.686
210	37.971	38.258	38.546	38.834	39.123	39.413	39.704	39.996	40.288	40.582
220	40.876	41.171	41.467	41.764	42.062	42.361	42.660	42.960	43.261	43.563
230	43.866	44.170	44.474	44.780	45.086	45.393	45.701	46.009	46.319	46.629
240	46.940	47.252	47.565	47.879	48.193	48.509	48.825	49.142	49.459	49.778
250	50.098	50.418	50.739	51.061	51.384	51.707	52.032	52.357	52.683	53.010
260	53.338	53.666	53.995	54.325	54.656	54.988	55.321	55.654	55.988	56.323
270	56.659	56.996	57.333	57.672	58.011	58.350	58.691	59.033	59.375	59.718
280	60.062	60.407	60.752	61.098	61.446	61.794	62.142	62.492	62.842	63.193
290	63.545	63.898	64.251	64.606	64.961	65.317	65.673	66.031	66.389	66.748
300	67.108	67.469	67.830	68.192	68.555	68.919	69.284	69.649	70.015	70.382

Table (7): Passing Discharge for Sharp Plated Weir of 0.5m Width

Head (H) (mm)	Flow Discharge in (L/s) for each one mm step									
	0	1	2	3	4	5	6	7	8	9
0	0.00	0.063	0.129	0.208	0.298	0.398	0.506	0.623	0.747	0.879
10	1.017	1.162	1.313	1.470	1.633	1.802	1.976	2.156	2.340	2.530
20	2.725	2.924	3.128	3.337	3.550	3.768	3.990	4.217	4.448	4.683
30	4.922	5.165	5.412	5.663	5.917	6.176	6.439	6.705	6.975	7.249
40	7.526	7.807	8.091	8.379	8.671	8.966	9.264	9.566	9.871	10.180
50	10.492	10.807	11.125	11.447	11.772	12.100	12.432	12.766	13.104	13.445
60	13.789	14.136	14.486	14.839	15.195	15.554	15.916	16.281	16.650	17.021
70	17.395	17.772	18.152	18.534	18.920	19.309	19.700	20.094	20.491	20.891
80	21.294	21.700	22.108	22.519	22.933	23.350	23.769	24.191	24.616	25.044
90	25.474	25.907	26.343	26.781	27.222	27.666	28.112	28.561	29.013	29.467
100	29.924	30.383	30.846	31.310	31.778	32.247	32.720	33.195	33.673	34.153
110	34.635	35.121	35.609	36.099	36.592	37.087	37.585	38.085	38.588	39.094
120	39.602	40.112	40.625	41.140	41.658	42.178	42.701	43.226	43.754	44.284
130	44.816	45.351	45.888	46.428	46.970	47.515	48.062	48.611	49.163	49.717
140	50.273	50.832	51.393	51.957	52.523	53.092	53.662	54.235	54.811	55.389
150	55.969	56.551	57.136	57.723	58.313	58.904	59.498	60.095	60.694	61.295
160	61.898	62.504	63.112	63.722	64.334	64.949	65.566	66.186	66.807	67.431
170	68.057	68.686	69.316	69.949	70.585	71.222	71.862	72.504	73.148	73.794
180	74.443	75.094	75.747	76.403	77.060	77.720	78.382	79.046	79.713	80.381
190	81.052	81.725	82.401	83.078	83.758	84.440	85.124	85.810	86.498	87.189
200	87.882	88.577	89.274	89.973	90.674	91.378	92.084	92.792	93.502	94.214
210	94.929	95.645	96.364	97.085	97.808	98.533	99.260	99.990	100.721	101.455
220	102.191	102.929	103.669	104.411	105.155	105.902	106.650	107.401	108.154	108.908
230	109.665	110.425	111.186	111.949	112.714	113.482	114.251	115.023	115.797	116.573
240	117.351	118.131	118.913	119.697	120.483	121.271	122.062	122.854	123.649	124.445

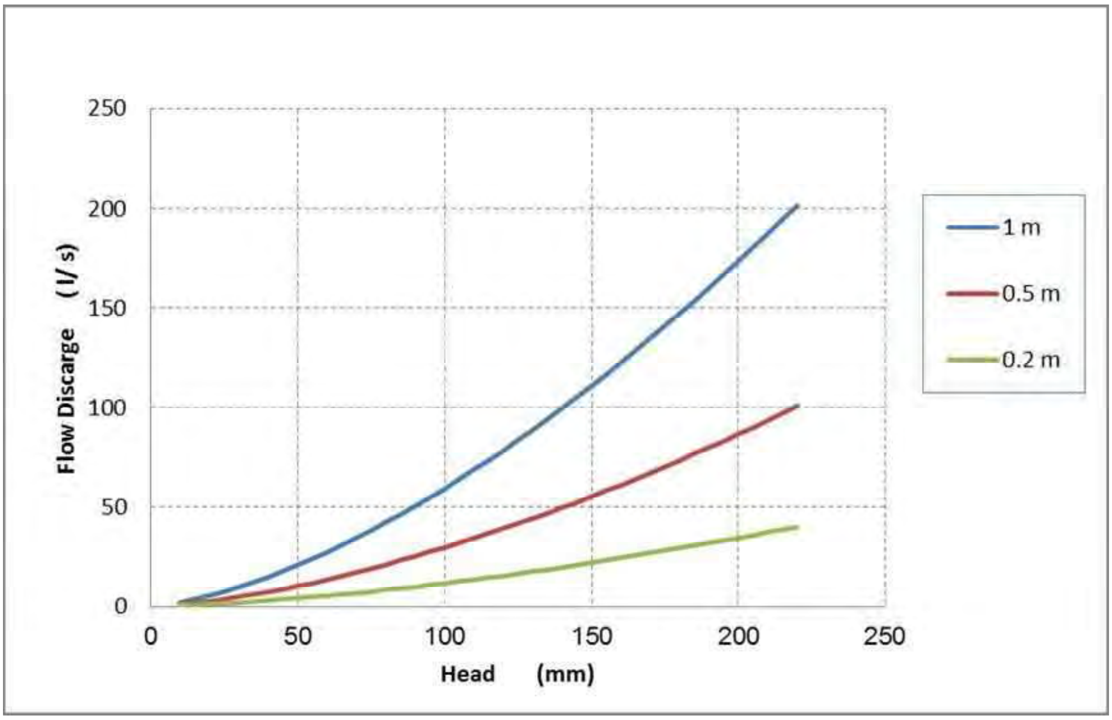


Figure (12): Calibration Chart for Sharp Plated Weir

5. SIMULATED FLOW CONDITIONS

The model would be operated according to four flow circumstances that representing various and possible flow conditions in the prototype which can be reviewed as follows:

1. Calibration flow condition
2. Maximum and minimum flow conditions
3. Dominant flow condition

Hydraulic and morphological characteristics of each of the above four flow cases were worked out in view point of the passing flow discharge and the corresponding water surface flow upstream and downstream of the existing "DGR" for each branched canal. Calculation of each flow case and the application in the model would be summarised as follows:

5.1. Calibration Flow Condition

This flow condition illustrates the existing hydraulic and hydrologic flow conditions upstream and downstream "DGR" as well as through each of the branched canals during the field survey work. Those measurements were especially carried out not only to scale down and build the model, but also to indicate the horizontal velocity distribution along some cross sections within the project reach which covered El-Ibrahimia canal upstream "DGR" and each branched canal as shown in Figure (13). The water surface slope through the seven branched canals was also measured during the field measurements which ranged between 4.30 cm/km for Irad Delgaw canal and 8.9 cm/km for El-Dairutia canal.

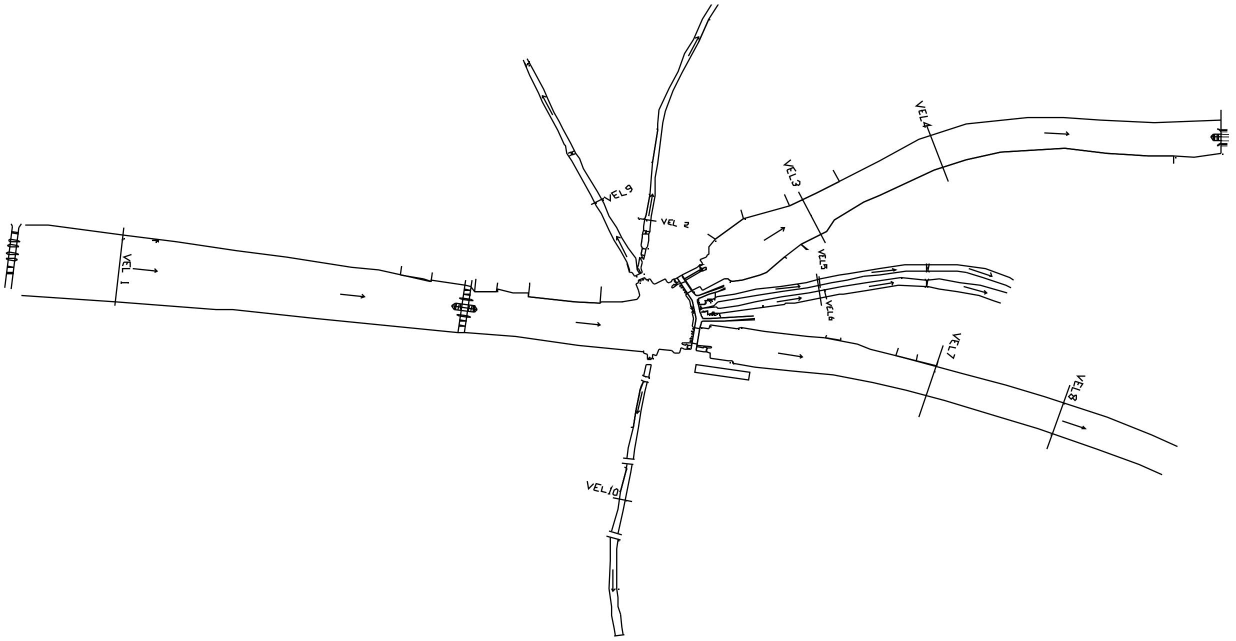


Figure (13): Location of the Measured Velocity Profiles

Those measurements would be utilized to check and assure the simulation between the model and prototype conditions as well as to guarantee model performance and validity. According to the achieved field measurements by "HRI" field group, the attainable results for the measured flow discharges as well as the corresponding water surface levels upstream and downstream the existing "DGR" are listed in Table (8).

Table (8): Hydrological Condition during Calibration

No.	Canal name	Vel. No.	Discharge		Water level (m)		
			(mm^3/day)	(m^3/s)	U/S	D/S	At C.S.
1	Ibrahimia canal U/S "DGR"	[1]	30.672	355.00	(46.02)	--	(46.100)
2	Irad Delgaw canal	[9]	0.185	2.150		(44.80)	(44.794)
3	Abo Gabal canal	[2]	0.530	6.134		(45.75)	(45.725)
4	Bahr-Yusef canal (1)	[3]	14.738	170.578		(45.82)	(45.803)
5	Bahr-Yusef canal (2)	[4]	14.915	172.627		(45.82)	(45.786)
6	Badraman canal	[5]	0.528	6.111		(45.70)	(45.684)
7	Diroutiah canal	[6]	0.794	9.190		(45.90)	(45.879)
8	Ibrahimia canal D/S "DGR" (1)	[7]	13.591	157.303		(45.05)	(45.017)
9	Ibrahimia canal D/S "DGR" (2)	[8]	13.723	158.830		(45.05)	(44.998)
10	Saheleya canal	[10]	0.265	3.067		(45.80)	(45.718)

The equivalent model flow discharge through El-Ibrahimia main canal upstream of "DGR" as well as that through the seven branched canals downstream of "DGR" and the corresponding water surface level – within the model boundaries - were worked out and adjusted in the model as listed in Table (9). Those values were calculated according to the decided model scale of 1 to 25 in the vertical and horizontal directions and according to the similarity rules.

Table (9): Model Discharges during Calibration

No.	Canal	Prototype discharge		Model discharge (l/s)
		(mm^3/day)	(m^3/s)	
1	Ibrahimia canal U/S "DGR"	30.672	355.00	113.600
2	Irad Delgaw canal	0.185	2.150	0.688
3	Abo Gabal canal	0.530	6.134	1.963
4	Bahr-Yusef canal	14.738	170.578	54.585
5	Badraman canal	0.528	6.111	1.956
6	Diroutiah canal	0.794	9.190	2.941
7	Ibrahimia canal D/S "DGR"	13.723	157.303	50.337
8	Saheleya canal	0.265	3.067	0.981

Each of the flow discharges and water surface levels for each of the seven branched canals were adjusted according to that listed in Tables (8 and 9) applying two steps. Using the affixed head regulators leaf gates and the point gauges upstream each of the sharp crested weirs the assigned flow discharge through each branched canal was adjusted during the first step. Therefore, using the installed tail gate at the downstream end of each branched canal, the corresponding water surface level through each branch was adjusted during the second step. Several attempts were tried during each of the first and second steps till reach the final setting as listed in Table (10).

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Table (10): Model Records at Calibration Stage

No.	Hydraulic Article	Measured water surface levels along the modeled branches							
1	Canal Number	1	2	3	4	5	6	7	8
2	Canal Name	Ibrah US	I.Delgaw	AboGabal	BahrYusef	Badraman	Dirotiah	Ibrah DS	Sahelia
3	Canal code	AA	BB	CC	DD	EE	FF	GG	HH
4	Prototype Discharge Q_P (mm^3/day)	30.52	0.23	0.54	14.67	0.52	0.78	13.44	0.34
5	Prototype Discharge Q_P (m^3/s)	350.00	2.15	6.134	170.578	6.111	9.190	157.303	3.067
6	Model discharge Q_m (l/s)	113.600	0.688	1.963	54.585	1.956	2.941	50.337	0.981
7	Weir head H (mm)	---	16.89	30.09	146.18	29.39	38.85	139.12	22.96
8	Reference reading for weirs (cm)	---	[10.47]	[13.30]	[17.29]	[5.60]	[6.10]	[30.61]	[29.28]
9	Weir readings (cm)		8.781	10.291	2.672	2.661	2.215	16.698	26.984
10	D/S/ water surface level (m)	((46.02))	(44.80)	(45.75)	(45.82)	(45.70)	(45.90)	(45.05)	(45.80)
11	Water surface slope (cm/km)	---	4.30	7.13	6.19	6.51	8.90	7.40	4.65
12	Gauging location in model (m)	----	3.68	3.33	14.50	9.37	10.50	10.28	2.67
13	Gauging location in prototype (m)	---	92.00	83.25	362.50	234.25	262.50	257.00	66.75
14	WSL drop (cm)	----	0.396	0.594	2.244	1.525	2.336	1.901	0.310
15	WSL at point gauge (m)	----	(44.796)	(45.744)	(45.798)	(45.685)	(45.877)	(45.031)	(45.797)
16	Reference reading for WSL (cm)	[52.12]	[53.39]	[54.49]	[54.50]	[56.26]	[57.28]	[55.34]	[59.35]
17	Gauge readings (cm)	24.46	33.57	34.55	35.69	41.59	48.62	40.83	54.01

5.2. Max. & Min. Flow Conditions

Those tests would be experimentally carried out following the achieved model calibration results. The intention of those two tests is to monitor the existing hydraulic and hydrological conditions and different flow parameters at various possible flow circumstances before building the new "DGR". Those measurements can be repeated after the construction of the proposed new "DGR" to allocate any variation in flow arrangements and morphology than that at the existing condition. However, such study should be related to the actual maximum and minimum capacities of El-Ibrahimia canal which used to be distributed through the branched canals in the downstream. This in other words means that the overall some of the maximum and minimum capacities of the downstream branched canals would be more and less than the actual prototype values in El-Ibrahimia canal upstream of "DGR" respectively.
Therefore to deal with such case in realistic way as well as to imitate the real hydrological prototype conditions, the maximum and minimum flow discharges and water surface levels through El-Ibrahimia canal head regulator at Assuit during last ten years from 2005 to 2014 were employed as listed in Table (11) and shown Figure (14).

Table (11): Hydrological Data of El-Ibrahimia Head Regulator

No.	Year	W.S.L. U.S. Dairut (m)		Discharge at Assuit (m m^3/day)	
		Max.	Min.	Max.	Min.
1	2005	46.00	42.40	39.500	2.000
2	2006	46.20	43.60	41.000	1.500
3	2007	46.50	42.80	41.800	2.000
4	2008	46.20	42.30	41.000	1.000
5	2009	46.16	43.60	37.500	2.000
6	2010	45.92	43.40	36.700	1.800
7	2011	45.98	43.50	37.800	1.000
8	2012	45.98	43.30	37.900	1.800
9	2013	46.10	43.15	38.300	0.850
10	2014	45.98	42.60	38.800	2.000

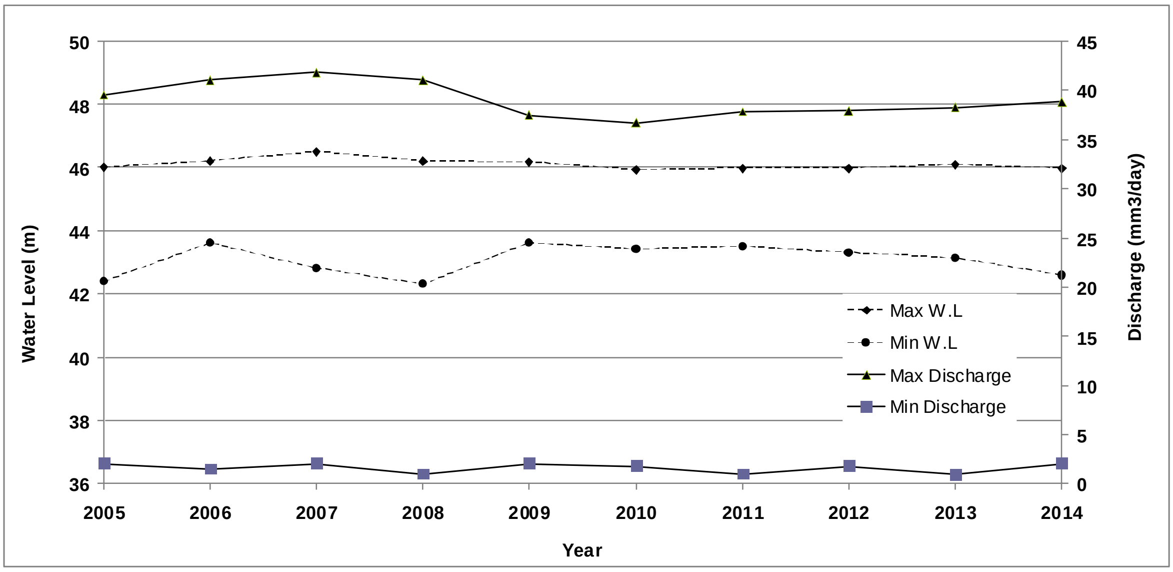

Figure (14): Historical Hydrological Records U.S. El-Ibrabimia Head Regulator

The above Table and Figure was then utilized to determine the flow discharge through each of "DGR" head regulators and the corresponding upstream and downstream water surface level for each branched canal at the case of minimum and maximum flow conditions as follows:

- The maximum flow discharge downstream El-Ibrahimia head regulator at Assuit during last ten years was worked out as 41.80 m m^3/day which was recorded in 8/6/2007
- The minimum flow discharge downstream El-Ibrahimia head regulator at Assuit during last ten years was worked out as 0.850 m m^3/day which was recorded in 7/1/2013
- Suppose one day lag time and two days lag time for the flow to reach upstream "DGR" at the case of the maximum and minimum flow discharges respectively, therefore the maximum and minimum flow discharges upstream Dairut are expected on 9/6/2007 and 9/1/2013 respectively.
- As the accessible records for the above mentioned dates are limited to the existing water surface levels downstream each branched canal and only the flow discharge through Bahr Yussef and El-Ibrahimia canals, the reported flow ratio distribution by "JICA" study was used to produce the required flow discharge through each branched canal as listed in Tables (12 and 13).

Table (12): Hydrological Records at Maximum Discharge

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	El-Ibrahimia U/S "DGR"	36.444	421.81	46.00	-
2	Irad Delgaw canal	0.737	8.53		45.00
3	Abo Gabal canal	0.528	6.11		45.85
4	Bahr-Yusef canal	17.662	204.42		45.60
5	Badraman canal	0.711	8.23		45.85
6	Diroutiah canal	1.000	11.574		45.85
7	El-Ibrahimia D/S "DGR"	15.447	178.78		45.15
8	Sahelyia canal	0.359	4.16		45.85

Table (13): Hydrological Records at Minimum Discharge

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	El-Ibrahimia U/S "DGR"	1.959	22.67	43.35	-
2	Irad Delgaw canal	0.040	0.46		***
3	Abo Gabal canal	0.028	0.32		***
4	Bahr-Yusef canal	1.600	18.52		42.55
5	Badraman canal	0.038	0.44		***
6	Diroutiah canal	0.054	0.63		***
7	El-Ibrahimia D/S "DGR"	0.180	2.08		41.55
8	Sahelyia canal	0.019	0.22		***

In this case the actual flow discharge though El-Ibrahimia and Bahr Yussef canals on 9/6/2007 (at the case of maximum discharge) which are equivalent to 15.447 and 17.662 mm^3/day represented 36.95% and 42.25% of the total entering discharge downstream the main El-Ibrahimia head regulator at Assuit during the previous day respectively. While on 9/1/2013 (at the case of minimum discharge) which are equivalent to 0.180 and 1.600 mm^3/day represented

21.18% and 188.23% of the total entering discharge downstream the main El-Ibrahimia head regulator at Assiut during the previous day respectively. Knowing the model scale, the two reached hydrological records for the maximum and minimum flow conditions were worked out as listed in Tables (14 and 15) respectively. In this case, the passing discharge downstream of "DGR" during minimum flow would be mainly distributed between Bahr-Yussef and El-Ibrahimia canals, and the other five branches are nearly closed.

Table (14): Existing Hydrological Records at Maximum Discharge

No.	Canal name	Discharge		WSL	
		Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	El-Ibrahimia U/S "DGR"	421.81	134.98	46.00	-
2	Irad Delgaw canal	8.53	2.73		45.00
3	Abo Gabal canal	6.11	1.96		45.85
4	Bahr-Yusef canal	204.42	65.41		45.60
5	Badraman canal	8.23	2.63		45.85
6	Diroutiah canal	11.574	3.70		45.85
7	El-Ibrahimia D/S "DGR"	178.78	57.21		45.15
8	Sahelyia canal	4.16	1.33		45.85

Table (15): Existing Hydrological Records at Minimum Discharge

No.	Canal name	Discharge		WSL	
		Prototype (m^3/s)	Model (l/s)	U/S(m)	D/S (m)
1	El-Ibrahimia U/S "DGR"	22.67	7.25	43.35	-
2	Irad Delgaw canal	0.46	0.15		***
3	Abo Gabal canal	0.32	0.10		***
4	Bahr-Yusef canal	18.52	5.93		42.55
5	Badraman canal	0.44	0.14		***
6	Diroutiah canal	0.63	0.20		***
7	El-Ibrahimia D/S "DGR"	2.08	0.67		41.55
8	Sahelyia canal	0.22	0.07		***

Due to unavailable data records for the existing water surface slope through each branched canal during the maximum and minimum flow discharges, and as the flow through each branched canal just downstream of the existing "DGR" can be considered under gravity and following normal depth, the longitudinal water surface slope would be nearly parallel to the bed slope. Therefore, the magnitude of water surface slope during maximum and minimum flow discharges were considered as same as that measured during field investigation along each branched canal. Therefore, the corresponding point gauge readings for water surface levels and outflow discharges for each branched canal in the model were worked out for the maximum and minimum flow discharge cases as listed in Tables (16 and 17) respectively.

Table (16): Model Data for Maximum Flow Discharge

No.	Hydraulic Article	Measured water surface levels along the modeled branches							
1	Canal Number	1	2	3	4	5	6	7	8
2	Canal Name	Ibrah US	I.Delgaw	AboGabal	BahrYusef	Badraman	Dirotiah	Ibrah DS	Sahelia
3	Canal code	AA	BB	CC	DD	EE	FF	GG	HH
4	Prototype Discharge Q_P (mm^3/day)	36.444	0.737	0.528	17.662	0.711	1.000	15.447	0.359
5	Prototype Discharge Q_P (m^3/s)	421.81	8.53	6.11	204.42	8.23	11.574	178.78	4.16
6	Model discharge Q_m (l/s)	134.98	2.73	1.96	65.41	2.63	3.70	57.21	1.33
7	Weir head H (mm)		37.44	30.00	165.70	36.51	46.00	152.13	23.00
8	Reference reading for weirs (cm)	---	[10.47]	[13.30]	[17.29]	[5.60]	[6.10]	[30.61]	[29.28]
9	Weir readings (cm)	----	6.73	10.3	0.72	1.95	1.5	15.4	26.98
10	D/S Water Surface Level (m)	((46.00))	(45.00)	(45.85)	(45.60)	(45.85)	(45.85)	(45.15)	(45.85)
11	Water surface slope (cm/km)	---	4.30	7.13	6.19	6.51	8.90	7.40	4.65
12	Gauging location in model (m)	----	3.68	3.33	14.50	9.37	10.50	10.28	2.67
13	Gauging location in prototype (m)	---	92.00	83.25	362.50	234.25	262.50	257.00	66.75
14	WSL drop (cm)	----	0.396	0.594	2.244	1.525	2.336	1.901	0.310
15	WSL at point gauge (m)	----	(44.996)	(45.844)	(45.578)	(45.835)	(45.827)	(45.131)	(45.847)
16	Reference reading for WSL (cm)	[52.12]	[53.39]	[54.49]	[54.50]	[56.26]	[57.28]	[55.34]	[59.35]
17	Gauge readings (cm)	24.46	33.57	34.55	35.69	41.59	48.62	40.83	54.01

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Table (17): Model Data for Minimum Flow Discharge

No.	Hydraulic Article	Measured water surface levels along the modeled branches							
1	Canal Number	1	2	3	4	5	6	7	8
2	Canal Name	Ibrah US	I.Delgaw	AboGabal	BahrYusef	Badraman	Dirotiah	Ibrah DS	Sahelia
3	Canal code	AA	BB	CC	DD	EE	FF	GG	HH
4	Prototype Discharge Q_P (mm^3/day)	1.959	0.040	0.028	1.600	0.038	0.054	0.180	0.019
5	Prototype Discharge Q_P (m^3/s)	22.67	0.46	0.32	18.52	0.44	0.63	2.08	0.22
6	Model discharge Q_m (l/s)	7.25	0.15	0.10	5.93	0.14	0.20	0.67	0.07
7	Weir head H (mm)								
8	Reference reading for weirs (cm)	---	[10.47]	[13.30]	[17.29]	[5.60]	[6.10]	[30.61]	[29.28]
9	Weir readings (cm)	===							
10	D/S Water Surface Level (m)	((43.35))	***	***	(42.55)	***	***	(41.55)	***
11	Water surface slope (cm/km)		4.30	7.13	6.19	6.51	8.90	7.40	4.65
12	Gauging location in model (m)		3.68	3.33	14.50	9.37	10.50	10.28	2.67
13	Gauging location in prototype (m)		92.00	83.25	362.50	234.25	262.50	257.00	66.75
14	WSL drop (cm)		0.396	0.594	2.244	1.525	2.336	1.901	0.310
15	WSL at point gauge (m)		***	***	42.528	***	***	41.531	***
16	Reference reading for WSL (cm)	[52.12]	[53.39]	[54.49]	[54.50]	[56.26]	[57.28]	[55.34]	[59.35]
17	Gauge readings (cm)								

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5.3. Dominant Flow Condition

As the gap between maximum and minimum flow discharges corresponding to El-Ibrahimia canal at "DGR" is relatively wide, one more intermediate discharge stage was established. This flow discharge stage is called the dominant flow which is usually taken place for a considerable period during the midterm between the high and low flow seasons through the water year. Therefore, the present tests would be carried out applying three flow cases entitles the maximum, dominant, and minimum flow discharges. In this case, each of the three flow cases would be respectively evaluated at "DGR" according to the corresponding condition downstream El-Ibrahimia head regulator at Assuit. This would be carried out by considering the lag time and the outflow between El-Ibrahemia head regulator at Assuit and at km 60.600 just upstream of the existing "DGR".

On the other hand, to determine the dominant discharge, the daily passing flow discharge records downstream El-Ibrahimia head regulator at Assuit during the whole year of 2014 were analysed and plotted as shown in Figure (15). This year was deliberately selected as a last complete data for the recorded flow discharge downstream El-Ibrahimia head regulator at Assuit. Figure (15) revealed that maximum and minimum passing flow discharges downstream El-Ibrahimia head regulator at Assuit during year 2014 is 38.800 mm^3/day and 2.0 mm^3/day respectively which were recorded on 29th of May and the 3rd of January respectively. While the mean average value of the passing flow discharges is 25.798 mm^3/day.

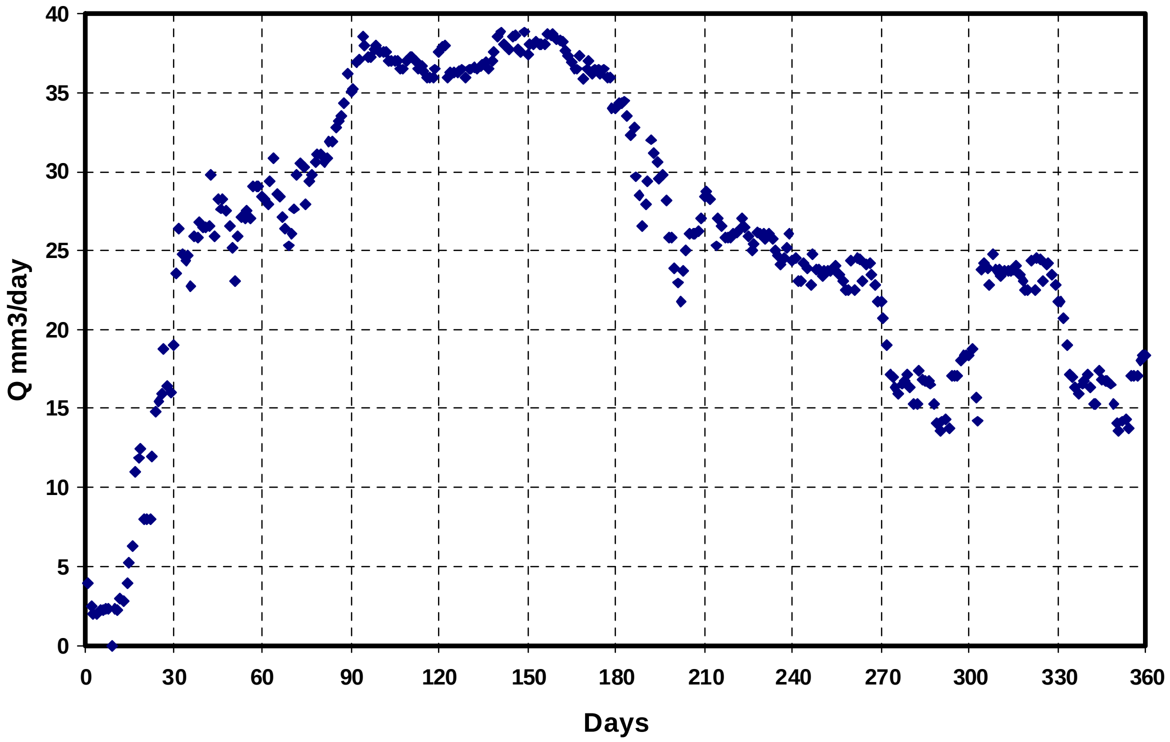

Figure (15): Daily Flow Records for El-Ibrahimia Head Regulator in Year 2014

The above Figure was then utilized to conclude the nearby value of dominant discharge downstream El-Ibrahimia head regulator at Assuit which is 25.00 mm^3/day and recorded on 22nd of July and 22nd of August 2014. Suppose one day lag time for the flow to reach upstream "DGR", the minimum flow discharge upstream Dairut can be expected to occur on 23/7/2014 and 23/8/2014. The received distributions for the flow discharges and water surface levels upstream and downstream "DGR" during the two mentioned dates were utilized to produce the hydraulic essentials at dominant discharge.
However, as the received data records were limited to the existing water surface levels downstream each branched canal and only the flow discharge through Bahr Yussef and El-Ibrahimia canals, the reported flow ratio distribution by "JICA" study in Table (18) was used to produce the required flow discharge as listed in Tables (19 and 20). The listed data in Table (18) was based on the existing commend of the served area and the quota which were reported in "JICA" study according to the agreement of Water Distribution Sector "WDS" in (2002) for the flow discharge distribution downstream of El-Ibrabimia canal.

Table (18): Design Discharge Based on the Quota at "DGR"

No.	Canal	Served Area (Fed)	Design discharge		Ratio (%)
			Min. (m^3/s)	Max. (m^3/s)	
1	Ibrahimia canal	576,700	23.63	161.62	36.84%
2	Bahr-Yusef canal	808,000	33.11	226.50	51.63%
3	Sahelyia canal	15,100	0.60	4.20	0.96%
4	Diroutiah canal	41,800	1.70	11.70	2.67%
5	Badraman canal	29,700	1.20	8.30	1.90%
6	Abo Gabal canal	22,000	0.90	6.20	1.41%
7	Irad Delgaw canal	30,800	1.30	8.60	1.97%
8	Direct intake(Upstream of DGR)	41,000	1.70	11.50	2.62%
Total		1,565,100	64.14	438.62	100%

Table (19): Hydrological Records at Dominant Discharge (23/7/2014)

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	El-Ibrahimia U/S "DGR"			45.67	
2	Irad Delgaw canal				
3	Abo Gabal canal				
4	Bahr-Yusef canal	12.750	147.57		44.85
5	Badraman canal				
6	Diroutiah canal				
7	El-Ibrahimia D/S "DGR"	11.000	127.31		44.40
8	Sahelyia canal				

Table (20): Hydrological Records at Dominant Discharge (23/8/2014)

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	El-Ibrahimia U/S "DGR"			45.65	
2	Irad Delgaw canal				
3	Abo Gabal canal				
4	Bahr-Yusef canal	13.000	150.46		44.90
5	Badraman canal				
6	Diroutiah canal				
7	El-Ibrahimia D/S "DGR"	11.250	130.21		44.95
8	Sahelyia canal				

The deduced values in the above two Tables (19 and 20) are uncompleted and still needed from Water Distribution Sector "WDS" of the Ministry of Water Resources and Irrigation "MWRI". The available data in Tables (19 and 20) were then merged to determine the mean values which would be recommended to represent the dominant discharge condition as listed in Table (21). Those values were then utilized to produce the corresponding elements to operate the model as listed in Table (22).

Table (21): Concluded Records at Dominant Discharge

No.	Canal name	Discharge		WSL (m)	
		(mm^3/day)	(m^3/s)	U/S	D/S
1	El-Ibrahimia U/S "DGR"			45.66	
2	Irad Delgaw canal				
3	Abo Gabal canal				
4	Bahr-Yusef canal	12.375	150.46		44.875
5	Badraman canal				
6	Diroutiah canal				
7	El-Ibrahimia D/S "DGR"	11.125	130.21		44.675
8	Sahelyia canal				

Table (22): Dominant Discharge Basics fore the Model

No.	Canal name	Discharge		WSL	
		Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	El-Ibrahimia U/S "DGR"			45.66	
2	Irad Delgaw canal				
3	Abo Gabal canal				
4	Bahr-Yusef canal	150.46	48.147		44.875
5	Badraman canal				
6	Diroutiah canal				
7	El-Ibrahimia D/S "DGR"	130.21	41.667		44.675
8	Sahelyia canal				

Considering the magnitude of water surface slope during dominant flow discharge as same as that measured for the case of maximum and minimum flow discharges along each branched canal. Therefore, the corresponding point gauge readings for water surface levels and outflow discharges for each branched canal in the model were worked out for the dominant flow discharge cases as listed in Table (23).

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Table (23): Model Data for Dominant Flow Discharge

No.	Hydraulic Article	Measured water surface levels along the modeled branches							
1	Canal Number	1	2	3	4	5	6	7	8
2	Canal Name	Ibrah US	I.Delgaw	AboGabal	BahrYusef	Badraman	Dirotiah	Ibrah DS	Sahelia
3	Canal code	AA	BB	CC	DD	EE	FF	GG	HH
4	Prototype Discharge Q_P (mm^3/day)								
5	Prototype Discharge Q_P (m^3/s)								
6	Model discharge Q_m (l/s)								
7	Weir head H (mm)								
8	Reference reading for weirs (cm)	---	[10.47]	[13.30]	[17.29]	[5.60]	[6.10]	[30.61]	[29.28]
9	Weir readings (cm)	===							
10	D/S Water Surface Level (m)								
11	Water surface slope (cm/km)		4.30	7.13	6.19	6.51	8.90	7.40	4.65
12	Gauging location in model (m)		3.68	3.33	14.50	9.37	10.50	10.28	2.67
13	Gauging location in prototype (m)		92.00	83.25	362.50	234.25	262.50	257.00	66.75
14	WSL drop (cm)		0.396	0.594	2.244	1.525	2.336	1.901	0.310
15	WSL at point gauge (m)								
16	Reference reading for WSL (cm)	[53.39]	[54.48]	[54.50]	[56.23]	[57.98]	[55.34]	[59.35]	[52.12]
17	Gauge readings (cm)								

While Table (24) lists summary of the represented hydraulic aspects for model operation during various flow conditions

Table (24): Represented Flow Conditions for Model Operation

No.	Flow case	Prototype discharge		Model discharge	U/S level
		(mm^3/day)	(m^3/s)	(l/s)	(m)
1	Calibration discharge	30.672	355.00	113.600	(46.02)
2	Minimum flow case	1.959	22.67	7.25	(43.35)
3	Dominant flow case	***	***	***	(45.66)
4	Maximum flow case	36.444	421.81	134.98	(46.00)

Noting that (***) in the above Table is referring to unavailable data.

6. MODEL OPERATION

As the model was constructed according to the recently conducted field measurements and the received drawings of the existing hydraulic structures (head regulators and cross bridges) at Dairut, the following preliminary experimental measures were carried out:

1. The reference point gauge reading - which indicates the water surface elevation just prior to bridge over the sharp crested weir - was determined for each of the seven installed sharp crested weirs at the model outlet.

2. The corresponding water surface elevation in the model to that in the prototype was determined at one appropriate location for each branched canal upstream and downstream of (DGR). This was carried out through the installed point gauge on the side well which can indicates the water surface levels precisely and read up to $\pm$ 0.1 mm accuracy. The point gauge locations for all branches were previously assigned to be downstream of the proposed location for the new "DGR" and in such a way as to avoid the back water curve upstream the mounted end tail gate downstream each of the seven branched canals.

The model was then adjusted to represent the prototype flow conditions during field measurements as listed in Table (25). In this case, using the mounted point gauge at each sharp crested weir and the head regulator gates, the calculated flow discharge through each branch was adjusted. The installed tail gate downstream the end of each branched canal was then utilized to adjust the corresponding water surface level through each branch. The measured water surface slope and the monitored downstream water surface elevation for each branch in the prototype was then utilized to determine the corresponding water surface level at the mounted point gauge for each branched canal as listed in Table (26). The applied magnitudes for water surface slopes in Table (26) for each branch was worked out by HRI field work team during field investigation.

Table (25): Hydrological Condition during Calibration

No.	Canal name	Passing discharge		Water level (m)	
		Prototype (m^3/s)	Model (L/s)	U/S	D/S
1	Ibrahimia canal U/S "DGR"	355.00	113.600	(46.02)	--
2	Irad Delgaw canal	2.150	0.688		(44.80)
3	Abo Gabal canal	6.134	1.963		(45.75)
4	Bahr-Yusef canal	170.578	54.585		(45.82)
5	Badraman canal	6.111	1.956		(45.70)
6	Diroutiah canal	9.190	2.941		(45.90)
7	Ibrahimia canal D/S "DGR"	157.303	50.337		(45.05)
8	Saheleya canal	3.067	0.981		(45.80)

Table (26): Water Surface Levels during Calibration

No.	Canal name	Gauging location D/S head regulator		Water surface slope (cm/km)	Water surface drop (cm)	WSL just D/S head regulator (m)	WSL at model Gauging location (m)
		Model (m)	Prototype (m)				
1	Irad Delgaw canal	3.68	92.00	4.30	0.396	(44.80)	(44.796)
2	Abo Gabal canal	3.33	83.25	7.13	0.594	(45.75)	(45.744)
3	Bahr-Yusef canal	14.50	362.5	6.19	2.244	(45.82)	(45.798)
4	Badraman canal	9.37	234.25	6.51	1.525	(45.70)	(45.685)
5	Diroutiah canal	10.50	262.50	8.90	2.336	(45.90)	(45.877)
6	El-Ibrahimia canal	10.28	257.00	7.40	1.901	(45.05)	(45.031)
7	Sahelyia canal	2.67	66.75	4.65	0.310	(45.80)	(45.797)

The flow velocities in the model were then measured using an Electro-Magnetic current-meter type E.M.S., manufactured by Delft Hydraulics, Holland as shown in Photo (24). The device was connected to a mean value meter to show the average velocity within a selected time period.

Photo (24): Used Electro-Magnetic Current-Meter type E.M.S.

7. CALIBRATION RESULTS

Model calibration is the process for judging reliability and consistency between the constructed model and prototype condition. In order to ensure that, the model should fulfill the geometric, kinematic and dynamic similarity conditions. The geometric similarity was already applied during the model construction. The kinematic and dynamic similarity would be accomplished by measuring some flow velocity profiles in the prototype then compared it with that in the model. Therefore, the model calibration should include all the above mentioned conditions in addition the water surface slope which should be the same in the model as prototype value.

The three dimensions "DGR" model would be calibrated with bathymetric and hydraulic measurements and flow conditions that carried out during "HRI" field investigations which were conducted on June 2015. The model was calibrated against one cross section velocity profile along each of the seven branched canals downstream of the existing "DGR". The flow discharge in the model and accordingly through each branched canal were worked out according to the flow condition during field measurements. The water surface slope through the seven branched canals was also measured during the field measurements which ranged between 4.30 cm/km for Irad Delgaw canal and 8.9 cm/km for El-Dairutia canal. Applying the above mentioned procedure for operating the model, the calibration process was carried out through the following three phases:

- Inflow discharge calibration
- Establishing calibration condition
- Velocity measurement calibration

The applied procedure for each phase and the attainable results can be illustrated as follows:

7.1. Inflow Discharge Calibration

This test was firstly carried out to assure the accuracy of the affixed Electro-Magnetic flow meter on the 10 inch diameter delivery pipe line upstream the model entrance. This group of tests was carried out by comparing the indicated flow discharges by the ultrasonic flow meter at the model entrance with the corresponding measured flow discharge on the affixed sharp crested weirs at the tail end of Bahr Yussef and El-Ibrahimia canals which are listed in Table (7). This test was carried out for six different discharges and the attainable results are Illustrated in Figures (16 and 17) and listed in Table (27).

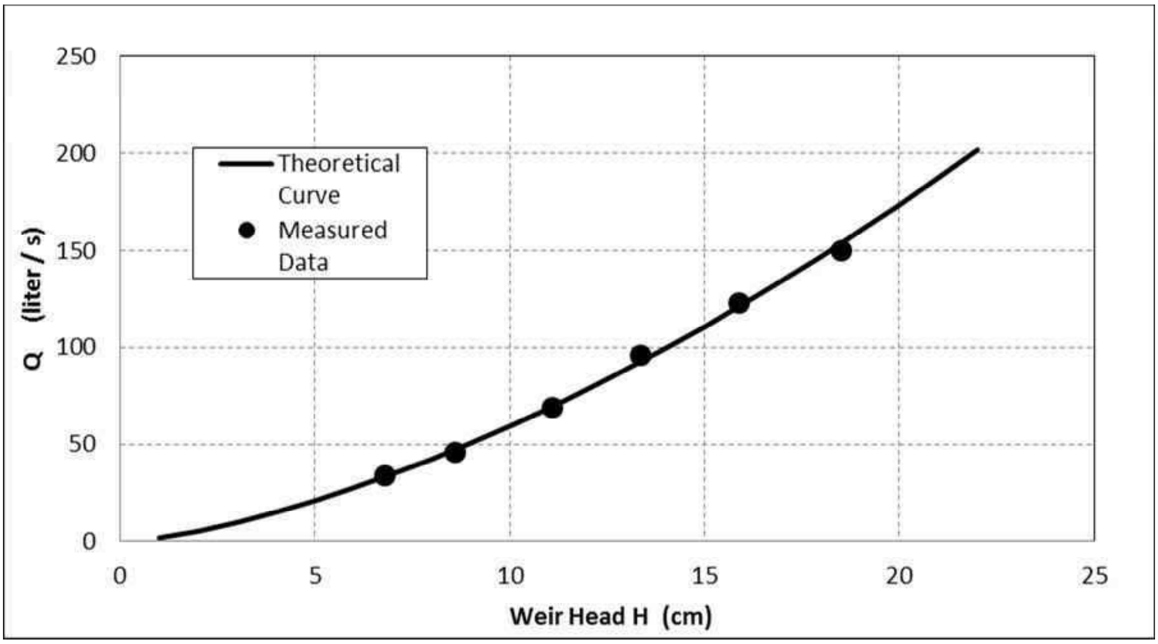

Figure (16): Calibration Results of Ultrasonic Flow Meter

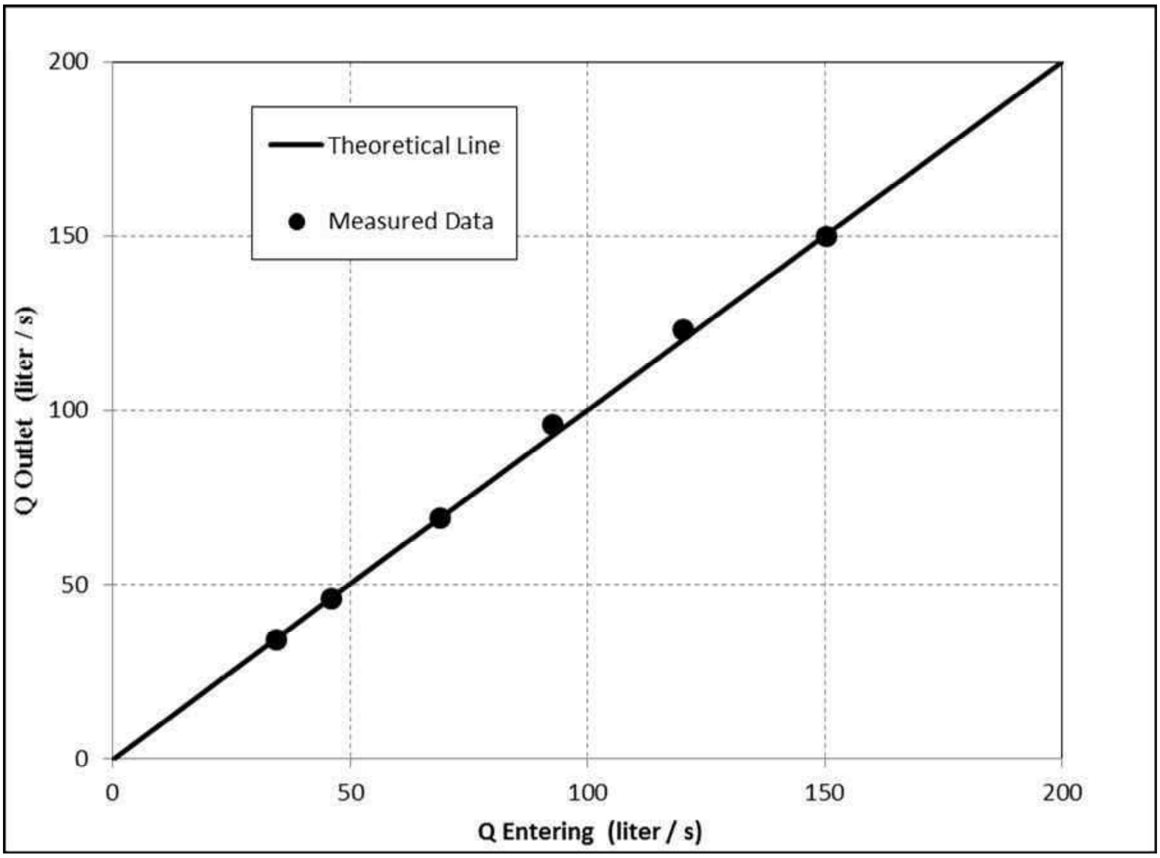

Figure (17): In and Outflow Calibration Results

Table (27): Entering Discharge Calibration

Test No.	Outlet discharge calculation							Entering flow discharge	Difference	Percent
	Bahr-Yusef canal (DD) DDQ = [171.6] mm			El-Ibrahimia canal (GG) GGQ = [308.5] mm			Total outlet discharge			
	Gauge (mm)	H_1 (mm)	Q_1 (l/s)	Gauge (mm)	H_2 (mm)	Q_2 (l/s)	(l/s)	(l/s)	(l/s)	(%)
1	336.6	165.0	64.949	50.20	193.5	85.467	150.416	150.00	+ 0.416	+ 0.28%
2	311.2	139.6	50.273	48.15	173.0	69.949	120.222	123.00	- 2.778	- 2.26%
3	291.7	120.1	39.602	45.35	145.0	53.092	92.694	96.00	- 3.306	- 3.44%
4	272.2	100.6	29.924	42.75	119.0	39.094	69.018	69.00	+0.018	+0.026%
5	241.8	70.2	17.395	40.58	97.3	28.564	45.956	46.00	-0.044	- 0.096%
6	227.2	55.6	12.266	39.08	82.3	22.103	34.374	34.00	+ 0.374	+ 1.10%

This test revealed high matching between the measured inflow rate by the mounted Electro-Magnetic flow meter at the model entrance and that over the sharp crested weir downstream each of the branched canals. In this case, the determined percentage difference between in and outflow did not exceed 3.44% as shown in Figures (16 and 17) and listed in Table (27) which are accepted results.

7.2. Establishing Calibration Condition

This test was carried out to check and assure the simulation between the model and prototype conditions as well as to guarantee model performance and validity by using the attainable results from the recently carried out field survey measurements. According to the achieved field measurements by "HRI" field group, the horizontal velocity distribution along ten cross sections were carried out which covered El-Ibrahimia canal upstream "DGR" and each branched canal downstream "DGR" as previously shown in Figure (12). The attainable results for the measured flow discharges as well as the corresponding water surface levels upstream and downstream the existing "DGR" are listed in Table (28).

Table (28): Hydrological Condition during Calibration

No.	Canal name	Vel. No.	Discharge		Water level (m)		
			(mm^3/day)	(m^3/s)	U/S	D/S	At C.S.
1	Ibrahimia canal U/S "DGR"	[1]	30.672	355.00	(46.02)	--	(46.100)
2	Irad Delgaw canal	[9]	0.185	2.150		(44.80)	(44.794)
3	Abo Gabal canal	[2]	0.530	6.134		(45.75)	(45.725)
4	Bahr-Yusef canal (1)	[3]	14.738	170.578		(45.82)	(45.803)
5	Bahr-Yusef canal (2)	[4]	14.915	172.627		(45.82)	(45.786)
6	Badraman canal	[5]	0.528	6.111		(45.70)	(45.684)
7	Diroutiah canal	[6]	0.794	9.190		(45.90)	(45.879)
8	Ibrahimia canal D/S "DGR" (1)	[7]	13.591	157.303		(45.05)	(45.017)
9	Ibrahimia canal D/S "DGR" (2)	[8]	13.723	158.830		(45.05)	(44.998)
10	Saheleya canal	[10]	0.265	3.067		(45.80)	(45.718)

It is clear from Table (28) that the velocity distribution was measured along two cross sections in each of Bahr Yussef canal and El-Ibrahimia canal downstream "DGR", while only one cross section was measured along the other canals. Although, the velocity distribution measurements were carried out for all branches during one day only, some diminutive variations were obtained in the calculated flow discharges in Bahr Yussef and El-Ibrahimia canals. The evaluated difference in Table (28) reached to 1.2% and 0.96% for the two canals respectively which can be neglected.

7.3. Velocity Measurements Calibration

Mid – depth velocity was measured in the model at different point along the entire length of each cross section for the seven branched canals. The measured velocity profiles in the model were compared with that of the prototype. In order to improve the similarity between the measured mid – depth flow velocity measurements in the model with that of the prototype, some trails and minor adjustment in bed roughness were made in a few locations in the model. The compared flow velocity between model and prototype at different cross sections are listed in Tables (from 29 to 35) and Figures (from 19 to 25).

Table (29): Mid-Depth Velocity Distribution on Irad Delgaw Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	0.00	0.00	00	0.00	0.00	0.00
2	2.00	0.15	8	3.2	2.00	0.16
3	4.00	0.12	16	2.3	4.00	0.14
4	6.00	0.15	24	3.0	6.00	0.15
5	8.00	0.15	32	3.2	8.00	0.16
6	12.00	0.00	48	0.00	12.00	0.00

Figure (19): Velocity Distribution at Irad Delgaw Canal

Table (30): Mid-Depth Velocity Distribution on Abou Gabal Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	0	0	0.00	0.00	0	0
2	2	0.61	8	12.6	2	0.63
3	4	0.65	16	12.0	4	0.6
4	6	0.63	24	12.0	6	0.6
5	8	0.368	32	9.0	8	0.45
6	9	0	36	0.00	9	0

Figure (20): Velocity Distribution at Abou Gabal Canal

Table (31): Mid-Depth Velocity Distribution on Bahr Yussef Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	2.00	0.38	8	5.0	2.00	0.25
2	3.75	0.43	15	10.2	3.75	0.51
3	10.00	0.59	40	11.6	10.00	0.58
4	16.25	0.72	65	16.0	16.25	0.80
5	22.50	0.82	90	14.0	22.50	0.70
6	28.75	0.89	115	15.0	28.75	0.75
7	35.00	0.89	140	16.8	35.00	0.84
8	41.25	0.82	165	15.6	41.25	0.78
9	47.50	0.77	190	14.6	47.50	0.73
10	53.75	0.67	215	12.0	53.75	0.60
11	60.00	0.49	240	9.0	60.00	0.45

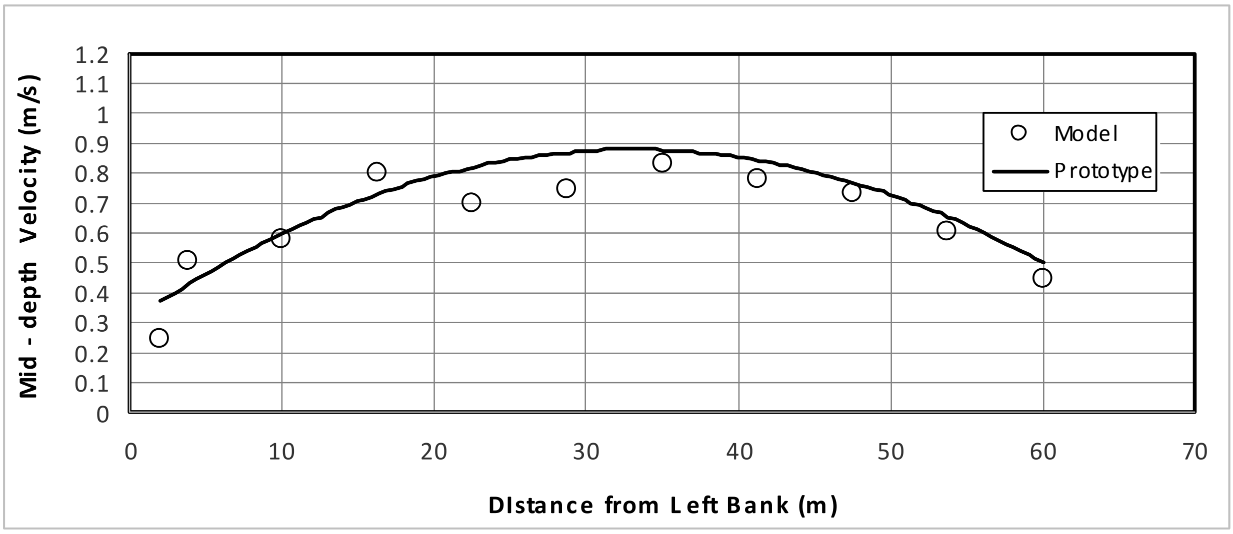

Figure (21): Velocity Distribution of Bahr Ussef Canal

Table (32): Mid-Depth Velocity Distribution on Badraman Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	0.00	0.00	0.00	0.00	0.00	0.00
2	2.00	0.36	8.0	8.2	2.00	0.41
3	4.00	0.42	16	7.8	4.00	0.39
4	6.00	0.39	24	8.0	6.00	0.40
5	8.00	0.25	32	5.6	8.00	0.28
6	10.40	0.00	42	0.00	10.50	0.00

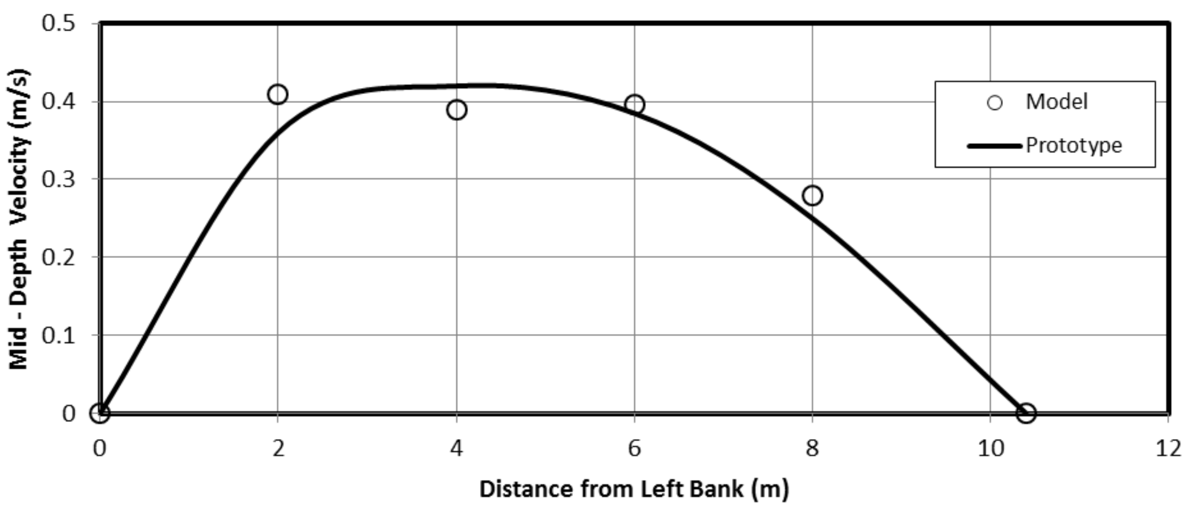

Figure (22): Velocity Distribution at Badraman Canal

Table (33): Mid-Depth Velocity Distribution on El-Dairutiah Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	0.00	0.00	0.00	0.00	0.00	0.00
2	1.75	0.20	7	4.0	1.75	0.20
3	2.28	0.33	9	6.2	2.28	0.31
4	3.68	0.13	15	3.0	3.75	0.15
5	5.42	0.44	22	8.2	5.50	0.41
6	6.31	0.37	25	8.2	6.25	0.41
7	7.50	0.40	30	8.0	7.50	0.40
8	8.75	0.41	35	7.8	8.75	0.39
9	10.00	0.39	40	7.8	10.00	0.39
10	11.19	0.32	45	6.0	11.25	0.30
11	12.50	0.34	50	7.0	12.50	0.35
12	14.75	0.00	59	0.00	14.75	0.00

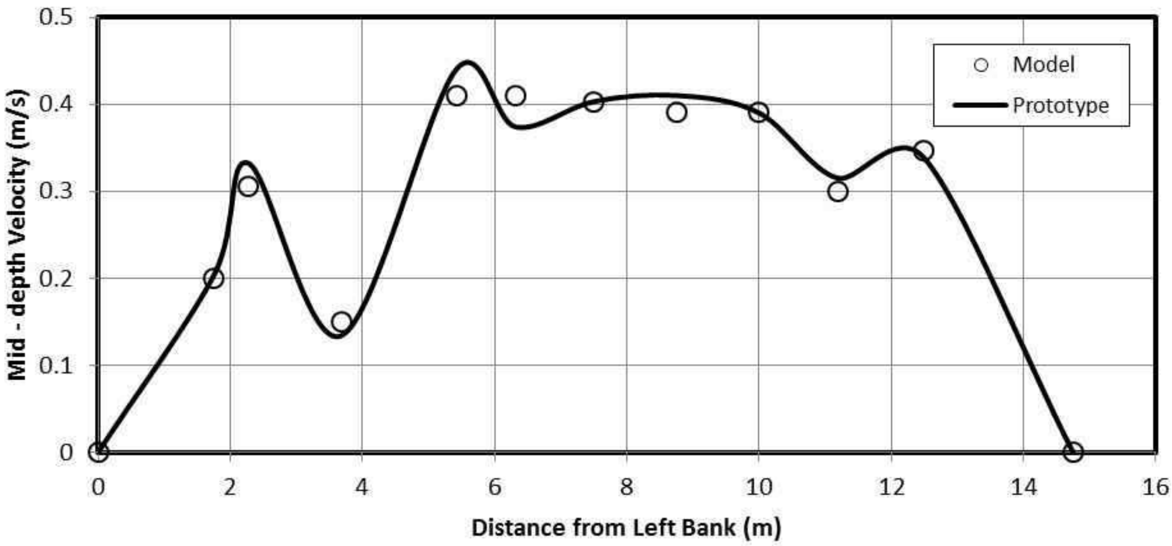

Figure (23): Velocity Distribution at El-Dairutia Canal

Table (34): Mid-Depth Velocity Distribution on El-Ibrahimia Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	6.25	0.40	25	10.6	6.25	0.53
2	12.50	0.64	50	16.4	12.50	0.82
3	18.75	0.79	75	15.4	18.75	0.77
4	25.00	0.89	100	16.0	25.00	0.80
5	31.25	0.90	125	17.0	31.25	0.85
6	37.50	0.88	150	18.2	37.50	0.91
7	43.75	0.77	175	15.4	43.75	0.77
8	50.00	0.58	200	12.8	50.00	0.64
9	56.25	0.34	225	5.0	56.25	0.25

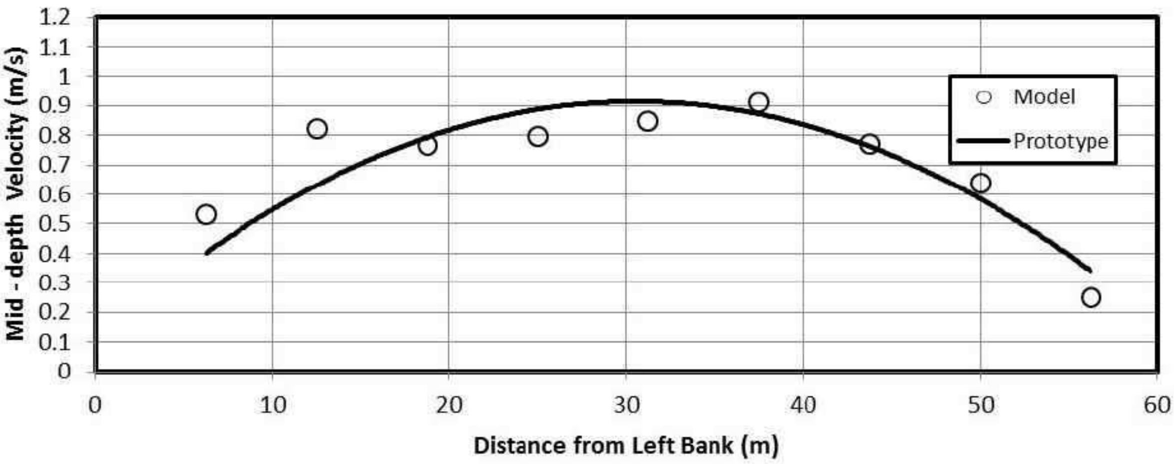

Figure (24): Velocity Distribution of El-Ibrahimia Canal

Table (35): Mid-Depth Velocity Distribution on El-Sahelia Canal

Point No.	Prototype data		Model data		Converted model data	
	Distance (m)	Velocity (m/s)	Distance (cm)	Velocity (cm/s)	Distance (m)	Velocity (m/s)
1	0.00	0.000	0.00	0.00	0.00	0.00
2	1.50	0.283	6.0	6.2	1.50	0.31
3	3.00	0.286	12.0	5.4	3.00	0.27
4	4.50	0.299	18.0	6.0	4.50	0.30
5	6.00	0.280	24.0	5.6	6.00	0.28
6	7.50	0.246	30.0	4.6	7.50	0.23
7	8.00	0.000	32.0	0.00	8.00	0.00

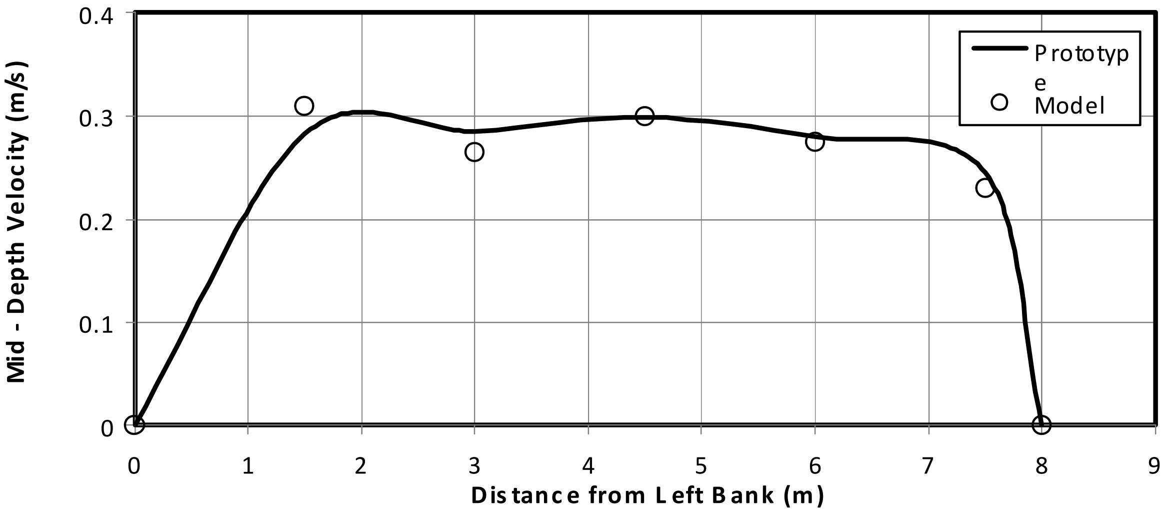

Figure (25): Velocity Distribution at El-Sahelia Canal

The achieved calibration results that illustrated in the above Tables and Figures revealed that the measured mid –depth velocity profiles in the model are following the same trend as that in the prototype. This in other words means that there are good agreement between the model and prototype and the model can be accurately simulate the prototype conditions.

Draft Report

Physical Model Study of Dairut Group of Regulators

Installation of the New Dirout Regulators and Flow Velocity Measurements

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CLIENT:	Reservoirs and Grand Barrage Sector (RGBs), Ministry of Water Resources and Irrigation (MWRI), Egypt
TITLE:	Physical Model Study of Dairut Group of Regulators Installation of the New Dirout Regulators and Flow Velocity Measurements

ABSTRACT

This report includes the following:

1. Installation of the New Regulators at the physical model according to the design drawings submitted by the RGBs and the D/D Consultant on April 27th 2016.
2. Flow velocity measurements according to the test program submitted by the RGBs and the D/D consultant of September 8th 2016.
3. The testing procedure includes:
    - Measuring the flow velocity distribution in a three consecutive cross sections downstream the new regulators of Ibrahimia and Bahr Yusef Canals.
    - The operation requirements of the test embrace the opening of Bahr Yusef Lock while closing Ibrahimia Canal Lock.
    - A floating debris and dye were used to track the flow pattern downstream the new regulators such as flow vortices and dead zones.

It was found that, the maximum flow velocity reaches up 2.8 m/s near the bed at cross section located 30 m from the gate (nearest cross section to the gate) while the flow is forced to pass under the gate. It is recommended to remove the dead zones area formed downstream the new regulators by filling it with a filler material to impose the flow distribution released from the gate.

VER	ORIGINATOR	DATE	REMARKS	REVIEW		APPROVED BY	
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1 INTRODUCTION

The construction of new regulators at Dirout to replace the existing one is imperative in the context of water resources management. This is because the existing regulator, which is responsible to deliver about 10 billion cubic meters of Nile water annually, is old and has been builtin 1872. The new regulators at Dirout will be constructed at a 140 m distance downstream of the existing one. The design of the new regulators at Dirout is done by Sanyu Consultant incorporation selected by Japan International Cooperation Agency (JICA). This is based on an agreement between the JICA and the Reservoir and Grand Barrage Sector (RGBS) of the Ministry of Water Resources and Irrigation, Egypt.

The RGBS commissioned the Hydraulics Research Institute (HRI), Egypt to conduct 3-D physical model to optimize the design of the new regulators. The HRI has completed the model, construction, and calibration. This includes the existing and the new regulators at Dirout. The physical model of the existing regulators was introduced in earlier progress reports. This report presents the physical model installation of the new regulators.

2 LAYOUT OF THE NEW REGULATORS

2.1 Location of the New Regulators

The location of new regulators of Bahr Yusef and IbrahimiaCanals and New Badraman Regulators are at 140m downstreamof the existing ones, and the other new small regulators of Sahelyia and Abo GabalCanals are in front of the existing regulators. Figure (1) shows the location of the new regulators.

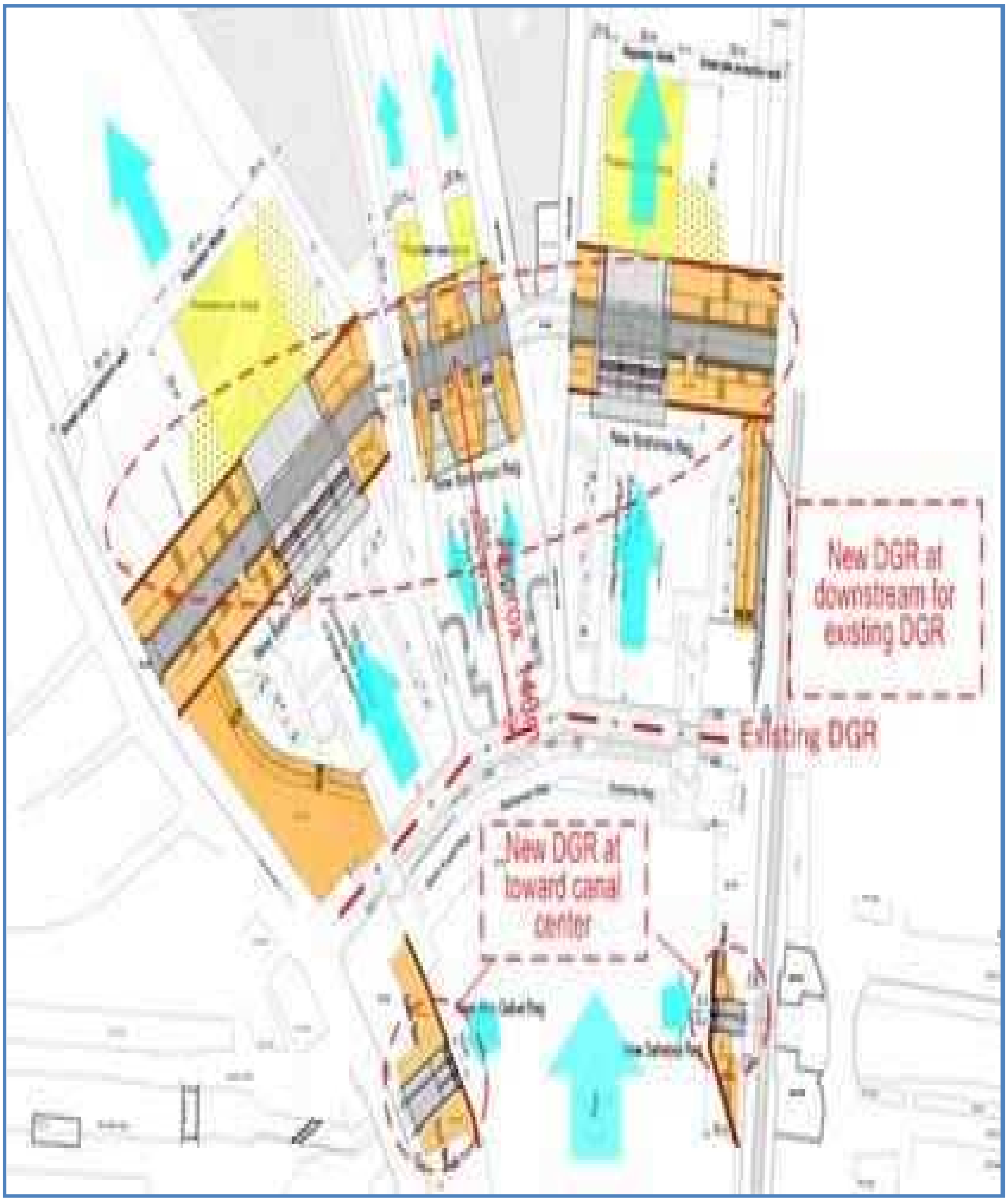

Figure 1: Schematic Diagram of the Location of the New Regulators

2.2 Gates

Overflow type double-leaf gate with hydraulic cylinder as hoisting devices will be installed in large regulators. On the other hand, slide gate instead of double leaf gate will be installed in small regulators, and hoisting devices will be electric rack and pinion. Figure (2) shows a schematic diagram of the selected over-flow type gate of the new regulators.

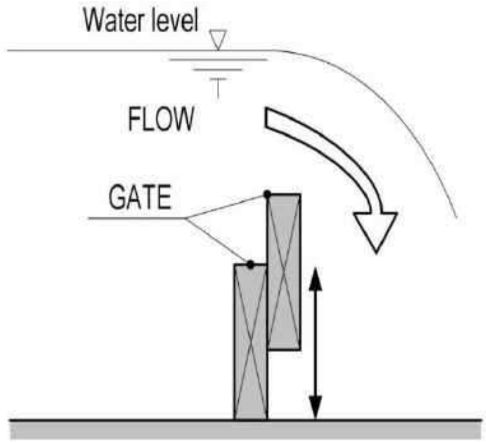

Figure (2): Selected Over-flow Type Gate for New "DGR"

2.3 Navigation Locks

The existing Bahr Yusef and Ibrahimia navigation locks are not operated since long time ago. According to a discussion between MWRI and River Transportation Authority (RTA) it was decidedthat there is no need to provide the new regulators of Ibrahimia and Bahr Yusef with navigation locks. So, the new group of regulators do not have navigation locks.

2.4 Elevation of the Top of Apron on Gate Section

The elevation for top of apron under the gate is determined by the location of the new regulators and the existing bed elevation of the canal in order not to incur any trouble induced by sediments.

The location of the new regulators is classified into two types: one for Abo Gabal and Sahelyia Regulators which are constructed in the upstream of DGRs at right angle against the flow direction (TYPE1), and another for Bahr Yusef, Badraman, and Ibrahimia Regulators which are constructed in the downstream of DGRs (TYPE2).Figure (3) shows a schematic diagram of the apron's top level for the two types. Table (1) shows the apron's top level for each canal at the gate section.

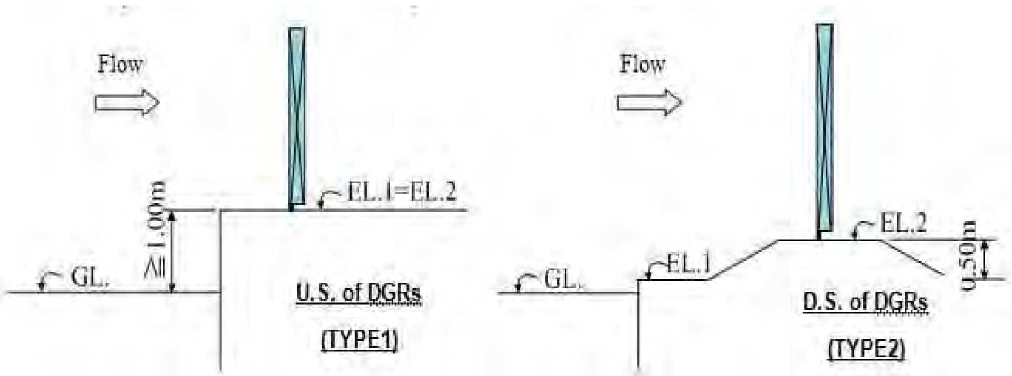

Figure 3: Schematic Drawing for Apron's Top Level on gate section

where:

GL: The existing bed level of the canal
El.1: Level of the apron of type 1 regulator
El.2: Level of the apron of type 2 regulator

Table 1: Top Level of the Apron of Each Branch Canal

Regulator	Existing Canal Bed Level GL. (m)	Level of the Apron: (El.1) (m)	Level of the apron at the gate section: (El.2) (m)
Abo Gabal	43.00	44.15	44.15
Sahelyia	44.00	44.65*	44.65
Bahr Yusef	39.50	39.50	40.00
Badraman	43.00	43.40	43.90
Diroutiah	43.50	43.70	44.20
Ibrahimia	39.50	39.50	40.00

2.5 Gate Height

The top level of the gate is designed as EL.46.55m (Upstream Maximum Design Water Level 46.30m + Free Board 0.25m). The height of the gate is designed as the difference in elevation between the top of the gate and the apron on the gate section, shown in Table (2). Figure (4) shows schematic drawing for top level of the gate and its height.

Table 2: Top Level of the Apron of Each Branch Canal

Regulator	Gate's top level (El.3) (m)	Apron's level (El.2) (m)	Gate Height H (m)	Gate Type
Bahr Yusef	46.55m	40.00m	6.55m	Double leaf
Ibrahimia	46.55m	40.00m	6.65m	Double leaf
Sahelyia	46.55m	44.65m	1.90m	Single leaf
Diroutiah	46.55m	44.20m	2.35m	Single leaf
Badraman	46.55m	43.90m	2.65m	Single leaf
Abo Gabal	46.55m	44.15m	2.40m	Single leaf

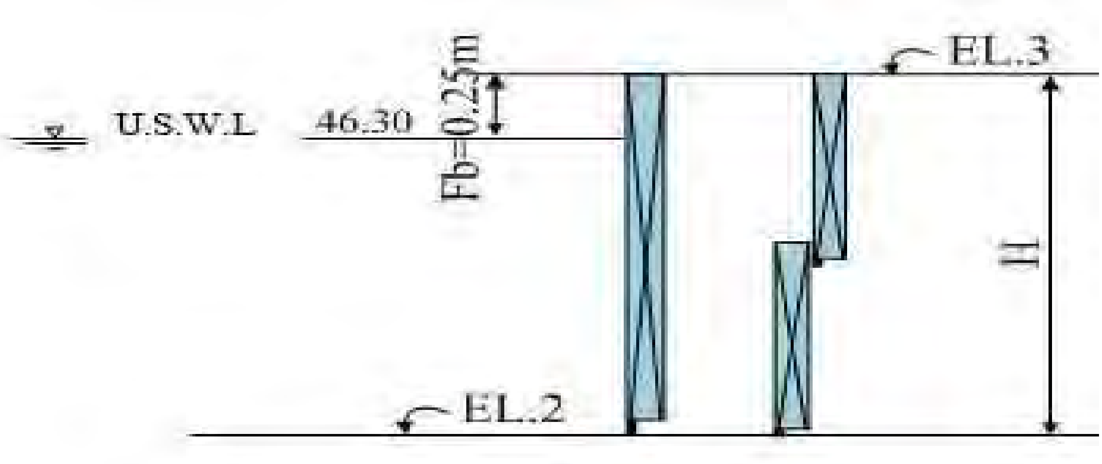

Figure 4: Schematic drawing for top elevation of the gate and its height

where:

El.3: Top level of the gate

2.6 Height and thickness of piers

The height of pier is determined by the bottom level and height of fully open gate, height of free-board, and the thickness of the regulator top floor. Table (3) shows the pier's height for each regulator. The thickness of pier should satisfy the enough room

for the groove, transfer the load of the gate into the pier body, and secure the enough stability from the structural aspect. The thickness of the piers is 2.50m for large scale regulators and 1.00 m for small scale regulators, as given from the D/D consultant.
The basic full design of the new regulators can be seen in the "Basic Design Report, 2016" submitted by the consultant. A full set of the design drawings can be seen in Annex (1).

Table 3: Height of pier for each regulator

Regulator	Bottom level of fully open gate (m)	Height of fully open gate (m)	Free board (m)	Top Thickness of regulator (m)	Top level of the pier (m)
Bahr Yusef	47.50	3.40	1.00	0.60	52.50
Ibrahimia	47.50	3.40	1.00	0.60	52.50
Sahelyia	47.50	1.90	0.50	0.50	50.40
Diroutiah	47.50	2.35	0.50	0.50	50.85
Badraman	47.50	2.65	0.50	0.50	51.15
Abo Gabal	47.50	2.40	0.50	0.50	50.90

3 INSTLLATION OF THE NEW REGULATORS IN THE MODEL

3.1. Manufacturing the New Regulators in the Workshop

To install the modeled new regulators in the physical model as designed by the consultant, the process starts with scaling down the design with the model scale which is 1:25. After that the new regulators were manufactured in the workshop of the Hydraulics Research Institute (HRI) by skilled labors. Top quality wood is used to form the different elements of the regulators then collected and fixed by using steel nails to form one unit as seen in the drawings. After that the wood is painted for protection purposes as it will be submerged in the water most of the time. Figure (5) shows the manufacturing of the regulator in the workshop. Figure (6) shows the painting of the modeled new regulator after construction.

Figure 5: Manufacturing of the New Regulators in the HRI workshop

Figure 6: Painting of the New Regulators in the HRI workshop

3.2. Installing the New Regulators in the Physical Model

It starts by preparing the physical model to install the regulator according to the correct coordinates and elevation. Figure (7) shows the process of preparing the model to install the model of the new regulator. Figure (8) shows the shape of the model of the new regulator after placing it into the physical model. It also shows the curtain wall in the east bank of the canal. Figure (9) shows the location of the new regulator with respect to the old one as made in the physical model. The new regulator is located downstream of the existing regulator.

Figure (7): Physical Model Preparation to Place the New Regulator

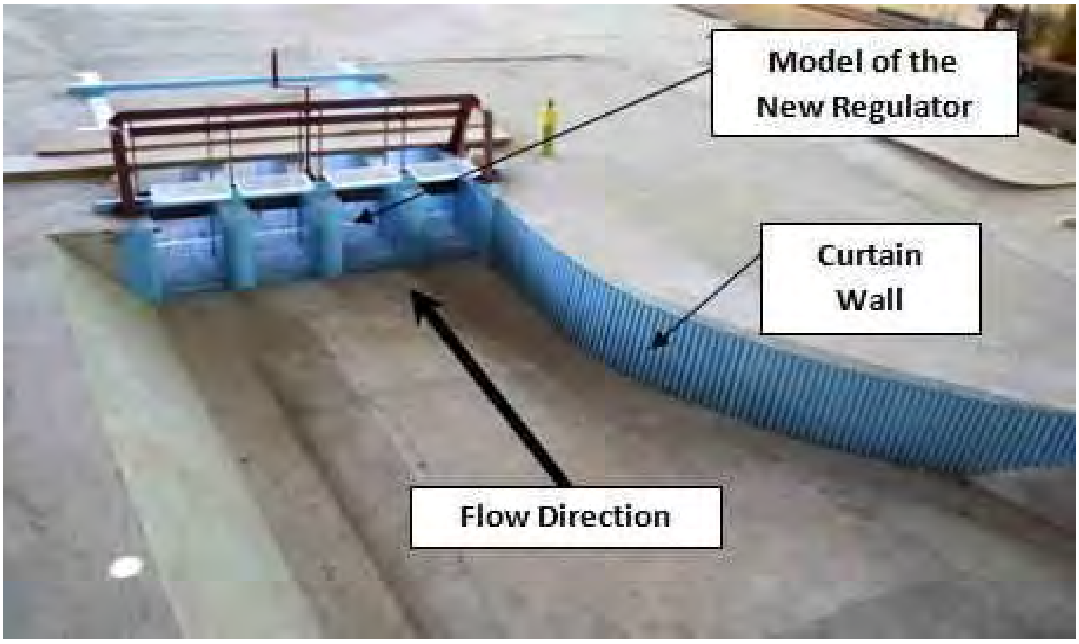

Figure (8): New Regulator and the Curtain Wall

Figure (10) shows how the gates of the model are operated to adjust the flow discharges. The gates are connected to each other by a horizontal steel bar which in turn is connected with a vertical screw bar which rotates on a roller. By moving the screw bar counter clockwise, the gates are going up to lessen the flow discharges and when it rotate clockwise the gates are going down to increase the discharges. This is in case of overflow discharges.

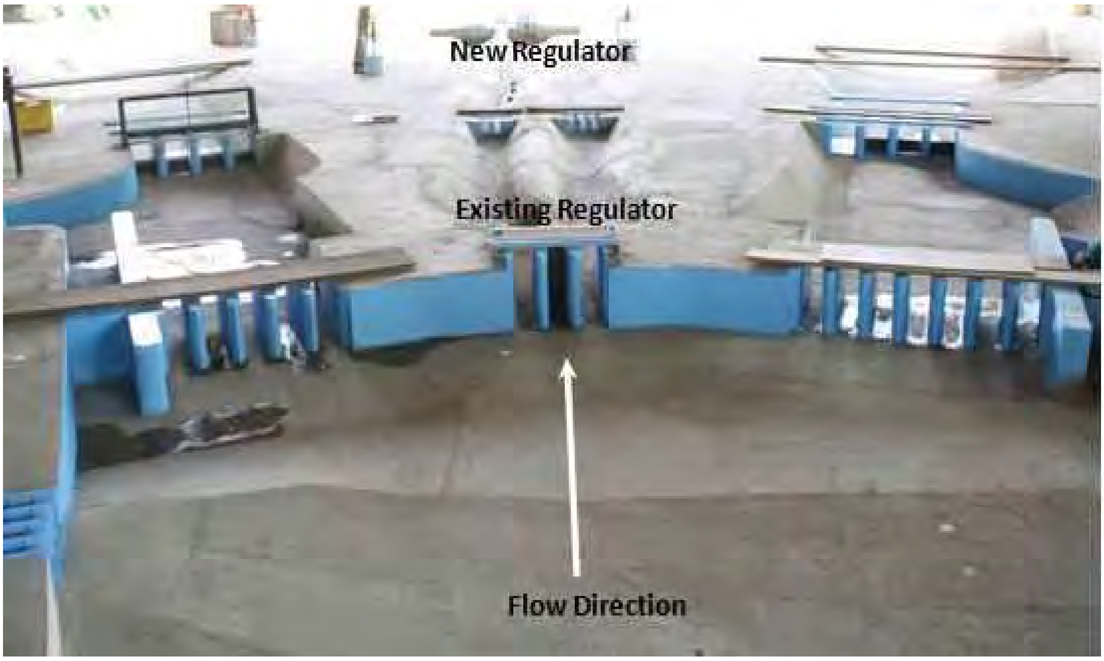

Figure (9): New and Existing Regulator

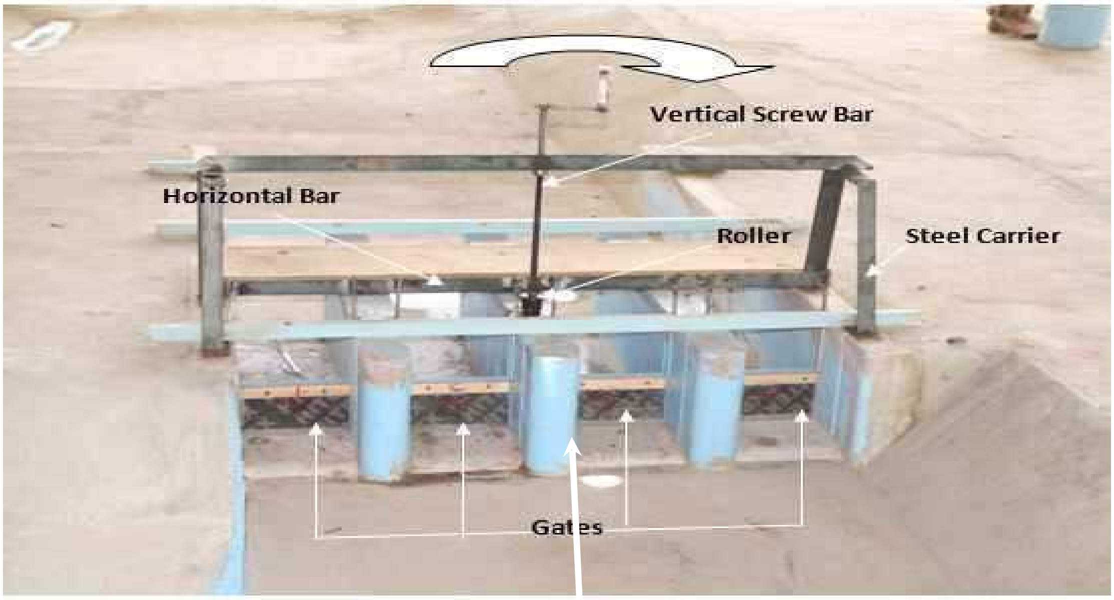

Figure (10): Operation of the Ga :es Using Vertical Screw Bar

4 HYDROLOGIC CONDITIONS

The flow velocity measurements after installing the new regulators would be acquired in the model under three circumstances that representing various and possible flow conditions in the prototype which can be named as maximum, dominant, and minimum flow conditions. The main characteristics of each of the three mentioned flow conditions are summarized in Table (4). The hydraulic characteristics of each of the above three flow cases were worked out in view point of the passing flow discharge and the corresponding water surface flow upstream and downstream of the existing "DGR" for each branched canal. Calculation of each flow case and the application in the model would be summarised as follows:

Table (4): Represented Flow Conditions for Model Operation

No.	Flow condition	Prototype discharge		Model discharge (l/s)	U/S water level (m)
		(mm^3/day)	(m^3/s)		
1	Maximum flow case	39.312	455.00	145.60	(46.30)
2	Dominant flow case	26.445	306.00	98.32	(46.30)
3	Minimum flow case	1.959	22.67	7.25	(46.30)

4.1 Distribution of the Maximum Flow Discharge

The maximum (design) flowconditionwas confirmed during the 6thTechnical Advisory Committee "TAC" meeting which was held in the Ministry of Water Resources and Irrigation "MWRI" on the 16thday of November 2015. The design hydrological data for the proposed new "DGR" were assigned as listed in Table (5). In this case the design high water surface level was (46.30) m.

Table (5): Hydrological Records for Maximum Flow Distribution

No.	Canal name	Discharge			WSL	
		Prototype (mm^3/day)	Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	IradDelgaw canal	0.778	9.00	2.88	(46.30)	45.00
2	Abo Gabal canal	0.605	7.00	2.24		45.85
3	Bahr-Yussef canal	19.613	227.00	72.64		45.60
4	Badraman canal	0.778	9.00	2.88		45.85
5	Diroutiah canal	1.037	12.00	3.84		45.85
6	El-Ibrahimia D/S "DGR"	16.070	186.00	59.52		45.15
7	Sahelyia canal	0.432	5.00	1.60		45.85
8	El-Ibrahimia U/S "DGR"	39.312	455.00	145.60		-

4.2 Distribution of the Dominant Flow Discharge

The dominant discharge was calculated by the Hydraulics Research Institute, HRI based on a daily data record from 2009 to 2014. This discharge was confirmed by both the project consultant and the GBRS. Table (6) shows the dominant discharge for each branch.

Table (6): Hydrological Records for Dominant Flow Distribution

No.	Canal name	Discharge			WSL	
		Prototype (mm^3/day)	Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	IradDelgaw canal	0.559	6.470	2.070	(46.30)	44.60
2	Abo Gabal canal	0.384	4.444	1.422		45.60
3	Bahr-Yussef canal	14.042	162.523	52.007		45.30
4	Badraman canal	0.513	5.938	1.900		45.60
5	Diroutiah canal	0.724	8.380	2.681		45.60
6	El-Ibrahimia D/S "DGR"	10.021	115.984	37.115		44.50
7	Sahelyia canal	0.261	3.021	0.967		45.65
8	El-Ibrahimia U/S "DGR"	26.494	306.644	98.126		-

4.3 Distribution of the Minimum Flow Discharge

Table (7) shows the minimum flow discharge passing through the new regulators. it should be noted that most of the flow discharge in the minimum flow period passes through Bahr Yusef and El-Ibrahemia Canals.

Table (7): Hydrological Records for Minimum Flow Distribution

No.	Canal name	Discharge			WSL	
		Prototype (mm^3/day)	Prototype (m^3/s)	Model (l/s)	U/S (m)	D/S (m)
1	IradDelgaw canal	0.040	0.46	0.15	(46.30)	***
2	Abo Gabal canal	0.028	0.32	0.10		***
3	Bahr-Yussef canal	1.600	18.52	5.93		42.55
4	Badraman canal	0.038	0.44	0.14		***
5	Diroutiah canal	0.054	0.63	0.20		***
6	El-Ibrahimia D/S "DGR"	0.180	2.08	0.67		41.55
7	Sahelyia canal	0.019	0.22	0.07		***
8	El-Ibrahimia U/S "DGR"	1.959	22.67	7.25		-

***** no flow**

5 TEST PROGRAM

The test program as submitted by the consultant of the project includes the operation scenarios of the gates of the new regulators (NDGRs), the location of the flow velocity measurements across the branch canals and the situation of the navigation locks of the existing regulator (DGRs). The following is the NDGRs operation during the flow velocity measurements.

5.1 Operating Scenarios for the Gates of the NDGRs

The consultant of the project confirmed the following operation rules for the gates of the small and large regulators as follows:

- For the small regulators (Abo Gabal, Badraman, Sahelyia and Diroutia), in all cases of maximum, minimum and dominant discharges have to be controlled by under flow gates.
- For the large regulator (Bahr Yusef and Ibrahemia Regulators), in cases of minimum and dominant discharges have to be controlled by over flow gate operation.
- For the large regulators (Bahr Yusef and Ibrahemia Regulators), in case of maximum discharge has to be controlled by over flow and under flow gate operation.

5.2 Flow Velocity Measurements of the Large Regulators

The consultant confirmed the following flow velocity measurements cross sections:

- Two cross sections at 30 and 50 m downstream of the center line of the new gate by necessity, and
- One cross section at 100 downstream of the center of the new gate if possible.
- For each cross section the flow velocity measurements include the average flow velocity (at the middle in the vertical direction) and the bottom flow velocity.

Figure (12) shows the location of the flow velocity measurements with respect to the large regulators at Ibrahemia and Bahr Yusef Canals.

5.3 Operating Scenarios for the Navigation Locks of the DGRs

The consultant of the project suggested the following scenarios for the operation of the navigation locks of the existing regulators of Bahr Yusef and Ibrahemia after the completion of the construction of the NDGRs:

- Gates of navigation lock of the existing Bahr Yusef have to be opened.
- Gates of navigation lock of the existing Ibrahemia Regulator have to be closed.

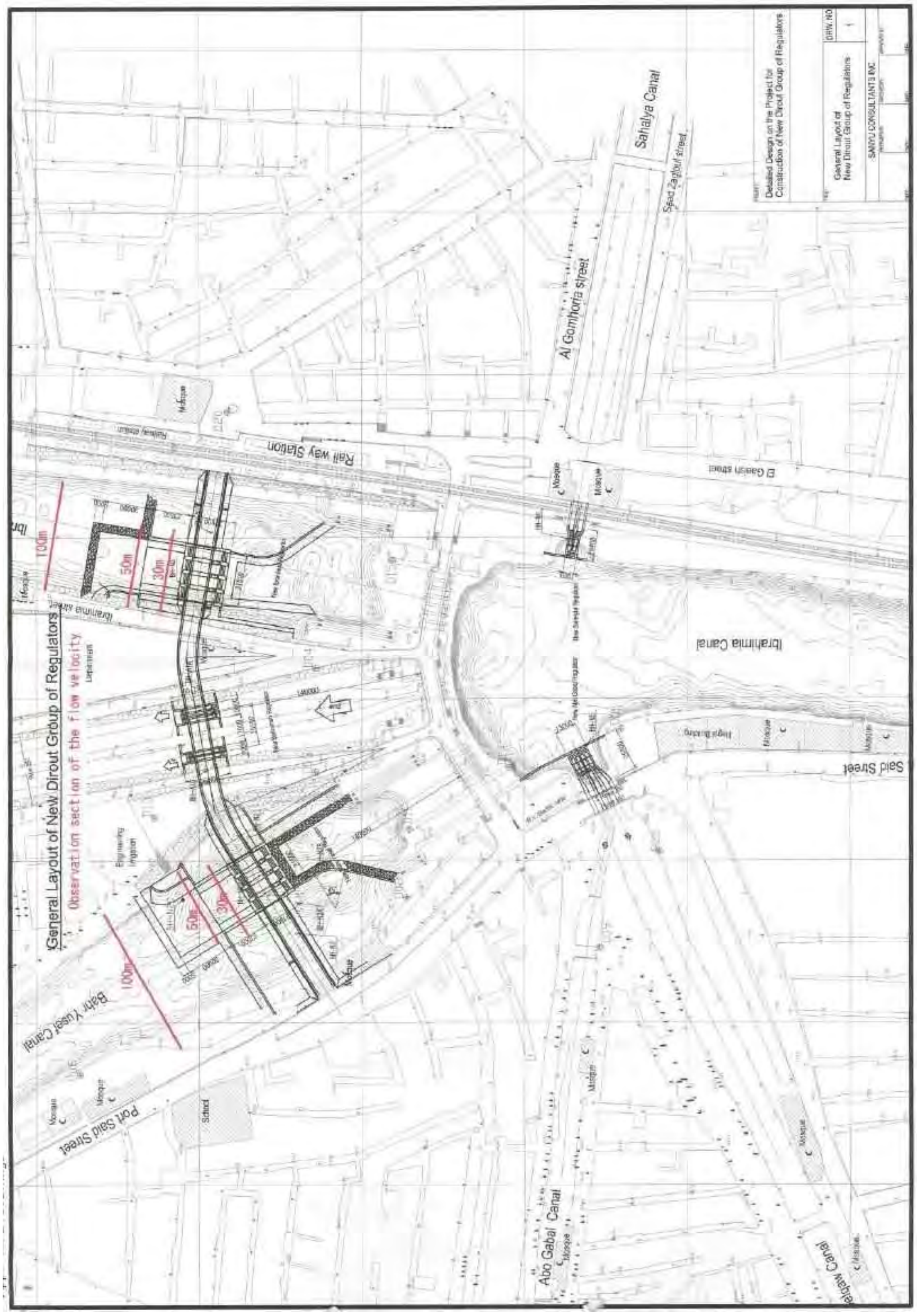

Figure (12): Location of the Flow Velocity Measurements

6 RESULTS

6.1 Gate Openings

Table (8) shows the gate openings of the new regulators at the maximum, dominant and minimum discharges. Also, it shows the gate openings of the large regulators of Bahr Yusef and Ibrahimia Canals when the discharges are flowing under the gates.

Table (8): Gate Openings of the Regulators at Different Discharges

No.	Canal name	Gate Openings (m)			
		Over Flow DischargeCase			Under Flow DischargeCase
		Maximum	Dominant	Minimum	Maximum
1	IradDelgaw canal	0.750	0.500	---	0.750
2	Abo Gabal canal	0.600	0.525	---	0.600
3	Bahr-Yusef canal	---	---	---	2.500
4	Badraman canal	0.625	0.525	----	0.950
5	Diroutiah canal	0.750	0.525	---	0.750
6	El-Ibrahimia D/S "DGR"	---	---	---	1.775
7	Sahelyia canal	0.450	0.300	---	0.450

6.2 Flow Velocity Distribution

Table (9) shows the absolute values of the maximum, minimum and average flow velocities in the successive cross sections 1, 2, and 3. Also, the flow velocity distribution for all the cases stated in the test program can be found in Annex 3. It can be seen from Table (9) and Annex 3 the following:

- To track the formation of dead zones and flow circulation zones, the flow velocity distribution in the longitudinal direction was used in this study.
- Negative flow velocity values as appeared in Annex 2 means that the flow direction reverses its direction to be from the downstream to upstream, while the positive flow velocity values means the flow direction is from the upstream to further downstream (flow direction).
- The maximum absolute flow velocity occurs when the discharge is passing under the gate in the maximum flow period.

- The maximum absolute flow velocity is 2.8 m/s and it occurs at section (1) downstream Ibrahimia new regulator.
- The maximum absolute flow velocity downstream Bahr Yusef new regulator is 2.52 m/s
- The flow distribution at section (1) is influenced by the regulator. A sinusoidal flow distribution is recognized with the peak velocity at the center of the vent and low velocity is at the center of the pier.
- Downstream Ibrahimia Regulator, it was recognized that the flow velocity values near the bottom of cross section (1) is larger than that in the mid depth velocity values in the same section in the case of maximum overflow conditions (see Annex 3). As an explanation to this phenomenon, in the maximum overflow condition the flow momentum dominates the gravity at this section causing a disturbance at the water surface while it increases the flow velocity in bottom layers leading to the above mentioned phenomena.

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Table (9): Absolute Values of the Flow Velocities at Sections downstream of the New Large Regulators for the Over flow and Underflow Conditions

Sec.	Canal	Over Flow									Under Flow		
		Maximum Discharge			Dominant Discharge			Minimum Discharge			Maximum Discharge		
		$V_{max.}$ (m/s)	$V_{min.}$ (m/s)	$V_{ave.}$ (m/s)	V_{max} (m/s)	$V_{min.}$ (m/s)	$V_{ave.}$ (m/s)	V_{max} (m/s)	$V_{min.}$ (m/s)	$V_{ave.}$ (m/s)	V_{max} (m/s)	$V_{min.}$ (m/s)	$V_{ave.}$ (m/s)
Sec. 1	Ibrahimia	2.60	0.50	1.55	1.80	0.28	1.05	0.28	0.01	0.14	2.80	0,60	1.70
	Bahr Yusef	1.20	0.20	0.70	0.57	0.02	0.30	0.28	0.02	0.15	2.52	0.89	1.70
Sec. 2	Ibrahimia	1.75	0.02	0.88	1.04	0.02	0.52	0.18	0.01	0.09	1.33	0.03	0.66
	Bahr Yusef	1.43	0.02	0.72	1.20	0.05	0.62	0.43	0.01	0.22	1.50	0.05	0.75
Sec. 3	Ibrahimia	1.05	0.07	0.53	0.82	0.04	0.43	0.27	0.07	0.14	0.90	0.03	0.46
	Bahr Yusef	1.12	0.02	0.56	0.96	0.16	0.56	0.266	0.07	0.16	1.08	0.06	0.57

6.3 Dead Zones and Flow Circulation

It can be realized from Figure (13) and Figure (14) the following:

- Formation of dead zone and flow circulation zone downstream of the new Ibrahimia regulator.
- The dead zone is attached to the right bank of Ibrahemia canal and occupies almost one third of the entire width of the canal and extends about 57.5 m further downstream of the new regulator.
- The average flow velocity in the circulation zone reads about 0.5 m/s in the maximum flow discharges and the flow direction is opposite to the main flow direction which is from the upstream of the NDGR to its downstream causing flow circulation as can be seen in Figure (13).

Figure (13): Formation of Dead Zone Downstream Ibrahimia New Regulator

Figure (14): Formation of Flow Circulation Zone Downstream Ibrahemia New Regulator

Figure (15) and Figure (16) show that a dead zone and a flow circulation zone took place attached to the left bank of Bahr Yusef Canal. The dead zone occupies almost half the entire width of the Bahr Yusef Canal and it extends a distance of 87.5 m further downstream of the new regulator. The average flow velocity at the circulation zone reads about 0.5 m/s and the maximum flow velocity under the gate is 2.8 m/s.

Figure (15): Formation of Dead Zone Downstream Bahr Yusef New Regulator

Figure (16): Formation of Flow Circulation Zone Downstream Bahr Yusef New Regulator

More photos of the circulation zone in the maximum, dominant and minimum flow conditions can be seen in Annex 3.

7 CONCLUSIONS

The operation of the new regulators (NDGRs) at Dirout shows the following:

- Formation of dead zones downstream of the new regulators at Bahr Yusef and Ibrahimia Canal.
- The flow distribution amongst the gates of the new regulators is influenced by the upstream arrangements such as the lock situation and the arrangement of the existing regulator vents with respect to the new regulators vents.
- the water level in Ibrahimia Canal upstream the existing regulator (DGRs) is influenced by the pool formed at water level of 46.30 m (MSL) between the existing and the new regulators.
- The flow distribution shape downstream the new regulator, especially at section (1), is influenced by the piers of the regulator.
- The maximum flow velocity at downstream the new regulator of Ibrahimia Canal is 2.8 m/s, while it is 2.52 m/s for Bahr Yusef Canal.
- It is recommended to remove the dead zones downstream the new regulators of Bahr Yusef and Ibrahimia Canals. This can be one by filling these zones with a filler material (e.g. sand, silt and clay mixture) and consider it as part of the bank of the canal.

- Cross section (1) is located in highly turbulent and hydraulically unstable vicinity.
- It is not recommended to measure the flow velocity distribution in this vicinity because it gives ambiguous results.

ANNEX 1
(Design Drawings of the New Dirout Regulators)

ANNEX 2
(Flow Velocity Measurements)

ANNEX 3
(Photos of theModeled New Dirout Regulators)

MAXIMUM DISCHARGES

SECTION # 1

OVER_FLOW

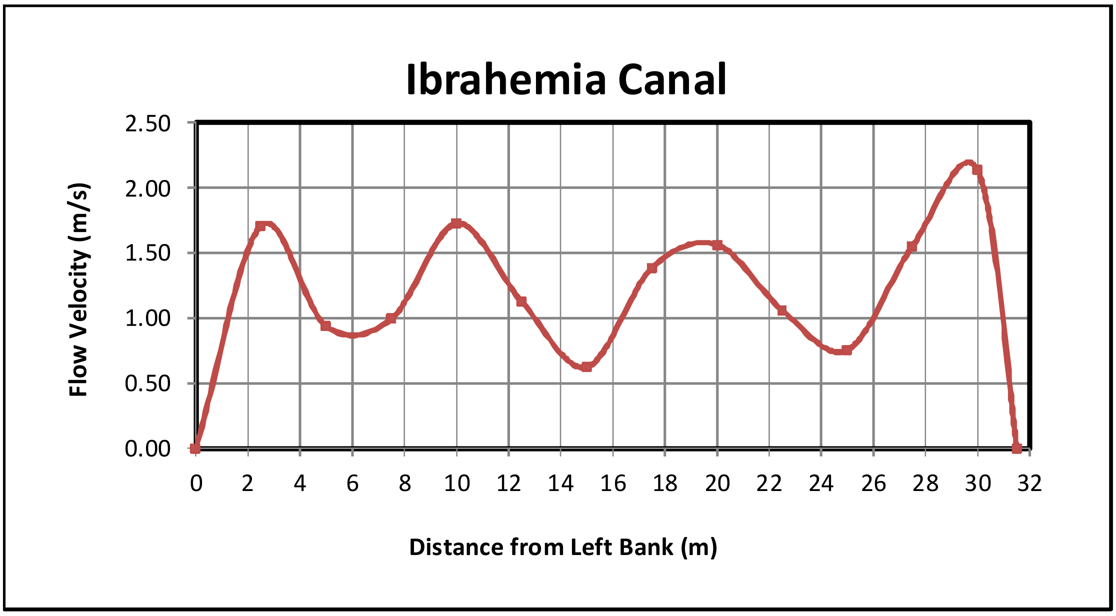


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 1

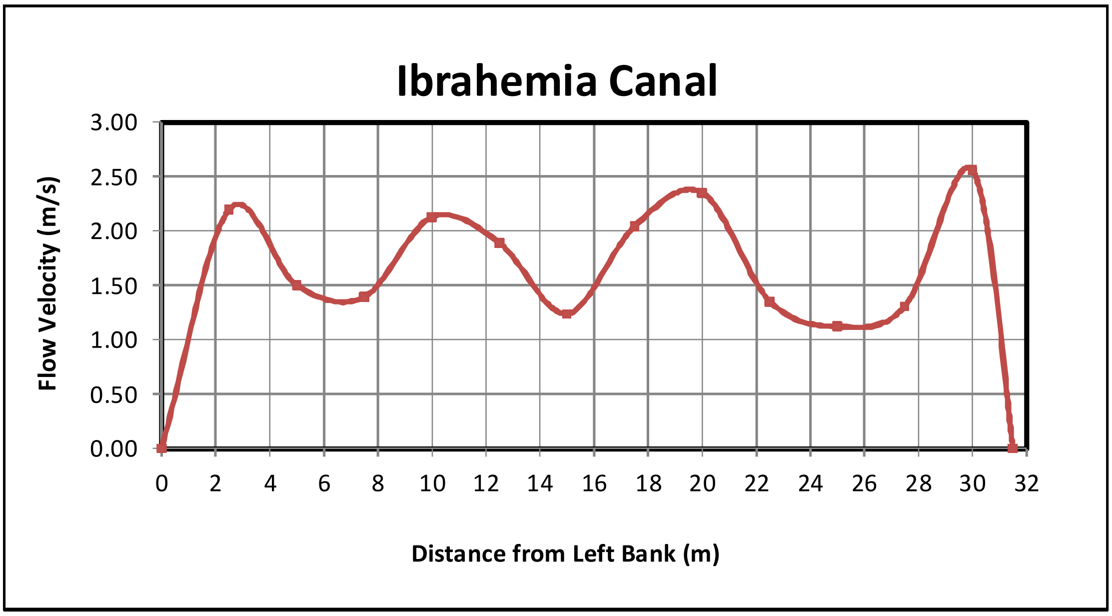


Figure (2): Bottom Flow Velocity Distribution at Cross Section 1

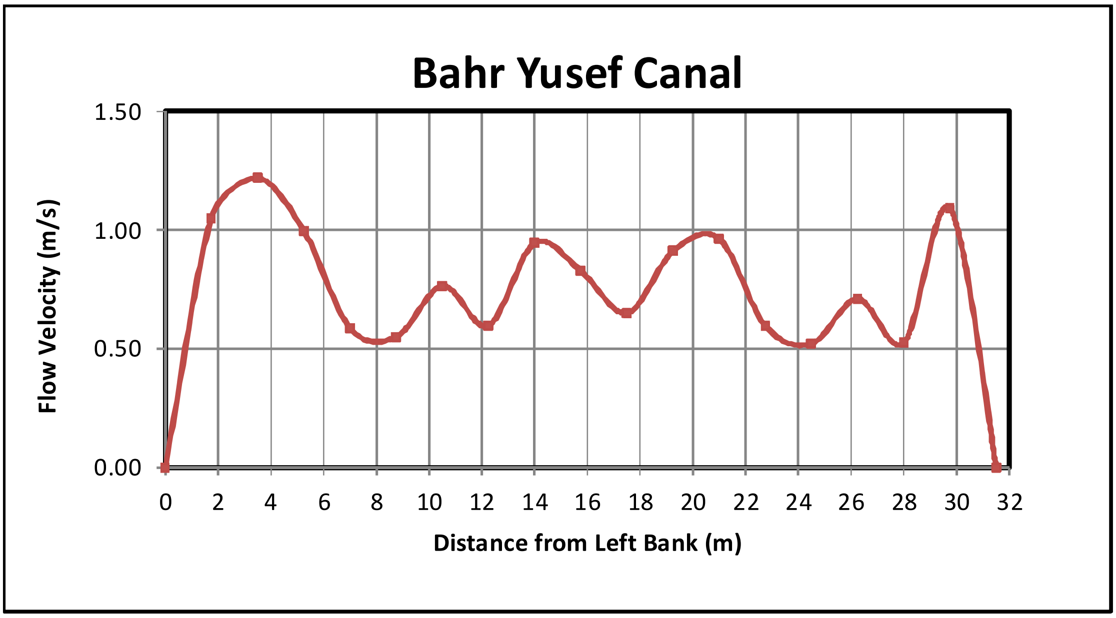


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 1

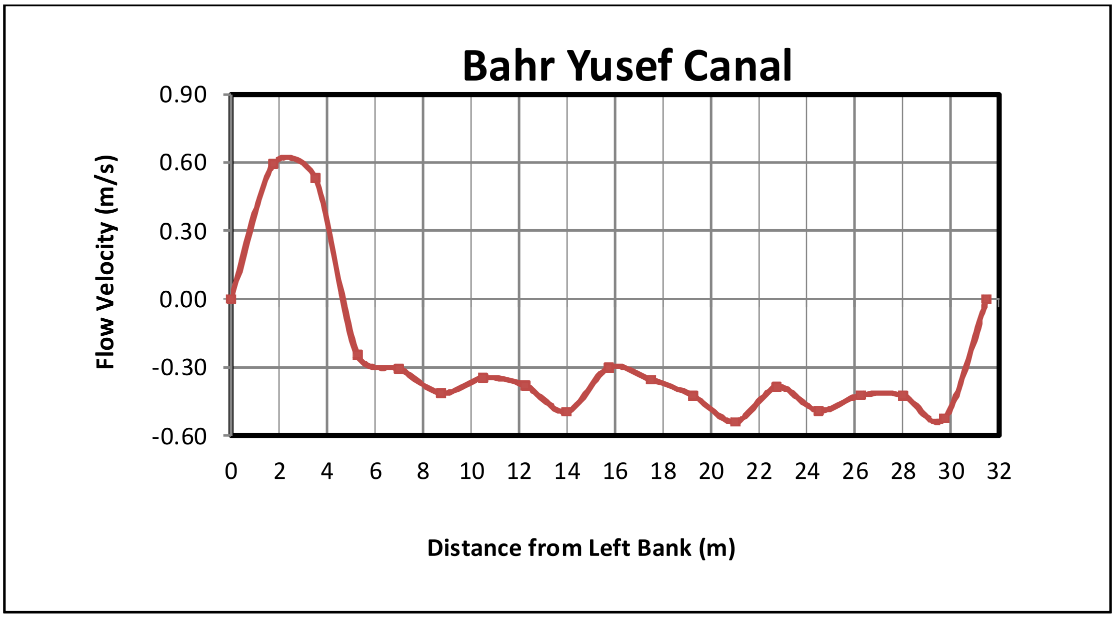


Figure (4): Bottom Flow Velocity Distribution at Cross Section 1

SECTION # 1

UNDUR_FLOW

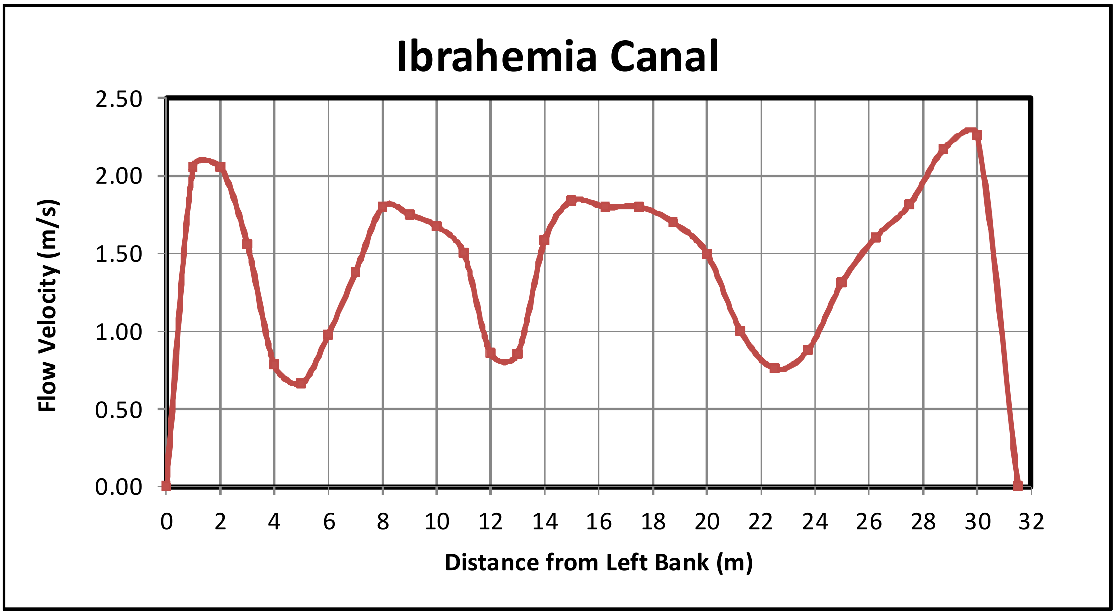


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 1

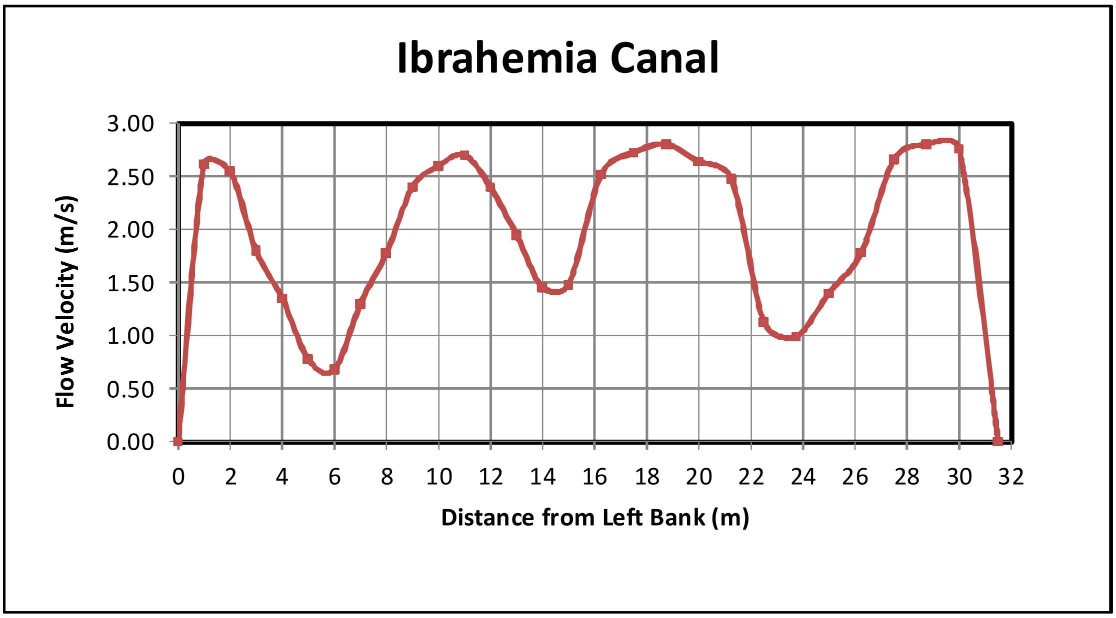


Figure (2): Bottom Flow Velocity Distribution at Cross Section 1

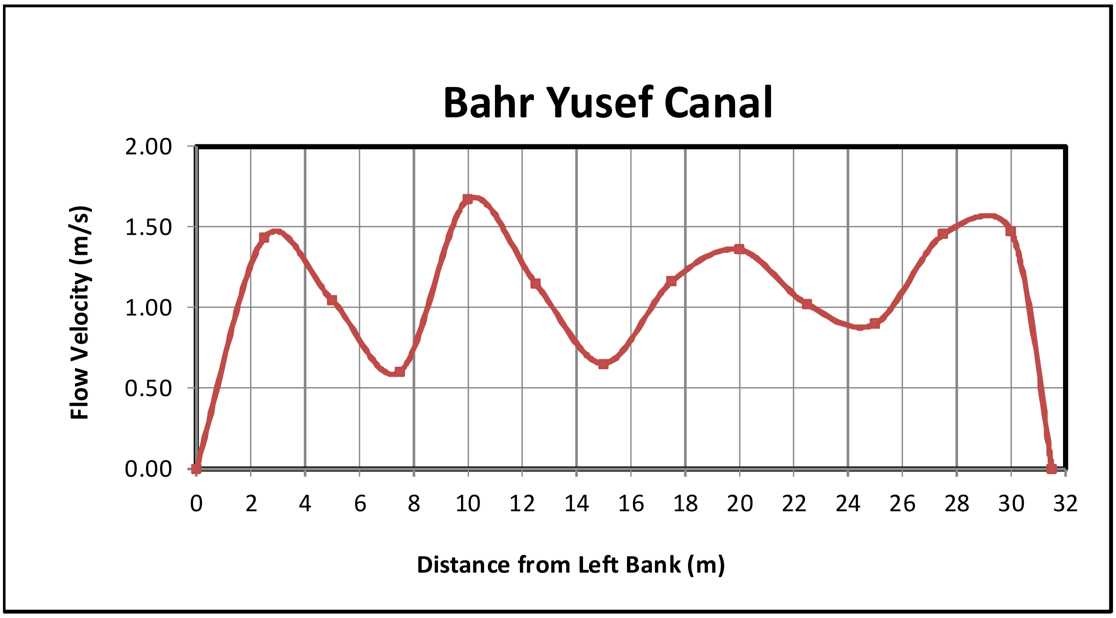


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 1

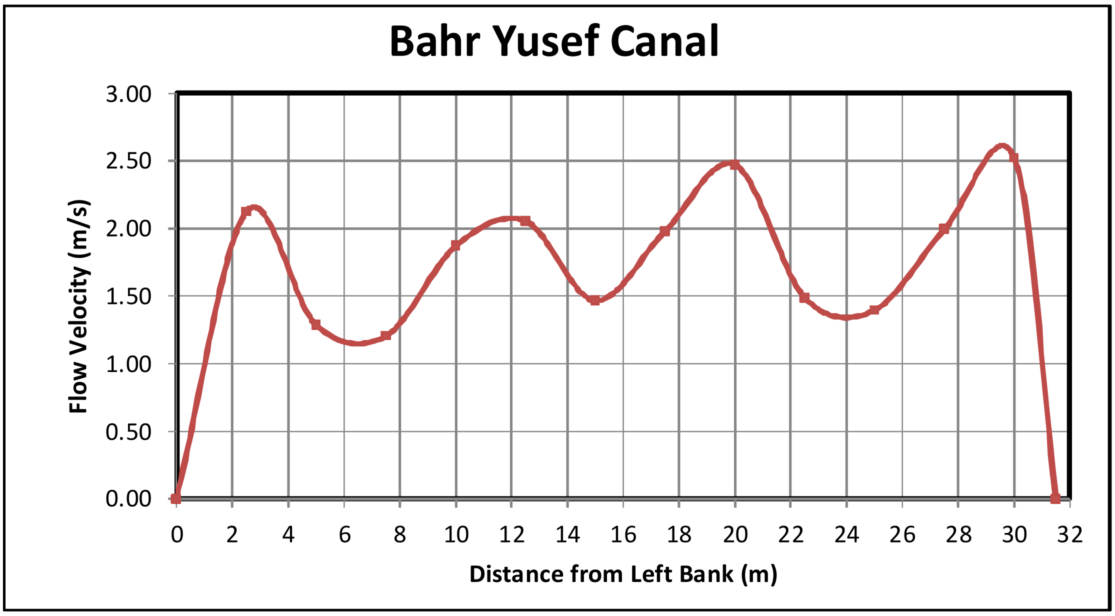


Figure (4): Bottom Flow Velocity Distribution at Cross Section 1

SECTION # 2

OVER_FLOW

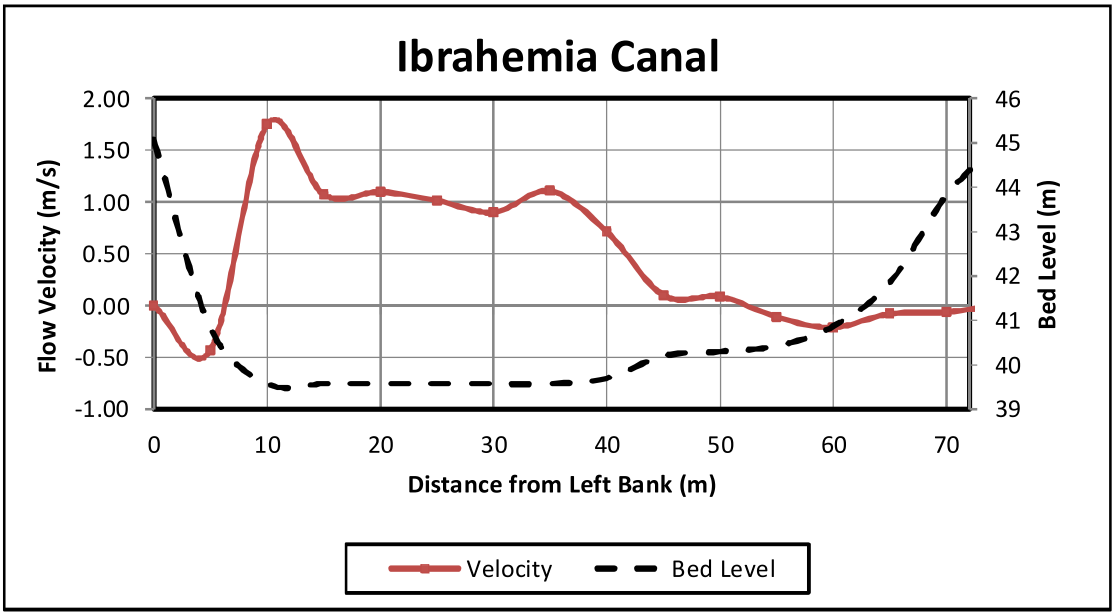


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 2

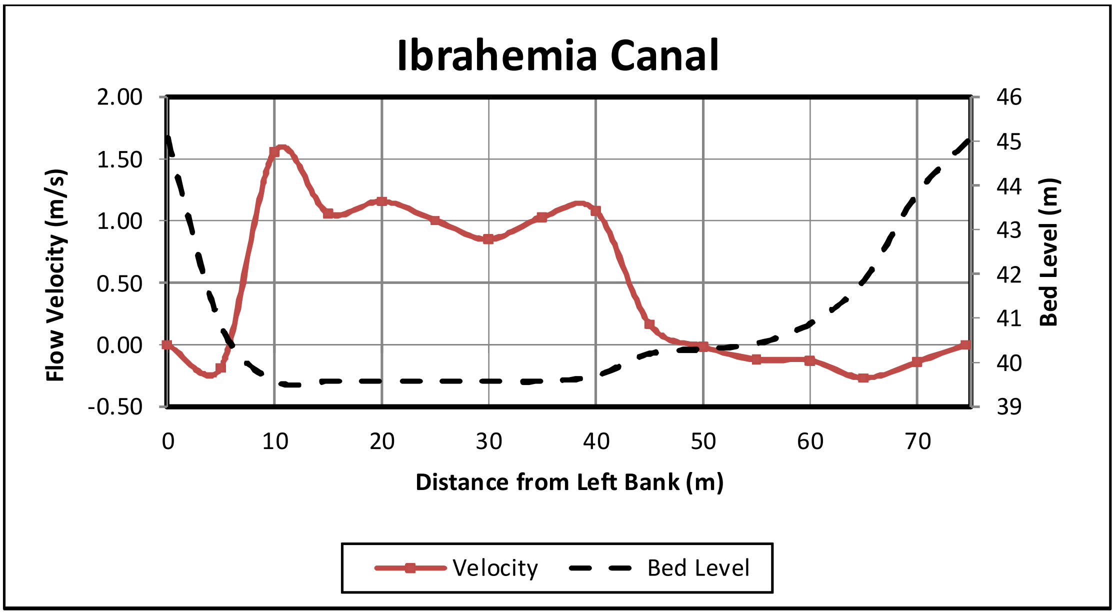


Figure (2): Bottom Flow Velocity Distribution at Cross Section 2

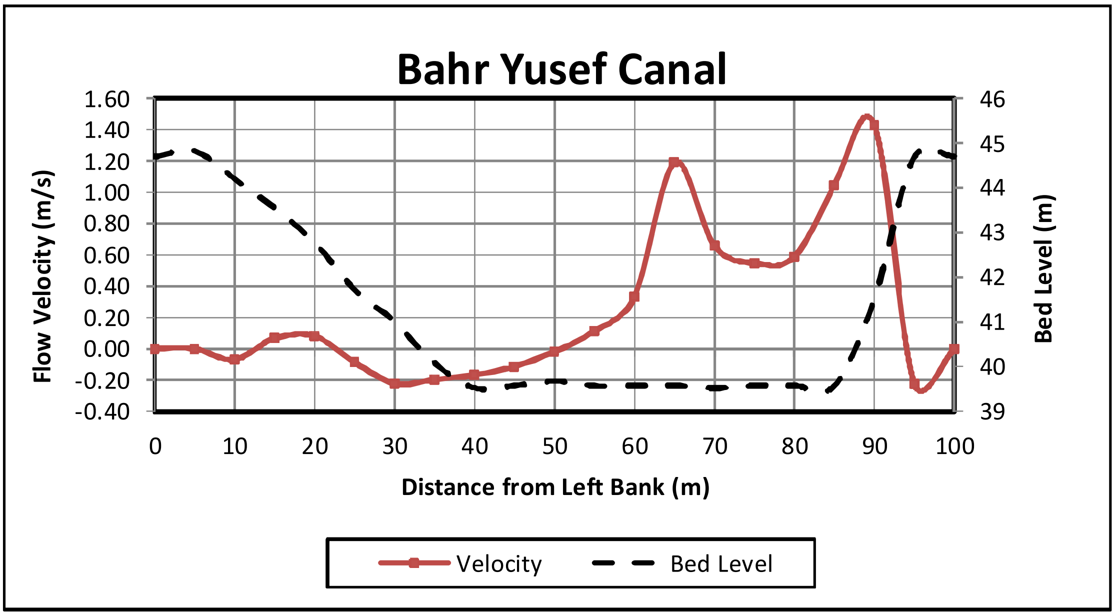


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 2

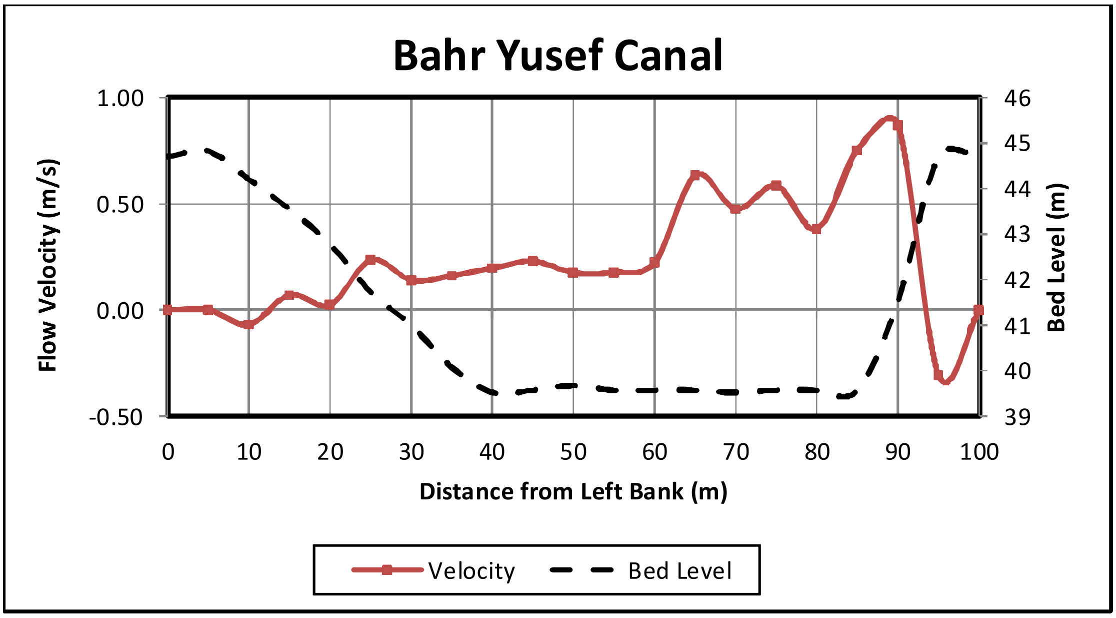


Figure (4): Bottom Flow Velocity Distribution at Cross Section 2

SECTION # 2

UNDUR_FLOW

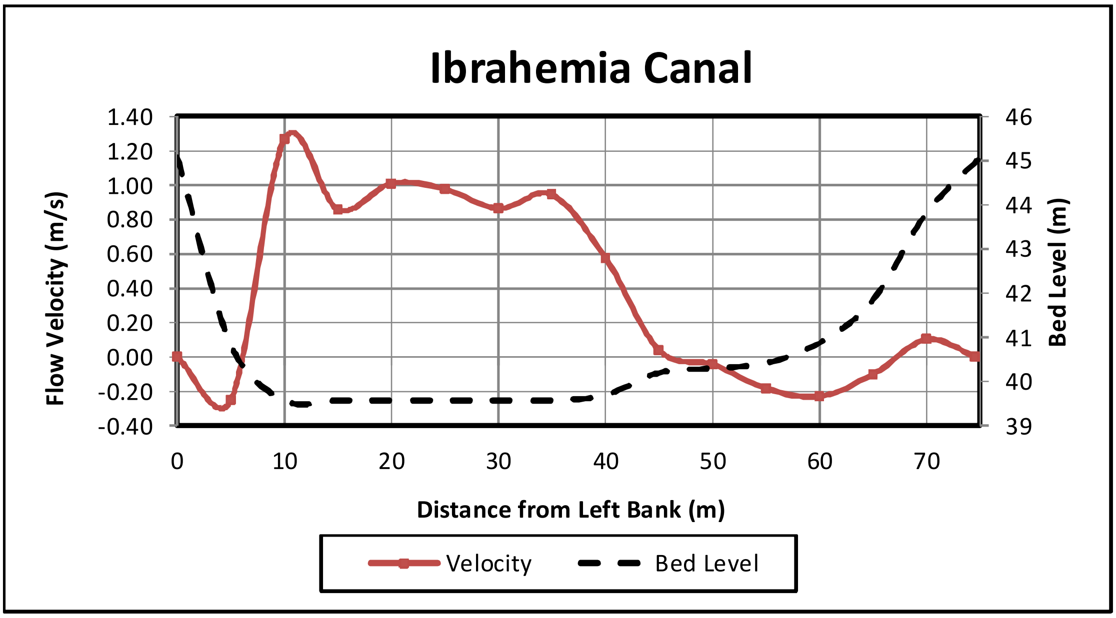


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 2

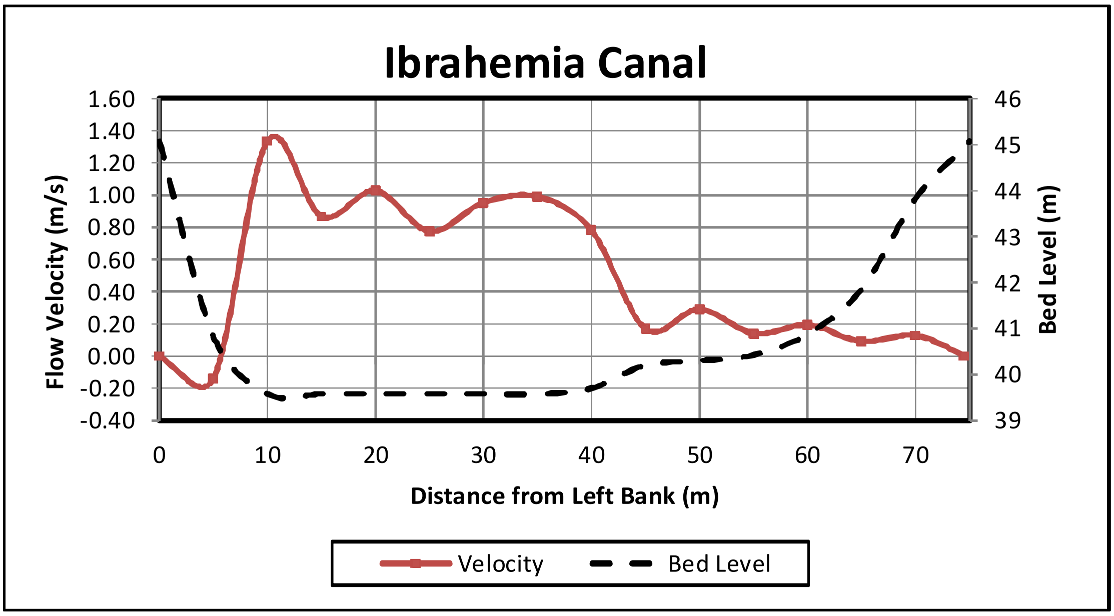


Figure (2): Middle Flow Velocity Distribution at Cross Section 2

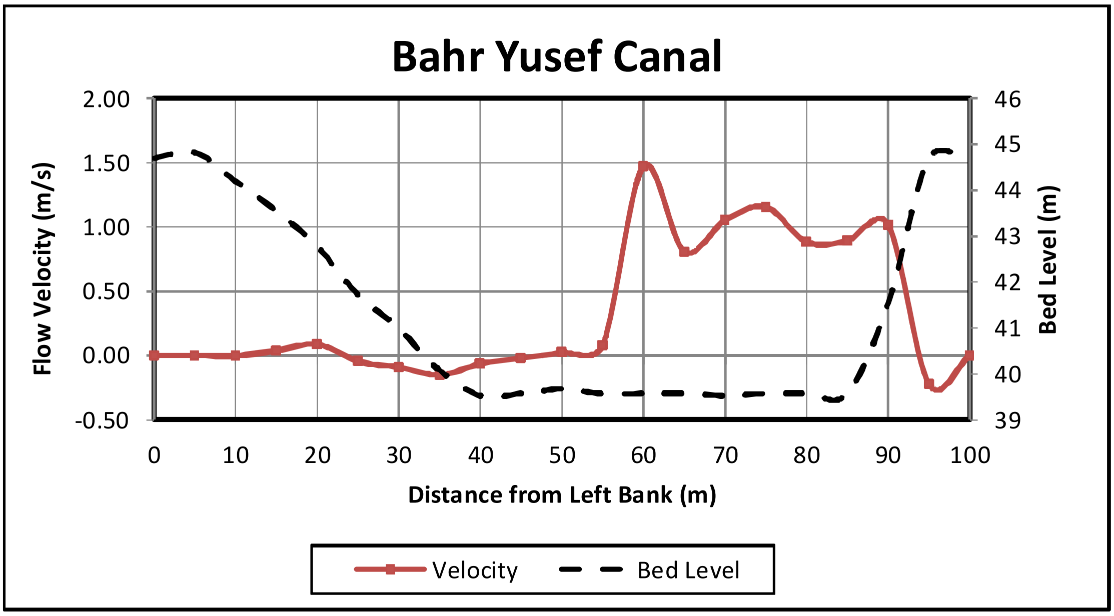


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 2

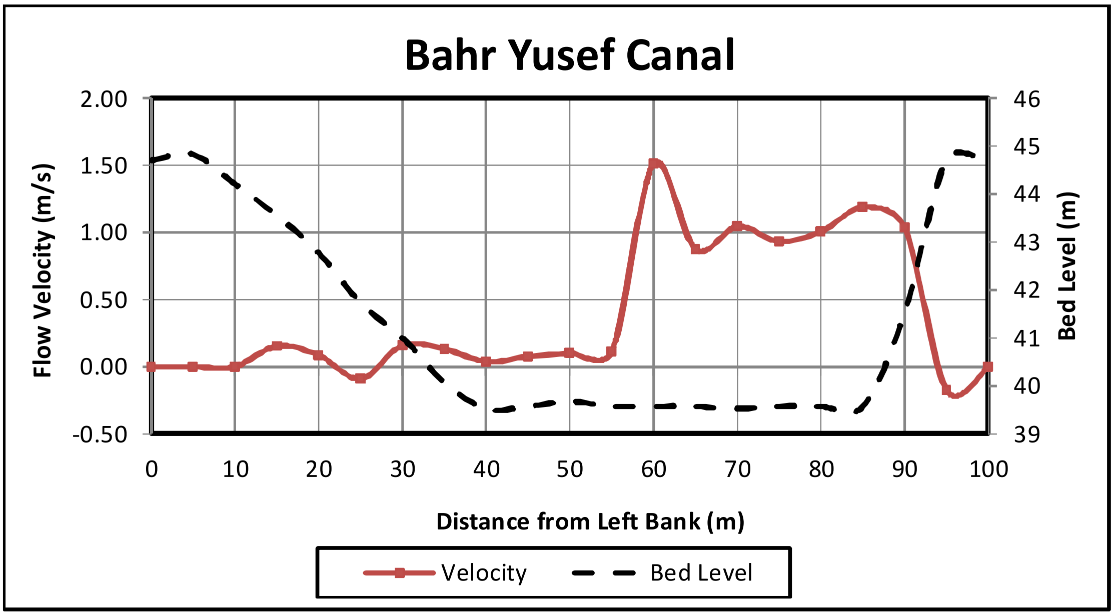


Figure (4): Bottom Flow Velocity Distribution at Cross Section 2

SECTION # 3

OVER_FLOW

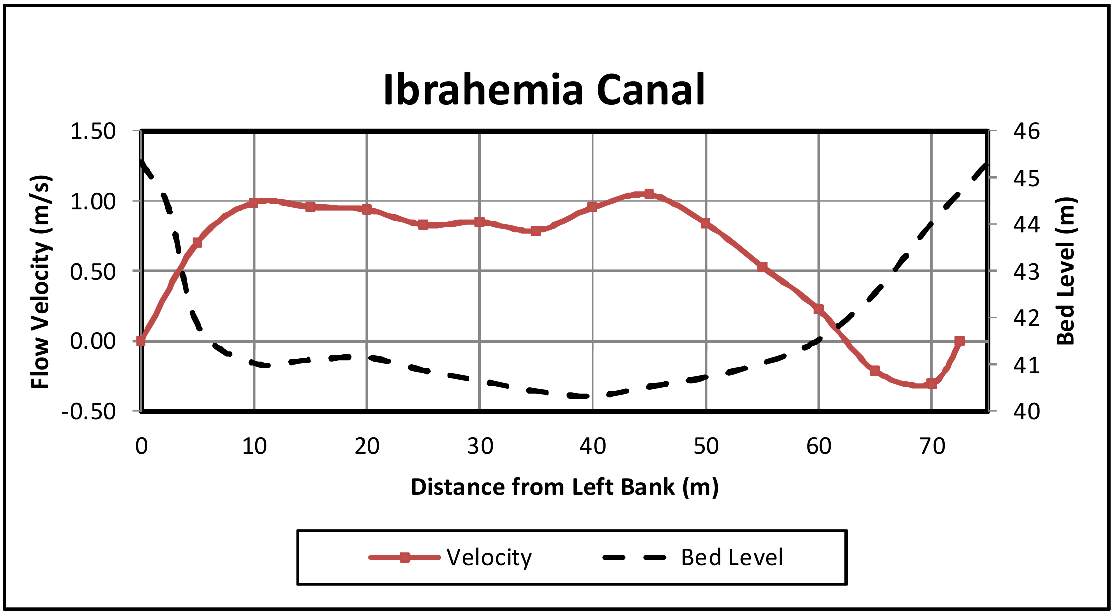


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 3

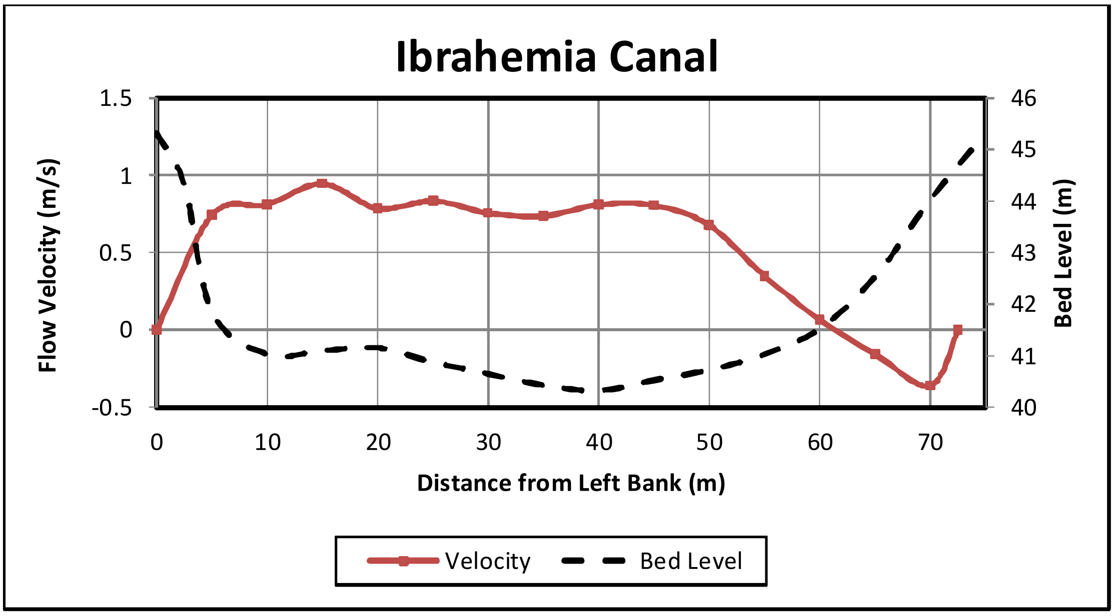


Figure (2): Bottom Flow Velocity Distribution at Cross Section 3

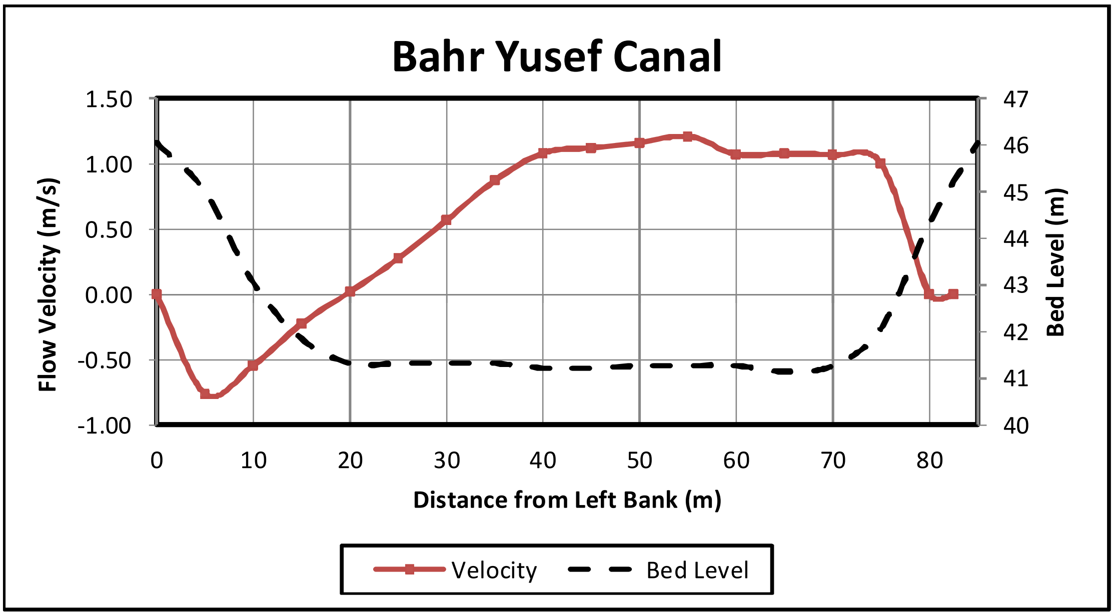


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 3

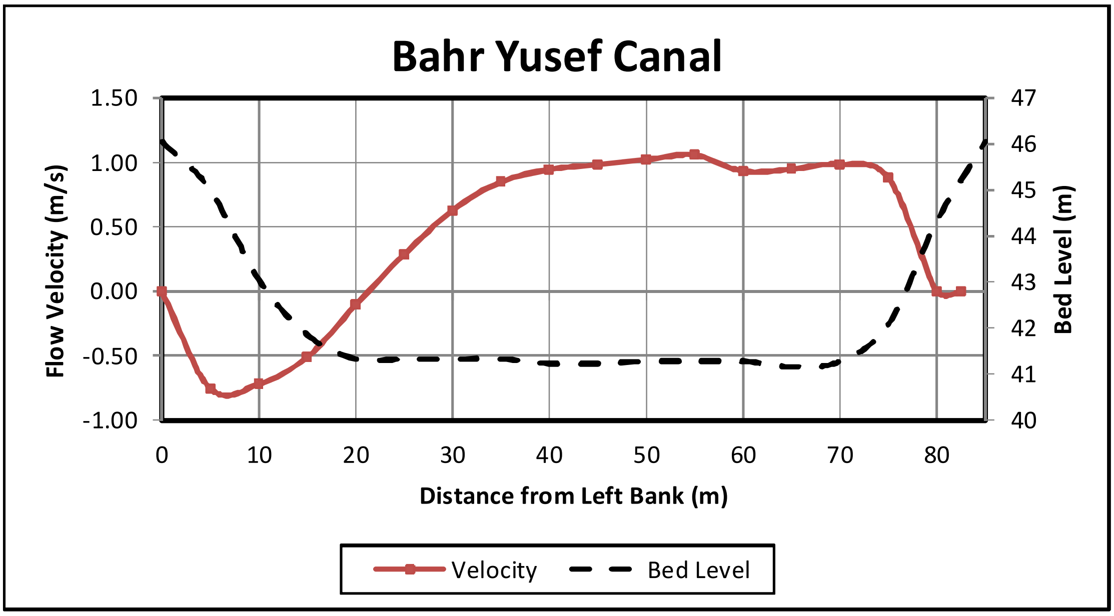


Figure (4): Bottom Flow Velocity Distribution at Cross Section 3

SECTION # 3

UNDUR_FLOW

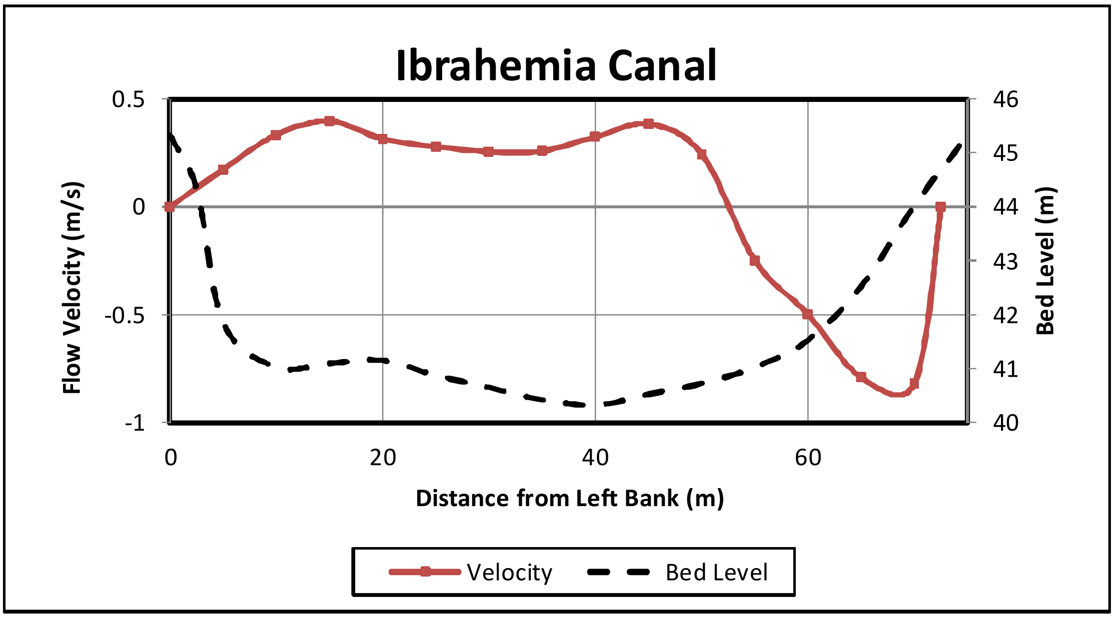


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 3

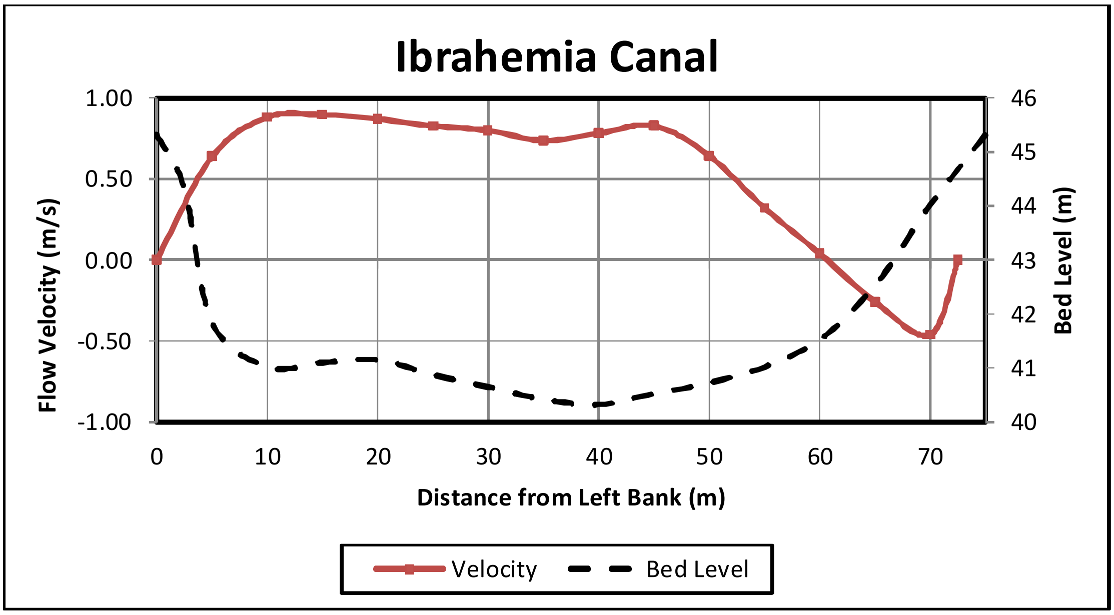


Figure (2): Bottom Flow Velocity Distribution at Cross Section 3

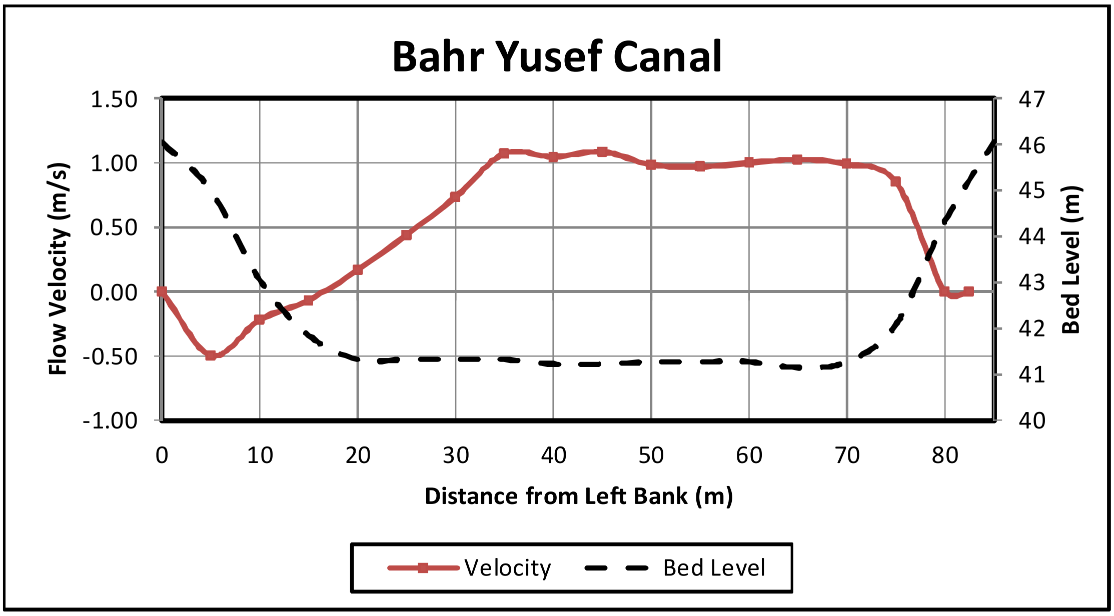


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 3

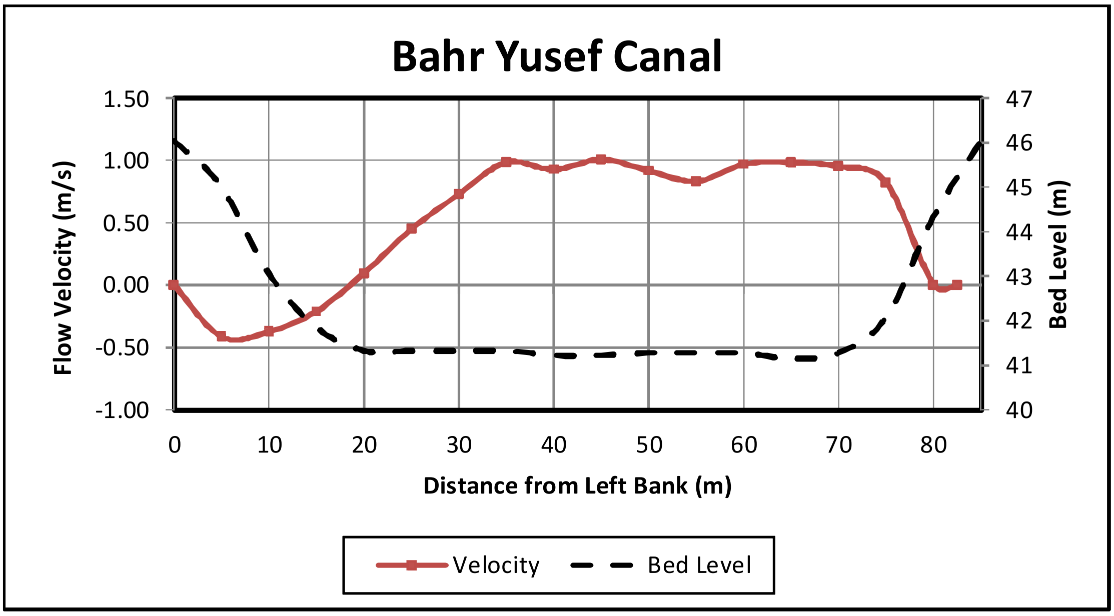


Figure (4): Bottom Flow Velocity Distribution at Cross Section 3

DOMINANT DISCHARGES

SECTION # 1

OVER_FLOW

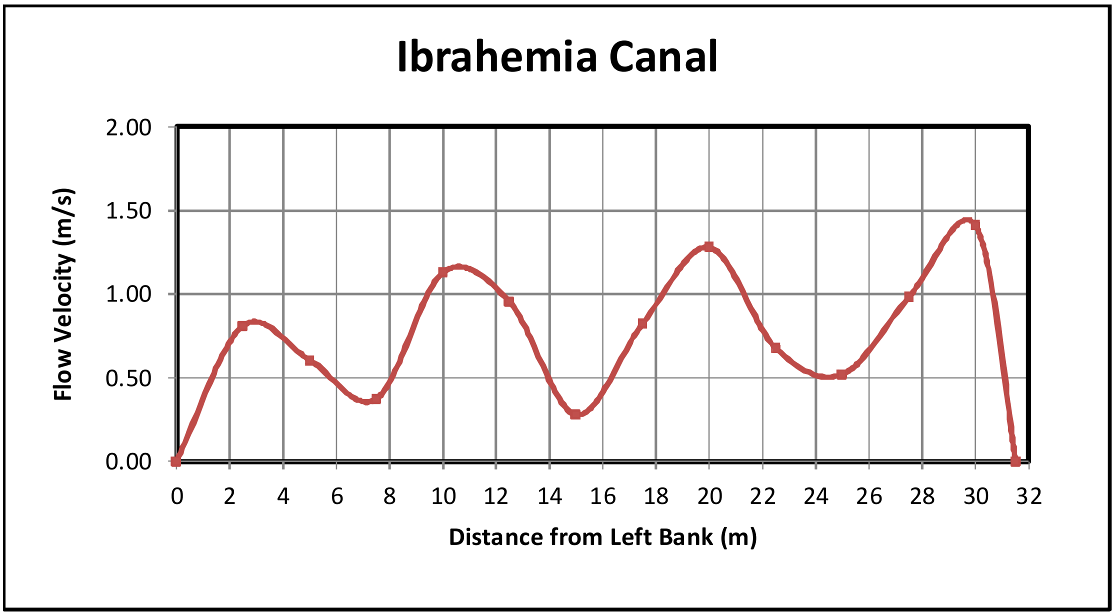


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 1

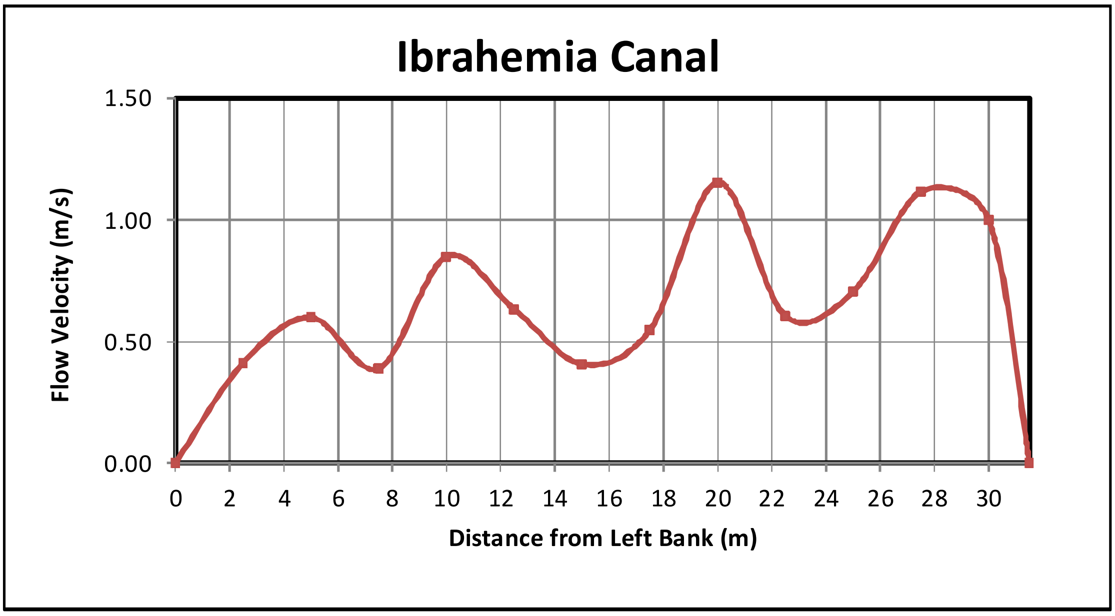


Figure (2): Bottom Flow Velocity Distribution at Cross Section 1

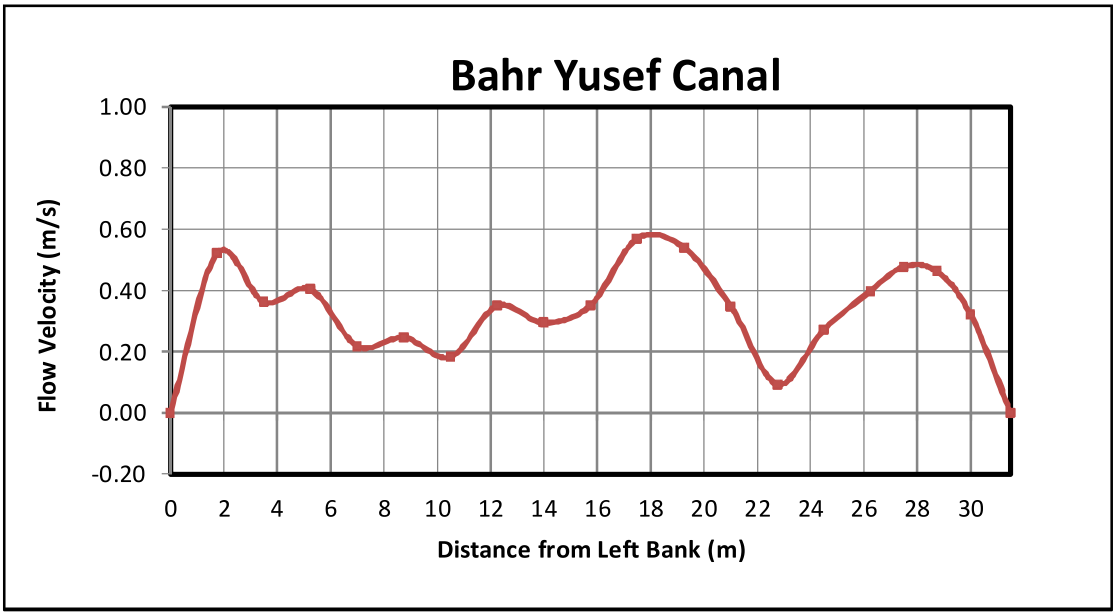


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 1

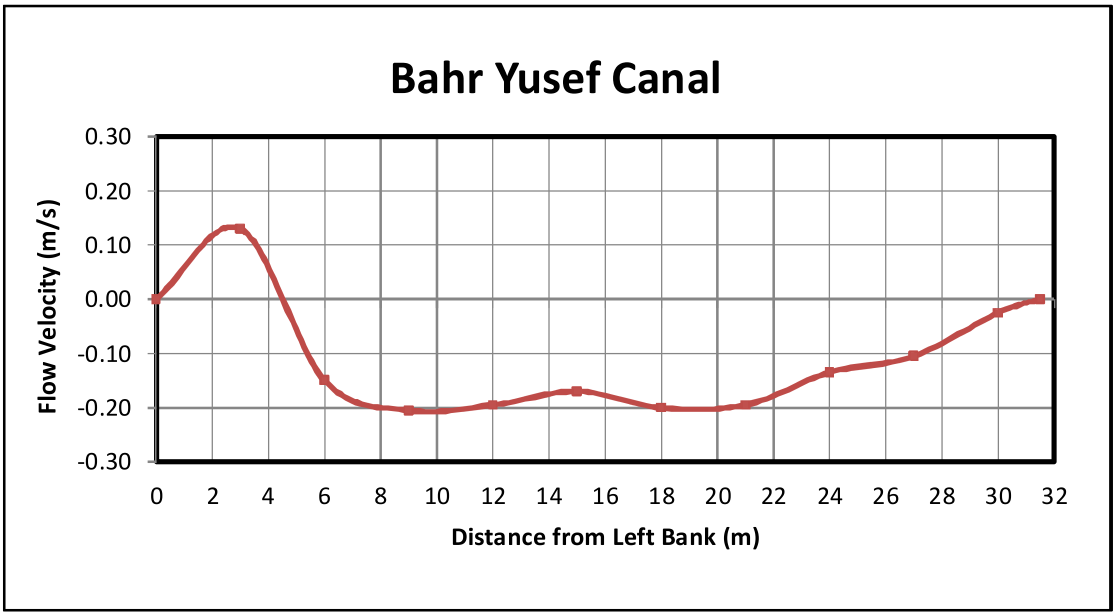


Figure (4): Bottom Flow Velocity Distribution at Cross Section 1

SECTION # 2

OVER_FLOW

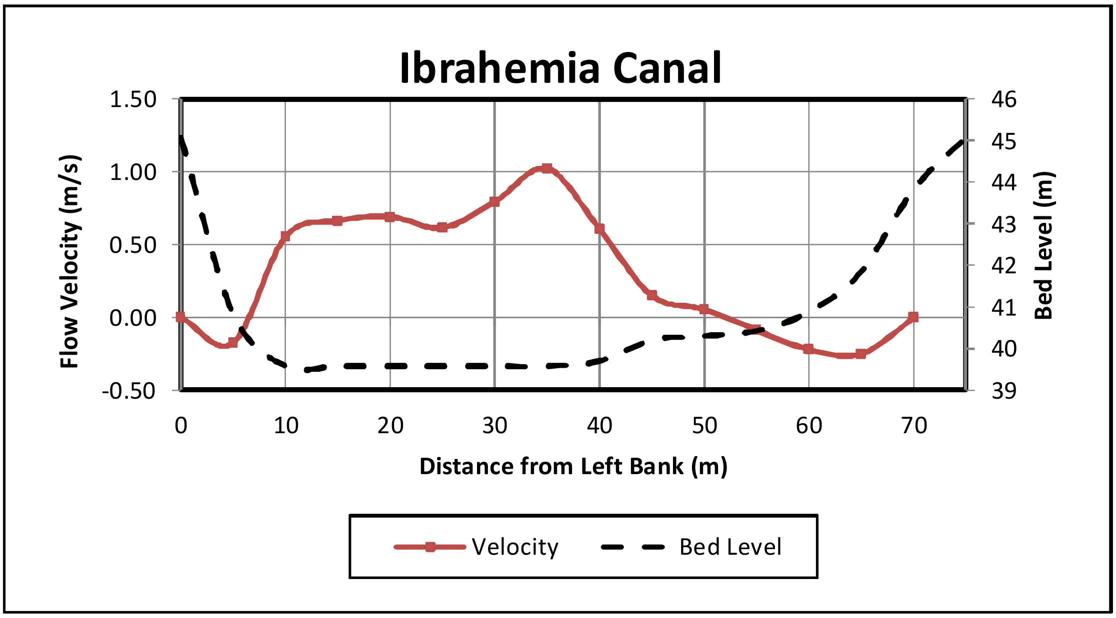


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 2

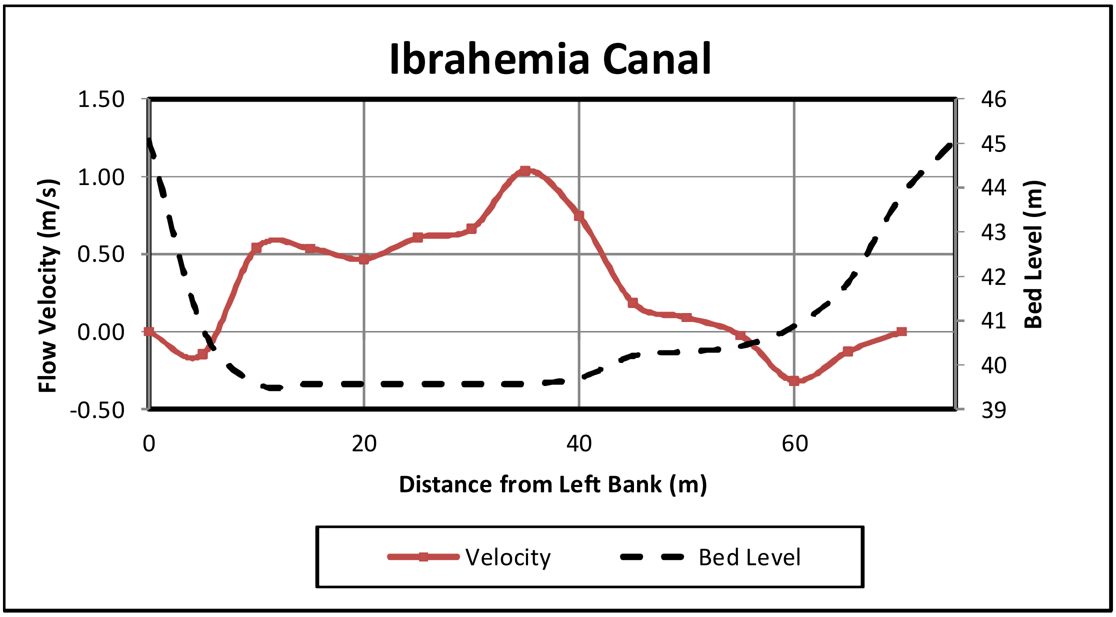


Figure (2): Bottom Flow Velocity Distribution at Cross Section 2

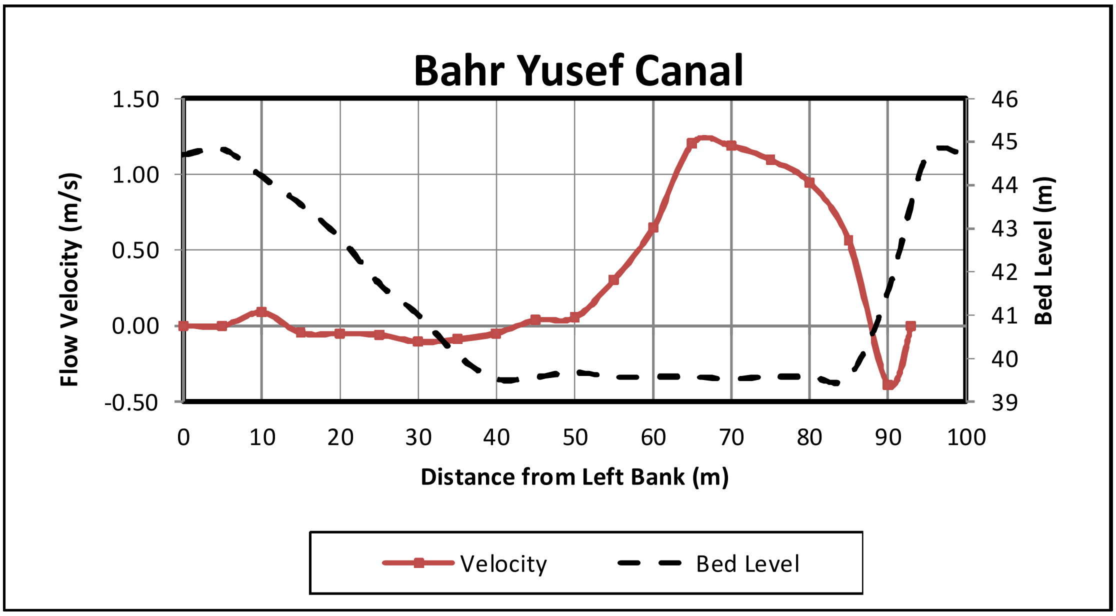


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 2

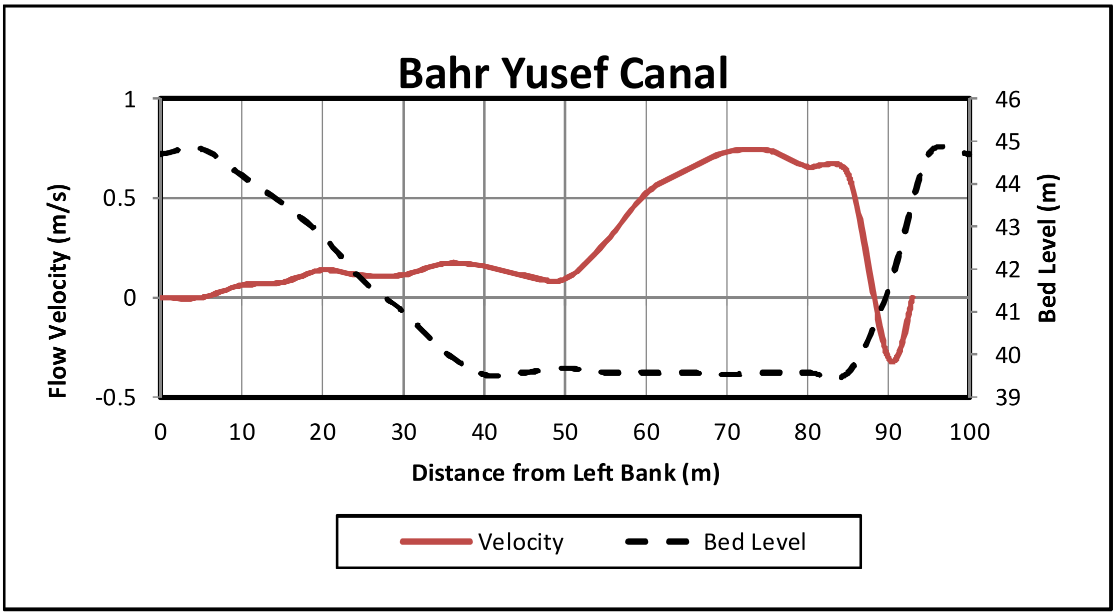


Figure (4): Bottom Flow Velocity Distribution at Cross Section 2

SECTION # 3

OVER_FLOW

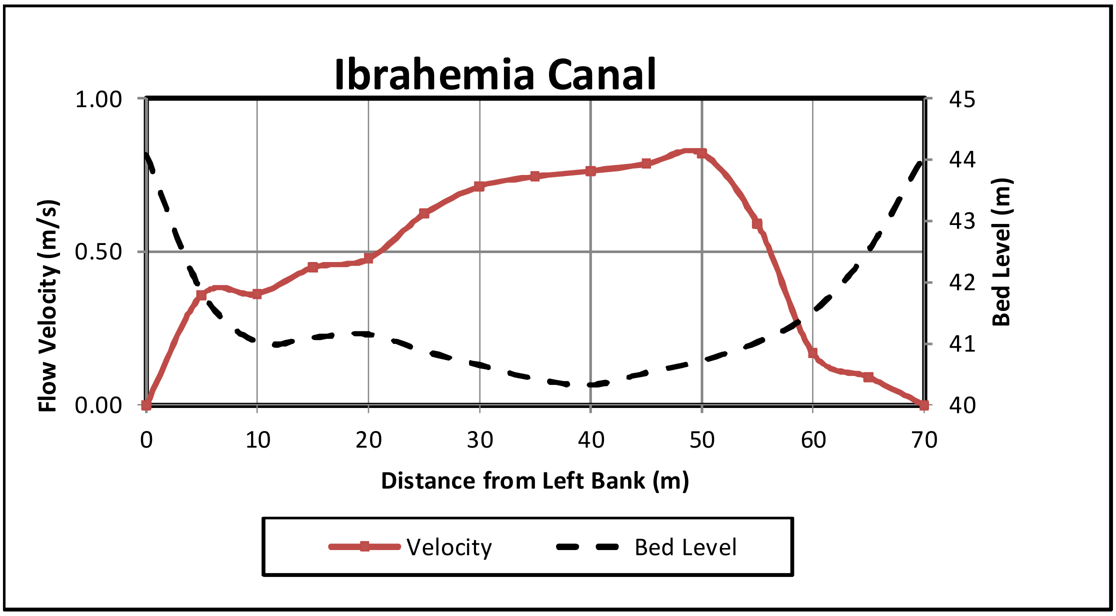


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 3

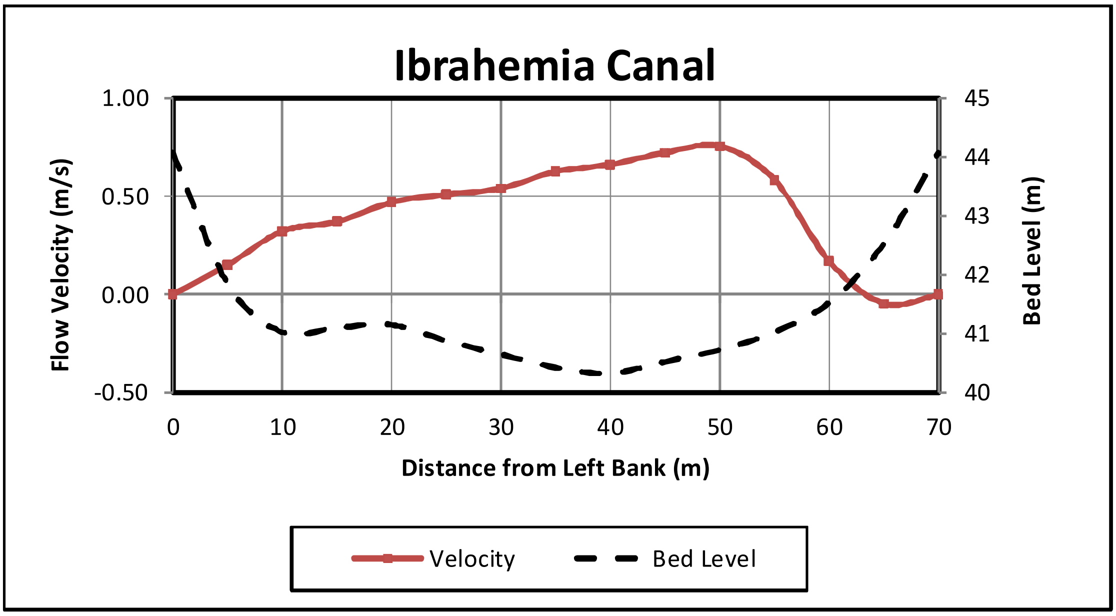


Figure (2): Bottom Flow Velocity Distribution at Cross Section 3

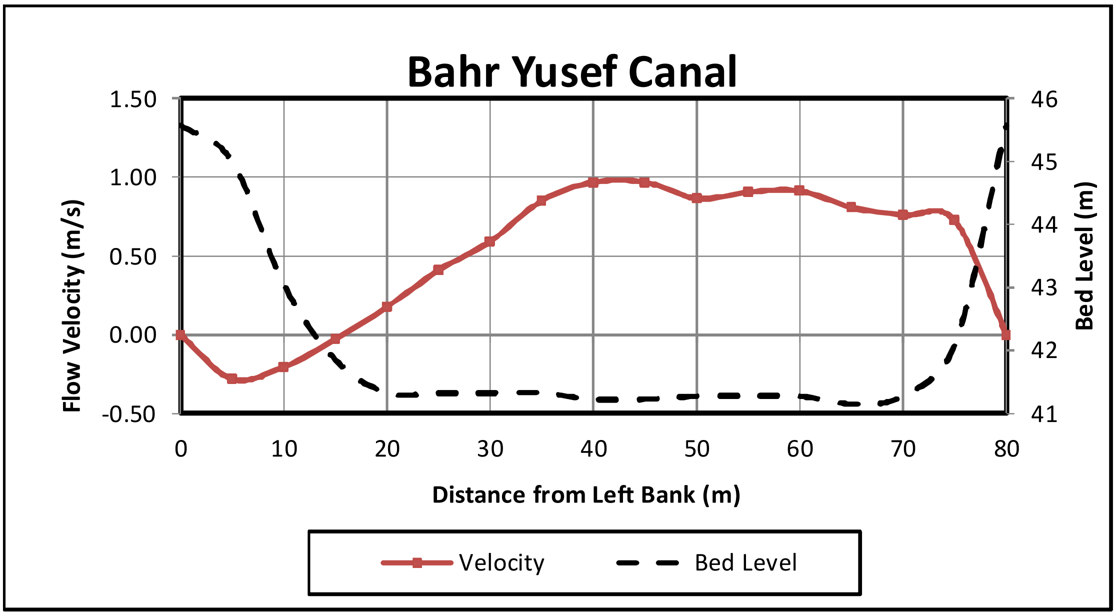


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 3

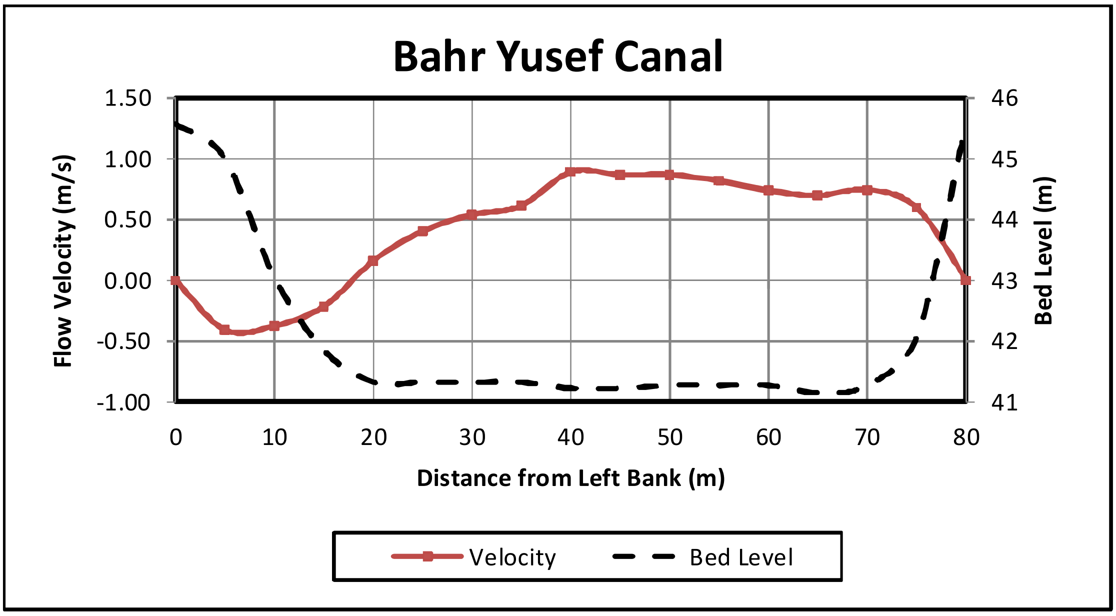


Figure (4): Bottom Flow Velocity Distribution at Cross Section 3

MINIMUM DISCHARGES

SECTION # 1

OVER_FLOW

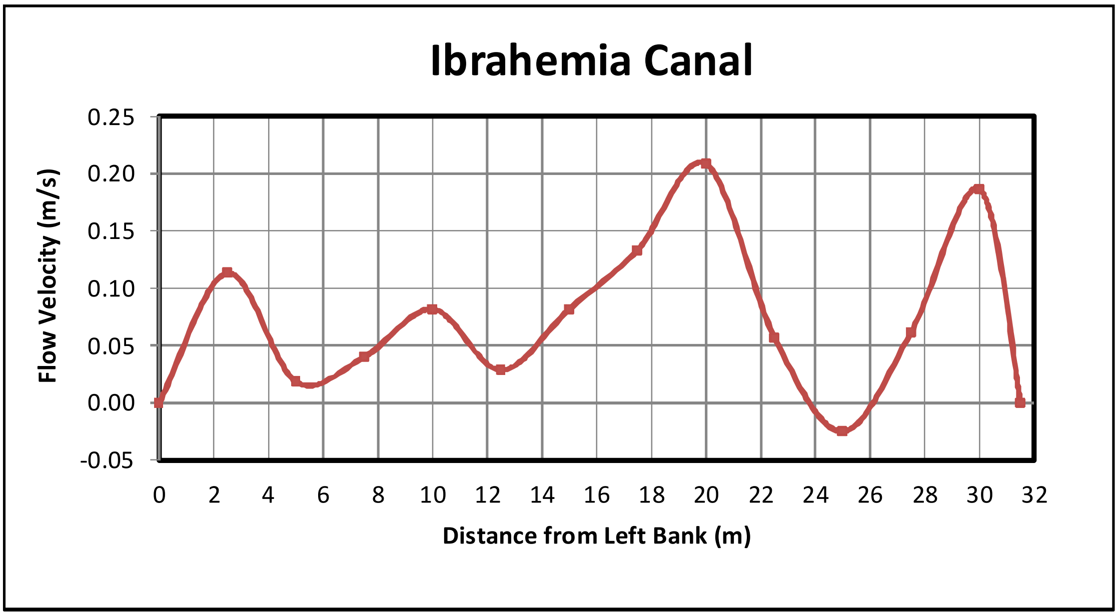


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 1

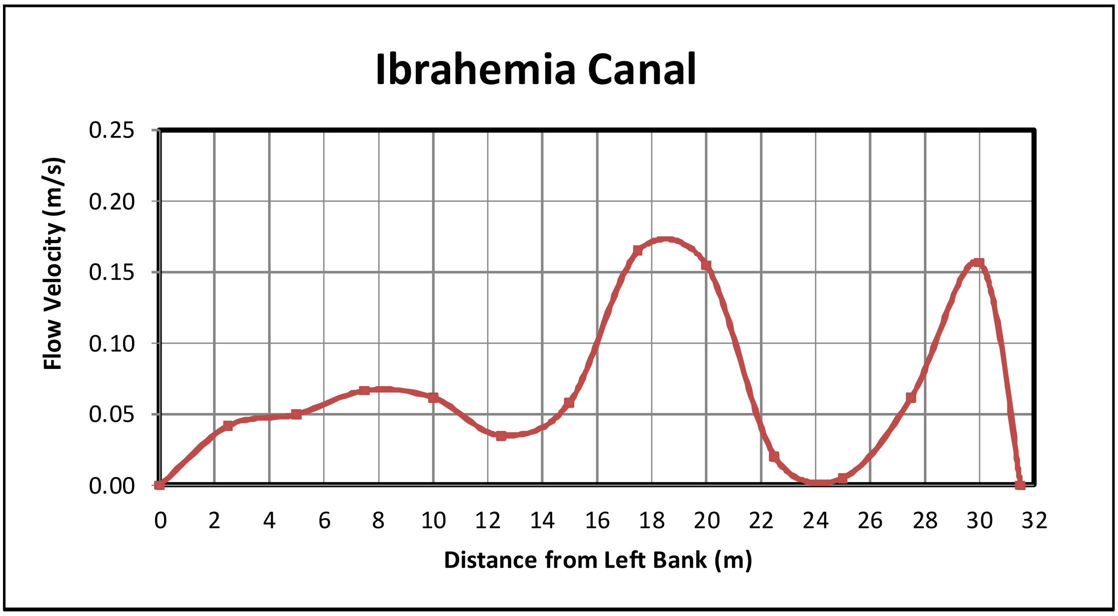


Figure (2): Bottom Flow Velocity Distribution at Cross Section 1

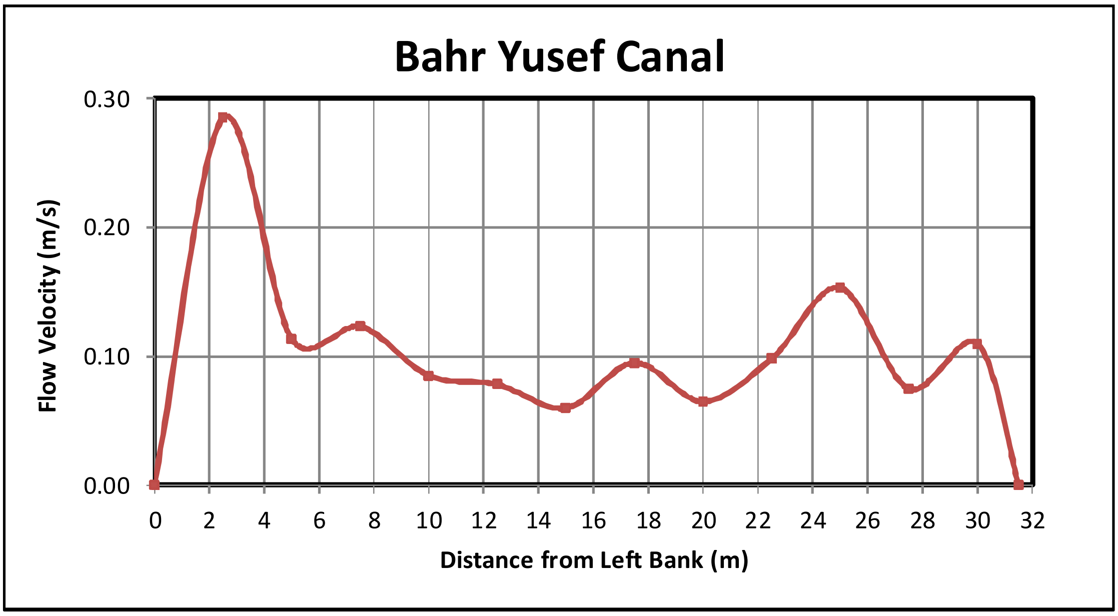


Figure (2): Flow Velocity Distribution at Mid Depth of Cross Section 1

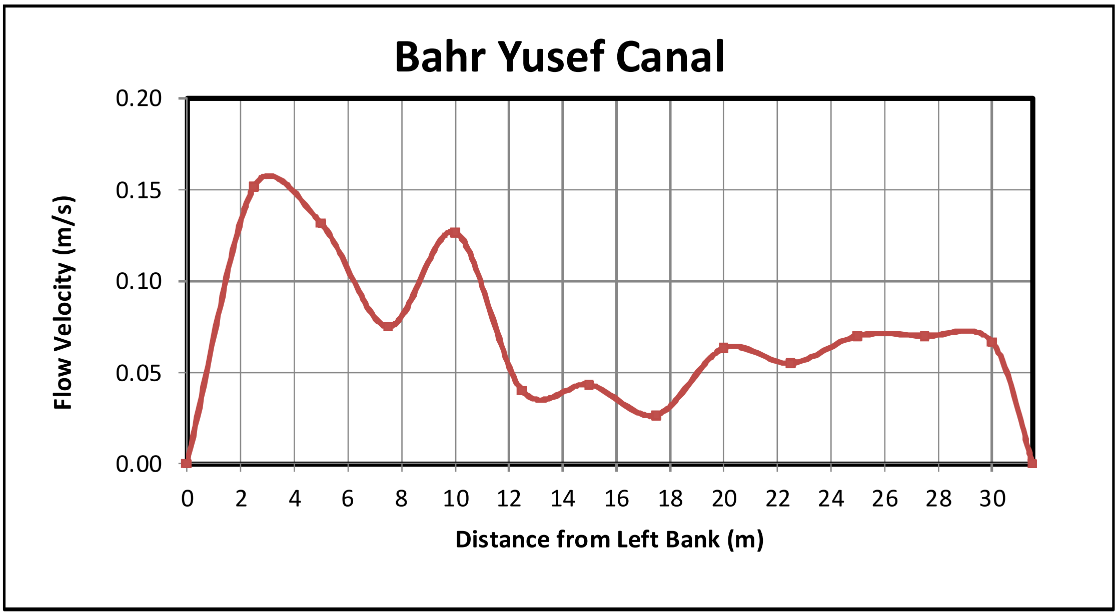


Figure (4): Bottom Flow Velocity Distribution at Cross Section 1

SECTION # 2

OVER_FLOW

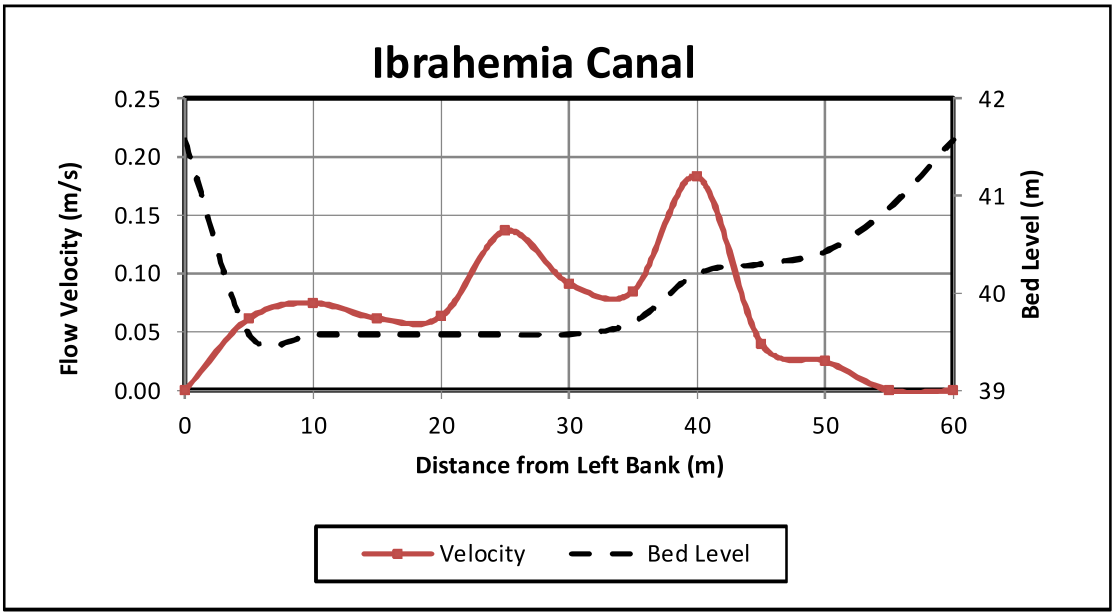


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 2

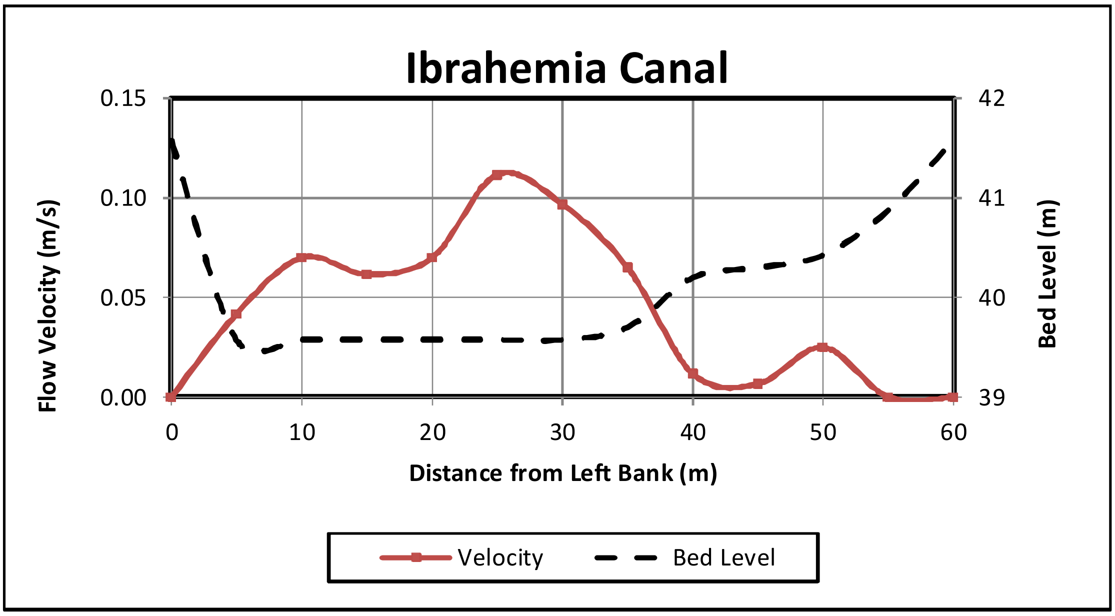


Figure (2): Bottom Flow Velocity Distribution at Cross Section 2

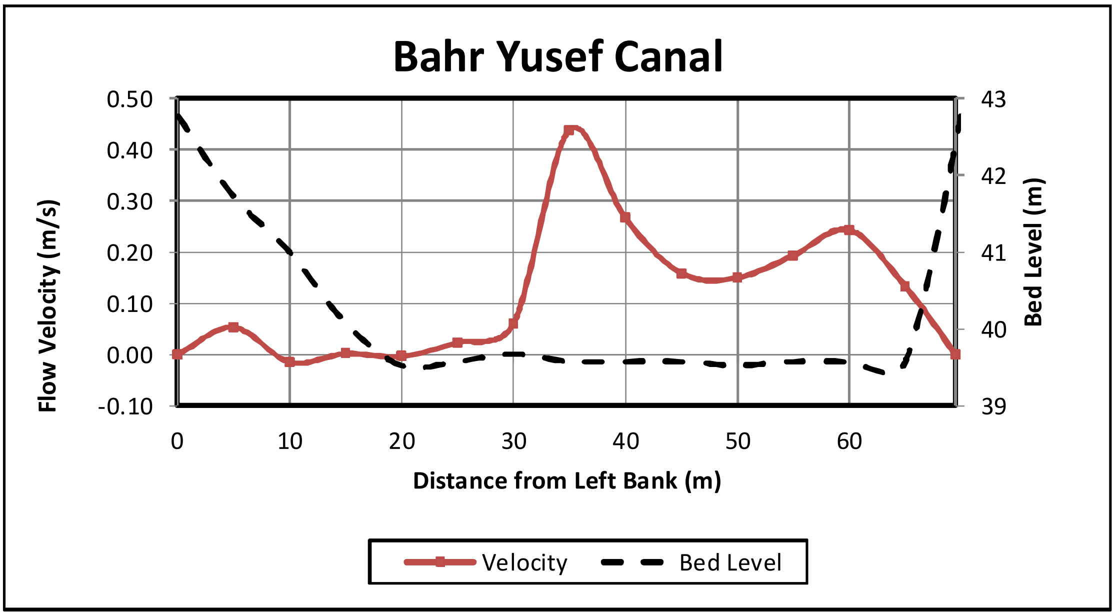


Figure (3): Flow Velocity Distribution at Mid Depth of Cross Section 2

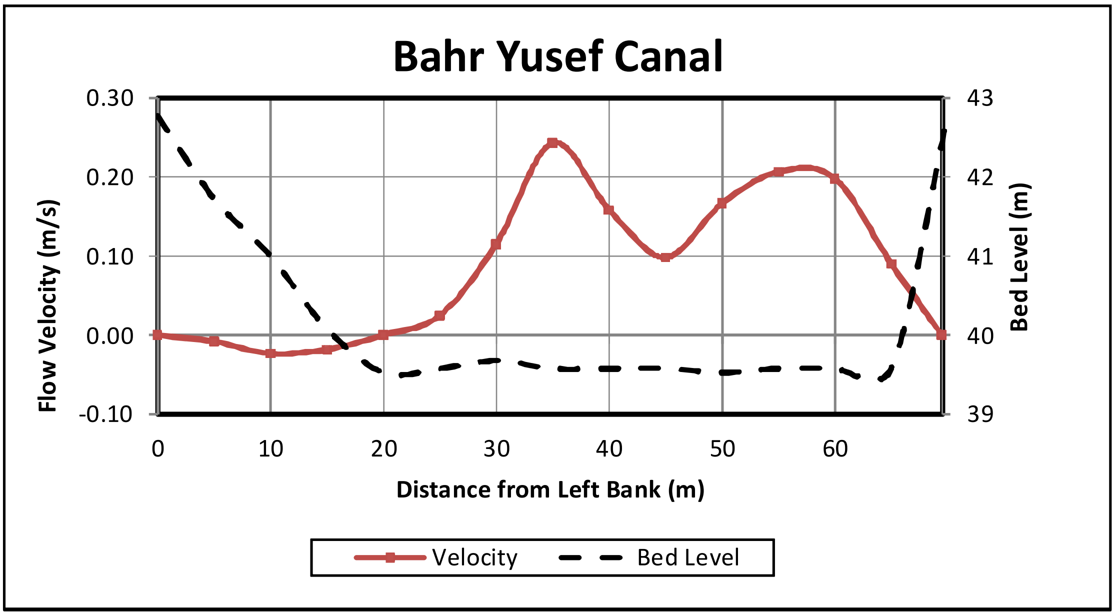


Figure (4): Bottom Flow Velocity Distribution at Cross Section 2

SECTION # 3

OVER_FLOW

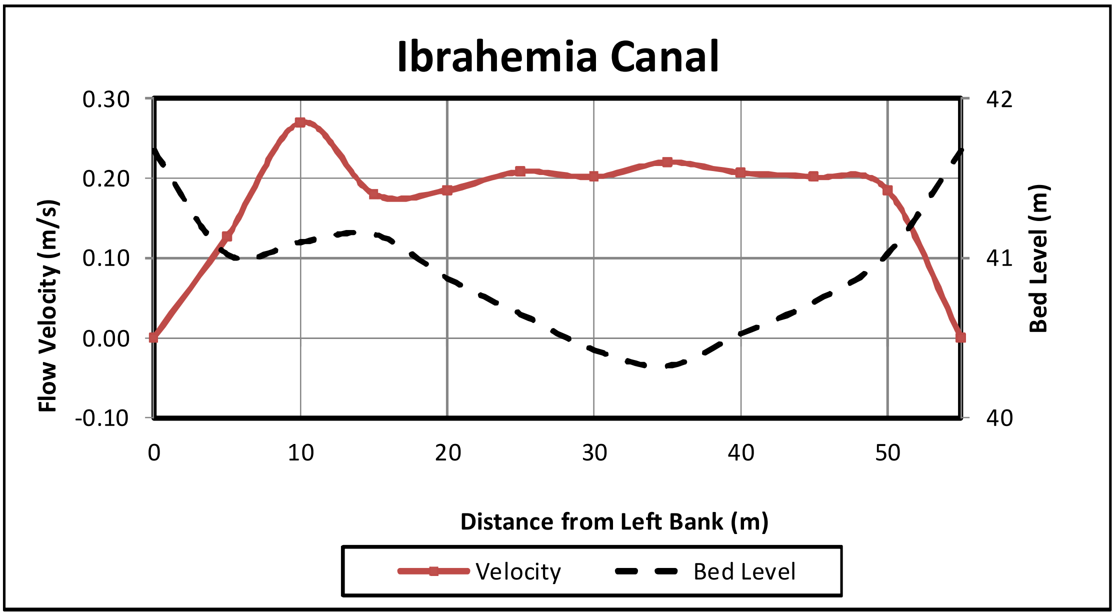


Figure (1): Flow Velocity Distribution at Mid Depth of Cross Section 3

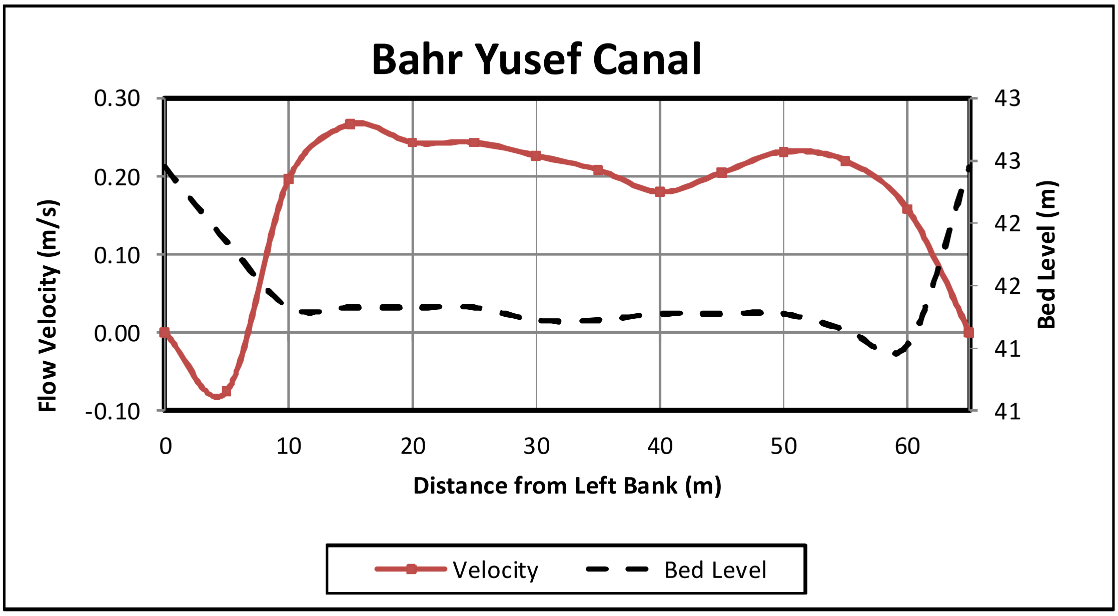
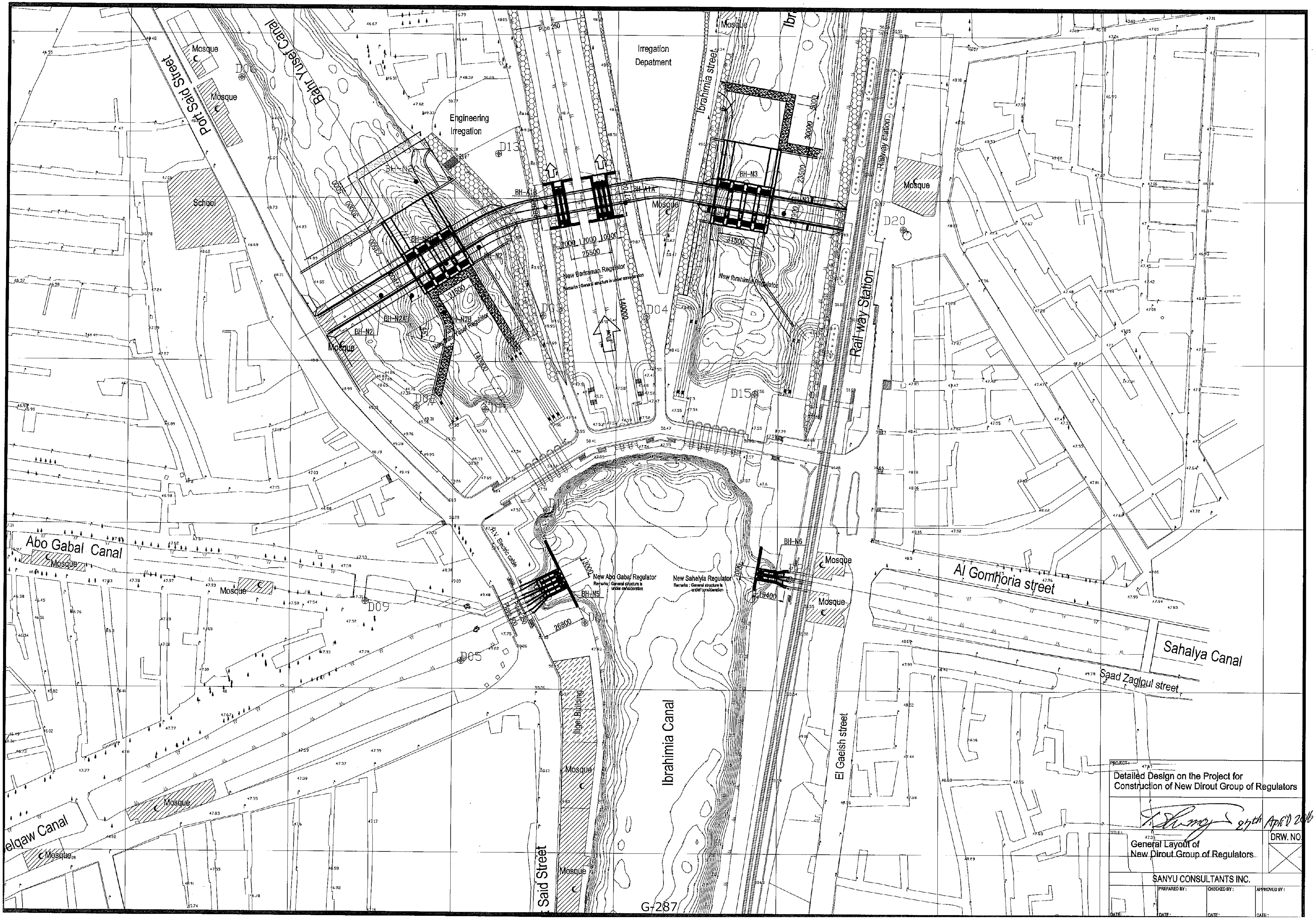
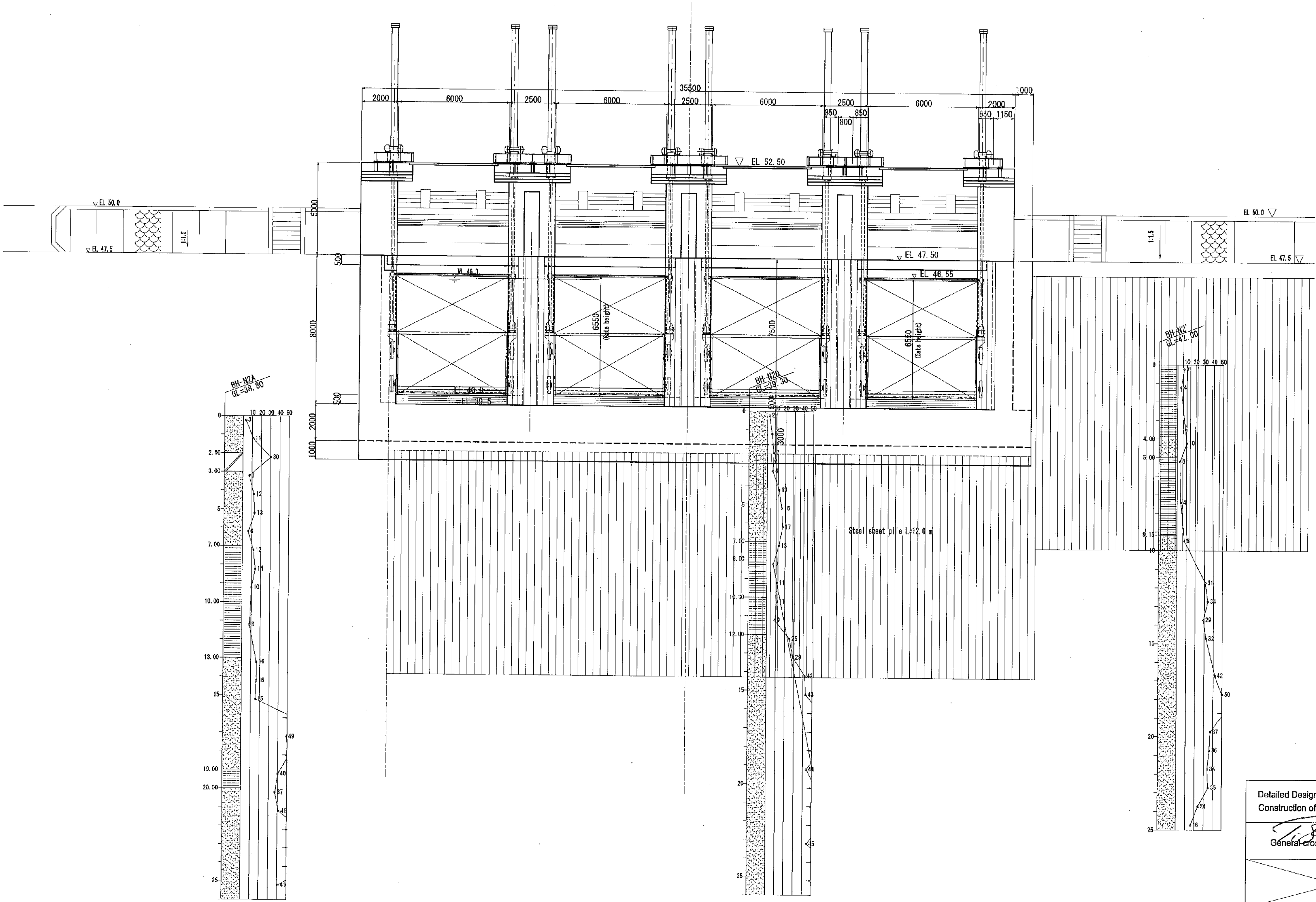


Figure (2): Flow Velocity Distribution at Mid Depth of Cross Section 3


Port Said Street
Mosque
Bahr Yusef Canal
Engineering
Irregation
Irregation
Depatment
Ibrahimia street
Railway station
School
New Badraman Regulator
Remarks : General structure is under consideration
New Ibrahimia Regulator
New Bahr Yusef Regulator
Railway Station
FLOW
BH-N2C
BH-N2
BH-N2A
BH-N2B
BH-A1B
BH-A1A
BH-N3
D20
D13
D02
D04
D15
D11
D09
D05
D01
Abo Gabal Canal
H.V. Electric cable
New Abo Gabal Regulator
Remarks : General structure is under consideration
BH-N5
New Sahalyia Regulator
Remarks : General structure is under consideration
BH-N6
Al Gomhoria street
Sahalya Canal
Saad Zaghloul street
Ibrahimia Canal
El Gaeish street
Said Street
elqaw Canal
G-287
PROJECT :
Detailed Design on the Project for
Construction of New Dirout Group of Regulators
27th April 2016
TITLE :
General Layout of
New Dirout Group of Regulators
DRW. NO.
SANYU CONSULTANTS INC.
PREPARED BY :
CHECKED BY :
APPROVED BY :
DATE :
DATE :
DATE :
DATE :

Standard section of the Bahr Yusef Regulator (Upstream)



Detailed Design on the Project for
Construction of the New Dirout Group of Regulators

General cross section of Bahr Yusef Regulator

27th April 2016

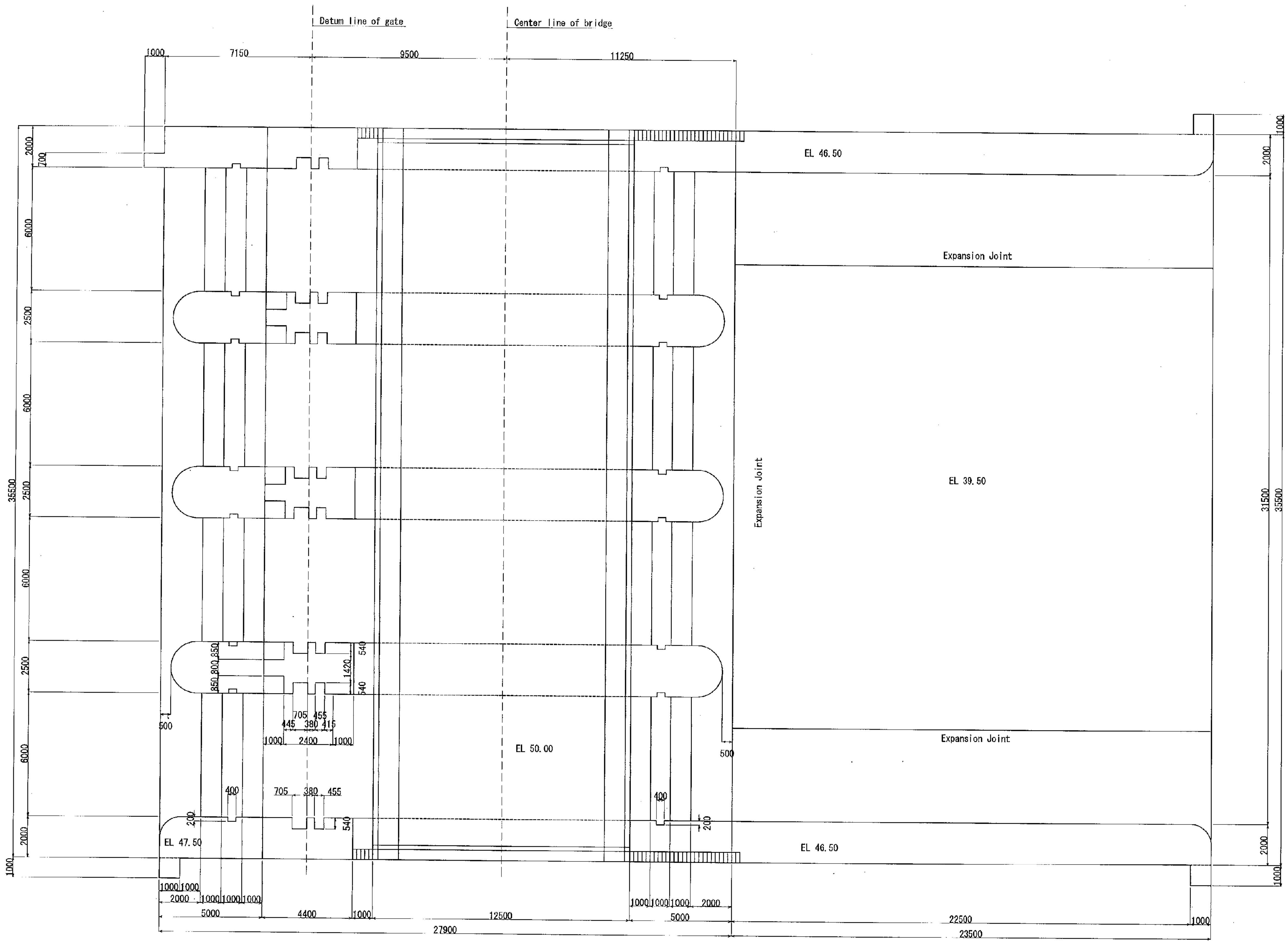
DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

Bahr-Yusef Reg

S=1:100



Ministry of Water Resources and Irrigation
Revisers Ground Barrage Sector
The Arab Republic of Egypt

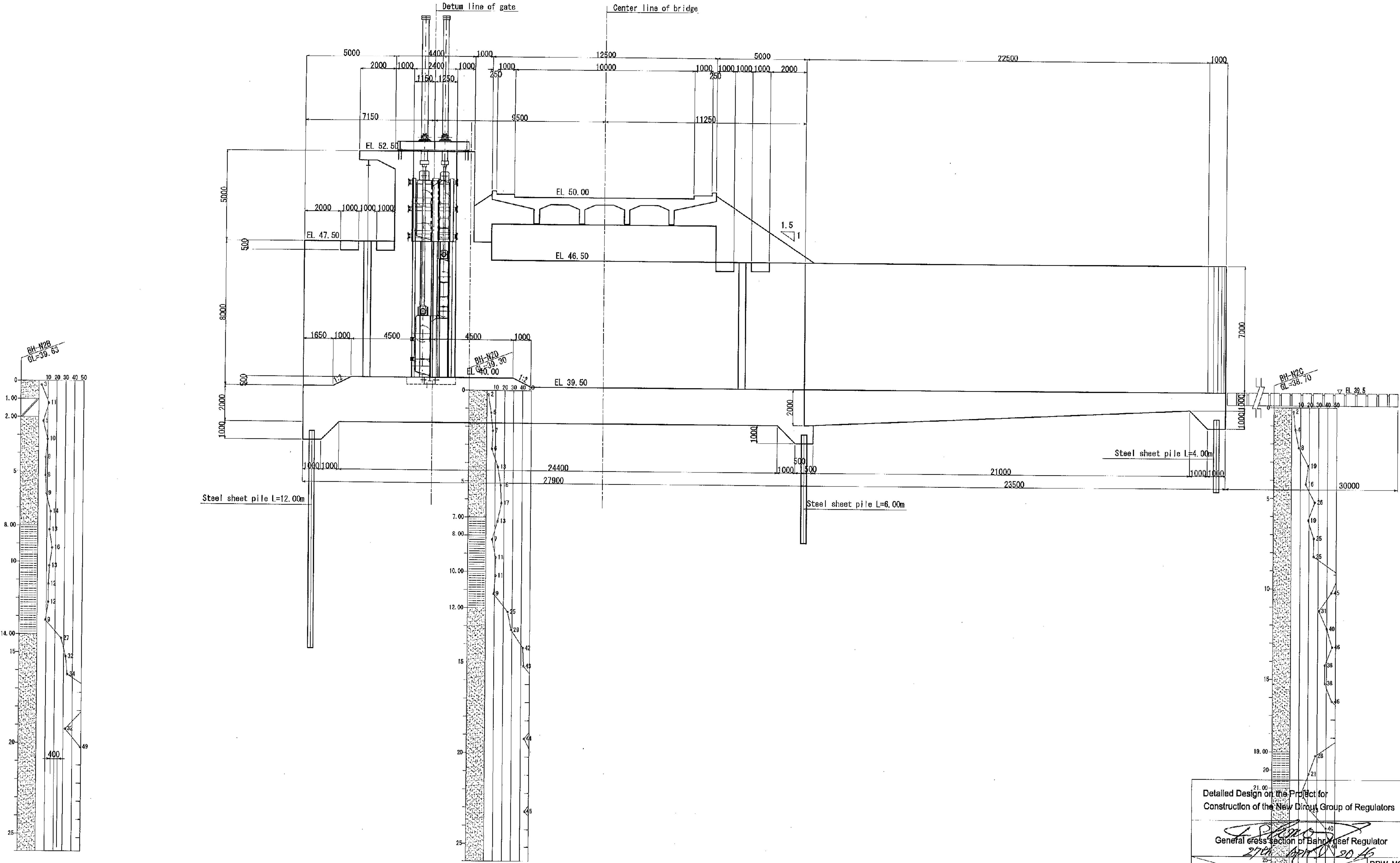
DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY: CHECKED BY: APPROVED BY:

DATE: DATE: DATE: DATE:

Standard section of the middle pier on Bahr Yusef Regulator



Detailed Design on the Project for Construction of the New Dirout Group of Regulators

General cross section of Bahr Yusef Regulator

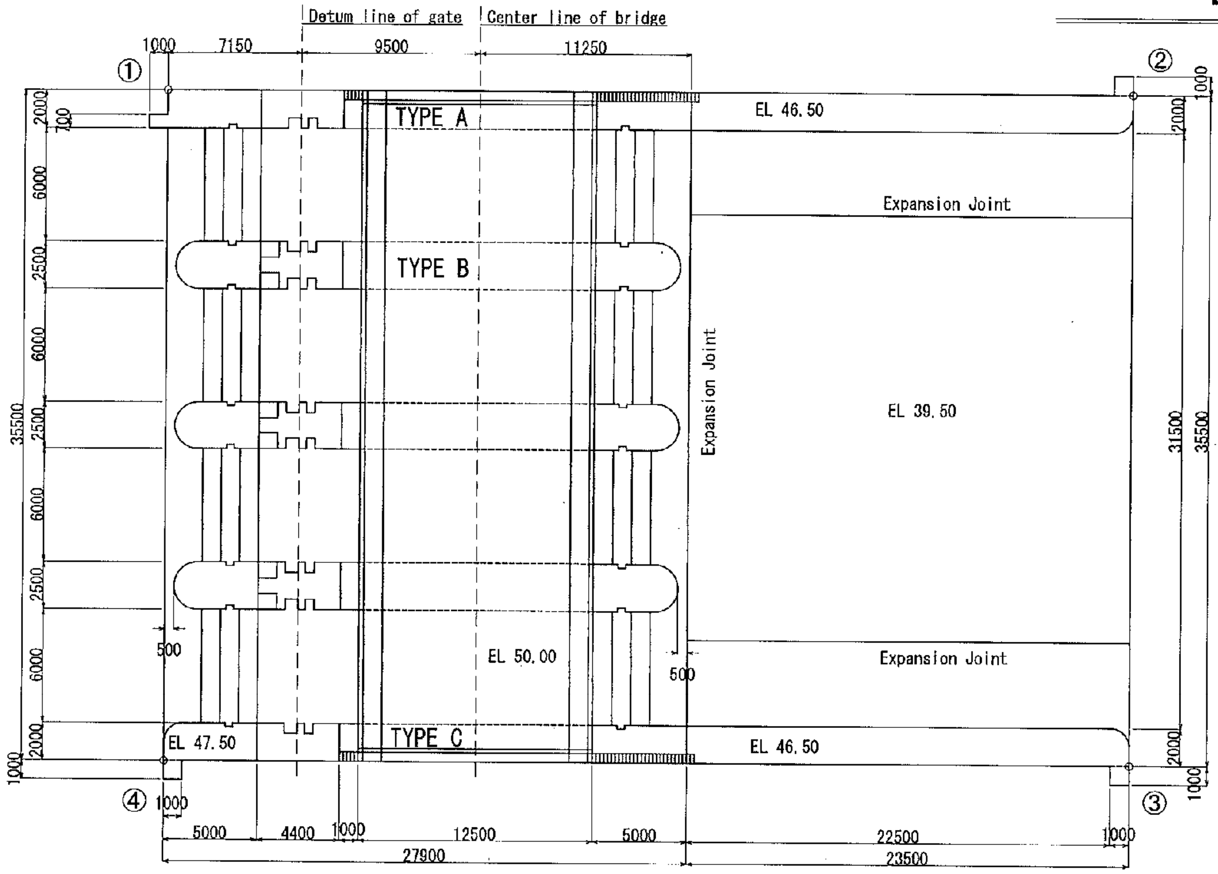
DRW. NO.

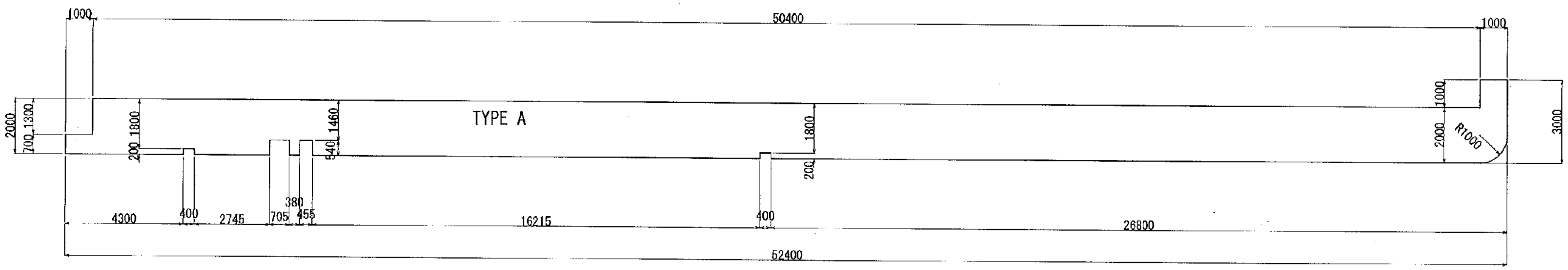
SANYU CONSULTANTS INC.

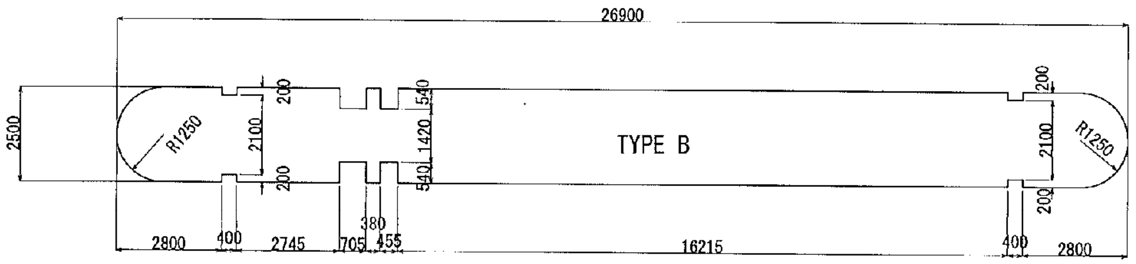
PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

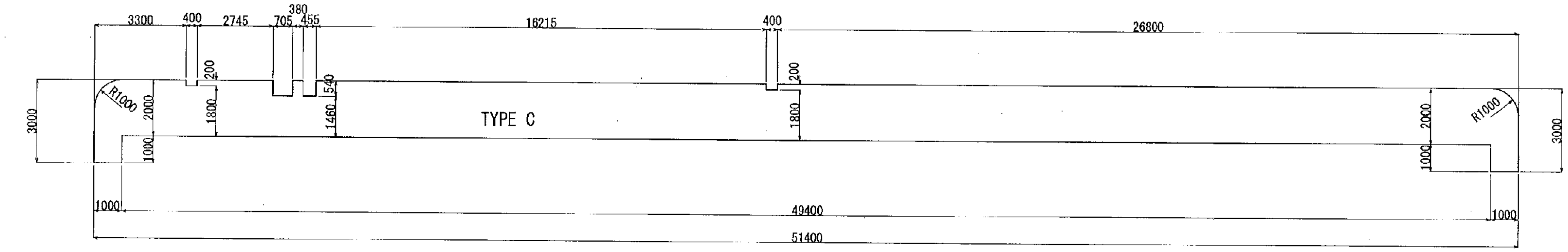
Bahr-Yusef Reg

S=1:100









Coordinates

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②	283754.832	3050384.679
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④	283812.096	3050359.718

Ministry of Water Resources and Irrigation
Reviseers Ground Barrage Sector
The Arab Republic of Egypt

27th April 2016

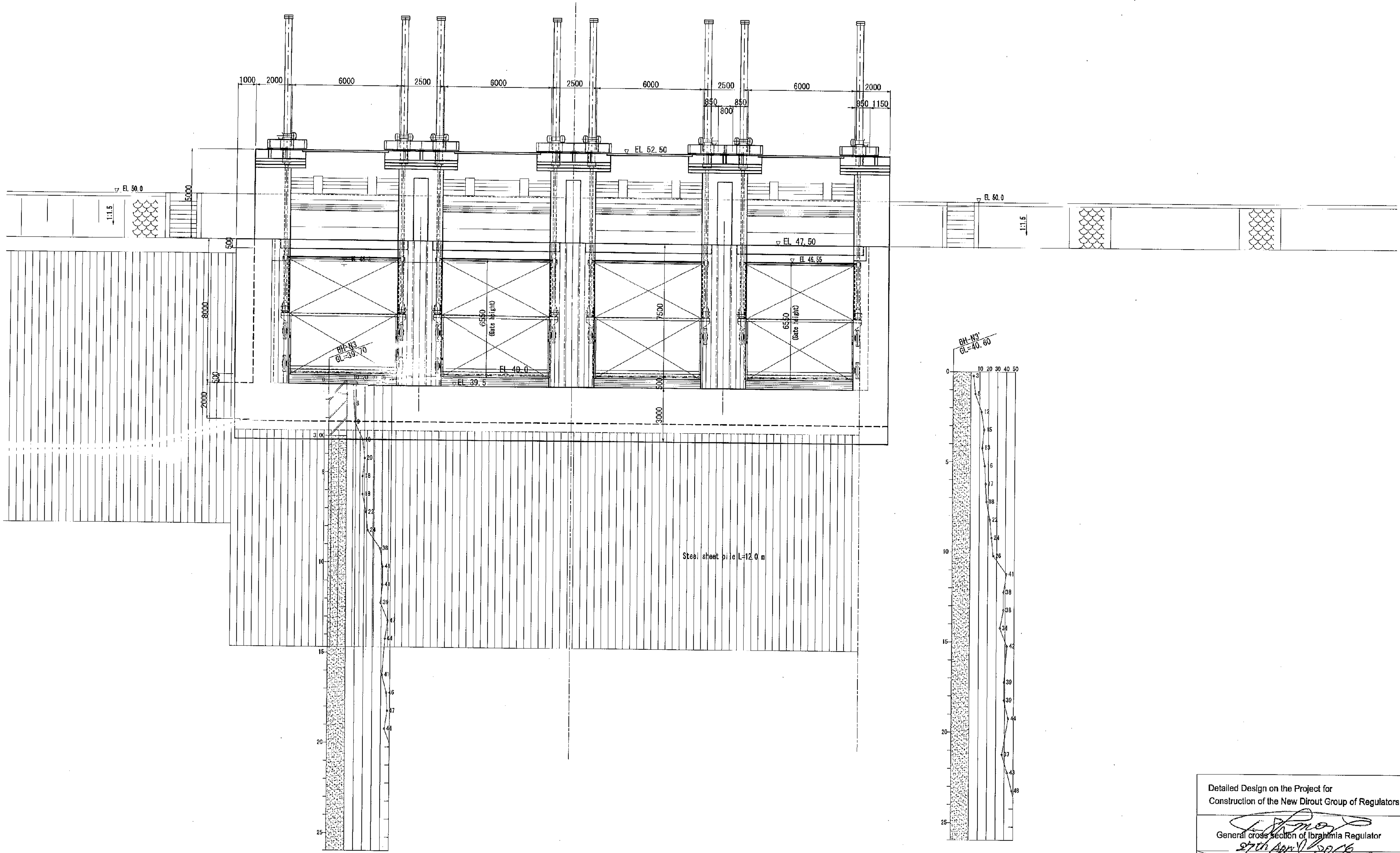
DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY: | CHECKED BY: | APPROVED BY:

DATE: | DATE: | DATE: | DATE:

Standard section of the Ibrahimia Regulator (Upstream)



Detailed Design on the Project for
Construction of the New Dirout Group of Regulators

General cross section of Ibrahimia Regulator

27th April 2016

DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

Ibrahimia Reg

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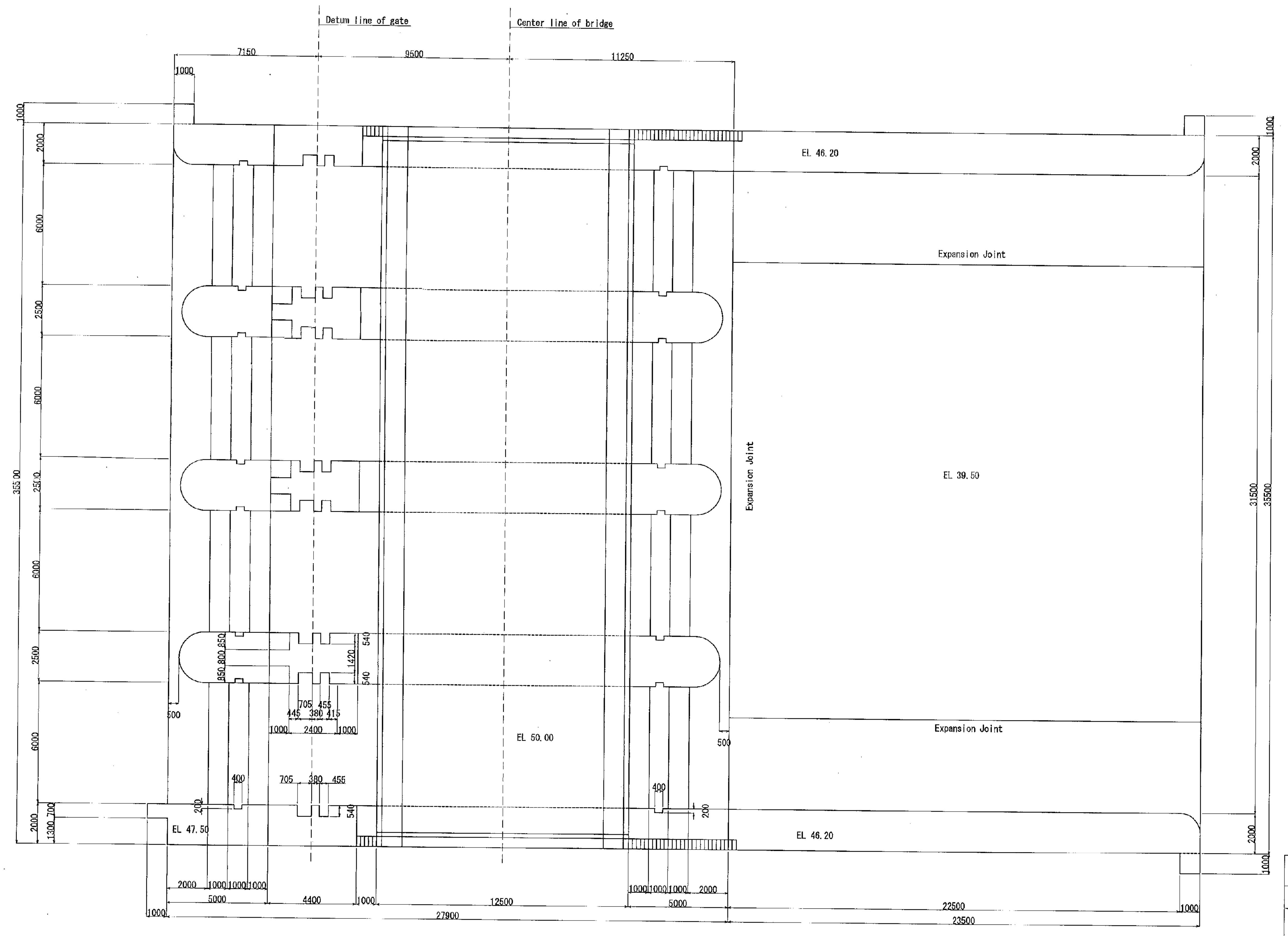


Ministry of Water Resources and Irrigation
Revisors Ground Barrage Sector
The Arab Republic of Egypt

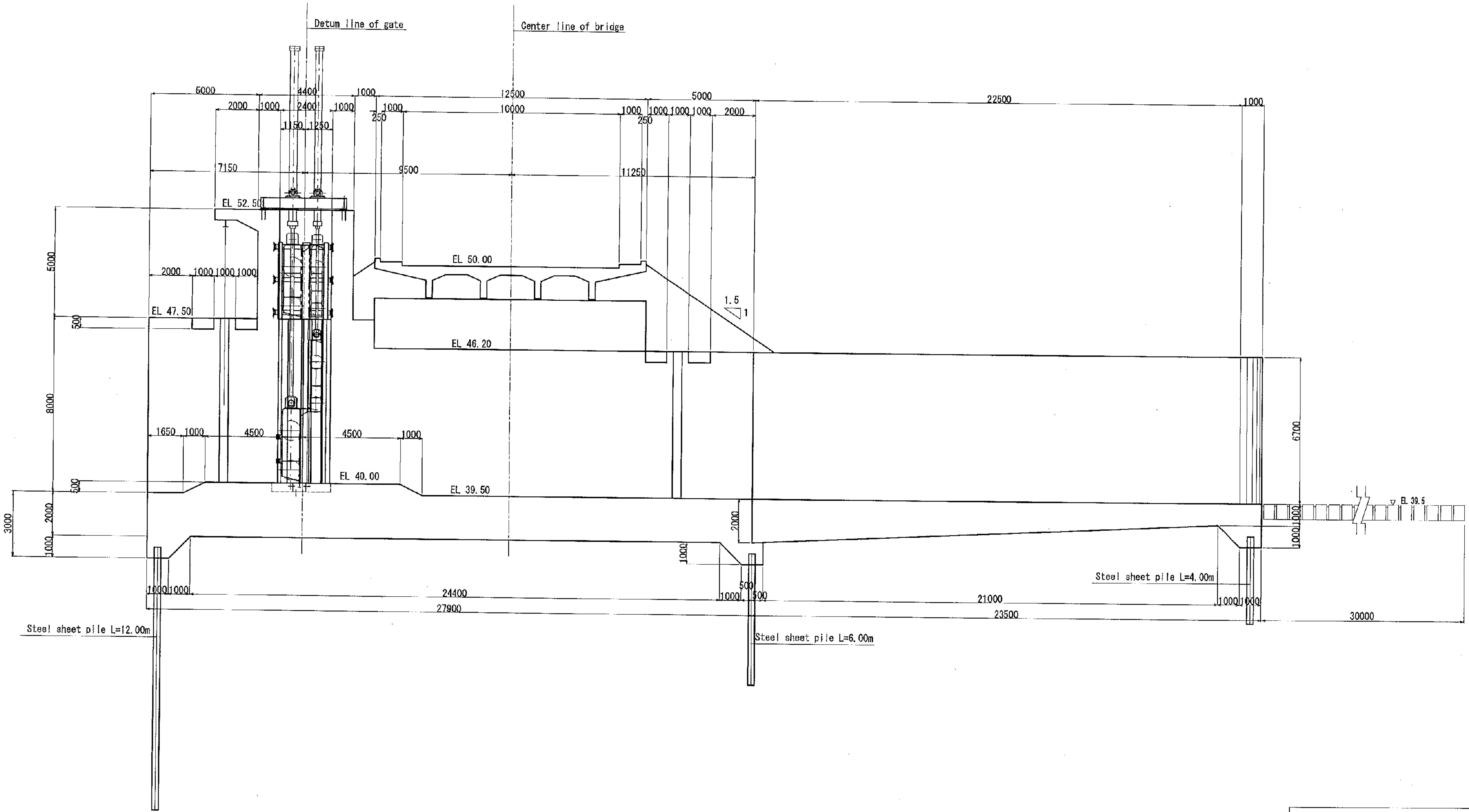
DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY: | CHECKED BY: | APPROVED BY:

DATE: | DATE: | DATE: | DATE:

Standard section of the middle pier on Ibrahimia Regulator



Detailed Design on the Project for
Construction of the New Dirout Group of Regulators

General cross section of Ibrahimia Regulator

27th April 2016

DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

Ibrahimia Reg

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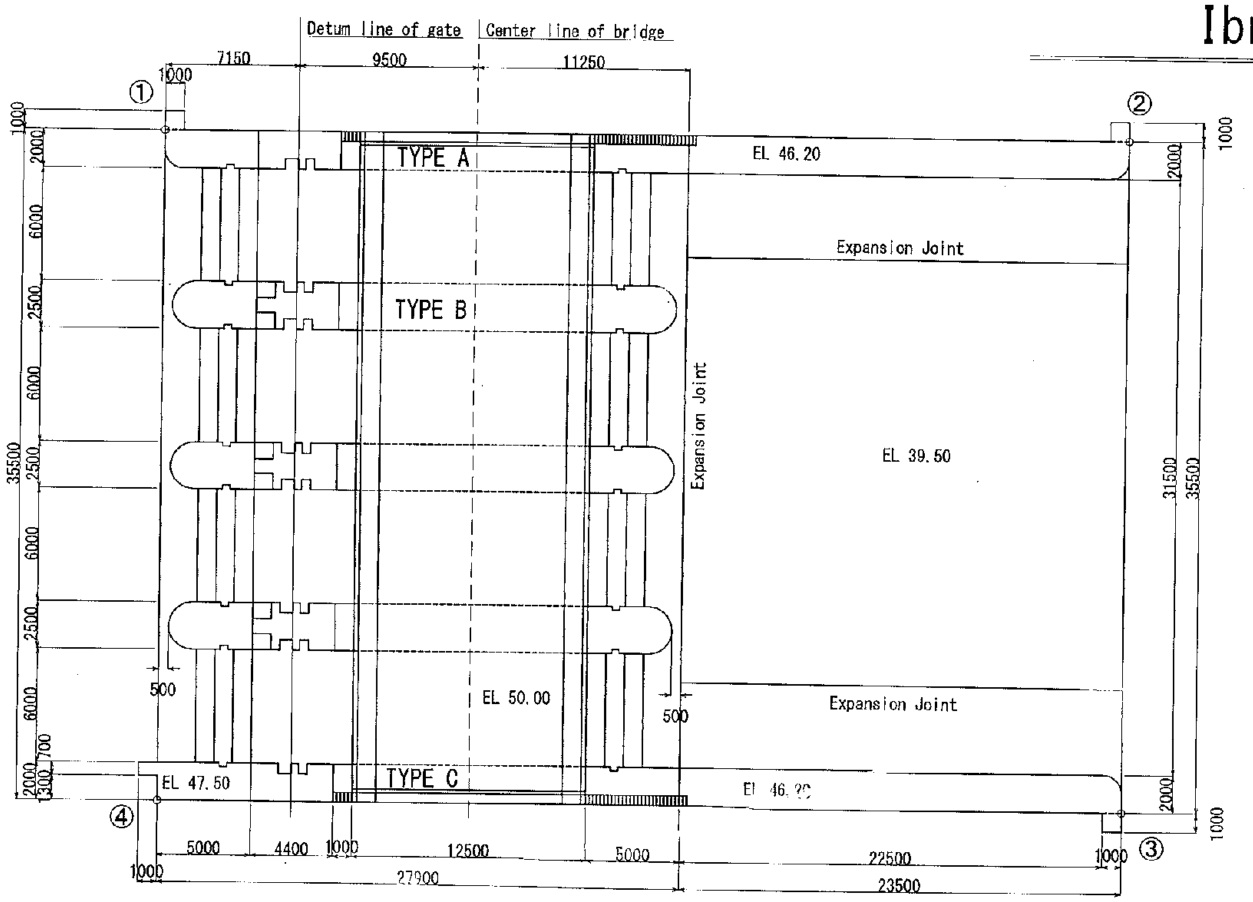

Coordinates

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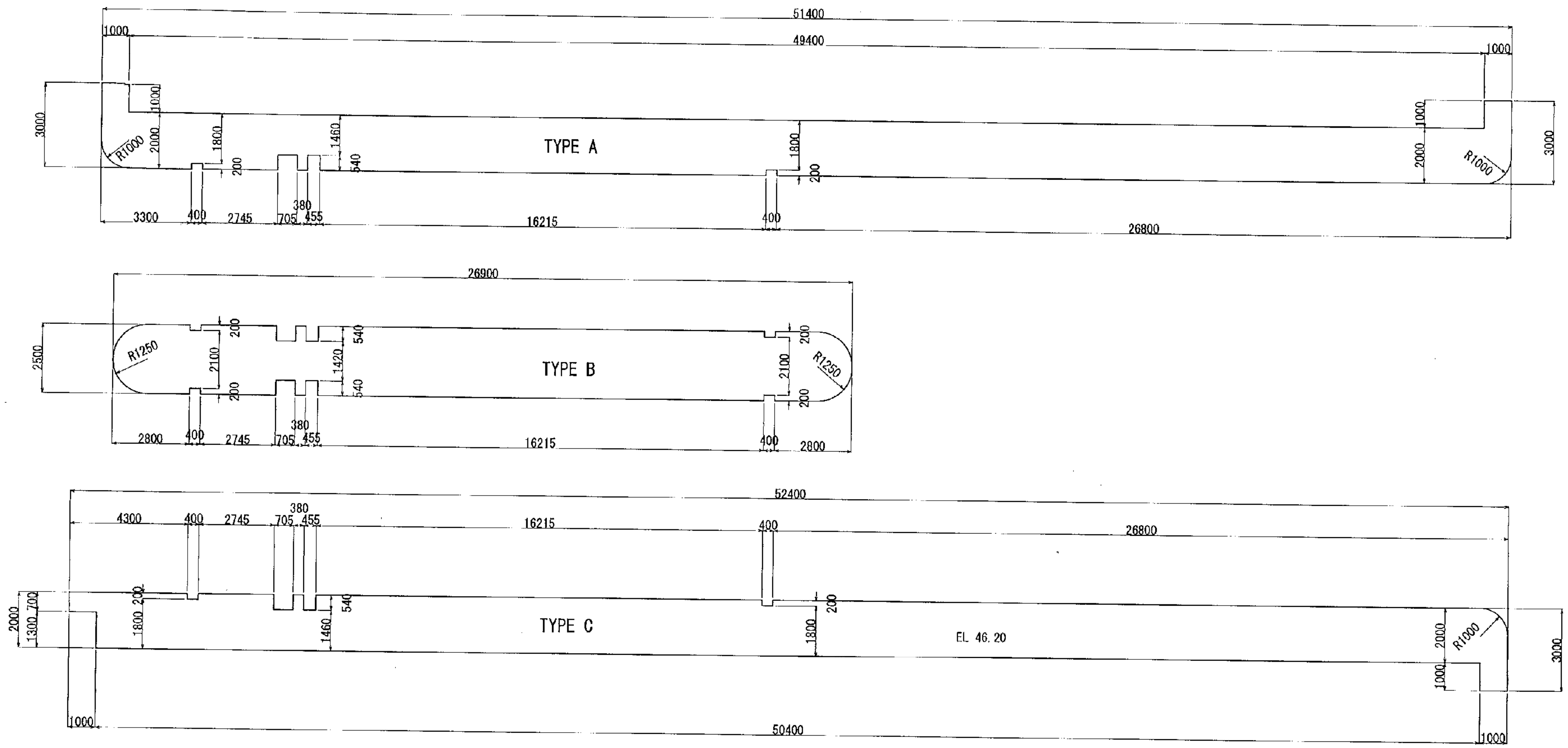


Ministry of Water Resources and Irrigation
Revisers Ground Barrage Sector
The Arab Republic of Egypt

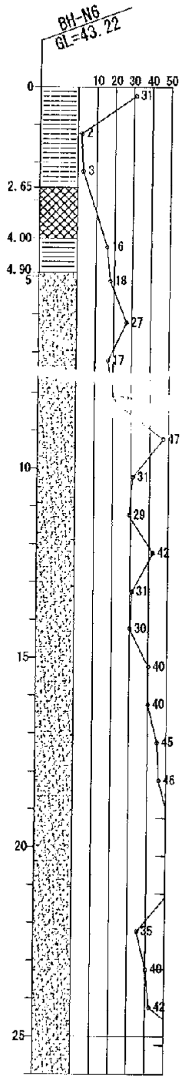
27th April 2016

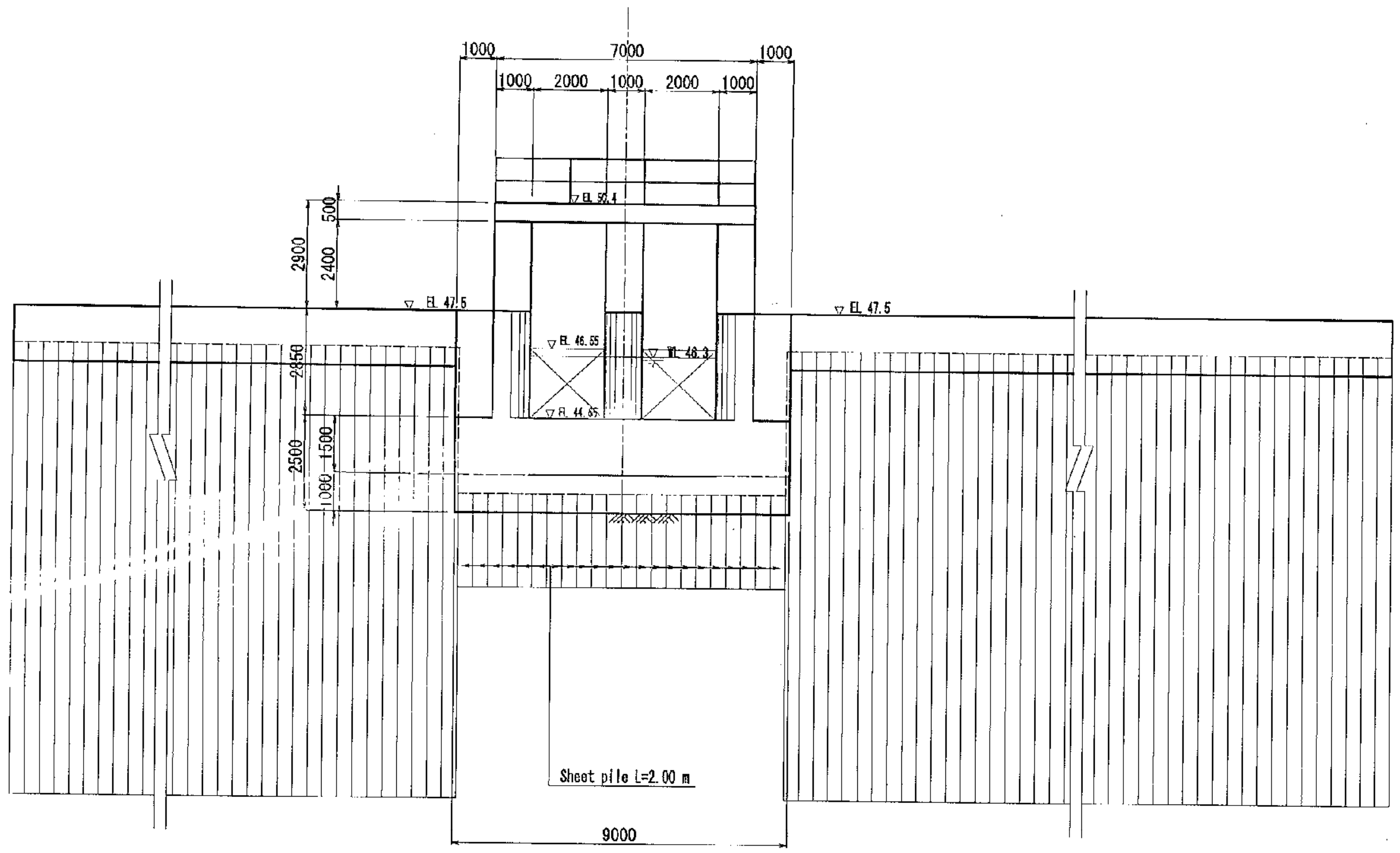
DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

Standard section of the Sahelyia Regulator (Upstream)





Ministry of Water Resources and Irrigation
Revisers Ground Barrage Sector
The Arab Republic of Egypt

27th April 2016

DRW. NO.

SANYU CONSULTANTS INC.

PREPARED BY:	CHECKED BY:	APPROVED BY:
DATE:	DATE:	DATE:

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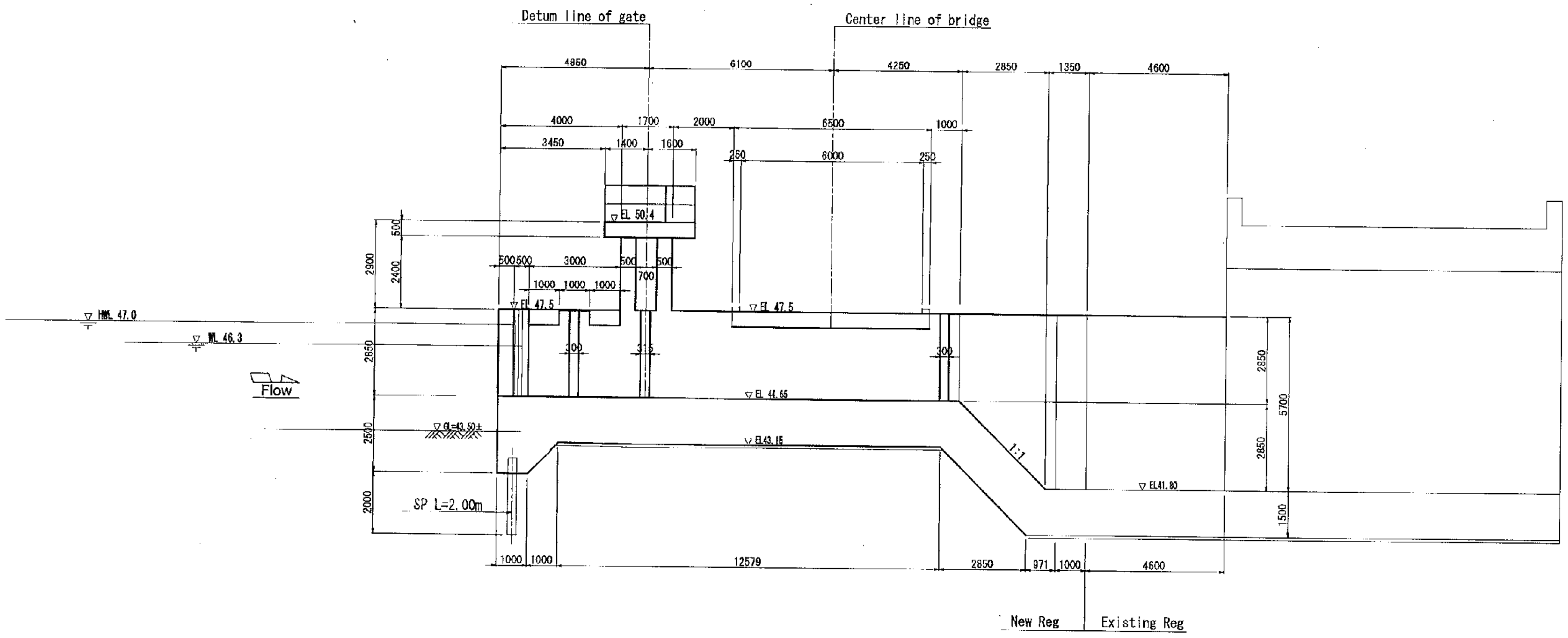
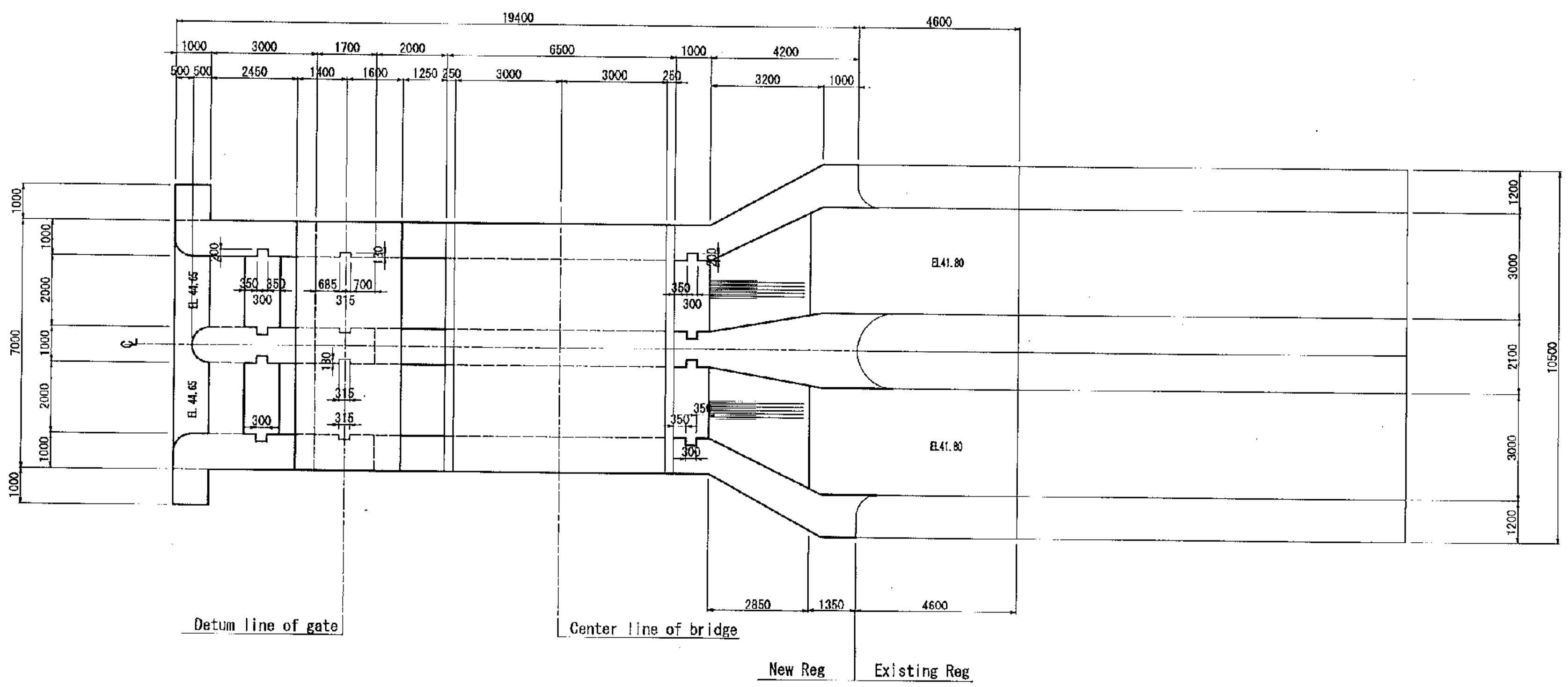
Sahelyia





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Revisers Ground Barrage Sector
The Arab Republic of Egypt

27th April 2016

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SANYU CONSULTANTS INC.

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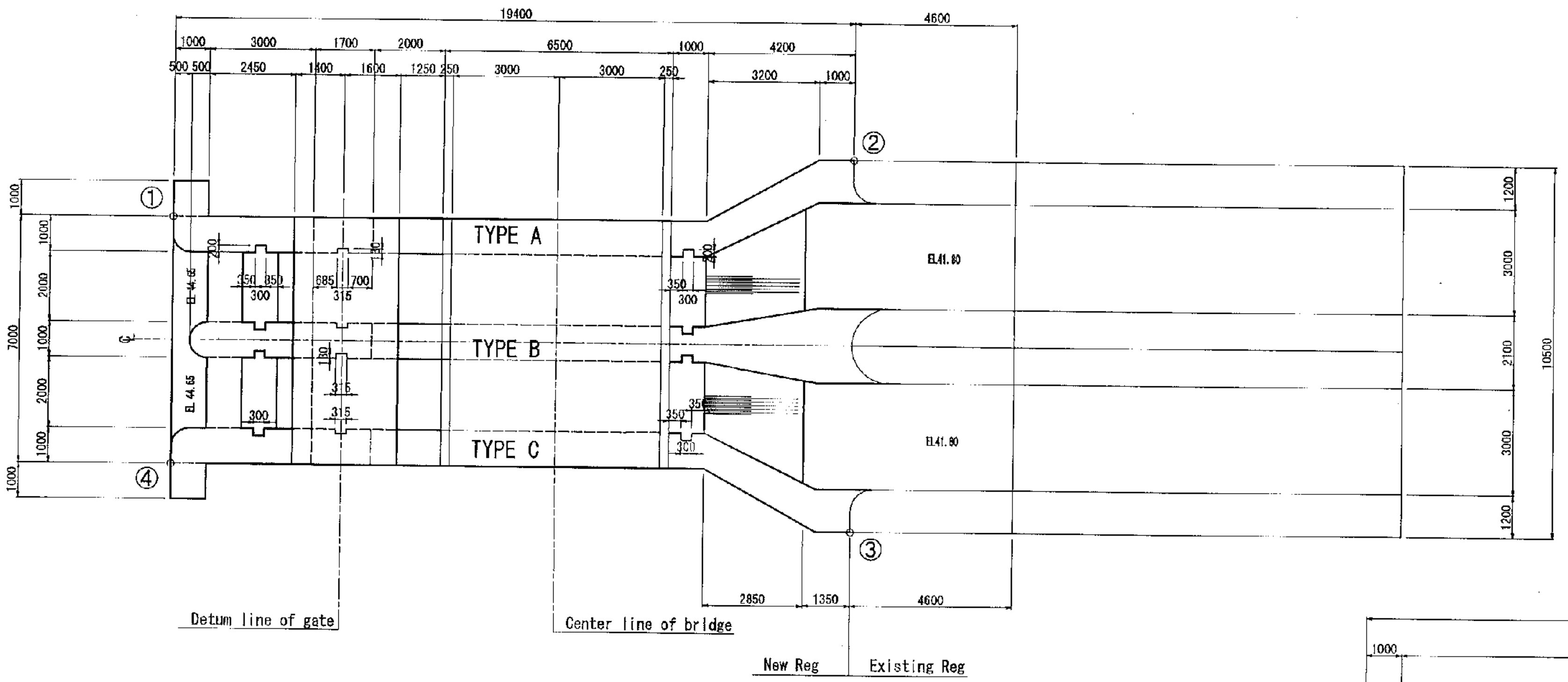

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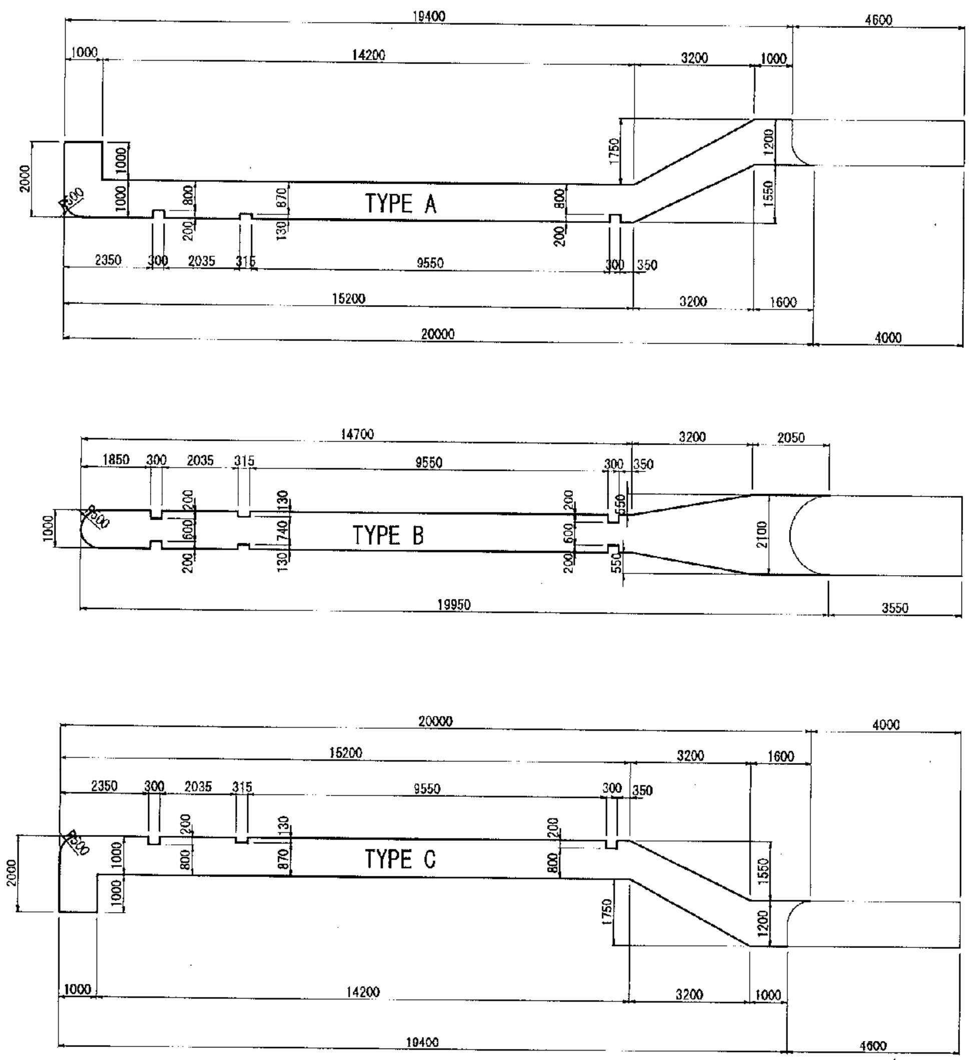

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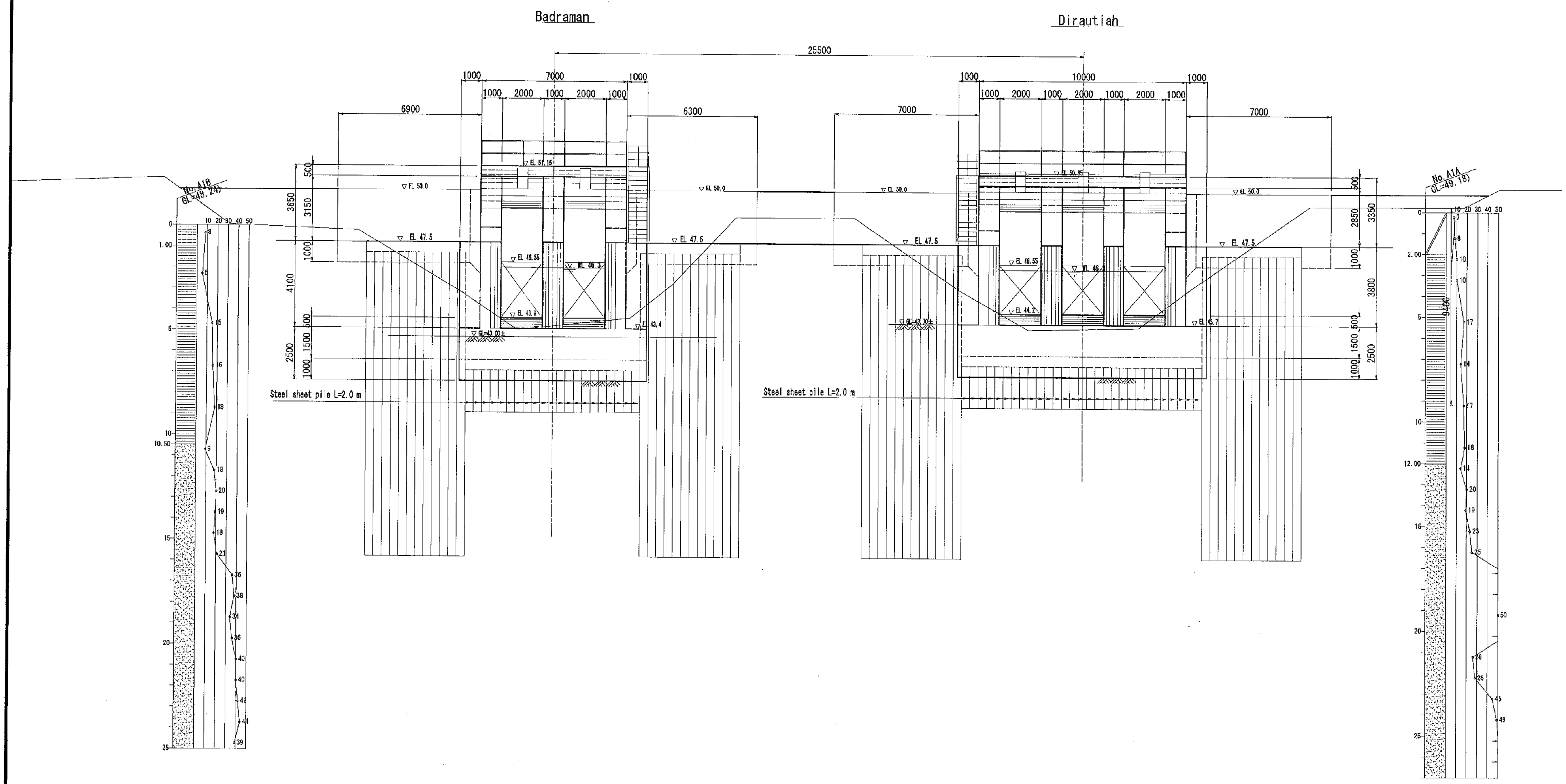
Standard section of New Badraman Regulator (Upstream)



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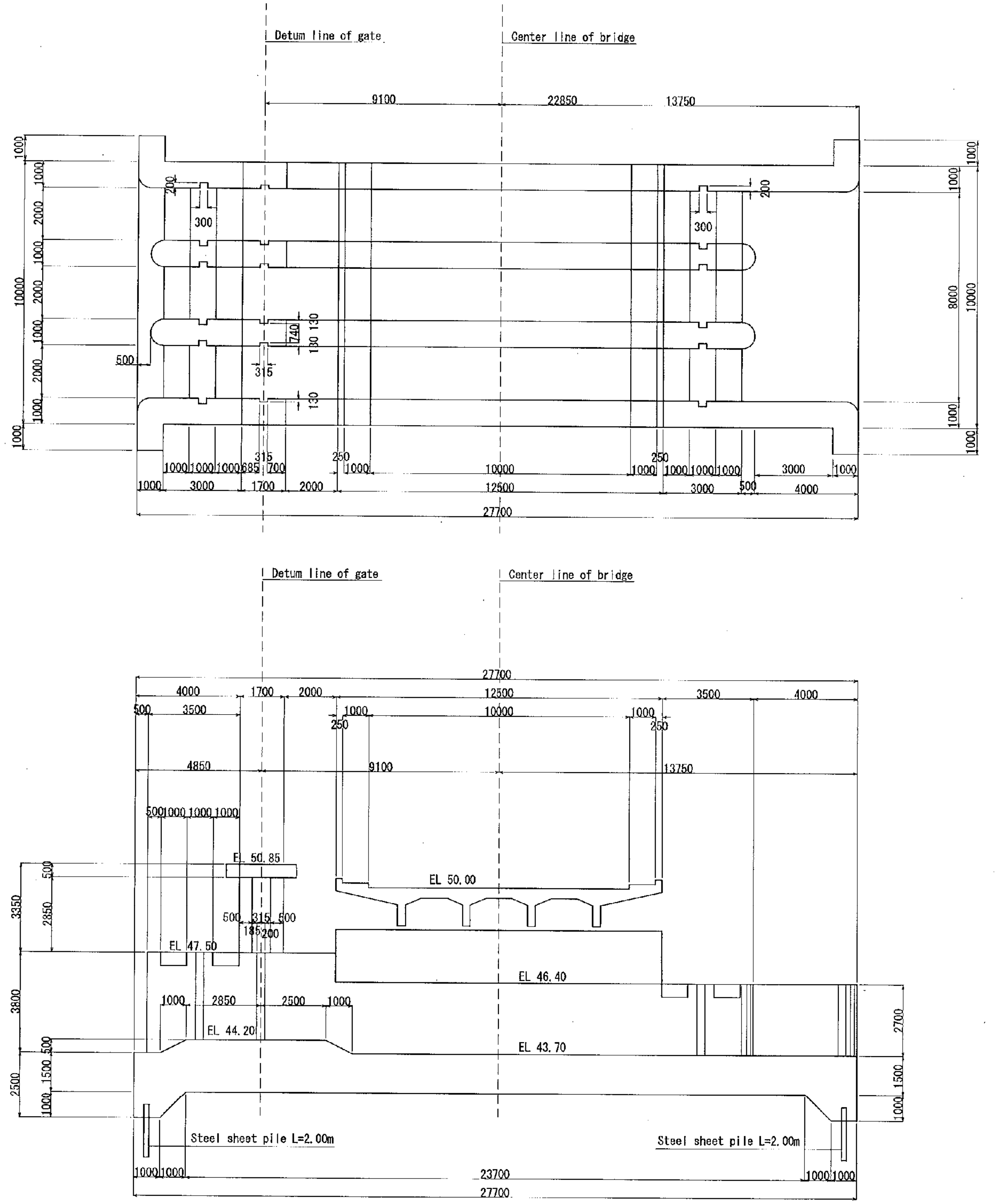

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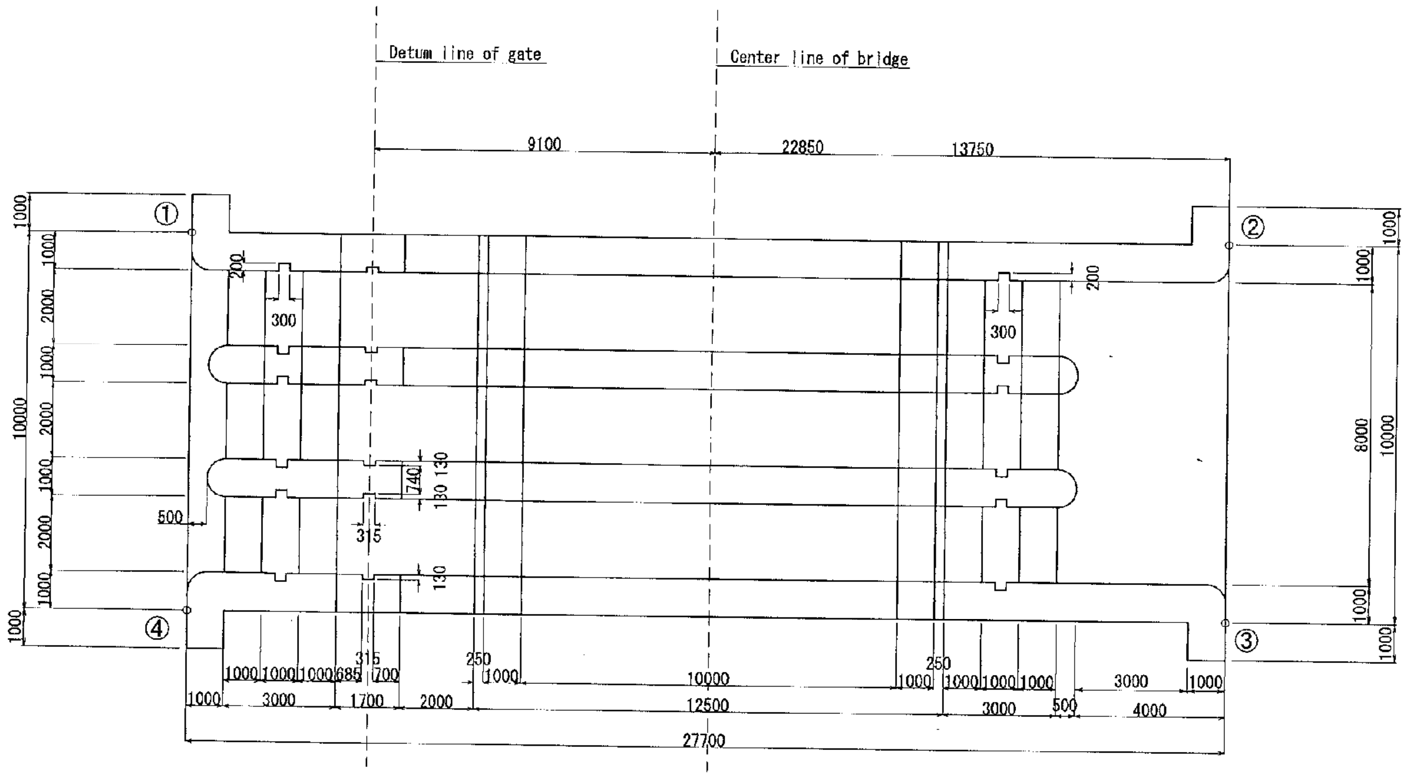

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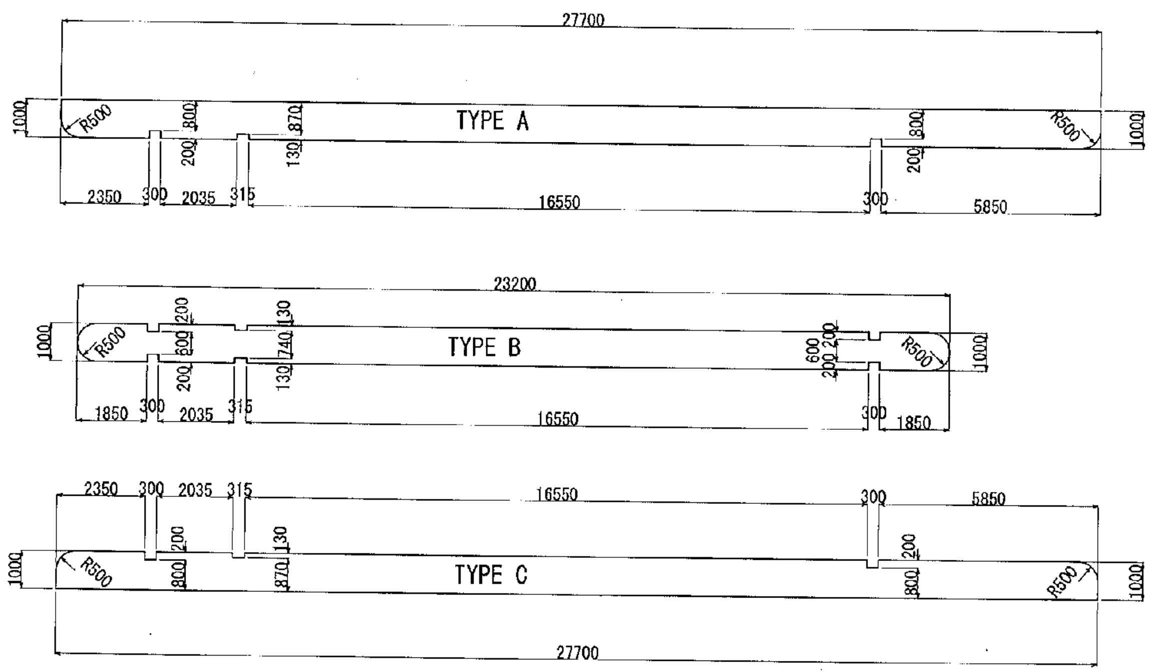

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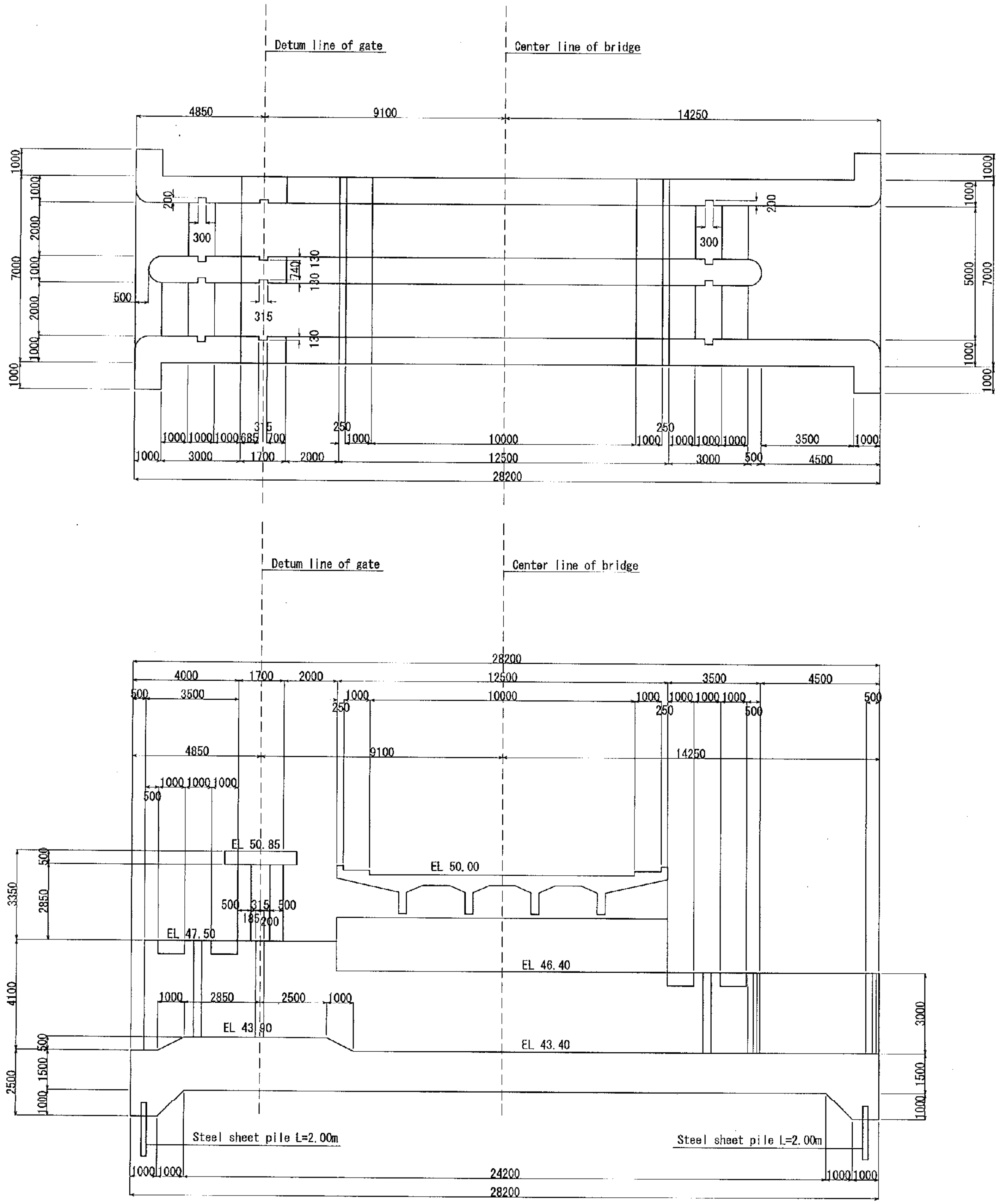

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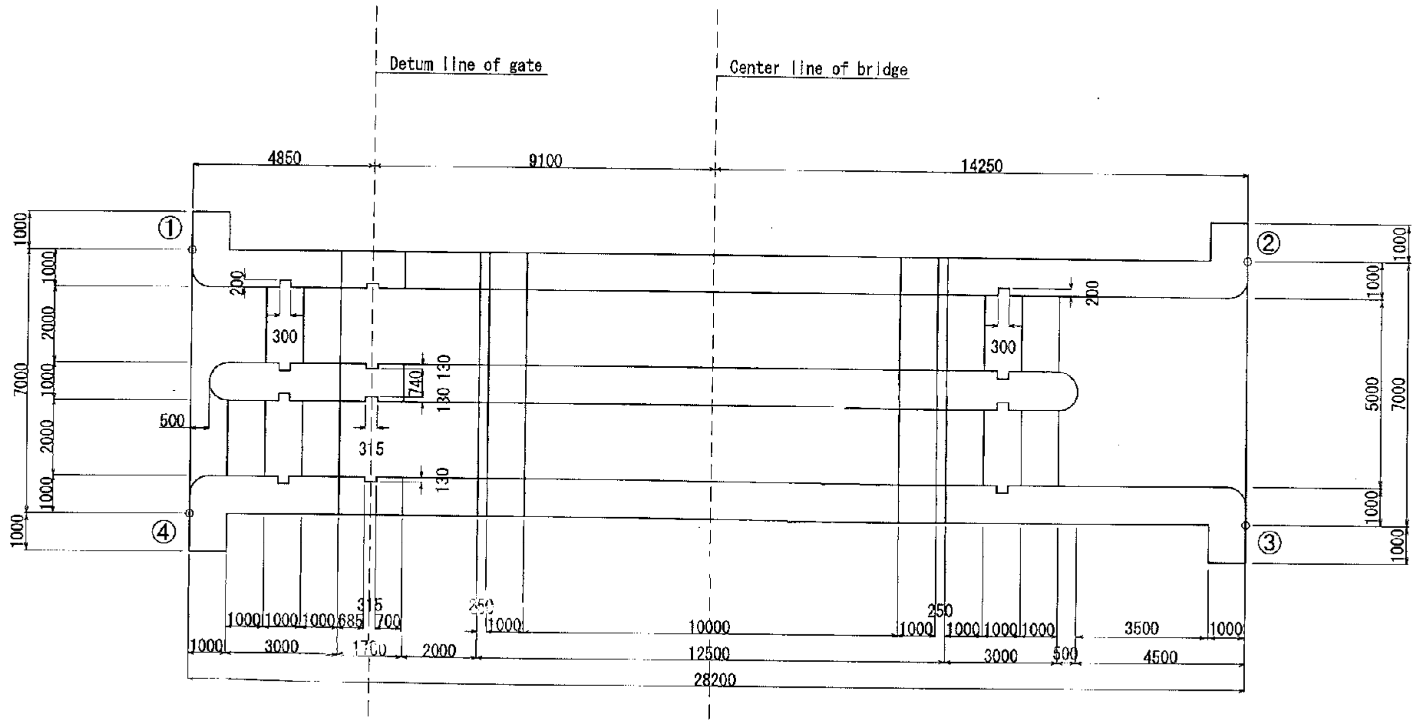

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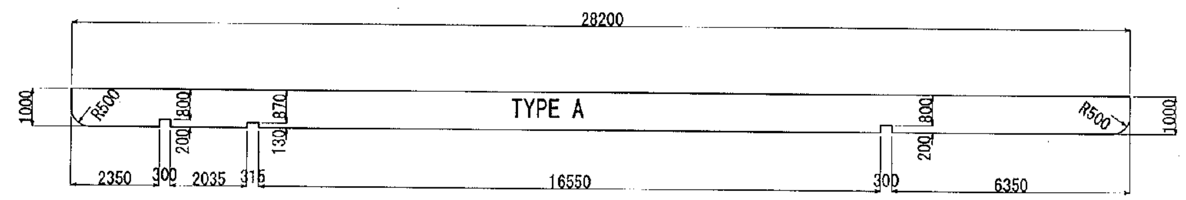

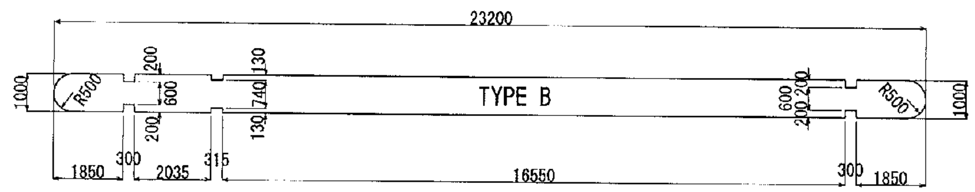

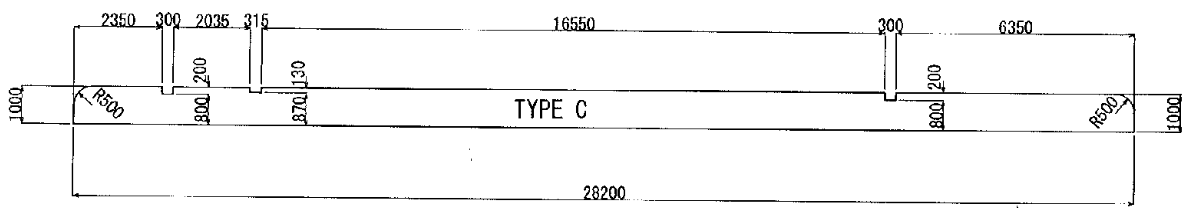

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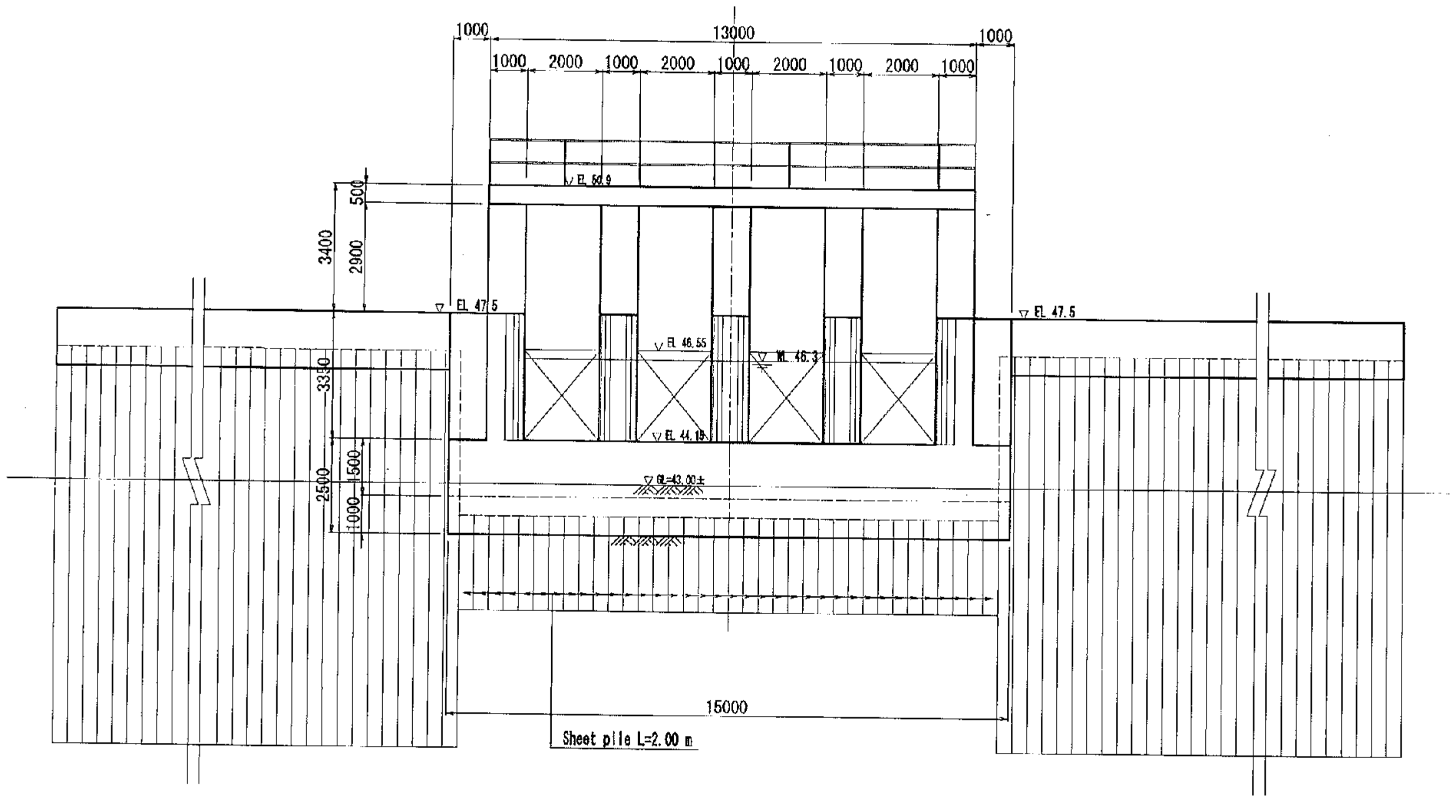
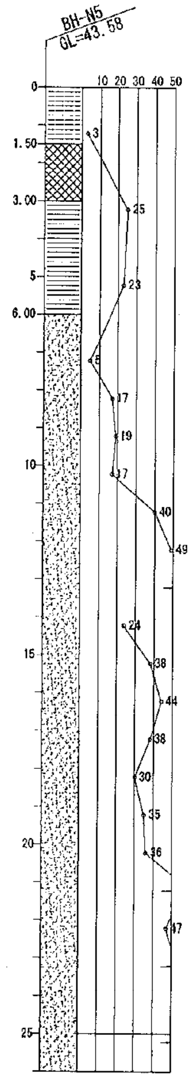
Standard section of the Abo Gabal Regulator (Upstream)





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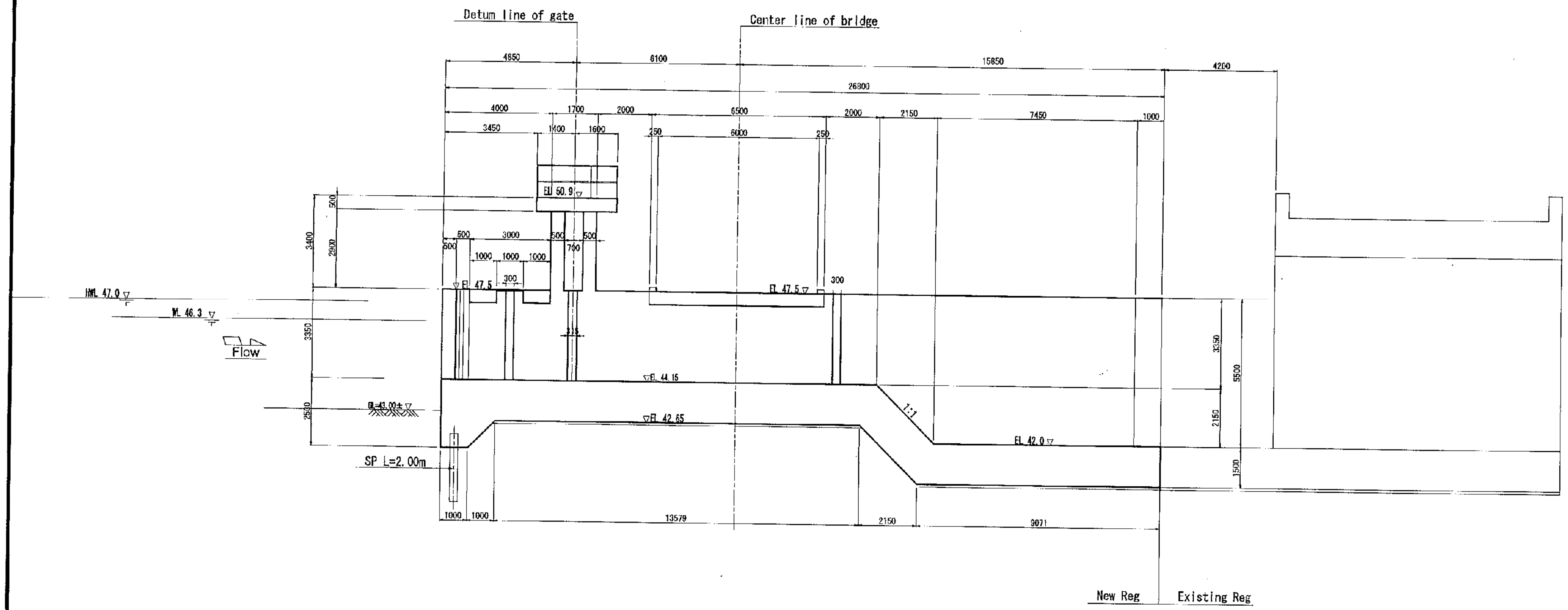
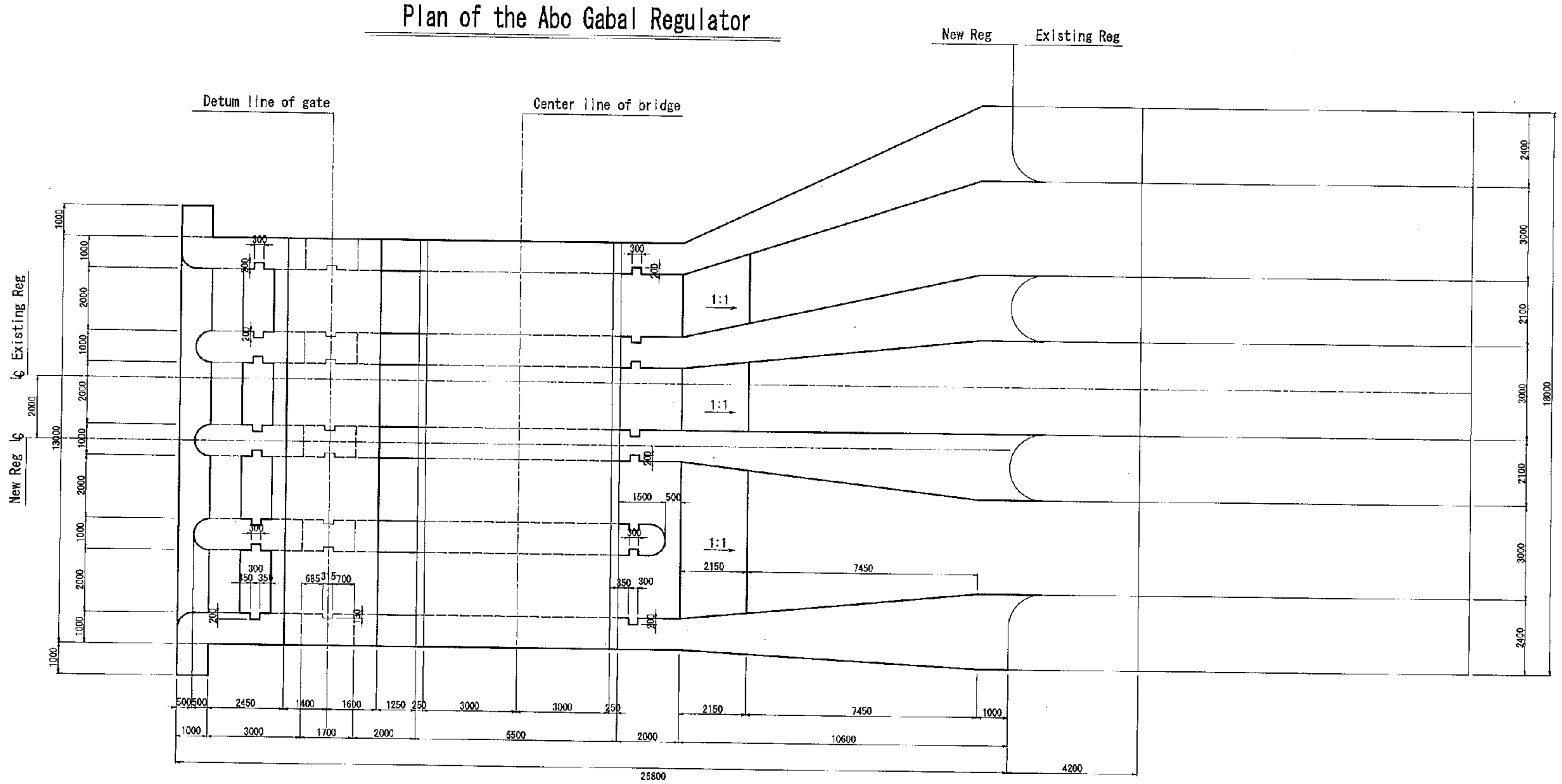
Standard section of the Abo Gabal Regulator



Plan of the Abo Gabal Regulator



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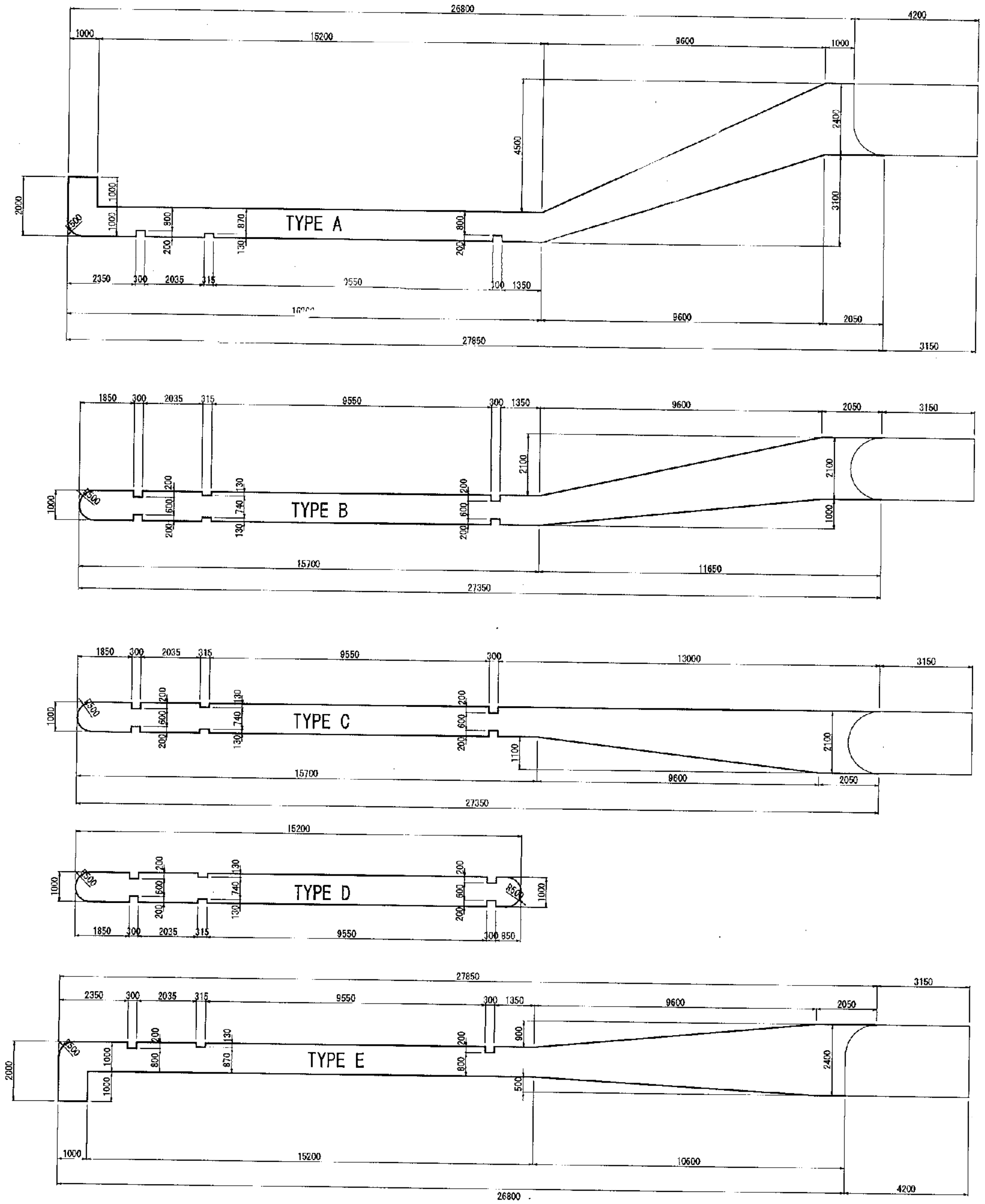
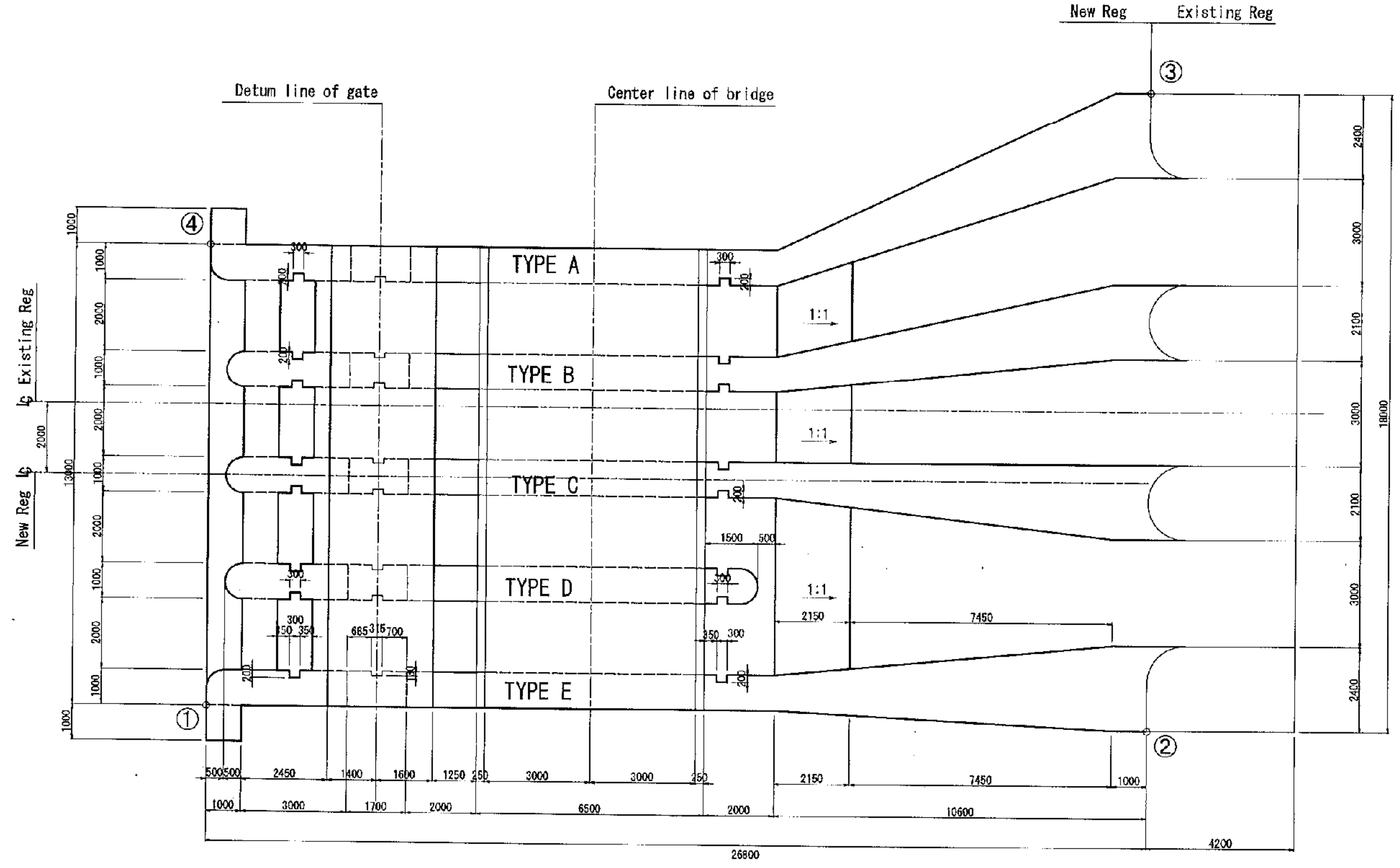
Standard section of the Abo Gabal Regulator





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Flow Tracking Upstream DGRs

Photo 1: Flow Tracking Upstream Existing DGRs Using Floating Debris

Photo 2 : Flow Tracking Upstream Existing DGRs Using Colored Dye

Flow Tracking Downstream NDGRs (Maximum Overflow Discharge)

Photo 3: Flow Tracking Downstream New Bahr Yusef Regulator Using Floating Debris

Photo 4: Flow Tracking Downstream New Bahr Yusef Regulator Using Colored Dye

Photo 5: Flow Tracking Downstream New Ibrahimia Regulator Using Floating Debris

Photo 6: Flow Tracking Downstream New Ibrahemia Regulator Using Colored Dye

Flow Tracking Downstream NDGRs (Dominant Overflow Discharge)

Photo 7: Flow Tracking Downstream New Bahr Yusef Regulator Using Floating Debris

Photo 8: Flow Tracking Downstream New Bahr Yusef Regulator Using Colored Dye

Photo 9: Flow Tracking Downstream New Ibrahimia Regulator Using Floating Debris

Photo 10: Flow Tracking Downstream New Inrahimia Regulator Using Colored Dye

Flow Tracking Downstream NDGRs (Minimum Overflow Discharge)

Photo 11: Flow Tracking Downstream New Bahr Yusef Regulator Using Floating Debris

Photo 12: Flow Tracking Downstream New Bahr Yusef Regulator Using Colored Dye

Photo 13: Flow Tracking Downstream New Ibrahimia Regulator Using Floating Debris

Photo 14: Flow Tracking Downstream New Ibrahimia Regulator Using Colored Dye

Flow Tracking Downstream NDGRs (Maximum Underflow Discharge)

Photo 15: Flow Tracking Downstream New Bahr Yusef Regulator Using Floating Debris

Photo 16 : Flow Tracking Downstream New Bahr Yusef Regulator Using Colored Dye

Photo 17: Flow Tracking Downstream New Ibrahimia Regulator Using Floating Debris

Photo 18: Flow Tracking Downstream New Ibrahimia Regulator Using Colored Dye

Final Report

Two Dimensional Model For
Bahr Yusef New Regulator

Authors

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Eng. Amira Samir

Supervised By

Dr. Abdelazim M. Ali

Director

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January 2017

HRI- 9 /2017

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Two Dimensional Model For Bahr Yusef New Regulator

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January 2017

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Ministry of Water Resources and Irrigation (MWRI)
P.O.Box 13621, Delta Barrage, Egypt.

CLIENT:	Reservoirs and Grand Barrage Sector, Ministry of Water Resources and Irrigation
TITLE:	Two Dimensional Model For Bahr Yousef New Regulator

ABSTRACT:

The Reservoirs and Grand Barrages Sector (RGBS), the Ministry of Water Resources and Irrigation (MWRI) requested (letter No. 1339, dated 8/5 2016) the Hydraulics Research Institute (HRI) to carry out a Two- Dimensional hydraulic physical model to study the impact of the hydraulic jump phenomenon on the downstream vicinity of one single bay of the new regulator of Bahr Yousef Canal as part of the New Dirout Group of Regulators (NDGRs). The study is aiming at optimizing the stilling basin dimensions, design (if required) of the energy dissipation blocks and optimize the design of the rip rap protection layers downstream the apron of the regulator. Complete hydrograph of Bahr Yousef Canal will be used for achieving the above goals. Rectangular flume with length of 26m, width of 1.0m and height of 1.2m will be used in order to construct the model which includes one bay of new Bahr Yousef regulator. The study comprises two phases, the first one tests the original design of new Bahr Yousef regulator and the second phase tests the final design that is approved by the technical committee.

VER	ORIGINATOR	DATE	REMARKS	REVIEW		APPROVED BY	
FV1	Eng. Ahmed Ibrahim	2017		Dr. Abdelazim M. Ali		Prof. Khaled Abdel Hai Ramadan	
FV1							
FV1							

PROJECT IDENTIFICATION:		HRI- 9 -2017						
CONTENTS:	TEXT PAGES	45	TABLES	13	FIGURES	34	Photo	17

CONFIDENTIAL: ☒ YES, until (date) ☐ NO

STATUS: ☐ PRELIMINARY ☐ DRAFT ☒ PROGRESS REPORT

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1 INTODUCTION

1.1 Dirout Group of Regulators (DGRs)

The Dirout Group of Regulators (DGR) is located at the City of Dirout at 310.0 km south of Cairo. The DGR is located at Ibrahimia Canal at 60.0 km downstream of the Ibrahimia Intake nearby Assiut Barrage. The DGR delivers annually about 9.6 BCM of the Nile Water to almost 1.43 million feddans (about 600,000 ha) through Ibrahimia Canal. The DGR distributes irrigation water of Ibrahimia Canal into seven canals, namely Ibrahimia Canal, Bahr-Yusef Canal, Sahelyia Canal, Diroutia Canal, Badraman Canal, Abo Gabal Canal and Irad Delgaw Canal, see **Figure 1.1**. The DGR was built in 1872 and serves the population of five governorates. These governorates are; Giza, Fayum, Beni Suef, Minya and Assiut. The total area of these governorates is almost 14% of the total area of Egypt and its population represents 26% of the total population of Egypt. For the effective use of the limited water resources and the exceedance the life of old DGR above the life time, the Government of Egypt requested the Government of Japan to study the construction of a new Dairout group of regulators (NDGRs) to increase the agricultural production in the served area.

1.2 Hydraulic Physical Models for NDGRs

The Reservoirs and Grand Barrages Sector (RGBS) of the Ministry of Water Resources and Irrigation (MWRI) requested the Hydraulics Research Institute (HRI) to carry out two and three dimensional (2D&3D) hydraulic physical models for NDGRs. The objective of the proposed testing program is to adopt the best alignment and hydraulic design for the new barrages group components which fulfils the new flow regime through Ibrahimia Canal after the construction of the new Assiut barrage. Flow capacity and velocity distribution upstream and downstream each of the new group components would be physically tested and investigated. The 3D physical hydraulic model of scale 1: 25 are used for the hydraulic investigation of NDGRs. Some hydraulic phenomena such as "Hydraulic Jumps" need larger scale to study in detail its characteristics and its impact on the downstream vicinity of the new regulators. A well designed 2-D hydraulic detail model with scale of 1:8.5 is the best tool to check the flow characteristics upstream and downstream of the proposed structure, check the efficiency of the stilling basin design and testing the bed protection (rip rap) downstream the stilling basin.

The current report will focus on the investigation study for one bay of new Bahr Yousef regulator. The model consists of one bay of Bahr Yousef regulator including two half piers, the stilling basin, the rip rap protection upstream and downstream of Bahr Yousef regulator.

Figure (1-1) Layout of Dirout Group Regulators (DGRs)

1.3 Study Objectives

The objectives of the 2D physical model can be summarized as follows:

- Study the flow characteristics along the stilling basin including formation of hydraulic jump.
- Optimize the stilling basin dimensions based on the typed intensity of hydraulic jump.
- Check the head losses due to the construction of new Bahr Yousef regulator with fully open gates.
- Investigate the stability of the rip-rap protection layer downstream the apron.

1.4 Study Tools

A well designed 2D hydraulic physical detail model for one bay of Bahr Yousef regulator is used. The model is constructed inside double glasses rectangular Flume with dimension of 26m long, 1.0m wide and 1.2m high. The inlet of the flume is provided with a sump which receives the discharge from the pump and followed by two boxes filled with gravel and 2 inch plastic pipes to dissipate the energy of the inflow to the model. The exit of the flume consists of tail gate which controls the downstream water level. The model area is located between the inlet and the exit of the flume. The stilling basin of the model is made of smooth wood and the two half piers are made of plexiglass which gives a good monitoring for the flow along the entire length of the model. The model bottom in the flume is shaped with sand overlain by rip-rap in upstream and downstream reaches, as shown in **Plate 1**.

Plate (1) 2D Flume in the Hydraulic Laboratory of the Hydraulics Research Institute (HRI), Egypt

2 THE PHYSICAL MODEL

A two dimensional model with an undistorted scale **1:8.5** was designed to simulate one bay of Bahr Yousef regulator, the stilling basin, the rip- rap in both upstream and downstream reaches. The model structure is made from Plexiglas material in a steel-framed glass walled flume of 26.0 m long and 1.0 m wide, and 1.2 m high as shown in **Figure 2.1**. The model bottom of the flume is shaped with sand overlaid by rip-rap in both upstream and downstream reaches, as shown in **Figure 2.2**. The glass panels allow visual observation and photographing of the flow patterns and other related phenomena in the vicinity of the tested structure.

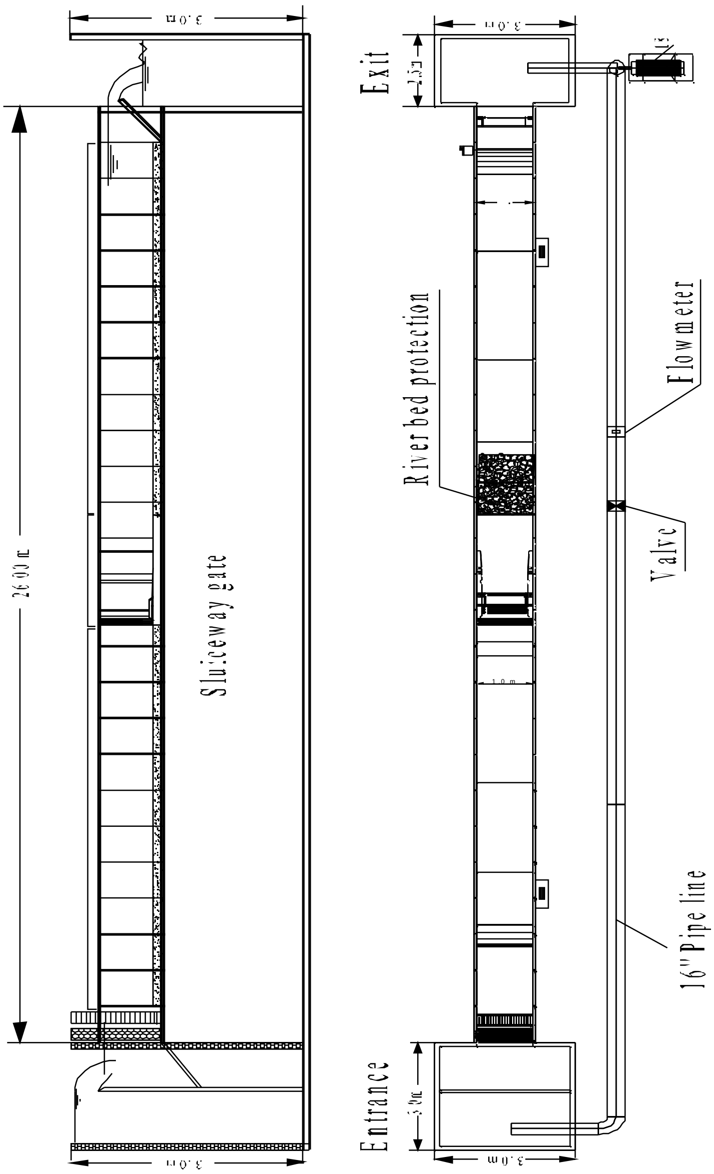

Figure (2-1) Model Layout in the Flume

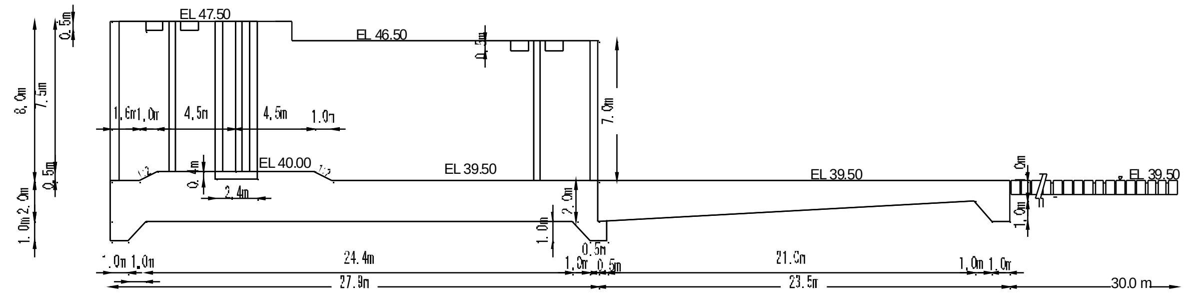

Figure (2-2) Longitudinal Section of the Proposed Design New Bahr Yousef Regulator

2.1 Model Similarity

For correct reproduction of the important hydraulic phenomena in a hydraulic model, a complete similarity including geometric and dynamic similarity between prototype and model must be fulfilled when determining the model scales.

Because the model has free surface flow, the inertia and gravitational forces are dominant. Therefore, for simulation, the model has to be based on Froude number equality with the prototype. To simulate the kinematics and dynamics of the flow field properly, an undistorted geometric scale model is required.

The Froude number, which represents the ratio of flow inertia forces to gravitational forces, is given by:

$$Fr = \frac{V}{\sqrt{gh}}$$

Where

F_r = Froude number,
v = average flow velocity, (m/s)
h = characteristic depth, (m)
g = gravitational acceleration, (m/s^2).

From the condition that the Froude Number in both prototype and model should be equal, the velocity scale ratio can be determined from which the other scale ratios can be derived:

Length Scale = n_L
Velocity scale ratio = n_v = $(n_L)^{0.5}$,
Discharge scale ratio = n_Q = $(n_L)^{2.5}$,
Time scale ratio = n_t = $(n_L)^{0.5}$.

An undistorted geometric scale of 1:8.5 was selected. Consequently, the ratios for the other quantities are:

n_h: depth scale ratio : h_p/h_m=8.5,
n_l: length scale ratio: l_p/l_m =8.5,

n_a: area scale ratio: n_l^2 =72.25,
n_v: velocity scale ratio: $n_h^{1/2}$ =2.92,
n_Q: discharge scale ratio: $n_l^{2.5}$ =210.64,
n_t: time scale ratio: $n_l^{1/2}$ = 2.92

In which (p) is the prototype and (m) is the model.

2.2 Model Arrangement

2.2.1 Model Construction

The model structure is made from Plexiglas material in a steel-framed glass walled flume of 26.0 m long, 1.0 m wide, and 1.2 m height as shown in **Figure 2.1 and 2.2**. The glass panels allow visual observation and photographing of the results of the flow patterns and other related phenomena in the vicinity of the tested structure. The model was constructed inside the Northern flume of HRI.

The modeled structure consists of one bay of the sluice way consists of two half piers of 1.25 m wide each (prototype scale) manufactured from Plexiglas. The upstream water level controlled by two gates made of Plexiglas each gate with 3.3m height. In the first test case the gates used as a weir. Under normal operations (case-2), the flow passes between the gate and the sill under gate which was made of wood in the model. The Stilling basin consists of 2 parts; Sill under gate followed by a horizontal apron. Both of them are made from special water tight wood. The geometry and the dimension used for constructing the proposed design in the model is shown in **Figure 2.3** as a plan view **and Plates (1), (2), and (3).**

The modeled structure was manufactured at HRI's workshop according to the detailed dimensions provided by consultant.

The model bed profile was shaped by sand of 2.5 mm mean diameter sand and overlaid by a rip-rap protection layer. The gradation of the rip rap protection downstream the apron of Bahr Yousef regulator has the following gradation; d_{15}=0.9cm, d_{50}=1.8cm and d_{85}=3.6cm. These layers were placed according to the elevation and location specified by the Consultant.

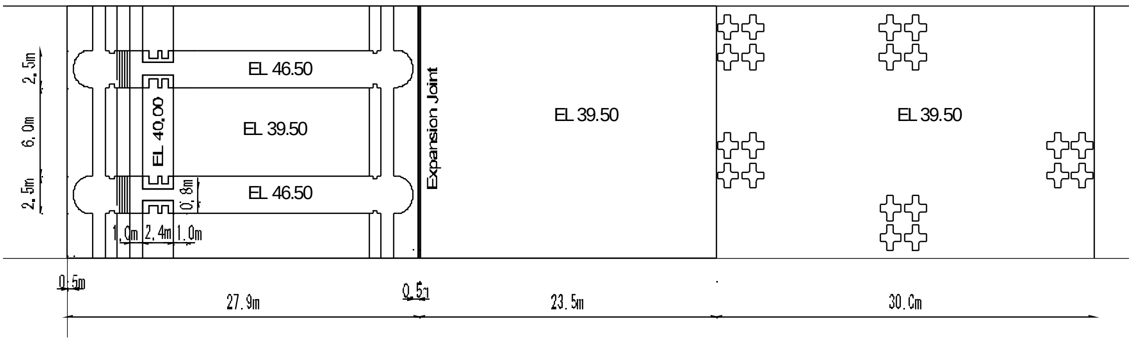

Figure (2-3) Plan Section of Bahr Yusef Regulator

Plate (2) The Sluiceway Gate and the Downstream Reach

Plate (3) The Upstream Reach

2.2.2 Model Feeding

The flume is provided with a recirculating system. The maximum feeding capacity of the system is 0.4 m^3 s (400 l s). This capacity is sufficient as the maximum scaled discharge of the model which is 269 l/s. The required discharge is pumped directly by pump with capacity of 269 l s, from an isolated underground reservoir reserved specially for this model.

This underground reservoir has a length of 30 m, width of 1.5 m and height of 1.25 m with a total capacity of 56.25 m^3 which is quiet sufficient for assuring non aeration of pumps during model operation.

The ultrasonic flowmeter is installed on 16 inch-diameter flow pipe to measure the discharge. The ultrasonic flowmeter has an accuracy of ±1%.

2.3 Model Description

The model consists of three main parts: model entrance, the modelled reach of Nile River, and model outlet. Herein, a brief description for each part is presented.

2.3.1 Model Entrance

The model entrance consists of a steel basin of 1.5 m wide, 2.0 m long and 2.0 m height. This basin is used to receive the delivered water from the two main pipelines of the circulating system. In order to dissipate the flow energy that entering the model and to avoid any disturbance, a mesh box filled with coarse gravel followed by a screen mesh box filled with 2.0 inches diameter plastic pipes, are provided. Also, a bed ramp was shaped at the entrance to help in absorbing the rest of water energy before approaching the barrage model.

2.3.2 The Modelled Reach

The model simulates a length of the Nile River about 221 m including the new sluiceway. (91.59 m upstream and 77.56 m downstream), see Figure 2.1 and 2.2. The flow through the regulator bay represented in the model was controlled by means of the plexiglas gate.

The bed material of the model were formed by sand of 2.5 mm mean diameter covered by coarser material (rip-rap) to protect upstream and downstream areas of the structure. The Rip-Rap protection covered distance 71.4 m upstream stilling basin and covered distance 41.74 m from the end of blocks area downstream new regulator at upstream of the new regulator. The designed mean characteristic particle diameter D_{50} of the river bed protection at both upstream and downstream of the new regulator are as following:

Just Upstream the regulator up to 8m:	D_{50}	=	153	mm*
Just Downstream the regulator up to 41.74m:	D_{50}	=	153	mm*

* D_{50} – mean characteristic particle diameter (mm)

2.3.3 Model Outlet

The model exit consists of a basin that starts directly at the end of the simulated reach of the Nile River followed by a steel tail control gate in the downstream to adjust the water surface level as shown in plate (4).

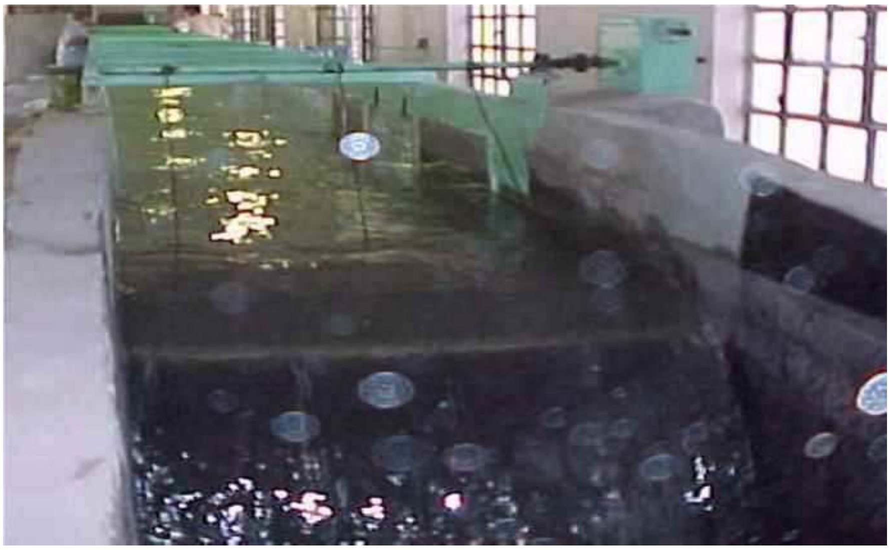

Plate (4) Tail Control Gate in the Downstream to Adjust the Water Surface Levels

2.4 Model Instrumentation

2.4.1 Ultra-sonic Flowmeter

To determine the flow discharge into the model accurately, an ultrasonic flowmeters were used. As shown in **plate (5)**, flowmeter were installed on 16 inch-diameter feeding pipelines. flowmeter measure the water flow rate with an accuracy of ± 1%. The Ultra-Sonic flowmeter type E.M.S. was used to measure the discharge in the model up to 400 l/s (model).

Plate (5) Ultra-Sonic Flowmeter for Inflow Discharge to the Model

2.4.2 Electro-Magnetic Currentmeter

The flow velocities in the model are measured using an Electro-Magnetic currentmeter type E.M.S., manufactured by Delft Hydraulics, Holland, **see plate (6)**. The device was connected to a mean value meter to show the average velocity within a selected time period.

Plate (6) Electro-Magnetic Currentmeter for Velocity Measurements in the Model

2.4.3 Point Gauges

To monitor and follow the water surface levels along the model, two point gauges with side stilling wells were installed at 60 m downstream and 60 m upstream the regulator crest, prototype scale. Also, mobile point gauge was used to measure the water surface elevations at any point along the flume length. These point gauges can read accurately up to + 0.1 mm. Plate (7) shows the Point Gauge device used in adjusting the water level in the model.

Plate (7) Point Gauge Device for Adjusting the Model Water level

2.4.4 Piezometer Tubes

In order to measure the pressure distribution on the horizontal apron, eight cells 37.93 m apart (prototype scale) were fixed at the centerline of the apron surface. These cells are connected to eight glass water manometers fixed on a vertical board to directly determine the pressure head above the inclined and horizontal apron, see **Plate (8)**.

Plate (8) Piezometer Tubes Board for Measuring Pressure Distribution on the Sill and the Horizontal Apron

2.4.5 Video and Photo - Camera

Video and Photo cameras documentations are essential in such hydraulic study to record flow patterns for different flow cases and to monitor the stability of the downstream rip-rap zones, see **Plate (9).**

Plate (9) Used digital Camera

2.5 Model Discharges and Boundary Water Levels

2.5.1 Model Discharges

The model was carried out to simulate different prototype discharges ranging from 18.52 m^3/s to 227 m^3 s. According to selected model arrangement and taking into account the Froude similarity, the model discharge is given by:

$$Q_{model} = \frac{1}{4} Q_{Sp.W.} \, n_h^{-2.5} = 0.001187 \, Q_{reg.W} \qquad \textbf{(1)}$$

2.5.2 Water Levels Conditions

Headpond levels

The headpond is operated according to the “Regulator Operating Strategy” (ROS) as defined by the Feasibility Study. The target levels of the headpond is 46.30 m+asl.

Important headpond levels and Barrage discharges are:

46.30 m msl	Minimum discharge	Q = 18.52 m^3 s
46.30 m msl	Dominant	Q = 162.52 m^3/s
46.30 m msl	Maximum Discharge	Q = 227 m^3/s

Tailwater levels

The tailwater rating curve to be used for the Dirout Group Regulator is defined by the following formula, valid for the present riverbed conditions (normal condition), without degradation, with $h_{tailwater}$ in [m asl] and Q in m^3/s:

$$h_{tailwater} = -0.00005\,Q^2 + 0.0287\,Q + 42.037 \quad \textbf{(2)}$$

Some plates during model construction is in **Annex (A).**

Plate (1A) Manufacturing of the Half Pier

Plate (2A) Cutting the Plexiglas of the Half Pier

Plate (3A) The Model Inside the Flume

Plate (4A) The Model During the Construction Inside the Flume

Plate (5A) The Model During the Operation (Flow over Gate)

3 MODEL TEST PROGRAM

3.1 Test Program

The investigation of the detaile model of the sluiceway comprises 3 cases. Each case comprises a series of tests to achieve its objectives.

Table 3.1: Test Program for the Proposed Cases

Case No.	Test No.	Discharge (Q) m^3/s	U.S.W.L (m) + MSL	D.S.W.L (m) + MSL	Condition
Case - 1	Test -1	18.52	46.3	42.55	Flow Over Gate
	Test -2	80.00	46.3	44.01	
	Test -3	120.00	46.3	44.76	
	Test -4	162.52	46.3	45.30	
	Test -5	195.00	46.3	45.73	
	Test -6	227.00	46.3	45.82	
Case - 2	Test -7	18.52	46.3	42.55	Flow Under Gate
	Test -8	80.00	46.3	44.01	
	Test -9	120.00	46.3	44.76	
	Test -10	162.52	46.3	45.30	
	Test -11	195.00	46.3	45.73	
	Test -12	227.00	46.3	45.82	
Case - 3	Test -13	18.52	46.3	42.55	Fully Open Gate
	Test -14	80.00	46.3	44.01	
	Test -15	120.00	46.3	44.76	
	Test -16	162.52	46.3	45.30	
	Test -17	195.00	46.3	45.73	
	Test -18	227.00	46.3	45.82	

The above test program comprises tests which were performed for discharges ranging from 18.52 m^3/s to 227 m^3/s and the upstream water level is a certain value 46.30m+msl and the downstream water value calculated from tail water rating curves. The following test conditions were applied for the current investigation:

- **Case 1:** tests from Test-1 to Test-6 were performed with over gate flow, consist of 6 tests.
- **Case 2:** tests from Test-7 to Test-12 were performed with flow passes under gate, consist of 6 tests.
- **Case 3:** tests from Test-13 to Test-18 were performed with fully open gate, consist of 6 tests.

Plates 3.1, 3.2 and 3.3 show the flow pass from upstream to downstream for the three tested cases.

Plate (3.1) Show the Flow over the Gate, case -1

Plate (3.2) Show the Flow under the Gate, case -2

Plate (3.3) Show the Flow through Fully Open Gate, case -3

3.2 The undertaken Measurements for Fully Open Gates

Through test series of gates fully open the following measurements were carried out:

3.2.1 Water level Measurement

The water level measurements were carried out approximately at the locations that given in **Table 3.2** along the centre-line of the flume. **Figure 3.1** shows the location of water level measurements along the longitudinal section of the flume.

Table 3.2: Locations of water level measurements

Location	Description
1	(32.53 m) upstream the gate
2	(24.03 m) upstream the gate
3	(15.53 m) upstream the gate
4	(7.88 m) upstream the gate
5	(5.33 m) upstream the gate
6	(3.63 m) upstream the gate
7	(0.62 m), directly downstream the gate
8	(4.87 m) downstream the gate
9	(9.12 m) downstream the gate
10	(13.37 m) downstream the gate
11	(17.62 m) downstream the gate
12	(19.83 m) downstream the gate
13	(22.04 m) downstream the gate
14	(30.54 m) downstream the gate
15	(39.04 m) downstream the gate
16	(47.54 m) downstream the gate
17	(56.04 m) downstream the gate
18	(64.54 m) downstream the gate

Numbers between brackets are in prototype scale.

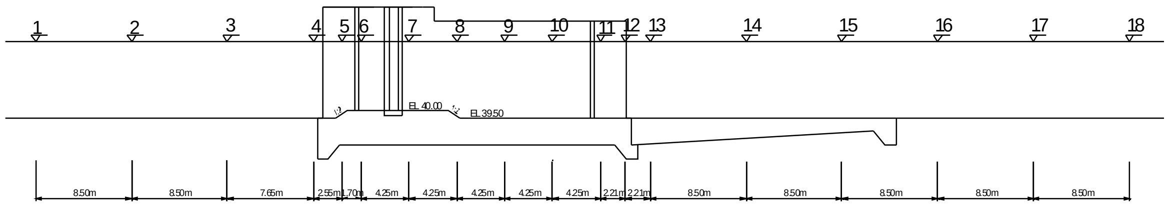

Figure 3.1 Locations of Measured Water Level

3.2.2 Pressure Measurements

The pressure head is measured at different locations starting at the end of sill under gate and ending at 3.4 m upstream the end of apron. **Figure 3.2** shows the location of the pressure measurements.

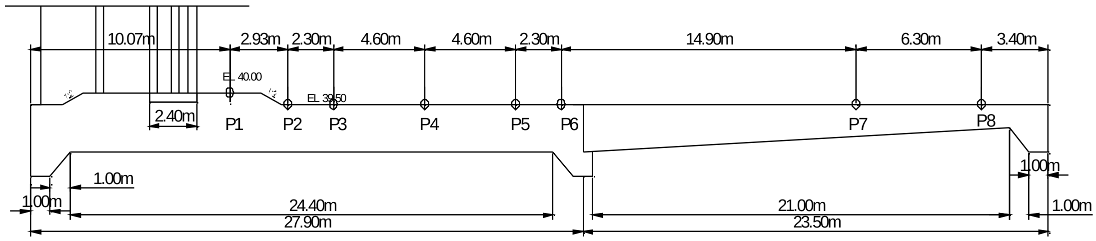

Figure 3.2 Locations of Pressure Cells

3.2.3 Head Losses

The total head losses between two sections were calculated. The locations of these two sections are at the upstream the gate by 32.53m (section 1) and downstream the gate by 64.54m (section 2). The total head losses were calculated based on the well-known Bernoulli equation.

3.3 The undertaken Measurements for Partially Open Gates

Through test series of partially open gates the following measurements were record:

3.3.1 Calibration of Sluiceway Radial Gates

In order to calibrate the sluiceway gate the gate opening was determined for each test during this phase of investigations with partially open gate. For better accuracy the gate opening was measured by micrometer device with high accuracy at three location under the gate on left, center and right in order to ensure that the radial gate is horizontal.

3.3.2 Flow Velocity Distribution

Velocity measurements were performed at six cross sections as shown in **Figure (3.3)**, for the headpond and discharge conditions as explained before. The location of the cross section measurements are defined as following:

Sections A to F located at 11.72m; 20.48m; 28.98m; 43m; 58.05m and 73.09m downstream the gate. It should be mentioned that there are additional cross section located 33.4m upstream the gate for case of fully open gate.

For each cross section the velocity was measured at the middle of the cross section at 0.2, 0.4, 0.6, 0.8 and 0.9 of the water depth as shown in **Figure 3.4**.

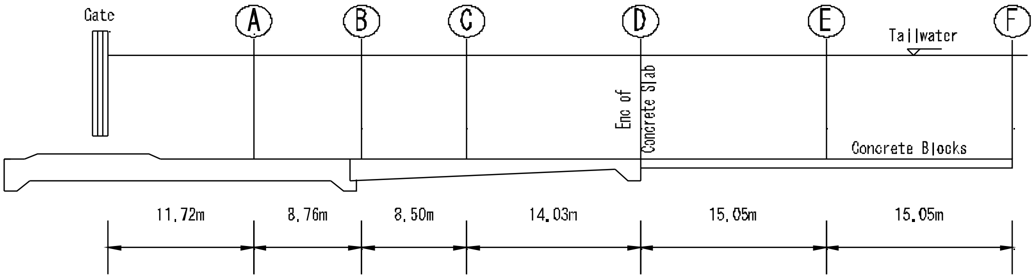

Figure 3.3 Locations of the Cross Section Velocity Measurements

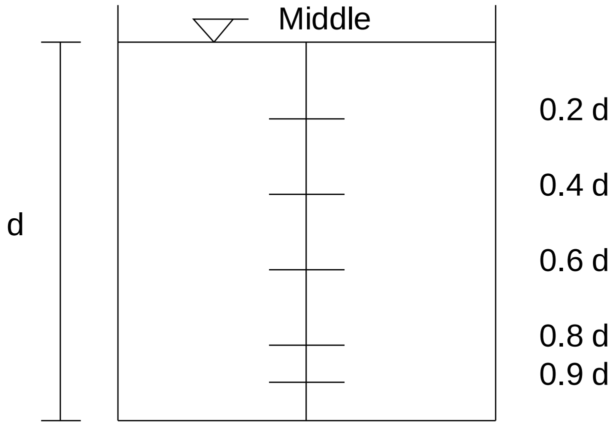

Figure 3.4 Point Depth Velocity Measurements at each Profile

3.3.3 Hydraulic Jump Characteristics

The hydraulic jump characteristics were measured for each test during the partially open gates investigation. The measurements include the height of the vena contracta, the backup water depth behind the gate and the gate openings. Based on these measurements the Froude Number at the vena contracta was calculated and the classification of the hydraulic jump was performed. Figure 3.5 shows the different parameters of the hydraulic jump.

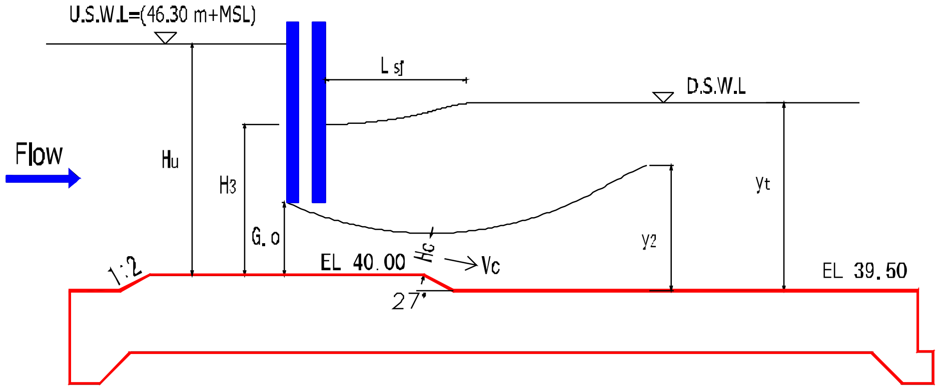

Figure 3.5 The Hydraulic Jump Parameters

Where:

- Upstream Water Depth, Hu (m)
- Tail Water Depth, yt (m)
- Thickness of flow jet at vena contracta, H_c (m)
- Backup water depth H_3 (m)
- Gate opening, G.o [m]
- Conjugate Depth, y_2 (m)
- Length of Submerged Jump, Lsj (m)

3.3.4 Pressure Measurements

Pressure along the stilling basin downstream the gate was recorded at different locations to verify whether the pressure remains above atmospherically pressure, e.g. the jet downstream the gate is not separating from the back slope of the sill under gate.

The measurements were done as follows:

- 8 pressure cells were arranged on the sill under gate and the horizontal apron as shown **Figure (3.2)**
- Pressure distribution on sill under gate and the horizontal apron along bay center line and with 4.46 m (model scale) distances.

3.3.5 Stability of Bed Protection

In order to ensure that the rip rap is stable the near bed velocity was measured at different location in both upstream (C.S 1) and downstream the gate C.S (D and F) in case of fully open gate, and in case of flow over gate and flow under gate the stability was checked at downstream only (Cross section D and F). The standard deviation was measured with each single velocity near to bed. The stability factor was calculated at different locations.

4 Results and Analysis

4.1 Case -1 "Flow over Gate"

4.1.1 Flow Velocity Distribution

The velocity distribution was measured at six cross sections downstream of the gate. These cross sections are sec. A, B, C, D, E and F. At each cross section the velocity distribution was measured at the center of the channel. **Figures from 4.1 to 4.6** shows the velocity distribution for the tested river discharges, the upstream water level is 46.30m+msl for all tests and downstream water level ranged from 42.55m+msl at minimum discharge and 45.82m+msl at maximum discharge. The following figures show that velocity distribution near bed over apron is backward flow and forward flow near surface. The velocity has normal distribution start from cross section D (at the end of concrete apron). The near bed velocity reaches 2.72m/s at test-3 corresponding to discharge 120m^3/s at C.S (A) directly downstream the gate, the near bed velocity reaches 0.85m/s at C.S (D) at test-5 with discharge 195m^3/s and the maximum near bed velocity at C.S (F) at the end of blocks area was at test-6 corresponding to discharge 227m^3/s and it was 0.98m/s.

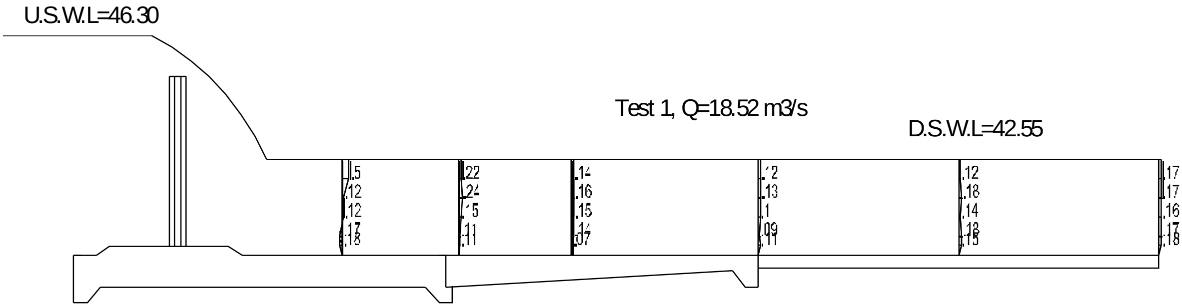

Figure 4.1 Velocity Distribution, Test-1, Case-1, Flow over Gate

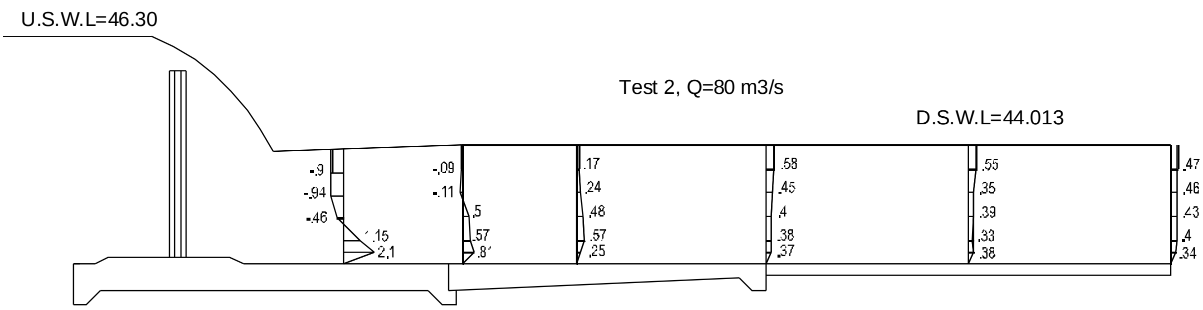

Figure 4.2 Velocity Distribution, Test-2, Case-1, Flow over Gate

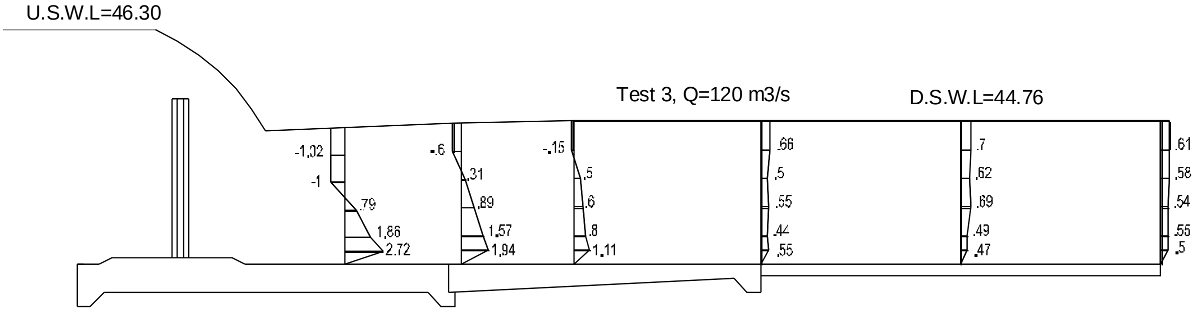

Figure 4.3 Velocity Distribution, Test-3, Case-1, Flow over Gate

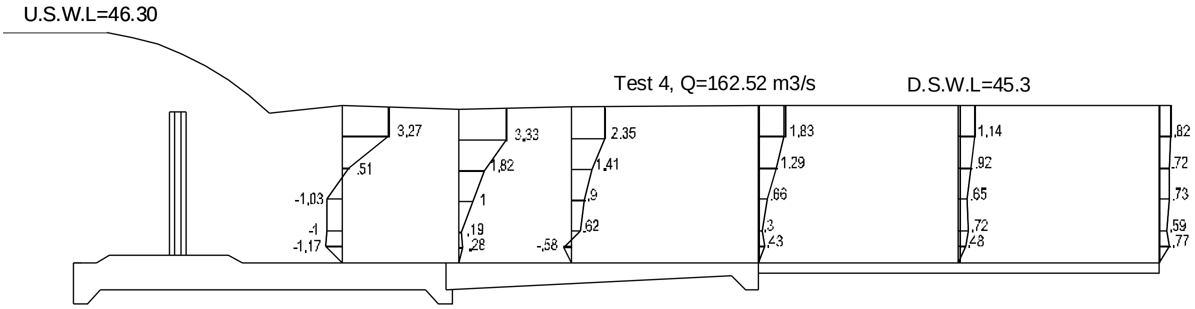

Figure 4.4 Velocity Distribution, Test-4, Case-1, Flow over Gate

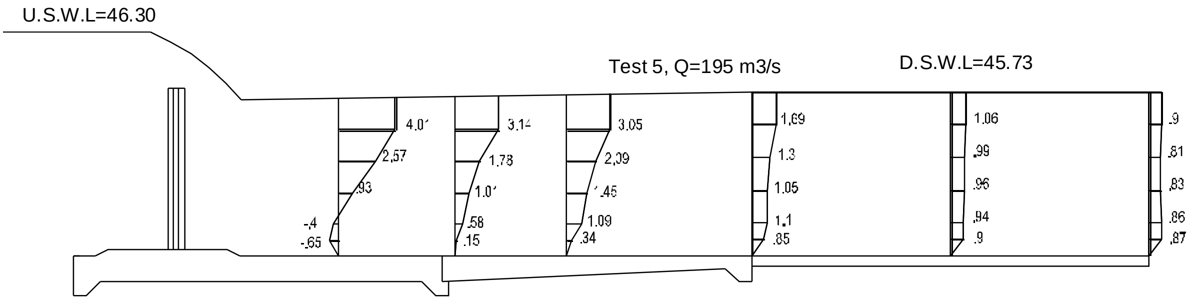

Figure 4.5 Velocity Distribution, Test-5, Case-1, Flow over Gate

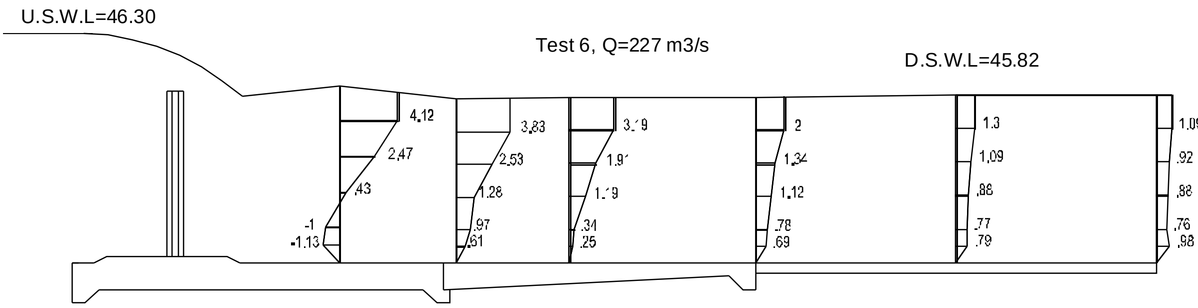

Figure 4.6 Velocity Distribution, Test-6, Case-1, Flow over Gate

4.1.2 Characteristics of Flow over Gate

The characteristics of flow over gate were investigated in order to define the discharge coefficient "C_d" with different operational mode and river flow conditions as shown in **Figure 4.7**. The discharge coefficient was calculated according to the following formula of the flow over gate (the gate acting as a weir) in presence of free hydraulic jump:

$$Q = \frac{2}{3} * Cd * B * \sqrt{2g} * H^{1.5} \qquad 4.1$$

Where:

Q	= the discharge/gate	(m^3/s)
C_d	= the discharge coefficient	(-)
B	= the width of the gate	(m)
g	= the gravity acceleration (9.81)	(m^2/s)
H	= the head over the gate	(m)

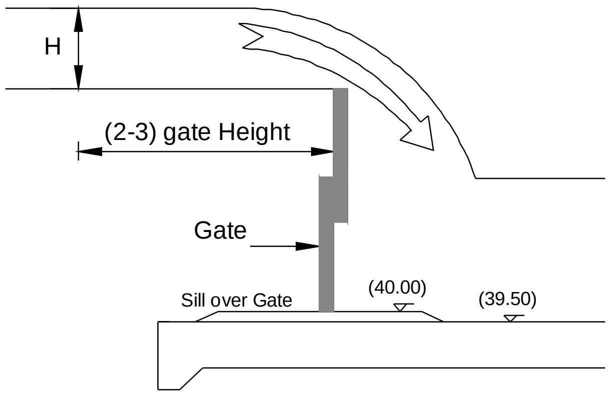

Figure 4.7 Flow over Gate

Table 4.1 show the discharge coefficient which was calculated based on the measured Head over gate "H" which obtained during the test run for all tests with different river flow conditions. From the experimental results the discharge coefficient "C_d" was ranged from 0.3 to 0.74. **Figure 4.8** shows the relation between the discharge and discharge coefficient for all obtained data.

Table 4.1 shows that when the gate rested on sill under gate we didn't control the upstream water level so it reaches 46.33m+msl in test-5 and 46.59m+msl in test-6.

Table 4.1 Calculated Discharge Coefficient and Height of Gate for each Test

Test No.	Q m^3/s	U.S.W.L m+MSL	D.S.W.L m+MSL	Height of Gate (m)	Gate Crest Level m+MSL	H (m)	C_d (-)
Test-1	18.52	46.3	42.55	5.38	45.38	0.92	0.30
Test-2	80.00	46.3	44.01	4.97	44.97	1.33	0.74
Test-3	120.00	46.3	44.76	4.56	44.56	1.74	0.74
Test-4	162.52	46.3	45.3	3.87	43.87	2.43	0.60
Test-5	195.00	46.33	45.73	3.32	43.32	3.02	0.53
Test-6	227.00	46.59	45.82	3.32	43.32	3.28	0.54

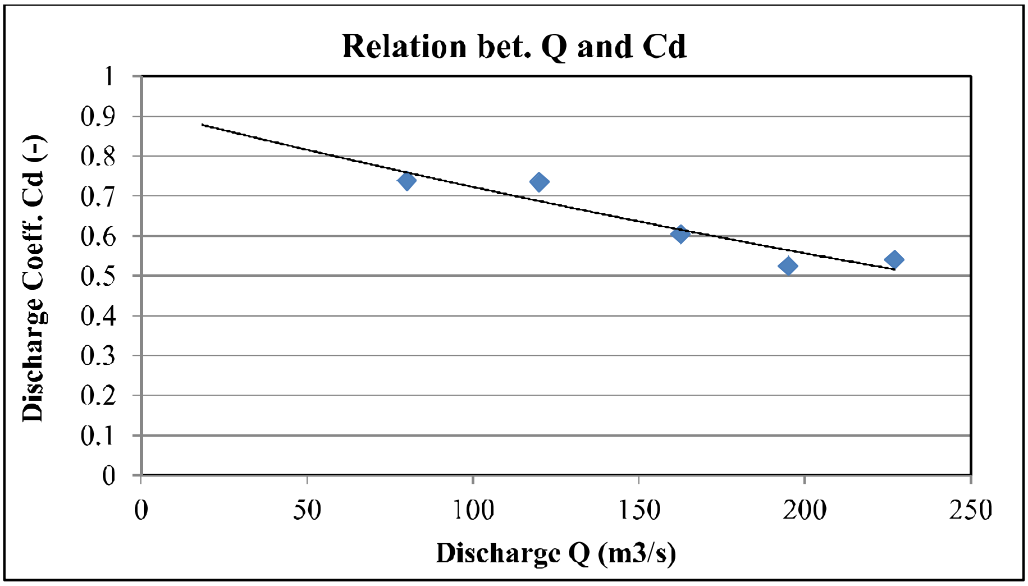

Figure 4.8 Relation between Discharge (Q) and Discharge Coefficient (C_d)

4.1.3 Pressure Distribution

The pressure distribution was measured at eight locations on the sill under gate and on the horizontal apron using eight pressure cells, 4.46m (model scale) distance as shown in **Figure 3.2** in the previous chapter. Pressure head measurements were carried out for different flow discharges ranging from 18.52m^3/s to 227m^3/s. The results are shown in **Table 4.2** and **Figure 4.9.**

Table 4.2 Pressure Head Distributions, Case-1 (Flow over Gate)

Test No	Pressure Head (m)							
	P1	P2	P3	P4	P5	P6	P7	P8
Test-1	3.17	3.41	3.19	3.17	3.16	2.98	3.15	3.13
Test-2	4.06	5.03	4.36	4.40	4.48	4.34	4.62	4.62
Test-3	4.44	5.87	5.17	5.06	5.13	4.22	5.29	5.32
Test-4	5.10	5.61	5.56	5.57	5.70	4.80	5.88	5.87
Test-5	5.57	6.06	6.04	6.04	6.13	5.63	6.31	6.31
Test-6	5.57	6.06	6.03	6.04	6.21	5.75	6.41	6.43

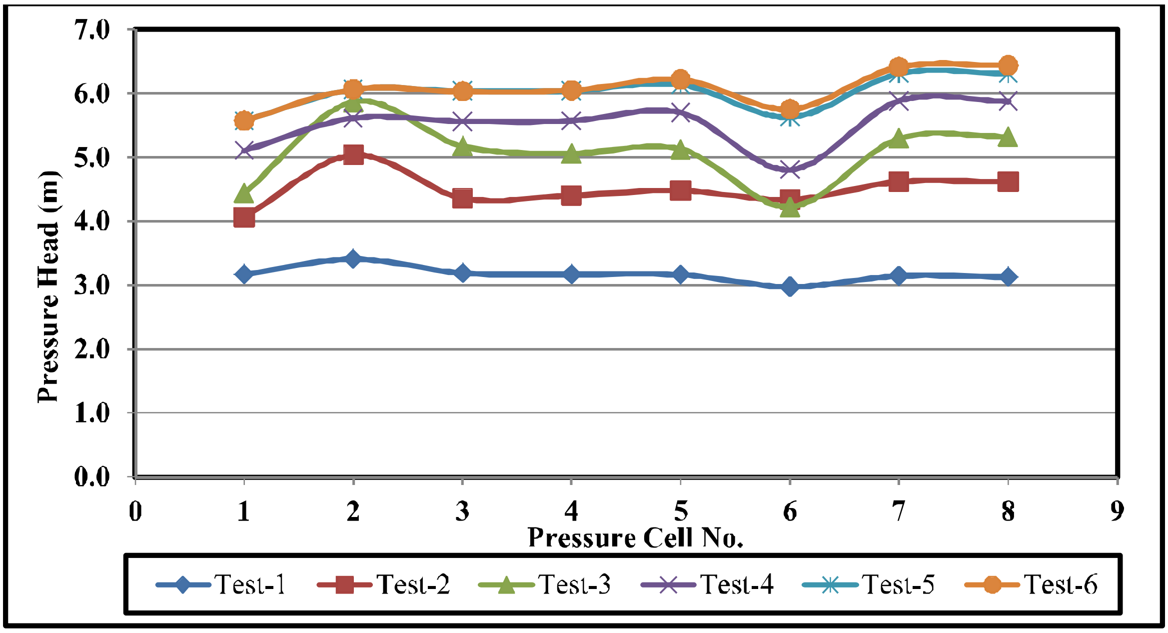

Figure 4.9 Pressure Head Distributions, Case-1 (Flow over Gate)

Figure 4.9 shows that the minimum pressure head was at the sill under gate (cell-1) for (test-2, test-5 and test-6) and for rest of tests the minimum pressure head was at the end of the pier (cell-6).

4.2 Case -2 "Flow under Gate"

4.2.1 Calibration of the Gate

The gate was calibrated to define the different gate openings for different flow conditions, the river flow discharges ranging from 18.52m^3/s to 227m^3/s. The upstream water level was 46.30m+msl for all tested river discharges and the downstream water levels were varying from 42.55 and 45.82m+msl. The model results of the calibration of the gate are shown in **Table 4.3 and Figure 4.10**.

All the obtained data were plotted for the relation between the discharge and the gate opening and the trend line shown in **Figure 4.10** with Power fitting.

Table (4.3) Calibration of the Regulator Openings with 4 Gates, Case-2, Flow under Gate

Test No.	Q_{River} (m^3/s)	U.S.W.L (m) + MSL	D.S.W.L (m) + MSL	Gate Opening (m)
Test-7	18.52	46.30	42.55	0.13
Test-8	80.00	46.30	44.01	0.60
Test-9	120.00	46.30	44.76	1.10
Test-10	162.52	46.30	45.30	1.76
Test-11	195.00	46.30	45.73	2.78
Test-12	227.00	46.30	45.82	3.02

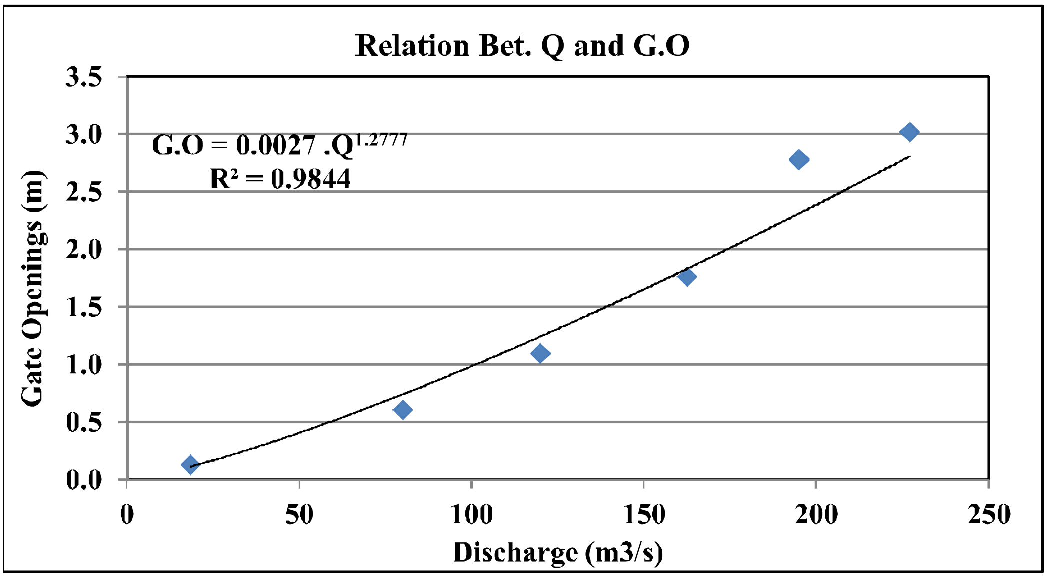

Figure 4.10 Calibration of the Gate, Case-2, Flow under Gate

4.2.2 Flow Velocity Distribution

The velocity distribution was measured at the same cross section of case-1,the velocity distribution was measured at the center of the Flume. **Figures from 4.11 to 4.16** shows the velocity distribution for the tested river discharges, the upstream water level is 46.30m+msl for all tests and downstream water level ranged from 42.55m+msl at minimum discharge and 45.82m+msl at maximum discharge. The following figures show that velocity distribution near bed on apron is forward flow and backward flow near surface at cross section close to gate. The near bed velocity reaches 3.69m/s at test-10 corresponding to discharge 162.52m^3/s at C.S (A) directly downstream the gate, the near bed velocity reaches 0.94m/s at test-12 with discharge 227m^3/s and the maximum velocity at C.S (F) at the end of blocks area was at test-12 corresponding to discharge 227m^3/s and it was 0.95m/s. the velocity distribution is became well distributed at the end of concrete slab (cross section D).

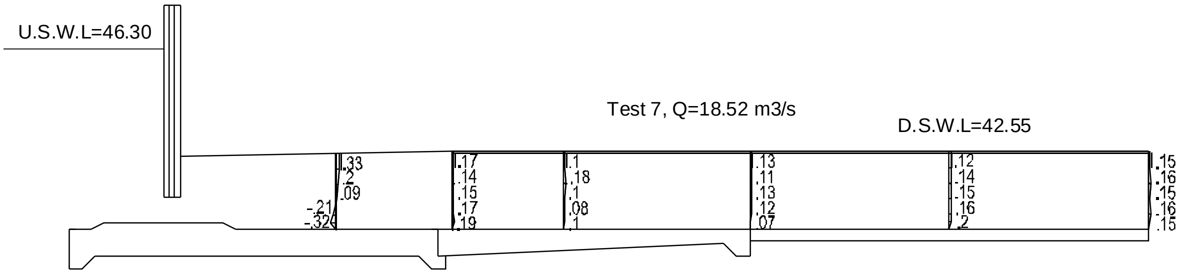

Figure 4.11 Velocity Distribution, Test-7, Case-2, Flow under Gate

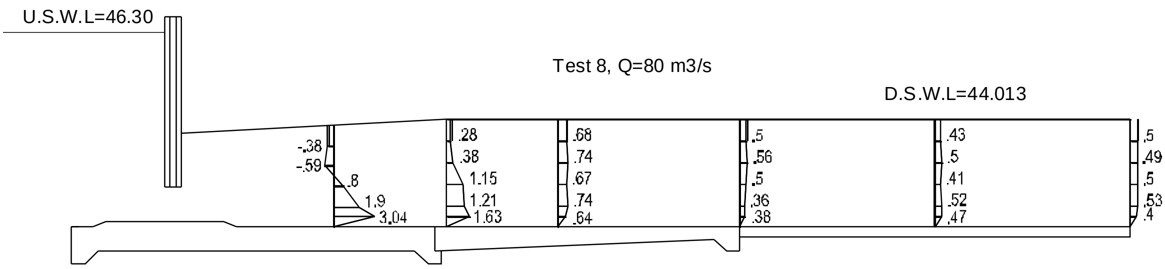

Figure 4.12 Velocity Distribution, Test-8, Case-2, Flow under Gate

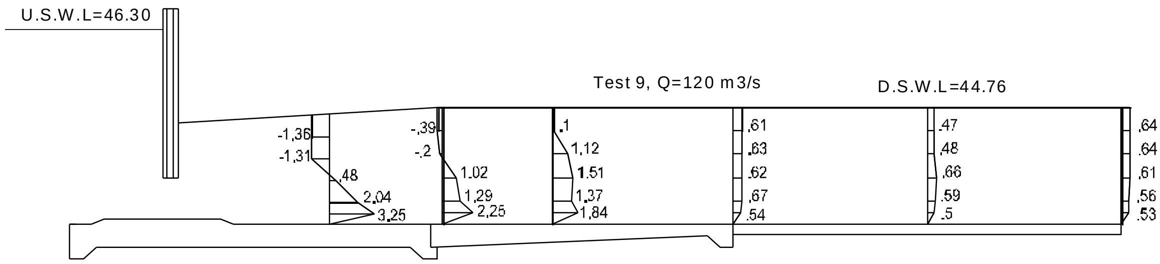

Figure 4.13 Velocity Distribution, Test-9, Case-2, Flow under Gate

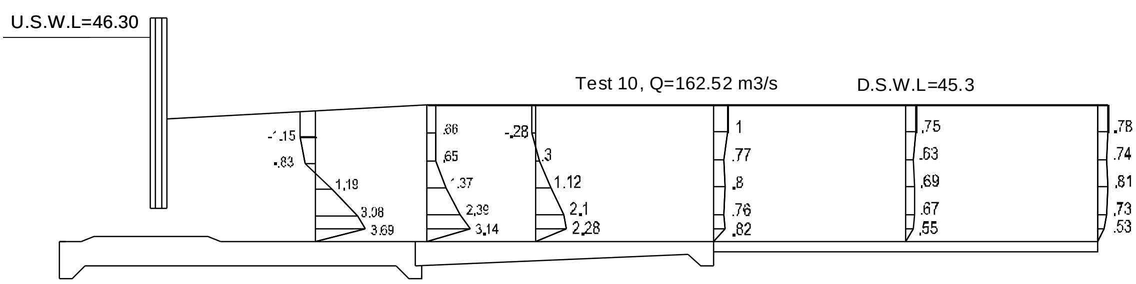

Figure 4.14 Velocity Distribution, Test-10, Case-2, Flow under Gate

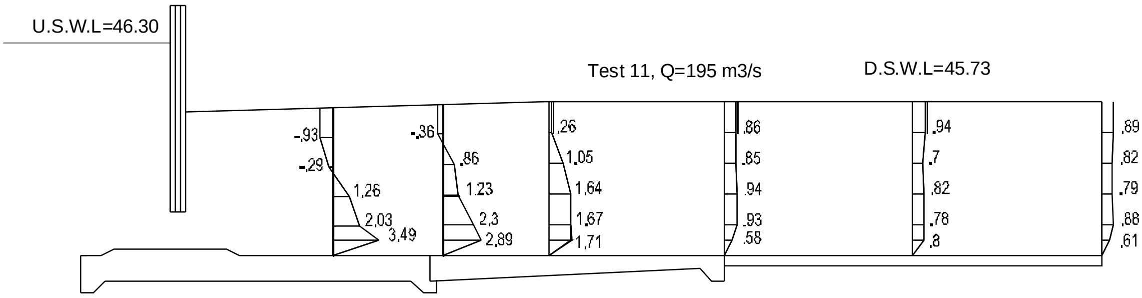

Figure 4.15 Velocity Distribution, Test-11, Case-2, Flow under Gate

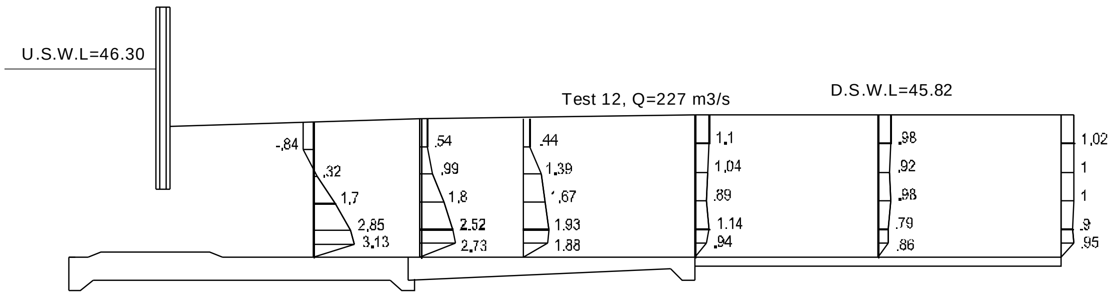

Figure 4.16 Velocity Distribution, Test-12, Case-2, Flow under Gate

4.2.3 Hydraulic Jump Characteristics

It is required to check the designed apron with regard to the hydraulic jump formations. The tests are conducted for the case of normal flow conditions. The flow characteristics under the gate and the flow condition downstream the gate. The characteristics of the hydraulic jump were investigated in order to classify its type. The conditions that applied for all tests and the measured and calculated parameters are shown in **Figure 4.17** and listed here below as following:

Test conditions:

* Sill under gate elevation: 40.00 m+msl
* Apron elevation: 39.50 m+msl
* Discharge: varying from 18.52m^3/s to 227m^3/s.

* Measured parameters:
  - Gate opening, GO [m]
  - Thickness of flow jet at vena contracta, H_c (m)
  - Backup water depth H_3 (m)

* Calculated parameters:
  - Velocity at vena contracta, v_c [m/s], $v_c = Q/(H_c\ b)$
  - Froude number, $F_{r1} = v_c/(g.H_c)^{0.5}$
  - Conjugate depth, y_2 (m)
  - Length of submerged hydraulic jump Lsj (m)
  - Relative energy losses E_L/E_1 (%)

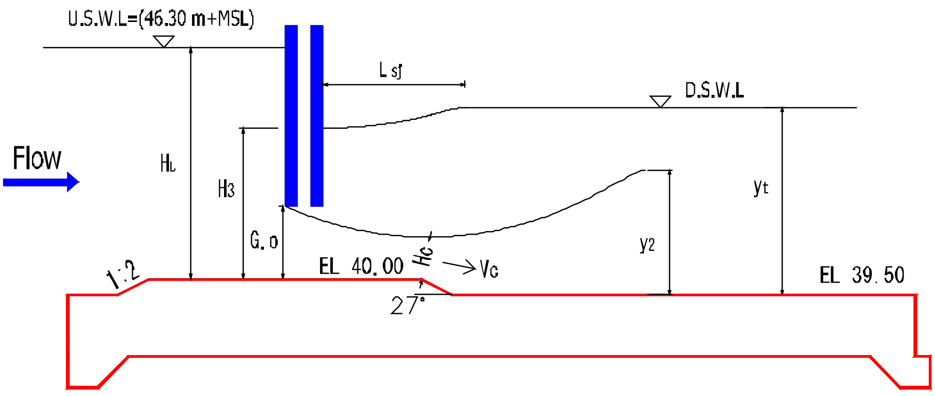

Figure 4.17 Parameters of the Hydraulic Jump Characteristics

Table 4.4 shows the measured results for the parameters of the hydraulic jump characteristics downstream the gates of new regulator. The measured parameters of the hydraulic jump are the height of the jet at vena contracta "Hc" and back up water depth downstream the gate "H_3". Also, the gate opening was measured too. Based on the measured parameters, the velocity at vena contracta "V_c", Froude No. "Fr_1" at vena contracta "Fr_1" and the length of submerged hydraulic jump "Lsj" were calculated as shown in **Table 4.5.**

The Froude No. "Fr_1" and the relative energy losses "EL/E1"were calculated. **Table 4.5** shows the calculated parameters of the hydraulic jump in order to evaluate the efficiency of the design of the stilling basin of new regulator.

The energy losses at section 1 (at vena contracta) was calculated by using the following formula:

$$E_1 = \frac{H3}{Hc} + \frac{(Fr1)^2}{2} \qquad \textbf{4.2}$$

Where:

- E_1 = the energy at section 1(at vena contracta)
- H_3 = the backup water depth (water depth just downstream the radial gate)
- Hc = the height of the jet at vena contracta
- Fr_1 = the Froude No. (at vena contracta)

Also, the total energy losses between section 1 and section 2 were calculated by using the following formula (Rajaratnam et al 1963:

$$E_L = \frac{H3}{Hc} - \left(\frac{1+S_t}{2}\right) \times \left(\sqrt{\left(1+8(Fr1)^2\right)} - 1\right) + \frac{(Fr1)^2}{2}\left(1 - \frac{4}{(1+S_t)^2 \times \left(\sqrt{\left(1+8(Fr1)^2\right)} - 1\right)^2}\right) \qquad \textbf{4.3}$$

Where:

- S_t = the submergence ratio $(y_t - y_2)/y_2$
- y_t = tail water depth
- y_2 = sequent water depth of the classical hydraulic jump

In addition, the relative energy losses E_L/E_1 *100 was also calculated in order to check the efficiency of the design of new regulator stilling basin.

Table (4.4) Hydraulic Jump Characteristics downstream the Gate

Test No.	Q	U.S.W.L	D.S.W.L	Gate Opening G.O	Backup Water Depth	Vena Contracta	Velocity at Vena. Contracta	Froude No.
	m^3/s	(m)+MSL	(m)+MSL	(m)	H_3(m)	H_c (m)	V_c (m/s)	Fr_1 (-)
Test - 7	18.52	46.3	42.55	0.13	2.25	0.17	4.54	3.51
Test - 8	80.00	46.3	44.013	0.60	3.49	0.77	4.36	1.59
Test - 9	120.00	46.3	44.76	1.10	4.34	0.68	7.35	2.85
Test - 10	162.52	46.3	45.3	1.76	4.89	1.23	5.49	1.58
Test - 11	195.00	46.3	45.73	2.78	5.31	2.00	4.07	0.92
Test - 12	227.00	46.3	45.82	3.02	5.44	2.38	3.97	0.82

Table (4.5) Calculated Hydraulic Jump Characteristics downstream the Gate

Test No.	Q	C_d	y_t	Energy Losses at Sec.1	Energy Losses(E_L)	Relative Energy Losses	Length of Sub. Jump	Length of Sub. Jump
	m^3/s	(-)	(m)	E_1 (m)	(m)	E_L/E_1 (%)	$(Lsj)_{meas.}$ (m)	$(Lsj)_{Cal.}$ (m)
Test - 7	18.52	0.71	3.05	19.43	8.53	43.90	5.40	16.46
Test - 8	80.00	0.82	4.51	5.82	1.42	24.44	17.60	24.37
Test - 9	120.00	0.83	5.26	10.43	3.92	37.58	19.64	29.28
Test - 10	162.52	0.87	5.80	5.21	1.29	24.79	14.96	31.67
Test - 11	195.00	0.87	6.23	3.08	0.57	18.66	21.08	33.27
Test - 12	227.00	1.02	6.32	2.62	0.46	17.61	25.25	33.76

4.2.4 Characteristics of Flow under Gate

The characteristics of flow under new regulator gate were investigated in order to define the discharge coefficient "C_d" with different operational mode and river flow conditions. The discharge coefficient was calculated according to the following formula of the flow under gate in presence of submerged hydraulic jump:

$$Q = C_d * B * G.O * \sqrt{2 * g * \Delta h} \qquad 4.4$$

Where:

Q	= the sluiceway discharge/gate	(m^3/s)
C_d	= the discharge coefficient	(-)
B	= the width of the gate	(m)
G.O	= the gate openings	(m)
g	= the gravity acceleration (9.81)	(m^2/s)
Δh	= the differential head	(m)

Table 4.5 show the discharge coefficient which was calculated based on the measured gate openings "G.O" which obtained during the test run for all tests with different river flow conditions. The results showed that the discharge coefficient was ranged from 0.71 to 1.02. **Figure 4.18** shows the relation between the discharge and discharge coefficient for all obtained data of case-2, at which **Figure 4.19** shows the relation between the gate openings and the discharge coefficient for the obtained data.

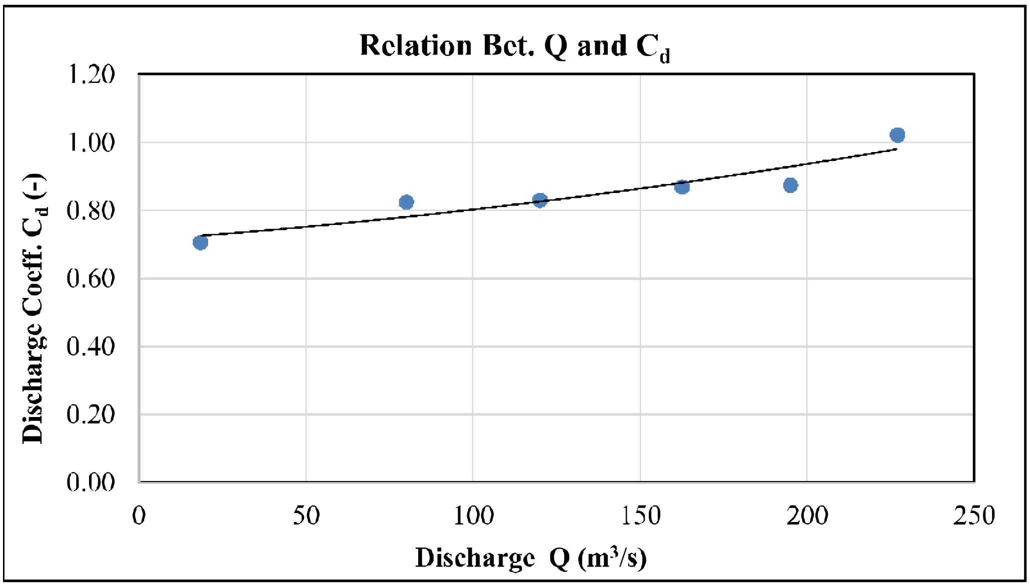

Figure 4.18 Relation between Discharge (Q) and Discharge Coefficient (Cd)

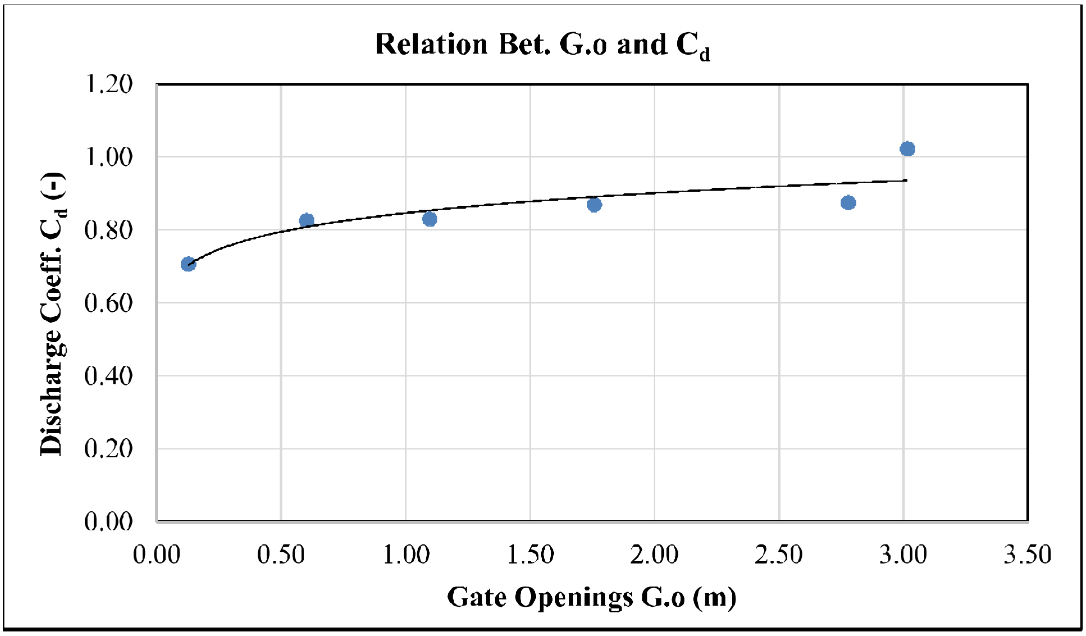

Figure 4.19 Relation between Gate Openings and Discharge Coefficient

4.2.5 Pressure Distribution

The pressure distribution was measured at eight locations on the sill under gate and on the horizontal apron using eight pressure cells, 4.46m (model scale) distance as shown in **Figure 3.2** in the previous chapter. Pressure head measurements were carried out for different flow discharges ranging from 18.52m^3/s to 227 m^3/s. The results are shown in **Table 4.6 and Figure 4.20.**

Table 4.6 Pressure Head Distributions, Case-2 (Flow under Gate)

Test No.	Pressure Head (m)							
	P1	P2	P3	P4	P5	P6	P7	P8
Test-7	2.42	3.12	3.10	3.15	3.16	2.98	3.14	3.15
Test-8	3.68	4.81	4.28	4.34	4.45	4.31	4.62	4.59
Test-9	4.48	4.90	4.28	5.06	5.12	4.91	5.34	5.36
Test-10	5.09	5.31	5.71	5.61	5.65	5.59	5.87	5.87
Test-11	5.59	5.90	6.16	6.05	6.09	6.12	6.28	6.31
Test-12	5.68	5.98	6.26	6.16	6.22	6.24	6.39	6.41

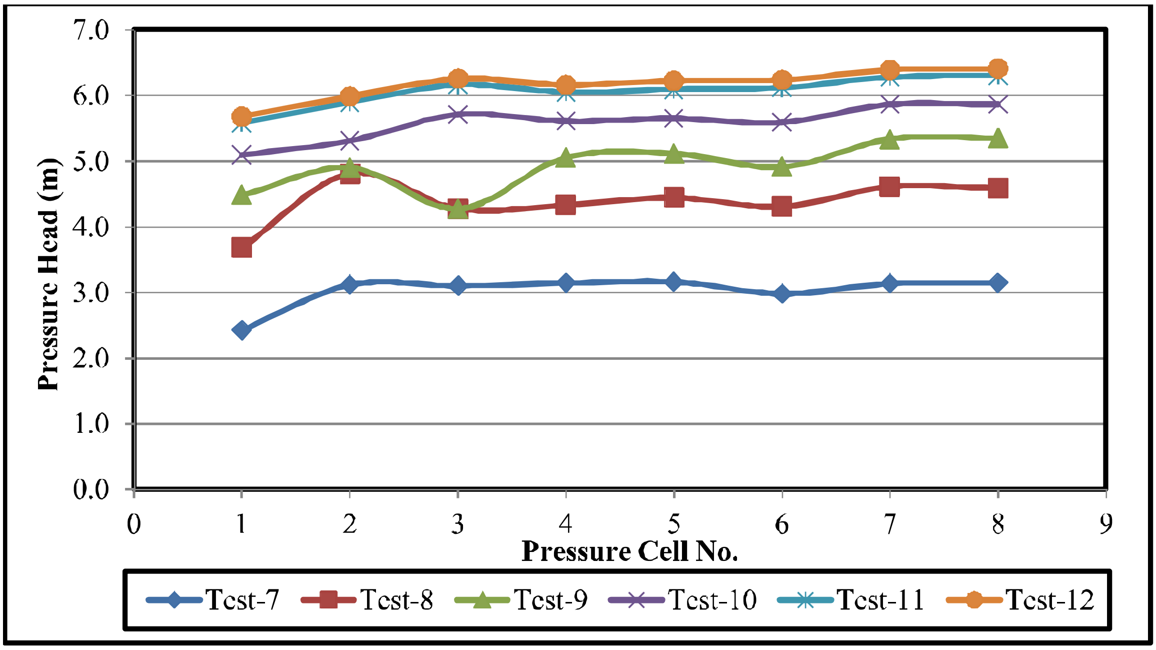

Figure 4.20 Pressure Head Distributions, Case-2 (Flow under Gate)

Figure 4.20 shows that the minimum pressure head was at the sill under gate (cell-1) for all tests except test-9 the minimum pressure head was at (cell-3).

4.3 Case-3 "Gates Fully Open"

4.3.1 Water Level Measurements

The water level was measured at the predefined locations as explained in the previous chapter along the center line of the flume between 32.53m upstream the gate and 64.54m downstream the gate as shown in **Figure 3.1**. **Table 4.7** shows the results of the measured water levels. Six tests were carried out which are Test 13 to Test 18 corresponding to discharges of 18.52, 80, 120, 162.52, 195 and 227 m^3/s respectively. The model results show that the maximum drop in the water level was 0.03, 0.03, 0.03, 0.09, 0.07, 0.08m for tests from 13 to 18 respectively, as shown in **Figure 4.21 and Plate 4.1.**

Table 4.7 Measured Water Level with Fully Open Gate

Location of Measured W.L	Measured Water Level (m+MSL)					
	Test-13	Test-14	Test-15	Test-16	Test-17	Test-18
Upstream (1)	**42.52**	**44.00**	**44.77**	**45.30**	**45.76**	**45.85**
2	42.56	44.01	44.76	45.30	45.76	45.83
3	42.53	43.99	44.77	45.30	45.75	45.84
4	42.55	44.01	44.76	45.27	45.70	45.82
5	42.55	43.99	44.74	45.27	45.71	45.79
6	42.55	43.98	44.74	45.27	45.69	45.78
7	42.55	43.98	44.74	45.27	45.69	45.77
8	42.55	43.98	44.74	45.27	45.70	45.77
9	42.55	43.99	44.74	45.27	45.70	45.77
10	42.55	43.99	44.74	45.28	45.70	45.79
11	42.54	43.99	44.74	45.27	45.70	45.79
12	42.52	44.00	44.74	45.27	45.70	45.78
13	42.54	43.99	44.74	45.27	45.71	45.81
14	42.55	44.01	44.76	45.22	45.72	45.84
15	42.54	44.01	44.75	45.31	45.72	45.82
16	42.54	44.00	44.76	45.30	45.73	45.85
17	42.55	44.01	44.76	45.30	45.73	45.82
Downstream (18)	**42.55**	**44.01**	**44.76**	**45.30**	**45.73**	**45.82**

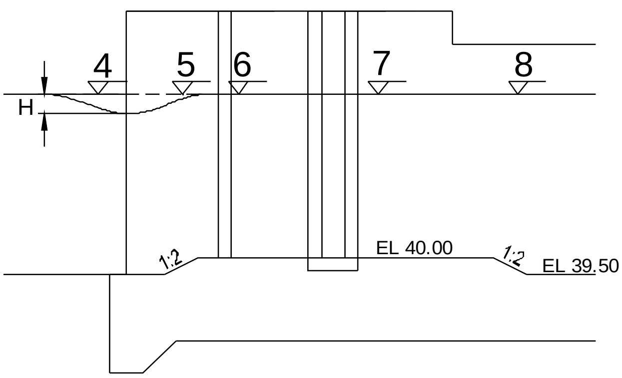

Figure 4.21 Drop in Water Level

Plate 4.1 Drop of Water around Pier, Test-17

4.3.2 Head Losses

Head losses were calculated between upstream U/S and downstream D/S at cross-sections 1 and 18 at 32.53 m upstream the gate and at 64.54 m downstream the gate (prototype scale). The head losses were calculated for six river discharges ranged from (18.52 and 227 m^3/s) for normal conditions of river bed. The head loss was calculated using the following equation:

$$Z_1 + H_1 + \frac{V_1^2}{2g} = Z_2 + H_2 + \frac{V_2^2}{2g} + h_L \quad \text{4.5}$$

Where:

Z_1 : Upstream elevation head (m),
Z_2 : Downstream elevation head (m),
H_1 : Upstream water depth (m),
H_2 : Downstream water depth (m),
V_1 : Upstream cross-sectional average velocity (m/s),
V_2 : Downstream cross-sectional average velocity (m/s), and
h_L : Head losses between section 1 & 18 (m).

The calculated head losses are based on the measured water level and the average velocity at the two locations, section 1 and 18. **Table 4.8** shows the calculated head losses for the six tested river discharges.

Table 4.8 Calculated Head Losses with Fully Open Gate

Test No.	Q (m^3/s)	U.S.W.L (m)+MSL	V_1 (m/s)	$V_1^2/2g$ (m)	D.S.W.L (m)+MSL	V_2 (m/s)	$V_2^2/2g$ (m)	h_L (m)
Test-13	18.52	42.57	0.24	0.003	42.55	0.18	0.002	0.02
Test-14	80	44.04	0.49	0.012	44.01	0.43	0.009	0.03
Test-15	120	44.80	0.64	0.021	44.76	0.59	0.018	0.04
Test-16	162.52	45.36	0.72	0.026	45.30	0.71	0.025	0.06
Test-17	195	45.80	0.90	0.042	45.73	0.79	0.031	0.08
Test-18	227	45.92	0.98	0.049	45.82	0.95	0.046	0.11

The maximum head loss values between cross sections no. (1) and (18) are 0.11m for the test Test-18 which corresponds to discharge of 227 m^3/s. Also, the minimum calculated head losses was found to be 0.02m which corresponding to discharge of 18.52 m^3/s.

It should be mentioned that the head losses which are calculated in the 2D flume is only due to the effect of the single one bay of the new sluiceway and not taking into consideration the effect of the whole structure across the river at the project site. So, based on that fact the final head losses should be measured in the 3-D model.

4.3.3 Pressure Head

The pressure head were measured at the predefined eight pressure cells on the sill under gate and horizontal apron with 37.93m as shown in **Figure 3.2**. During the fully open gates the pressure head is measured for six river discharges ranged from 18.52 to 227 m^3/s, **see Table 4.9 and Figure 4.22**.

Table 4.9 Pressure Head Distributions, Case-3 (Fully Open Gate)

Test No.	Pressure Head (m)							
	1	2	3	4	5	6	7	8
Test-13	2.70	3.22	3.21	3.18	3.17	3.16	3.15	3.15
Test-14	4.15	4.67	4.66	4.63	4.62	4.62	4.62	4.61
Test-15	4.89	5.41	5.40	5.38	5.37	5.36	5.36	5.36
Test-16	5.41	5.93	5.94	5.91	5.89	5.88	5.89	5.90
Test-17	5.83	6.35	6.36	6.32	6.32	6.32	6.32	6.32
Test-18	5.93	6.44	6.45	6.43	6.41	6.41	6.43	6.43

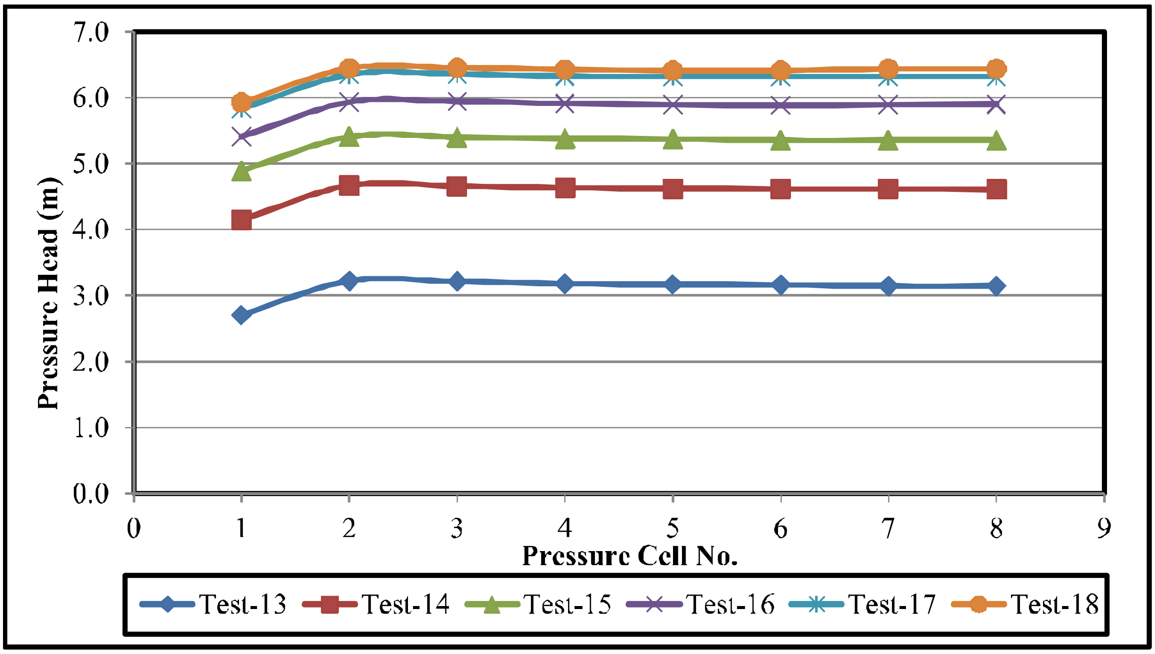

Figure 4.22 Measured Pressure head

Figure 4.22 shows that the minimum pressure head was at cell (1) and the pressure head at the rest of cells is approximately constant.

4.4 Stability of Rip-Rap Protection Layers

The stability of rip-rap protection layer was investigated for different flow discharges ranging from 18.52m^3/s to 227 m^3/s. The Rip-Rap protection shall be dimensioned for releases characterized by low Froude Numbers and small energy dissipation. The flow phenomena require that certain care is applied to determine stability of Rip-Rap particles used to prevent scouring downstream of the apron.

The criteria for selection of the Rip-Rap size include a "stability coefficient" **B'**. The stability coefficient **B'** indicates that the riprap is stable if **B'** below 1.25-1.30.Remembering that the stability of the Rip-Rap downstream of a stilling basin depends on both velocity and turbulence level, the stability coefficient was formulated by Römisch, K. et al ,1995[4]:

$$B' = \frac{v_{bottom}(1 + C.Tu)}{\sqrt{d_{50} \cdot g.\Delta'}} \qquad \textbf{4.6}$$

Where:

- B' = Stability coefficient ranges from 1.25-1.30
- v_{bottom} = Bottom velocity
- C = 3.00 to 3.17, **see [4]**
- Tu = Relative turbulence intensity
- d_{50} = Mean size of Rip-Rap particles
- Δ' = Relative density of the submerged Rip-Rap

No turbulence measurements were provided in the scope of the model tests. However, there were short duration measurements of the bottom velocity available with indications of bulk turbulence. Hence, the above formula was modified to include the measured velocity fluctuations **formula (4.7)**:

$$B' = \frac{V_{bottom}(1 + 3SDV)}{\sqrt{d_{50} \cdot g.\Delta'}} \qquad \textbf{4.7}$$

Where:

SDV = Standard deviation of the velocity fluctuations.

The rip rap stability was investigated at both upstream and downstream the gate for different operational mode and hydraulic flow condition. The stability of riprap were calculated at two cross sections downstream the gate these sections are **D and** F for Case-1 and Case-2 (flow over gate and flow under gate) respectively, and another section added upstream the gate (**cross section 1**) at Case-3 of fully open gate. **Cross section (D)** is located 43 m downstream the gate (at the end of stilling basin), **C.S. (F)** is located 30m downstream section D (at the end of blocks area) and C.S. (1) located 33.4m upstream the gate as shown in **Figure 4.23**.

The velocity used in Römisch formula is velocity at 0.9 from the water depth and standard deviation is also measured for near bed velocity.

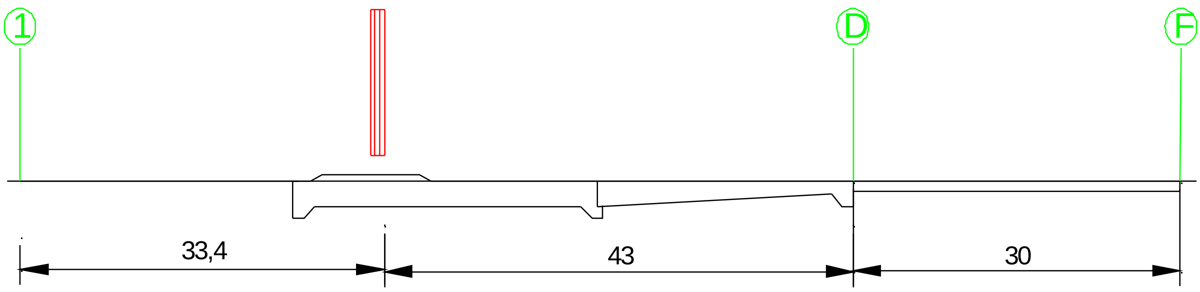

Figure 4.23 Location of Calculation of Stability of River Bed Protection

Table 4.10 shows the stability coefficient B' as calculated from modified formula with the measured standard deviation of the velocity fluctuations at the two cross sections (**D**) and (**F**) for tests from 1 to 12. Based on the measured near bed velocity fluctuation and the standard deviation the stability coefficient B' was found safe for all tested flow conditions of the Cases of flow over gate and flow under gate, see **Figures 4.24and 4.25**.

Table 4.11 and Figure 4.26 show the stability coefficient of case-3 (flow of fully open gate) and the table represents that river bed protection is stable for cross section **(1)** at upstream and cross sections **(D and F)** at downstream.

Table (4.10) Stability Coefficient for Rip-Rap Protection at Cross Sections D and F (Case-1 and Case-2)

Test No.	Q m^3/s	Cross Section (D)				Cross Section (F)			
		$V_{0.9}$ (m/s)	SD.V	B'	Safety	$V_{0.9}$ (m/s)	SD.V	B'	Safety
Test - 1	18.52	0.109	0.018	0.063	Safe	0.180	0.021	0.105	Safe
Test - 2	80	0.372	0.135	0.288	Safe	0.338	0.062	0.221	Safe
Test - 3	120	0.545	0.269	0.542	Safe	0.496	0.101	0.355	Safe
Test - 4	162.52	0.429	0.328	0.468	Safe	0.766	0.161	0.625	Safe
Test - 5	195	0.846	0.300	0.885	Safe	0.868	0.107	0.631	Safe
Test - 6	227	0.685	0.516	0.961	Safe	0.979	0.135	0.757	Safe
Test - 7	18.52	0.075	0.024	0.044	Safe	0.153	0.034	0.093	Safe
Test - 8	80	0.385	0.106	0.279	Safe	0.397	0.070	0.265	Safe
Test - 9	120	0.542	0.224	0.499	Safe	0.526	0.057	0.339	Safe
Test - 10	162.52	0.818	0.331	0.898	Safe	0.535	0.082	0.366	Safe
Test - 11	195	0.584	0.298	0.609	Safe	0.613	0.110	0.449	Safe
Test - 12	227	0.937	0.398	1.132	Safe	0.947	0.100	0.677	Safe

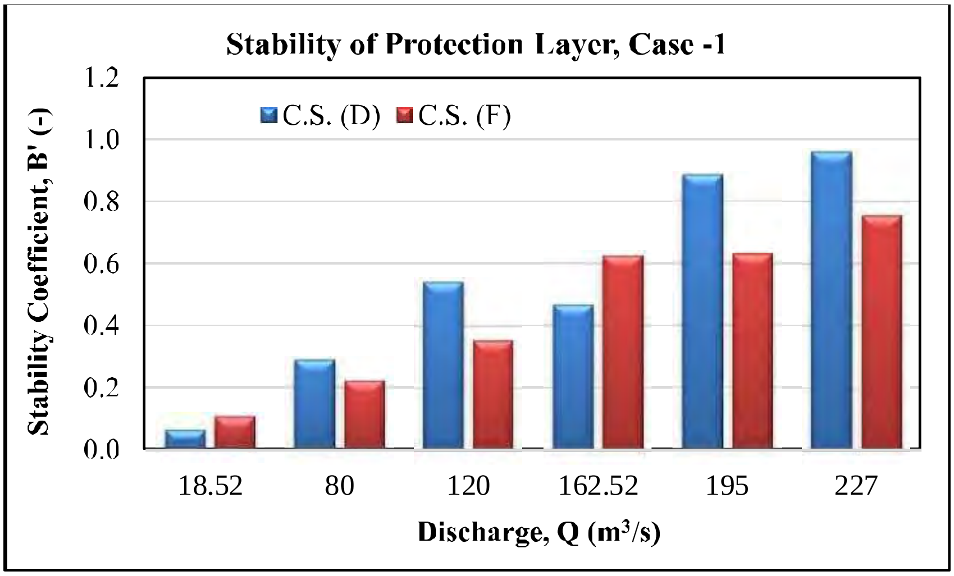

Figure 4.24 Stability Coefficient B' of Bed Protection, Flow over Gate

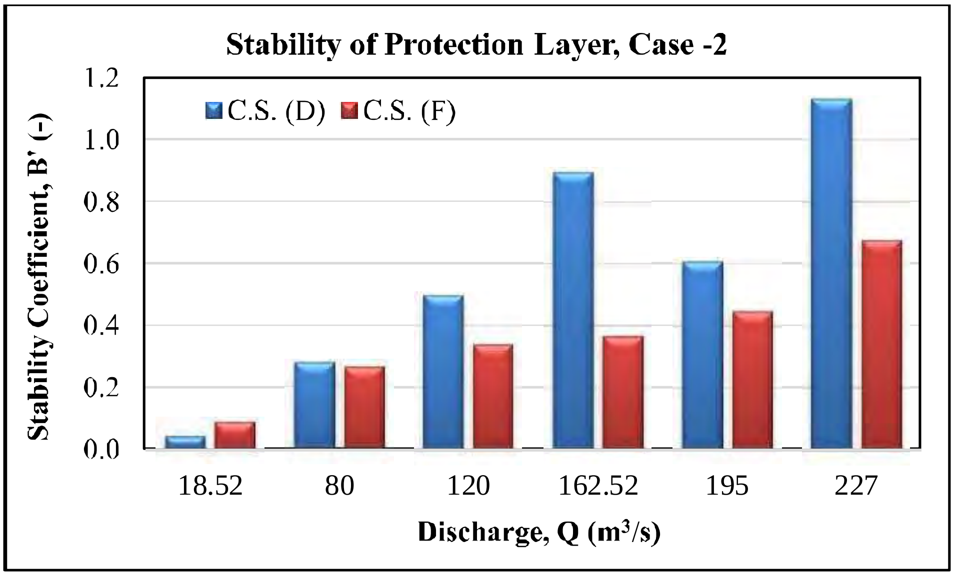

Figure 4.25 Stability Coefficient B' of Bed Protection, Flow under Gate

Table (4.11) Stability Coefficient for Rip-Rap Protection at Cross Sections1, D and F (Case-3)

Test No.	Q	Cross Section (1)				Cross Section (D)				Cross Section (F)			
	m^3/s	$V_{0.9}$ (m/s)	SD.V	B'	Safety	$V_{0.9}$ (m/s)	SD.V	B'	Safety	$V_{0.9}$ (m/s)	SD.V	B'	Safety
Test - 13	**18.52**	0.173	0.022	0.102	Safe	0.142	0.069	0.094	Safe	0.136	0.015	0.078	Safe
Test - 14	**80**	0.400	0.053	0.256	Safe	0.305	0.037	0.187	Safe	0.366	0.036	0.223	Safe
Test - 15	**120**	0.554	0.102	0.398	Safe	0.423	0.074	0.284	Safe	0.524	0.051	0.332	Safe
Test - 16	**162.52**	0.568	0.080	0.387	Safe	0.525	0.074	0.353	Safe	0.611	0.049	0.385	Safe
Test - 17	**195**	0.604	0.087	0.420	Safe	0.631	0.129	0.482	Safe	0.695	0.061	0.453	Safe
Test - 18	**227**	0.610	0.109	0.446	Safe	0.678	0.090	0.475	Safe	0.814	0.108	0.593	Safe

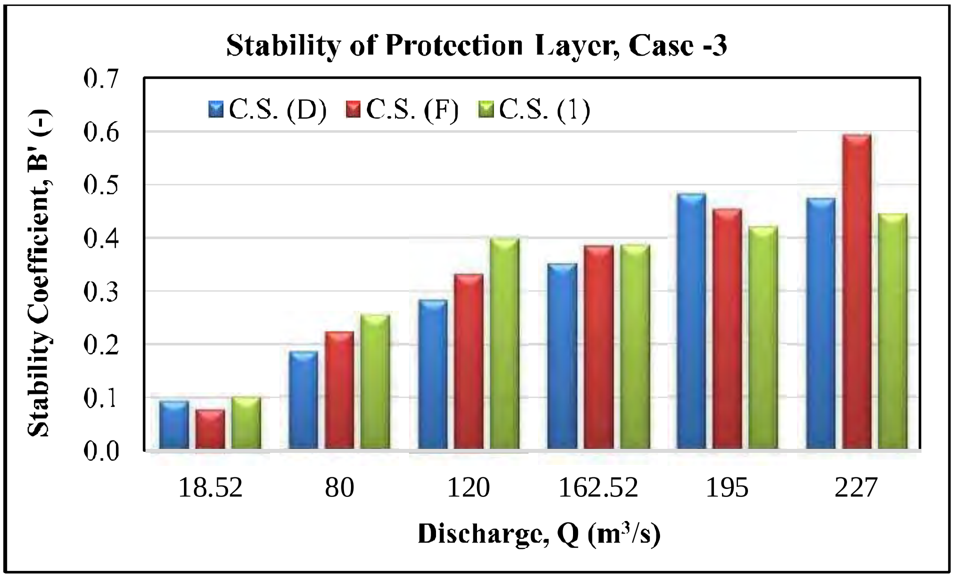

Figure 4.26 Stability Coefficient B' of Bed Protection, Fully Open Gate

5 CONLUSIONS AND RECOMMENDATION

5.1 Conclusions

A 2D model was carried out to investigate and optimize the proposed design of the stilling basin of new Bahr Yusuf regulator. The main aim of the model is to check the efficiency of the proposed design of stilling basin of new regulator. The model simulates one bay of the new regulator including the proposed design of the stilling basin and the gate in addition to canal reach of 91.59m upstream the gate and 77.56m at downstream.

The investigation tested the sluiceway with flow over gate, flow under gate and with fully open gate. The main findings of the hydraulic model for the new regulator are summarized as following:

1st.case the flow passes over the gate:

- In low discharges due to big difference between upstream and downstream levels, the velocity distributions close to the gate is forward flow near to bed and backward flow in the surface, the maximum velocity near to bed is 2.72m/s.
- In dominant and high discharges due to the low head difference between upstream and downstream the velocity distributions close to the gate is backward flow near to bed and forward flow close to surface.
- The maximum velocity near to bed at cross section (F) at the end of blocks area is 0.98m/s at high discharge (227m^3/s).
- The discharge coefficient "**C_d**" was ranged from 0.3 to 0.74.
- For discharges 195m^3/s and 227m^3/s the gate was rested on the sill under gate and we didn't control the upstream water level, so it reaches 46.33 and 46.59m+msl in test-5 and test-6 respectively.
- The river bed protection (riprap) was found stable for both cross sections D and F, cross section-D (at the end of the apron) and cross section-F (at the end of blocks area).
- The maximum stability coefficient **(B')** was found 0.961 at C.S.(D) and 0.757 at C.S.(F) for high discharge 227m^3/s.

2nd.case the flow passes under the gate:

- The gate openings were increased from **0.13m** with low discharge corresponding to 18.52m^3/s until it reaches **3.02m** with discharge227m^3/s (high discharge).
- In this case the velocity distribution near to gate is forward flow near to bed and backward flow close to the surface due to the jet of under gate flow, except test-7 (low discharge).
- The maximum value of forward velocity near to bed at C.S. No. (A) is 3.69m/s with the dominant discharge (162.52m^3/s).
- The maximum near bed velocity at cross section (F) is 0.95m/s with high discharge (227m^3/s).
- The measured vena contracta "H_c" was ranged from 0.17m in test-7 to 2.38m in test-12.
- The Froude No. "Fr_1" at vena contracta was ranged from 0.82 to 3.51.
- The discharge coefficient "C_d" was ranged from 0.71 to 1.02.
- The relative energy losses "E_L/E_1" was ranged from 17.61% in test-12 to 43.90% in test-7.
- The minimum value of pressure head was found at sill under gate (location-1).
- The river bed protection (riprap) was found stable for both cross sections D and F for all tests.

3rd.case the flow passes through a fully open gate:

- The maximum drop in the water level was 0.09m at point 14 in test-16 corresponding to discharge 162.52m^3/s.
- The maximum calculated head loss is found to be 0.11m for discharge 227m^3/s.
- The minimum calculated head loss is found to be 0.02m for minimum discharge.
- The minimum value of pressure head was found at sill under gate (location-1).
- The river bed protection (riprap) was found stable for both upstream for the calculated section and downstream for both cross sections D and F.
- The maximum stability coefficient in the upstream section is 0.446 and for downstream sections D and F are 0.482 and 0.593 respectively.

5.2 Recommendations

Based on the obtained results the following recommendations are achieved:

- No need for the area with concrete blocks downstream the apron and it can be replaced by riprap protection.
- The length of the riprap protection D/S the apron can be taken as 20-30m.

6. REFERENCE

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