

**PEOPLE'S REPUBLIC OF BANGLADESH**

**PREPARATORY SURVEY  
FOR  
SOUTHERN CHATTOGRAM REGION  
WATER SUPPLY PROJECT**

**FINAL REPORT  
(ADVANCE DISCLOSURE VERSION)**

**VOLUME-II  
SUPPORTING REPORT**

**FEBRUARY 2025**

**JAPAN INTERNATIONAL COOPERATION AGENCY**

**NIPPON KOEI CO., LTD.  
JAPAN WATER AGENCY**

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**PREPARATORY SURVEY  
FOR  
SOUTHERN CHATTOGRAM REGION WATER SUPPLY PROJECT**

**Composition of Final Report**

**Volume-I      MAIN REPORT**

|                                         |
|-----------------------------------------|
| <b>Volume-II      SUPPORTING REPORT</b> |
|-----------------------------------------|

**Supporting Report A : HYDROLOGY AND CLIMATE CHANGE  
ANALYSIS**

**Supporting Report B : PRELIMINARY DESIGN OF PROJECT  
FACILITIES**

# PREPARATORY SURVEY FOR SOUTHERN CHATTOGRAM REGION WATER SUPPLY PROJECT

## ABBREVIATIONS

| English |                                                                                                      | Japanese                                      |
|---------|------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| ADCP    | Acoustic Doppler Current Profiler                                                                    | 音波式ドップラー流速計                                   |
| Al      | Aluminum                                                                                             | アルミニウム                                        |
| As      | Arsenic                                                                                              | 砒素                                            |
| BADC    | Bangladesh Agricultural Development Corporation                                                      | バングラデシュ農業開発公社                                 |
| BBS     | Bangladesh Bureau of Statistics                                                                      | バングラデシュ統計局                                    |
| BD      | Bangladesh                                                                                           | バングラデシュ                                       |
| BDP2100 | Bangladesh Delta Plan 2100                                                                           | バングラデシュデルタプラン 2100                            |
| BETS    | Bangladesh Engineering and Technological Services                                                    | BETS 社(再委託業務コンサルタント<br>ト地下水調査)                |
| BEZA    | Bangladesh Economic Zones Authority                                                                  | バングラデシュ経済特区庁                                  |
| BIG-B   | Bengal Bay Growth Zone Plan                                                                          | ベンガル湾成長地帯構想                                   |
| BIWTA   | Bangladesh Water Transport Authority                                                                 | バングラデシュ内陸水運公社                                 |
| BMD     | Bangladesh Meteorological Department                                                                 | バングラデシュ気象局                                    |
| BOD     | Biochemical Oxygen Demand                                                                            | 生物化学的酸素要求量                                    |
| BPDB    | Bangladesh Power Development Board                                                                   | バングラデシュ電力開発庁                                  |
| BREB    | Bangladesh Rural Electrification Board                                                               | バングラデシュ地方電化庁                                  |
| BRRI    | Bangladesh Rice Research Institute                                                                   | バングラデシュ稲研究協会                                  |
| BSMSN   | Bangabandhu Sheikh Mujib Shilpanagar                                                                 | Bangabandhu Sheikh Mujib<br>Shilpa Nagar 経済特区 |
| BUET    | Bangladesh University of Engineering and Technology                                                  | バングラデシュ工科大学                                   |
| BWDB    | Bangladesh Water Development Board                                                                   | バングラデシュ水開発庁                                   |
| CC-MIDI | Moheshkhali and Matarbari Integrated Infrastructure<br>Development Initiative Coordination Committee | モヘシュカリ・マタバリ統合的イン<br>フラ開発イニシアティブ調整委<br>員会      |
| Cd      | Cadmium                                                                                              | カドミウム                                         |
| CEGIS   | The Center for Environmental and Geographic Information<br>Services                                  | CGIS 社(再委託業務コンサルタント<br>ト：概略環境調査)              |
| CEPZ    | Chittagong Export Processing Zone                                                                    | チョットグラム輸出加工区                                  |
| CHT     | Chattogram Hill Tract                                                                                | チョットグラム丘陵地                                    |
| Cl-     | Chloride                                                                                             | 塩化                                            |
| CN-     | Cyanides                                                                                             | シアン化物                                         |
| COD     | Chemical Oxygen Demand                                                                               | 化学的酸素要求量                                      |
| CPA     | Chattogram Port Authority                                                                            | チョットグラム港湾機構                                   |
| CPGCBL  | Coal Power Generation Company. Bangladesh Limit                                                      | バングラデシュ石炭火力発電会社                               |
| Cr      | Chrome                                                                                               | クロム                                           |
| Cu      | Copper                                                                                               | 銅                                             |
| CWASA   | Chattogram Water Supply and Sewerage Authority                                                       | チョットグラム上下水道公社                                 |
| DAE     | Department of Agriculture Extension                                                                  | 農業普及局                                         |
| DBHWD   | Department of Bangladesh Haor and Wetlands<br>Development                                            | バングラデシュハオール・湿地開<br>発局                         |
| DC      | Deputy Commissioner                                                                                  | 県副行政官                                         |
| DEM     | Digital Elevation Model                                                                              | 数値標高モデル                                       |
| DFR     | Draft Final Report                                                                                   | ドラフトファイナルレポート                                 |
| DLRS    | Department of Land Record and Surveys                                                                | 土地記録調査局                                       |
| DO      | Dissolved Oxygen                                                                                     | 溶存酸素量                                         |
| DOE     | Department of Environment                                                                            | 環境局                                           |
| DPHE    | Department of Public Health Engineering                                                              | 公衆衛生工學局                                       |
| EA      | Environmental Assessment                                                                             | 環境評価                                          |
| EC      | Electro Conductivity                                                                                 | 伝導率                                           |
| ECR     | Environmental Consideration Rules                                                                    | 環境保護規則                                        |
| EIA     | Environmental Impact Assessment                                                                      | 環境影響評価                                        |
| ECNWRC  | Executive Committee of the National Water Resources<br>Council                                       | 国家水資源評議会執行委員会                                 |
| EIP     | Eco Industrial Park                                                                                  | 環境に配慮した工業団地                                   |

|              |                                                                         |                             |
|--------------|-------------------------------------------------------------------------|-----------------------------|
| EL           | Elevation                                                               | 標高                          |
| EPWAPD<br>A  | East Pakistan Water and Power Development Authority                     | 東パキスタン水資源・電力開発局             |
| EZ           | Economic Zone                                                           | 経済特区                        |
| F-           | Fluoride                                                                | フッ化物                        |
| FAO          | Food and Agriculture Organization                                       | 国連食糧農業機関                    |
| FAP          | Flood Action Plan                                                       | 洪水行動計画                      |
| Fe           | Iron                                                                    | 鉄分                          |
| FPCO         | Flood Plan Coordination Organization                                    | 洪水計画調整機構                    |
| FR           | Final Report                                                            | ファイナルレポート                   |
| GOB          | Government of Bangladesh                                                | バングラデシュ国政府                  |
| GPS          | Global Positioning System                                               | 全地球測位システム                   |
| GSMaP        | Global Satellite Mapping of Precipitation                               | 降水量グローバル衛星マッピング             |
| Hg           | Mercury                                                                 | 水銀                          |
| IBRD         | International Bank for Reconstruction and Development                   | 国際復興開発銀行                    |
| ICR          | Inception Report                                                        | インセプションレポート                 |
| IEZ-SDP      | Industrial and Economic Zone Sector Development Plan                    | 産業経済特区セクター開発計画              |
| ISO          | International Organization for Standardization                          | 国際標準化機構                     |
| ITR          | Interim Report                                                          | インテリムレポート                   |
| IUCN         | International Union for Conservation of Nature and Natural Resources    | 国際自然保護連合                    |
| IWM          | Institute of Water Modelling                                            | 水モデル研究所                     |
| JAXA         | Japan Aerospace Exploration Agency                                      | 宇宙航空研究開発機構                  |
| JETRO        | Japan External Trade Organization                                       | 独立行政法人日本貿易振興機構              |
| JICA         | Japan International Cooperation Agency                                  | 国際協力機構                      |
| JP           | Japan                                                                   | 日本                          |
| JRC          | Joint Rivers Commission                                                 | バングラデシュ合同河川委員会              |
| JSS          | Japan Security Service                                                  | 日本セキュリティサービス                |
| JWA          | Japan Water Agency                                                      | 水資源機構                       |
| KKCD         | Khuta Khali Chara Dam                                                   | Khuta Khali Chara ダム        |
| LG           | Local Government                                                        | 地方政府                        |
| LGD          | Local Government Division                                               | 地方行政総局                      |
| LGED         | Local Government Engineering Department                                 | 地方政府技術局                     |
| MCM          | Million Cubic Meters                                                    | 百万立方メートル                    |
| MDG          | Millennium Development Goal                                             | ミレニアム開発目標                   |
| MIDI         | Mohekhali and Matabari Integrated Infrastructure Development Initiative | モヘシュカリ・マタバリ統合的インフラ開発イニシアティブ |
| MLD          | Million Liter per Day                                                   | 百万立法リットル/日                  |
| MoA          | Ministry of Agriculture                                                 | 農業省                         |
| Mn           | Manganese                                                               | マンガン                        |
| MoDMR        | Ministry of Disaster Management and Relief                              | 防災支援省                       |
| MOE          | Ministry of Energy                                                      | エネルギー省                      |
| MoEF         | Ministry of Environment and Forests                                     | 環境森林省                       |
| MoLGRD<br>&C | Ministry of Local Government, Rural Development and Cooperatives        | 地方自治・農村開発協同組合省              |
| MoS          | Ministry of Shipping                                                    | 海運省                         |
| MoU          | Memorandum of Understanding                                             | 了解覚書                        |
| MoWR         | Ministry of Water Resources                                             | 水資源省                        |
| MPEMR        | Ministry of Power, Energy and Mineral Resources                         | 電力、エネルギー、鉱物資源省              |
| M/P          | Master Plan                                                             | マスタープラン                     |
| MPO          | Master Plan Organization                                                | マスタープラン機関                   |
| MSL          | Mean Sea Level                                                          | 平均潮面                        |
| mS           | Milli Siemens                                                           | ミリジーメンズ                     |
| MW           | Mega Watt                                                               | メガワット                       |
| NGO          | Non-governmental Organization                                           | 非政府組織                       |
| N-NH4        | Ammonium-nitrogen                                                       | アンモニウム窒素                    |
| N-NO3        | Nitrous-nitrogen                                                        | 亜硝酸窒素                       |
| NTU          | Nephelometric Turbidity Unit                                            | 比濁法濁度単位                     |
| NWMP         | National Water Management Plan                                          | 国家水管理計画                     |
| NWPo         | National Water Policy                                                   | 国家水政策                       |
| NWRC         | National Water Resources Council                                        | 国家水資源評議会                    |
| O&M          | Operation and Maintenance                                               | 運用管理                        |

|        |                                                    |                  |
|--------|----------------------------------------------------|------------------|
| ODA    | Official Development Assistance                    | 政府開発援助           |
| PD     | Project Director                                   | プロジェクト統括責任者      |
| PCU    | Platinum Cobalt Units                              | 色度               |
| PDB    | Power Development Board                            | 電力開発庁            |
| PFI    | Private Finance Initiative                         | 民間資金主導           |
| PMO    | The Prime Minister's Office                        | 大統領官邸            |
| PPP    | Public Private Partnership                         | 官民パートナーシップ       |
| PPPA   | Public Private Partnership Authority               | 官民パートナーシップ庁      |
| QCBS   | Quality and Cost Based Selection                   | 技術・価格評価          |
| Qtu    | Qtu                                                | 現世堆積物（砂丘砂、海岸砂）   |
| RRI    | River Research Institute                           | 河川研究所            |
| RDCD   | Rural Development and Co-operatives Division       | 農村開発協同組合総局       |
| SDGs   | Sustainable Development Goals                      | 持続可能な開発目標        |
| SEZ    | Special Economic Zone                              | 経済特区             |
| SIA    | Social Impact Assessment                           | 社会影響評価           |
| SRTM   | Shuttle Radar Topography Mission                   | スペースシャトル立体地形データ  |
| SoB    | Survey of Bangladesh                               | バングラデシュ測量局       |
| SPM    | Single-Point Mooring                               | 一点係留             |
| STWG   | Sub-Technical Working Group                        | サブテクニカルワーキンググループ |
| Tmbb   | Bokabil Formation                                  | ボカビル層            |
| Tmts   | Tipam Formation                                    | ティパム層            |
| Tmub   | Upper Part of Bhuban Formation                     | ブバン上層            |
| ToR    | Terms of Reference                                 | 付託条項             |
| Tpmd   | Dupitila Formation                                 | ドゥピティラ層          |
| TWG    | Technical Working Group                            | テクニカルワーキンググループ   |
| UNICEF | United Nations Children's Fund                     | 国際連合児童基金         |
| USAID  | United States Agency for International Development | アメリカ合衆国国際開発庁     |
| WASA   | Water Supply and Sewerage Authority                | 上下水道公社           |
| WHO    | World Health Organization                          | 世界保健機関           |
| WL     | Water Level                                        | 水位               |
| WLG    | Water Level Gauge                                  | 水位計              |
| WR     | Water Resource                                     | 水資源              |
| WRDOs  | Water Resources Development Options                | 水資源開発オプション       |
| WARPO  | Water Resources Planning Organisation              | 水資源計画機構          |
| Zn     | Zinc                                               | 亜鉛               |

*Supporting Report A*

***HYDROLOGY***  
*and*  
***CLIMATE CHANGE ANALYSIS***

**PREPARATORY SURVEY  
FOR  
SOUTHERN CHATTOGRAM REGION WATER SUPPLY PROJECT**

**FINAL REPORT**

**Supporting Report A: Hydrology and Climate Change Analysis**

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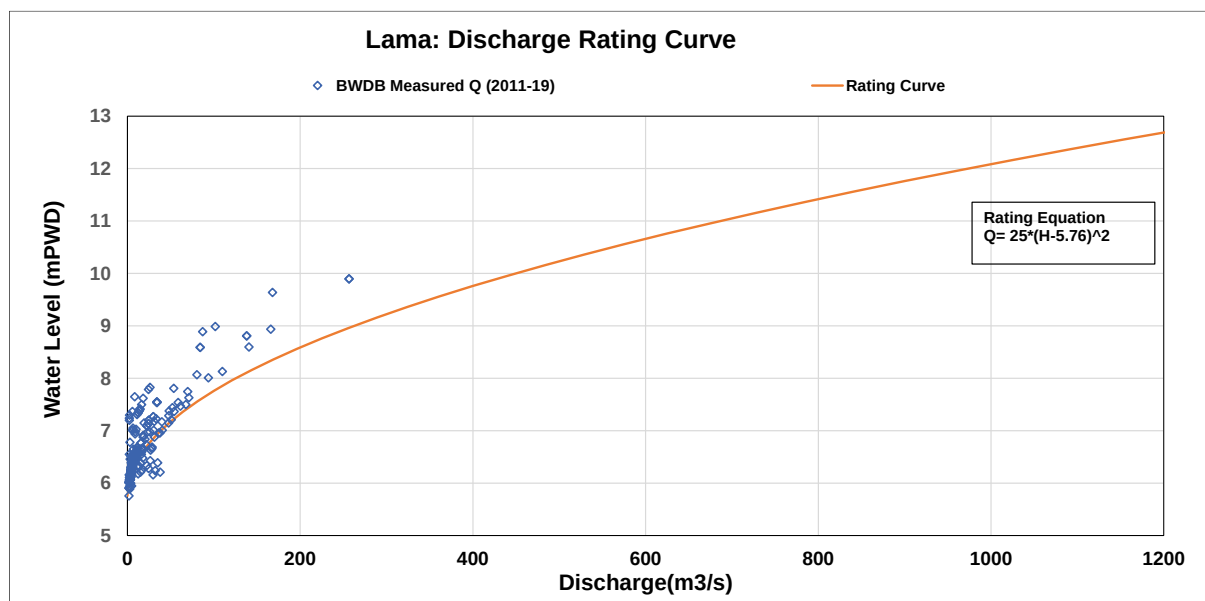
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## CHAPTER A1 HYDROLOGY

### A1.1 Estimation of River Discharge by H-Q Curve

Although Daily WL has been observed in Lama station, river discharge has not been observed. Thus, it is necessary to estimate river discharge by H-Q equation at Lama point. In previous study (Data Collection Survey on Water Resources Development in Southern Chattogram), following H-Q curve (Figure A1.1.1) was proposed and used for estimation of river discharge at Lama after confirmation of accuracy of relationship between H and Q. This H-Q curve was also followed in this study for estimation of river discharge.



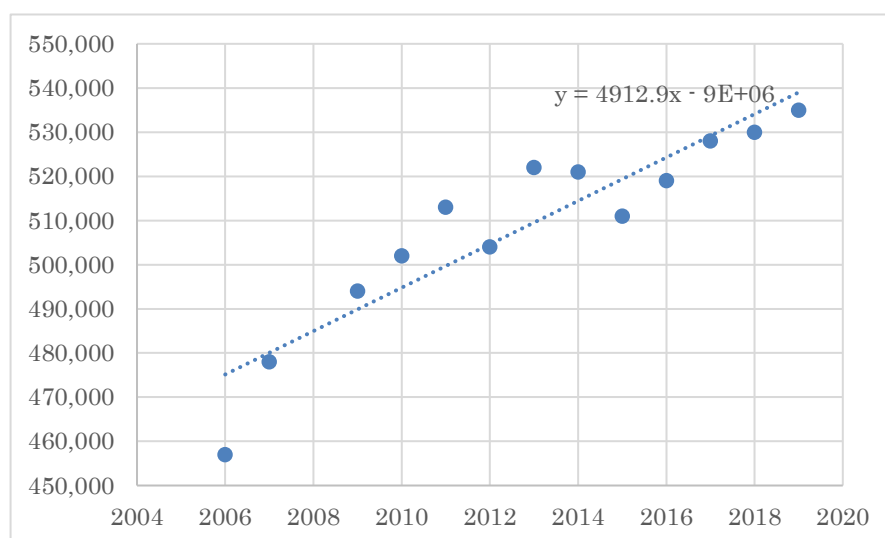
Source: Data Collection Survey on Water Resources Development in Southern Chattogram

**Figure A1.1.1 H-Q Curve for Estimation of River Discharge at Lama**

### A1.2 Estimation of Irrigation Water Demand

#### A1.2.1 Increase of Irrigation Area

In forecasting the water demand for agricultural water, the study on the master plans of irrigation development in the target area revealed that there is only an abstract description of the future plan, but no specific numerical description. The growth rate was calculated to be 0.96%/year, based on which calculated were the surface water irrigated areas from 1966 to 2019 by upazila. Therefore, the forecasted irrigation areas for 2041 were calculated, using the above-mentioned growth rate of irrigated area of 0.96%/year, which was calculated using past data (2006 - 2019) as shown on Figure A1.1.2.



Source: Data Collection Survey on Water Resources Development in Southern Chattogram

**Figure A1.1.2 Growth Rate of Irrigated Area from BBS Data (2006 – 2019)**

### A1.2.2 Cropping Pattern

It was unable to obtain the data specifying the cropping patterns for each upazila, but it was able to obtain the document “Diversity of Cropping Systems in Chittagon Region (BRRI: 2017)” that describes the typical cropping patterns in the Chattogram region. In accordance with this document, there are 93 types of cropping patterns implemented in the region, and the top 14 patterns out of them account for more than 82% in the region. Since these top 14 patterns represent the cropping pattern in the region, the unit water requirements of these 14 patterns were calculated by the Penman Method. The calculated values were multiplied by the occupancy rate of each pattern in the river basin, and the total of each unit water requirement became the unit water requirement representing the river basin.

Cropping pattern was set for each half month (24 nos per year) as shown on Figure A.1.1.3.

| Month                            | Jan                     | Feb | Mar | Apr                                | May | Jun | Jul                    | Aug | Sep | Oct                              | Nov | Dec |
|----------------------------------|-------------------------|-----|-----|------------------------------------|-----|-----|------------------------|-----|-----|----------------------------------|-----|-----|
| Season                           | Rabi (Dry Season): Boro |     |     | Kharif I (Pre Monsoon Season): Aus |     |     | Kharif II (Wet Season) |     |     | Kharif II (Monsoon Season): Aman |     |     |
| Days/Cropping Patterns           | 15                      | 16  | 14  | 15                                 | 16  | 15  | 15                     | 16  | 15  | 15                               | 16  | 15  |
| 1. Boro - Fallow - T. Aman       | Rabi (Dry Season): Boro |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 2. Fallow - Fallow - T. Aman     | Fallow                  |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 3. Boro - Fallow - Fallow        | Rabi (Dry Season): Boro |     |     | Fallow                             |     |     | Fallow                 |     |     | Fallow                           |     |     |
| 4. Grasspea - Fallow - T. Aman   | Grasspea                |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 5. Fallow - Aus - T. Aman        | Fallow                  |     |     | Aus                                |     |     | Aus                    |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 6. Soybean - Aus - T. Aman       | Soy Bean                |     |     | Aus                                |     |     | Aus                    |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 7. Soybean - Jute - T. Aman      | Soy Bean                |     |     | Jute                               |     |     | Jute                   |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 8. Soybean - Fallow - T. Aman    | Soy Bean                |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 9. Vegetab - Fallow - T. Aman    | Vegetable               |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 10. Grasspea - Aus - T. Aman     | Grasspea                |     |     | Aus                                |     |     | Aus                    |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 11. Boro - Aus - T. Aman         | Rabi (Dry Season): Boro |     |     | Aus                                |     |     | Aus                    |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 12. Fallow - Fallow - T. Aman    | Fallow                  |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 13. Chili - Fallow - T. Aman     | Chilli                  |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |
| 14. Groundnut - Fallow - T. Aman | Chilli                  |     |     | Fallow                             |     |     | Fallow                 |     |     | Monsoon (Rainy Season): T. Aman  |     |     |

Source: JICA Survey Teams

**Figure A1.1.3 Cropping Pattern**

**A1.2.3 Calculation of unit water requirement**

In calculating the unit water requirement, ETo (reference evapotranspiration) is calculated by the Penman Method, using the meteorological data of 1966 – 2019 in each basin. For the effective rainfall, (i) the daily rainfalls of 80 mm to 5 mm multiplied by 0.8 and (ii) those of 5 mm or more multiplied by 0.8 are used for the paddy field and the upland field, respectively. As the irrigation efficiency, 0.38 recommended by BADC is applied. It is judged that this value is reasonable in due consideration of the fact that the value of irrigation efficiency adopted in each Asian country has varied from 18% to 40% (IWMI 1998).



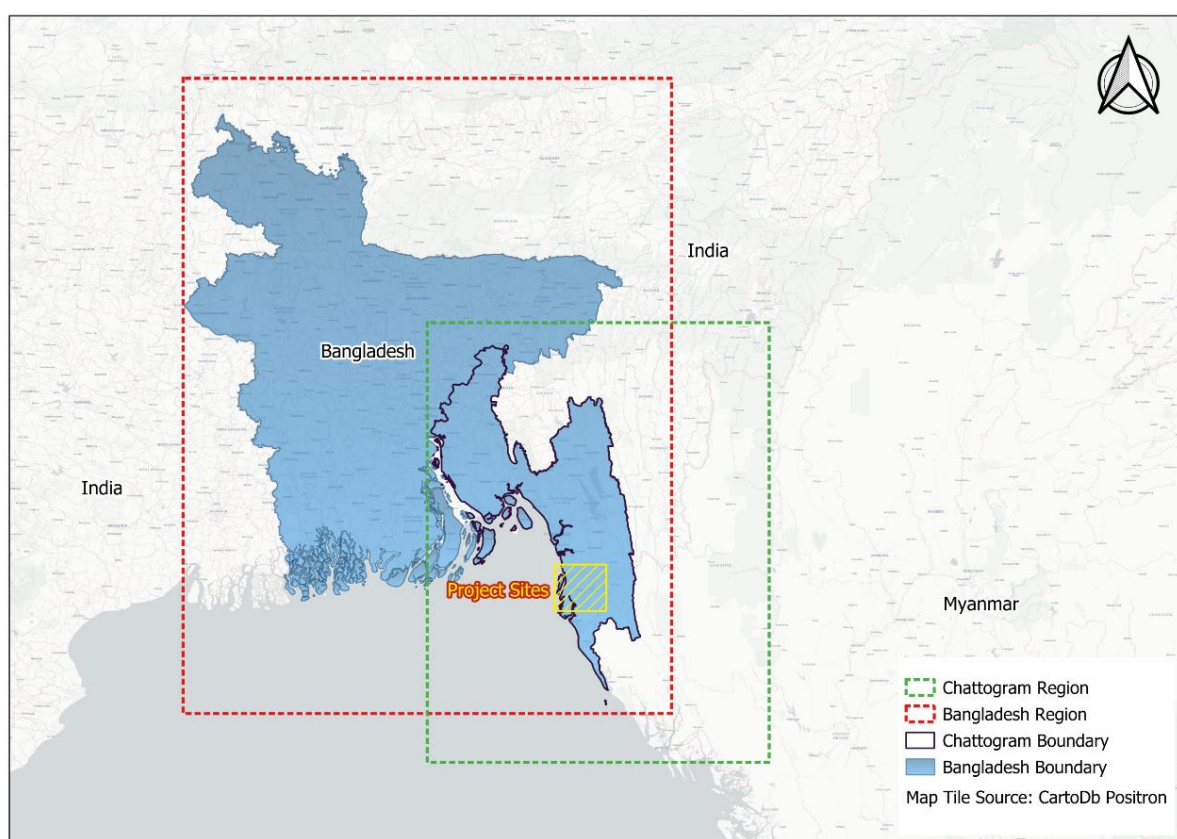
## CHAPTER A2 CLIMATE CHANGE STUDY

### A2.1 Condition

#### A2.1.1 Study Area and Condition

Climate change analysis was conducted in Chattogram region of Bangladesh to study the effect of future climate on water resources for the proposed water supply project as shown in Figure A2-1. Bangladesh is a nation in South Asia bordering with India, Myanmar and Bay of Bengal, and Chattogram is its second-largest city after Dhaka. Chattogram is a tropical region influenced by the monsoon which has two main seasons: 1. dry season (Nov-Apr) and 2. rainy season (May-Oct).

Analysis of climate change in Bangladesh and the Chattogram region was carried out based on CMIP5 - Coupled Model Intercomparison Project Phase 5 using the climate change analysis model developed by Nippon Koei Co., Ltd. Future precipitation and temperature were analyzed by using reanalysis meteorological data EWEMBI as the historical observation data (1981~2005) with 0.5° spatial and daily temporal resolution and projected under four RCPs (Representative Concentration Pathways) from low (RCP2.6) to high (RCP8.5) greenhouse gas emission in the mid-21<sup>st</sup> century (2038~2062).



Source: The Consultant

**Figure A2-1 Area Map of Bangladesh and Chattogram Region for Climate Change Analysis**

### A2.1.2 Global Climate Models (GCMs)

The Global Climate Models (GCMs) is a global climate model that divides the three-dimensional space of the globe into a grid and simulates meteorological phenomena (Figure A2-2). Many GCMs with different characteristics such as dynamic models and spatio-temporal resolution have been developed by research institutes around the world. Among them, 61 GCMs adopted in CMIP5) will be selected from the perspective of the accuracy of reproducing past climate data and spatio-temporal resolution of the target area to be used for future climate data. In this study, the accuracy of GCMs were evaluated, and GCMs were selected based on two indicators: temporal and spatial correlation against observed data (EWEMBI).

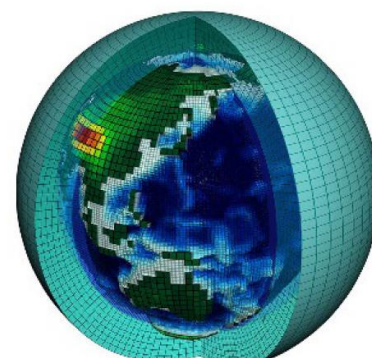


**Figure A2-2 Image of GCMs**

Source: JAMSTEC

There are a variety of models being developed by various research institutes around the world. In CMIP5 (Coupled Model Intercomparison Project 5, 46 out of 54 GCMs presented in the IPCC 5<sup>th</sup> Assessment Report (Figure A2-3) are used in this study.

|                                                                                     |                    |                                                                                     |                  |                                                                                     |                 |                                                                                     |                |                                                                                       |              |
|-------------------------------------------------------------------------------------|--------------------|-------------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------------|-----------------|-------------------------------------------------------------------------------------|----------------|---------------------------------------------------------------------------------------|--------------|
|   | ACCESS1.0          |   | CESM1 (WACCM)    |   | GFDL-CM2.1      |   | HadGEM2-AO     |   | MPI-ESM-LR   |
|  | ACCESS1.3          |  | CESM1 (FASTCHEM) |  | GFDL-CM3        |  | HadGEM2-CC     |  | MPI-ESM-MR   |
|  | BCC-CSM1.1         |  | CMCC-CESM        |  | GFDL-ESM2G      |  | HadGEM2-ES     |  | MPI-ESM-P    |
|  | BCC-CSM1.1(m)      |  | CMCC-CM          |  | GFDL-ESM2M      |  | INM-CM4        |  | MRI-AGCM3.2H |
|  | BNU-ESM            |  | CMCC-CMS         |  | GFDL-HIRAM-C180 |  | PSL-CM5A-LR    |  | MRI-AGCM3.2S |
|  | CanCM4             |  | CNRM-CM5         |  | GFDL-HIRAM-C360 |  | IPSL-CM5A-MR   |  | MRI-CGCM3    |
|  | CanESM2            |  | CSIRO-Mk3.6.0    |  | GISS-E2-H       |  | IPSL-CM5B-LR   |  | MRI-ESM1     |
|  | CCSM4              |  | EC-EARTH         |  | GISS-E2-H-CC    |  | MIROC4h        |  | NCEP-CFSv2   |
|  | CESM1(BGC)         |  | FGOALS-g2        |  | GISS-E2-R       |  | MIROC5         |  | NorESM1-M    |
|  | CESM1(CAM5)        |  | FGOALS-s2        |  | GISS-E2-R-CC    |  | MIROC-ESM      |  | NorESM1-ME   |
|  | CESM1 (CAM5.1.FV2) |  | FIO-ESM v1.0     |  | HadCM3          |  | MIROC-ESM-CHEM |                                                                                       |              |

Source: Atmosphere and Ocean Research Institute, The University of Tokyo

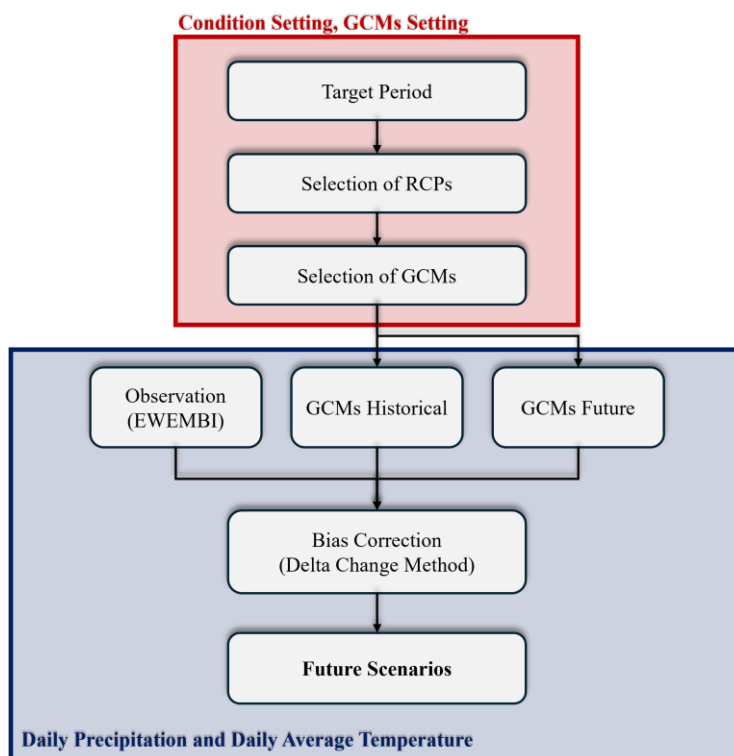
(<https://www.env.go.jp/policy/kenkyu/special/movie/pdf/h27mov04slide.pdf>)

**Figure A2-3 List of Global Climate Models Presented in the IPCC 5<sup>th</sup> Assessment Report**

### A2.1.3 GCMs Evaluation and Selection

The future climate projections from 46 global climate models (GCMs) were evaluated using SCCM (Spatial Correlation of Climatic Means) and TCCM (Temporal Correlation of Climatic Means) with the historical observation data (1981~2005) of temperature and rainfall. The reanalysis data EWEMBI (Earth2Observe, WFDEI and ERA-Interim data Merged and Bias-corrected for ISIMIP) used as historical observation data. EWEMBI is a dataset compiled by ISIMIP (Inter-Sectoral Impact Model Intercomparison Project), an international project on the assessment of the impact of global warming.

EWEMBI has a spatial resolution of 0.5° (approximately 50 km) and a daily time resolution, and is characterized by being written out as prediction (rainfall and snowfall) rather than rainfall (rainfall only) among climate data. The conceptual framework of GCMs selection to produce future scenarios of precipitation and temperature in the target area of this study is shown in the Figure A2-4 below.



Source: The Consultant

**Figure A2-4 Flowchart of Climate Change Analysis**

The Table A2-1 shows the condition setting for selecting GCMs in Bangladesh and Chattogram:

**Table A2-1 Condition Setting for GCMs Selection in Bangladesh and Chattogram**

| Variable used in the model | Input variables |   |           | Description                                                       |
|----------------------------|-----------------|---|-----------|-------------------------------------------------------------------|
| theLat, theLon             | 23.785851       | , | 90.411118 | Observatory location latitude and longitude (°)                   |
| thTCCMtas, thTCCMpr        | 0.9             | , | 0.9       | TCCM threshold for temperature and precipitation evaluation (0-1) |
| thSCCMtas, thSCCMpr        | 0.3             | , |           | SCCM threshold for temperature and precipitation evaluation (0-1) |
| region                     | Bangladesh      |   |           |                                                                   |
| lat_bnds                   | 20.5            | ~ | 27        | Analysis range (latitude) (°)                                     |
| lon_bnds                   | 88              | ~ | 93        | Analysis range (longitude) (°)                                    |
| histTimeIni, histTimeEnd   | 1981            | ~ | 2005      | Analysis period (Historical 25 years)                             |
| futTimeIni, futTimeEnd     | 2038            | ~ | 2062      | Analysis period (Near future 25 years)                            |
| gridsize, gsize            | 0.5             | , | 0.5       | Reanalysis data, GCM grid spacing (°)                             |

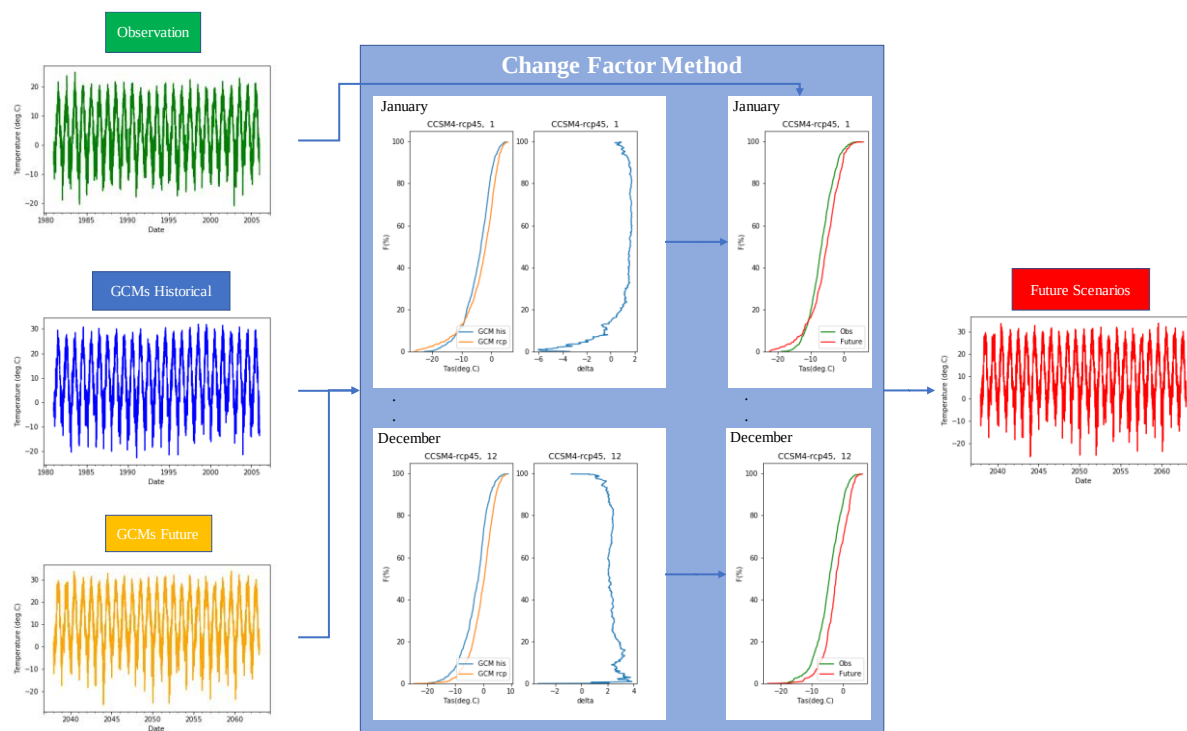
  

| Variable used in the model | Input variables |   |         | Description                                                       |
|----------------------------|-----------------|---|---------|-------------------------------------------------------------------|
| theLat, theLon             | 22.21947        | , | 92.1813 | Observatory location latitude and longitude (°)                   |
| thTCCMtas, thTCCMpr        | 0.9             | , | 0.9     | TCCM threshold for temperature and precipitation evaluation (0-1) |
| thSCCMtas, thSCCMpr        | 0.7             | , |         | SCCM threshold for temperature and precipitation evaluation (0-1) |
| region                     | Chattogram      |   |         |                                                                   |
| lat_bnds                   | 20              | ~ | 24.5    | Analysis range (latitude) (°)                                     |
| lon_bnds                   | 90.5            | ~ | 94      | Analysis range (longitude) (°)                                    |
| histTimeIni, histTimeEnd   | 1981            | ~ | 2005    | Analysis period (Historical 25 years)                             |
| futTimeIni, futTimeEnd     | 2038            | ~ | 2062    | Analysis period (Near future 25 years)                            |
| gridsize, gsize            | 0.5             | , | 0.5     | Reanalysis data, GCM grid spacing (°)                             |

Source: The Consultant

**A2.1.4 Bias Correction on Selected GCMs** For the impact assessment, the change factor method (also referred to as delta change method) was applied to generate future climate scenarios of precipitation and temperature. Figure A2-5 shows the schematic diagram of the change factor method applied for temperature. The method uses the differences of GCM simulations between future and control (historical) periods as change factor, and then applies the factor to the observations. The Delta Change method was used to correct the bias in the projected climate data, and are summarized as follows:

- 1) Past and future climate data from the GCM are arranged into a cumulative distribution function.
- 2) Compare the intensity of the same probability in the past and future, and take the difference for temperature data and the ratio for precipitation data.
- 3) The obtained differences and ratios are treated as changes from the past to the future and are added to or multiplied by the reanalysis data to obtain future data.



Source: The Consultant

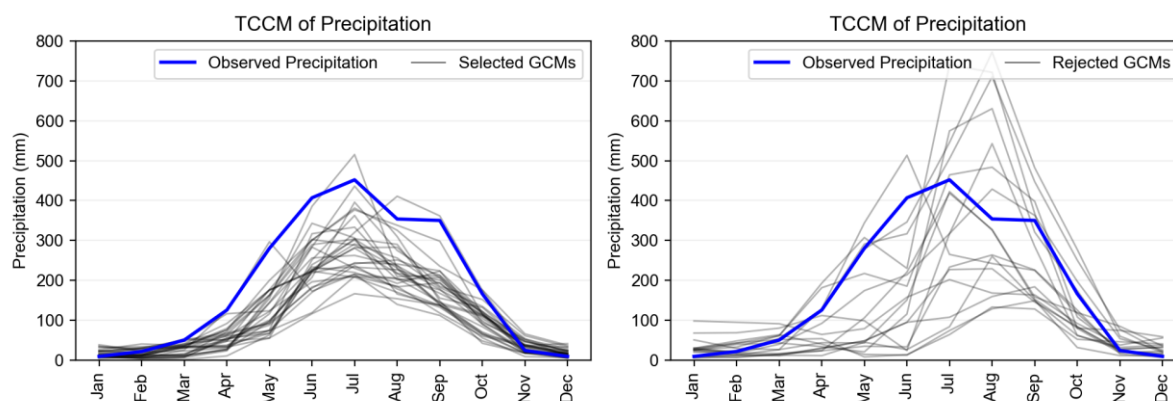
**Figure A2-5 Schematic Diagram of Change Factor Method**

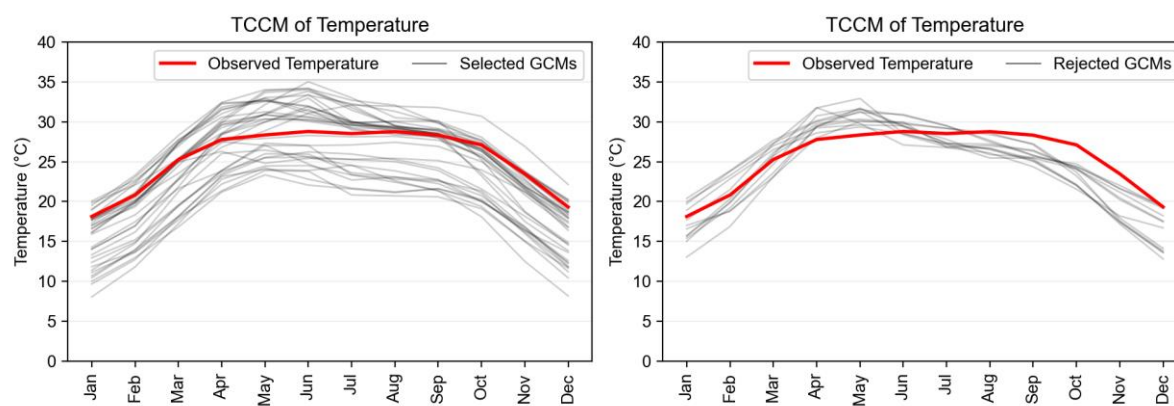
## A2.2 Result of Climate Change Analysis

### A2.2.1 Climate Change in Bangladesh

#### ❖ GCMs Selection in Bangladesh

Figure A2-6 shows the selected and rejected GCMs of precipitation and temperature based on their temporal correlation with observed historical data in Bangladesh. Considering the spatial correlation result and data availability by RCPs, 23 GCMs for precipitation and 21 GCMs for temperature were selected for further analysis as presented in Figure A2-7 and Table A2-2. Bias-correction was then applied to all GCMs to estimate future climate following each RCP.

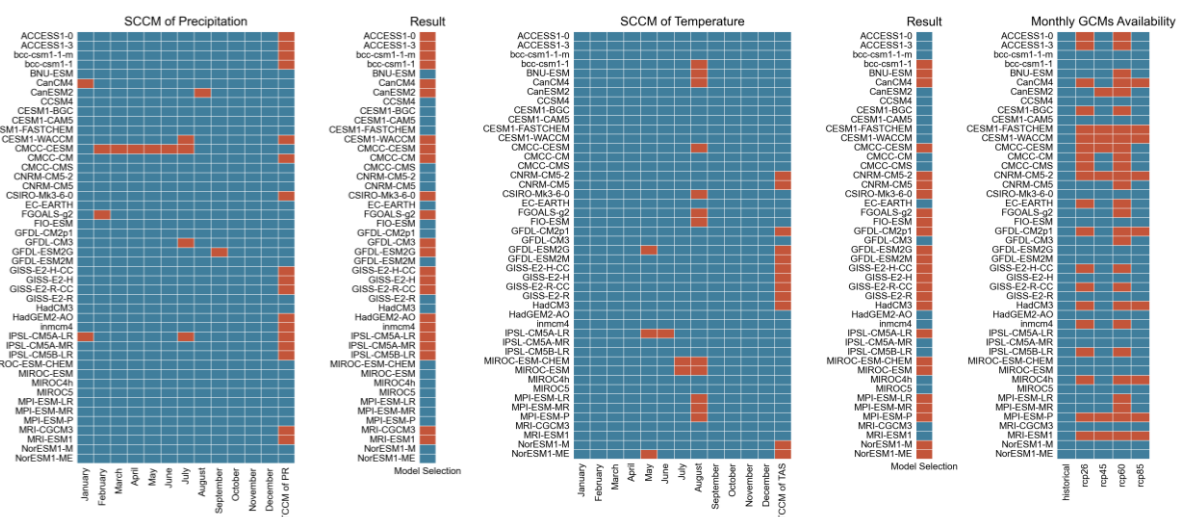




- Selected GCM : GCMs that fall into TCCM condition
- Rejected GCM : GCMs that doesn't fall into TCCM condition

**Figure A2-6 Result of GCMs Selection Based on TCCM in Bangladesh**

Source: The Consultant



Blue: Selected, Red: Not Selected

Source: The Consultant

**Figure A2-7 Result of GCMs Selection Based on TCCM, SCCM and Data Availability by RCPs in Bangladesh**

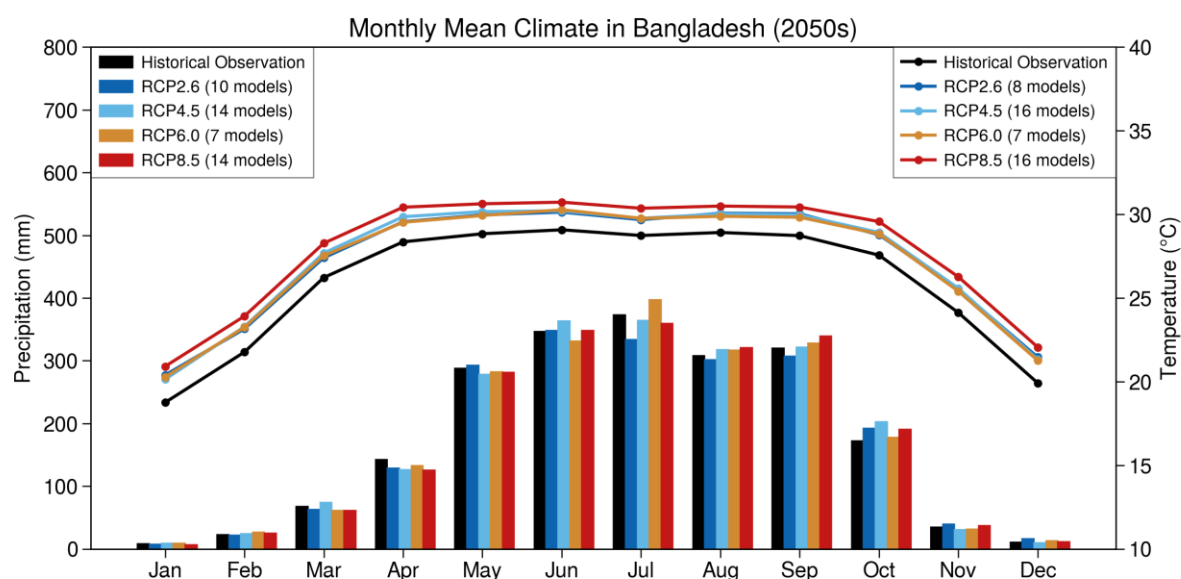
**Table A2-2 Number of Selected GCMs for Precipitation and Temperature by RCPs in Bangladesh**

| Pathway | GCMs for Precipitation | GCMs for Temperature |
|---------|------------------------|----------------------|
| RCP 2.6 | 10 models              | 8 models             |
| RCP 4.5 | 14 models              | 16 models            |
| RCP 6.0 | 7 models               | 7 models             |
| RCP 8.5 | 14 models              | 16 models            |

Source: The Consultant

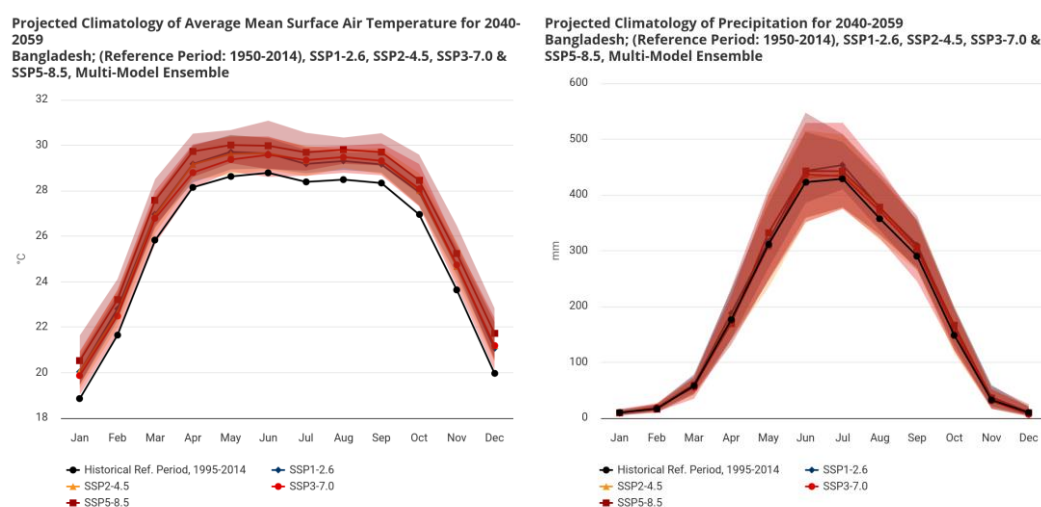
### ❖ Future Climate in Bangladesh

Future monthly average mean temperature (in °C) and precipitation (in mm/month) in Bangladesh were projected under CMIP5 dataset as shown in Figure A2-8. The figure shows the projected monthly climate for Bangladesh in the near future of 2050s under four RCP scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). The projection result of climate for 25 years (2038-2062) in this study shows similar result of projected climate for 20 years (2040-2059) by World Bank Climate Change Knowledge Portal as can be seen in Figure A2-9.



Source: The Consultant

**Figure A2-8 Projected Seasonal Temperature and Precipitation for the dry season (Nov-Apr) and the rainy season (May-Oct) in Chattogram Regions in 2050s.**



Source: World Bank Climate Change Knowledge Portal

**Figure A2-9 Projected Climatology of Average Mean Surface Air Temperature and**

### Precipitation in Bangladesh for 2040-2059 (20 years).

The climate change analysis for Bangladesh indicates notable variations in precipitation and temperature under different future emission scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) as presented in Table A2-3. Total annual precipitation is projected to vary slightly, with values ranging from 2,054.12 mm under RCP2.6 to 2,112.63 mm under RCP8.5, showing minor decreases or increases depending on the scenario. Rainy season precipitation remains relatively stable, while dry season precipitation shows slight reductions, particularly under RCP8.5, where it decreases from the current 287.22 mm to 269.68 mm. September, the month with the highest precipitation, is expected to experience significant reductions under all scenarios, with the largest decline occurring under RCP2.6. Temperature projections reveal consistent increases across all scenarios. The annual average temperature, currently 25.92°C, is expected to rise to between 27.18°C under RCP2.6 and 27.84°C under RCP8.5. Seasonal temperatures follow a similar trend, with rainy and dry season averages increasing, and June, the hottest month, projected to warm from 29.08°C to as high as 30.73°C under RCP8.5.

**Table A2-3 Seasonal Result of Climate Change Analysis in Bangladesh**

| Season                                  | Present Climate | Future Climate |          |          |          | Changing Factor |        |        |        |
|-----------------------------------------|-----------------|----------------|----------|----------|----------|-----------------|--------|--------|--------|
|                                         |                 | RCP2.6         | RCP4.5   | RCP6.0   | RCP8.5   | RCP2.6          | RCP4.5 | RCP6.0 | RCP8.5 |
| Total Annual Precipitation              | 2,097.84        | 2,054.12       | 2,125.51 | 2,111.29 | 2,112.63 | 0.979           | 1.013  | 1.006  | 1.007  |
| Total Precipitation in Rainy Season     | 1,810.62        | 1,779.44       | 1,850.00 | 1,835.95 | 1,842.95 | 0.983           | 1.022  | 1.014  | 1.018  |
| Total Precipitation in Dry Season       | 287.22          | 274.69         | 275.50   | 275.35   | 269.68   | 0.956           | 0.959  | 0.959  | 0.939  |
| Highest Precipitation Month (September) | 373.66          | 308.36         | 321.75   | 328.79   | 339.54   | 0.825           | 0.861  | 0.880  | 0.909  |

| Season                              | Present Climate | Future Climate |        |        |        | Changing Factor |        |        |        |
|-------------------------------------|-----------------|----------------|--------|--------|--------|-----------------|--------|--------|--------|
|                                     |                 | RCP2.6         | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6          | RCP4.5 | RCP6.0 | RCP8.5 |
| Annual Average Temperature          | 25.92           | 27.18          | 27.24  | 27.15  | 27.84  | 1.049           | 1.051  | 1.047  | 1.074  |
| Average Temperature in Rainy Season | 28.64           | 29.78          | 29.84  | 29.75  | 30.37  | 1.040           | 1.042  | 1.039  | 1.060  |
| Average Temperature in Dry Season   | 23.19           | 24.58          | 24.65  | 24.54  | 25.31  | 1.060           | 1.063  | 1.058  | 1.091  |
| Hottest Temperature Month (June)    | 29.08           | 30.13          | 30.21  | 30.28  | 30.73  | 1.036           | 1.039  | 1.041  | 1.057  |

Source: The Consultant

The Figure A2-10 summarizes the projected changes in temperature due to climate change in Bangladesh, categorized by months and future scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). The analysis separates the year into two distinct seasons: the rainy season (May to October) and the dry season (November to April).

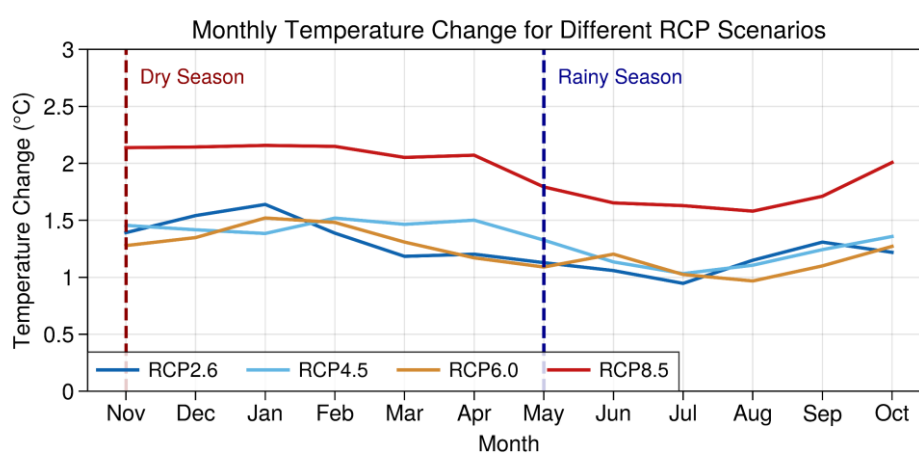
#### - Dry Season (November to April)

During the dry season, temperatures are projected to rise significantly under all scenarios. January, the coolest month, is expected to experience warming of up to 2.16°C under RCP8.5, increasing the average temperature from 18.75°C to 20.91°C. February and March also show substantial increases, with temperature rises of up to 2.15°C and 2.05°C, respectively, under RCP8.5. The hottest month in this season, April, sees the most significant warming of 2.07°C, pushing the future temperature to 30.43°C.

under the highest emission scenario. Even under the low-emission scenario (RCP2.6), temperature increases during this season range from 1.18°C to 1.64°C, underscoring the clear warming trend.

#### - Rainy Season (May to October)

The rainy season also shows a consistent warming trend, though less pronounced compared to the dry season. May, marking the transition to the rainy season, shows an increase of up to 1.79°C under RCP8.5, with future temperatures reaching 30.63°C. The mid-rainy season months, June through August, exhibit more moderate warming, with temperature rises between 0.95°C (July under RCP2.6) and 1.65°C (June under RCP8.5). September and October show slightly higher warming, particularly October, which reaches a temperature increase of up to 2.01°C under RCP8.5.



| Month | Present Temperature | Future Temperature |        |        |        | Temperature Change |        |        |        |
|-------|---------------------|--------------------|--------|--------|--------|--------------------|--------|--------|--------|
|       |                     | RCP2.6             | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6             | RCP4.5 | RCP6.0 | RCP8.5 |
| Jan   | 18.75               | 20.39              | 20.13  | 20.27  | 20.91  | 1.64               | 1.38   | 1.52   | 2.16   |
| Feb   | 21.76               | 23.15              | 23.28  | 23.25  | 23.91  | 1.39               | 1.52   | 1.48   | 2.15   |
| Mar   | 26.22               | 27.40              | 27.68  | 27.53  | 28.27  | 1.18               | 1.46   | 1.31   | 2.05   |
| Apr   | 28.36               | 29.56              | 29.86  | 29.53  | 30.43  | 1.20               | 1.50   | 1.17   | 2.07   |
| May   | 28.84               | 29.97              | 30.17  | 29.93  | 30.63  | 1.13               | 1.33   | 1.09   | 1.79   |
| Jun   | 29.08               | 30.13              | 30.21  | 30.28  | 30.73  | 1.06               | 1.13   | 1.20   | 1.65   |
| Jul   | 28.74               | 29.68              | 29.77  | 29.76  | 30.36  | 0.95               | 1.03   | 1.02   | 1.63   |
| Aug   | 28.92               | 30.07              | 30.02  | 29.88  | 30.50  | 1.15               | 1.11   | 0.97   | 1.58   |
| Sep   | 28.73               | 30.04              | 29.97  | 29.83  | 30.44  | 1.31               | 1.24   | 1.10   | 1.71   |
| Oct   | 27.56               | 28.78              | 28.92  | 28.83  | 29.57  | 1.22               | 1.36   | 1.27   | 2.01   |
| Nov   | 24.12               | 25.52              | 25.58  | 25.40  | 26.26  | 1.39               | 1.46   | 1.28   | 2.14   |
| Dec   | 19.92               | 21.46              | 21.33  | 21.26  | 22.06  | 1.54               | 1.42   | 1.35   | 2.14   |

Source: The Consultant

**Figure A2-10 Monthly Temperature Change for Different RCP Scenarios in Bangladesh in 2050s.**

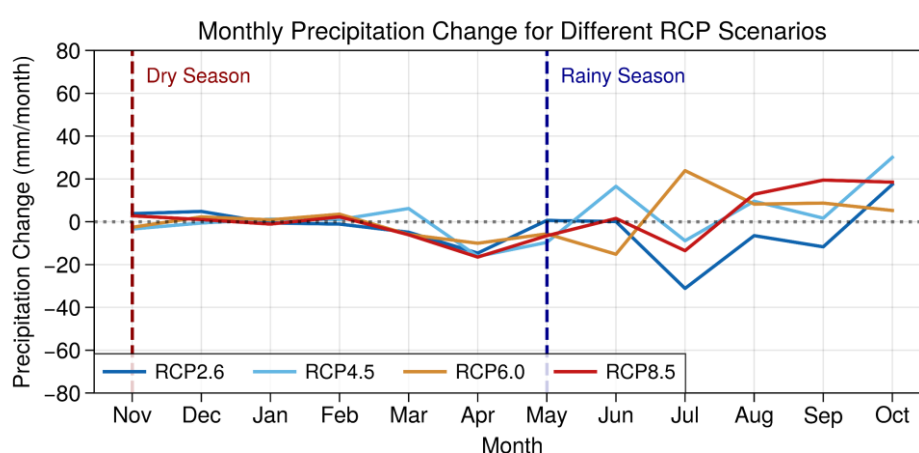
The Figure A2-11 presents the results of a climate change analysis for precipitation in Bangladesh, showing present and projected future monthly precipitation under various emission scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). The analysis is divided into the dry season (November to April) and the rainy season (May to October).

### - Dry Season (November to April)

During the dry season, precipitation shows variable trends depending on the month and emission scenario. In January, precipitation decreases under most scenarios, with the largest reduction of 1.08 mm under RCP8.5. February and March exhibit mixed changes, with February showing an increase of up to 3.53 mm under RCP6.0 but a slight decrease under RCP2.6. March sees significant reductions of up to 6.07 mm under RCP8.5. April, the wettest month of the dry season, shows a consistent decline in precipitation across all scenarios, with reductions ranging from 10.04 mm (RCP6.0) to 16.50 mm (RCP8.5). This highlights a drying trend during the latter part of the dry season.

### - Rainy Season (May to October)

The rainy season, characterized by high rainfall, exhibits mixed trends in future precipitation. May shows a slight reduction of up to 6.53 mm under RCP8.5, while June demonstrates an increase under some scenarios (up to 16.54 mm under RCP4.5) and a decrease under others (15.17 mm under RCP6.0). July and August show variability, with July exhibiting increases of up to 23.89 mm under RCP6.0 but decreases under other scenarios. August generally sees smaller changes, with an increase of up to 12.84 mm under RCP8.5. September exhibits a rising trend, with increases reaching 19.47 mm under RCP8.5. October, marking the end of the rainy season, sees significant increases in precipitation across all scenarios, with the highest increase of 30.07 mm under RCP4.5.



| Month | Present Precipitation | Future Precipitation |        |        |        | Precipitation Change |        |        |        |
|-------|-----------------------|----------------------|--------|--------|--------|----------------------|--------|--------|--------|
|       |                       | RCP2.6               | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6               | RCP4.5 | RCP6.0 | RCP8.5 |
| Jan   | 8.09                  | 7.54                 | 9.32   | 8.98   | 7.01   | -0.55                | 1.23   | 0.89   | -1.08  |
| Feb   | 23.18                 | 22.09                | 24.20  | 26.71  | 25.47  | -1.09                | 1.02   | 3.53   | 2.29   |
| Mar   | 67.86                 | 62.98                | 74.05  | 61.90  | 61.80  | -4.89                | 6.19   | -5.97  | -6.07  |
| Apr   | 142.70                | 128.06               | 126.51 | 132.66 | 126.20 | -14.64               | -16.19 | -10.04 | -16.50 |
| May   | 288.39                | 289.01               | 278.75 | 282.75 | 281.86 | 0.62                 | -9.64  | -5.64  | -6.53  |
| Jun   | 347.17                | 347.26               | 363.71 | 332.00 | 348.73 | 0.09                 | 16.54  | -15.17 | 1.56   |
| Jul   | 373.66                | 342.51               | 364.81 | 397.55 | 360.16 | -31.15               | -8.85  | 23.89  | -13.51 |
| Aug   | 308.73                | 302.25               | 318.31 | 316.98 | 321.57 | -6.48                | 9.58   | 8.25   | 12.84  |
| Sep   | 320.07                | 308.36               | 321.75 | 328.79 | 339.54 | -11.71               | 1.68   | 8.73   | 19.47  |
| Oct   | 172.60                | 190.05               | 202.67 | 177.88 | 191.10 | 17.45                | 30.07  | 5.27   | 18.50  |
| Nov   | 34.72                 | 38.52                | 31.34  | 32.15  | 37.50  | 3.80                 | -3.38  | -2.57  | 2.78   |
| Dec   | 10.67                 | 15.50                | 10.08  | 12.96  | 11.70  | 4.83                 | -0.59  | 2.28   | 1.03   |

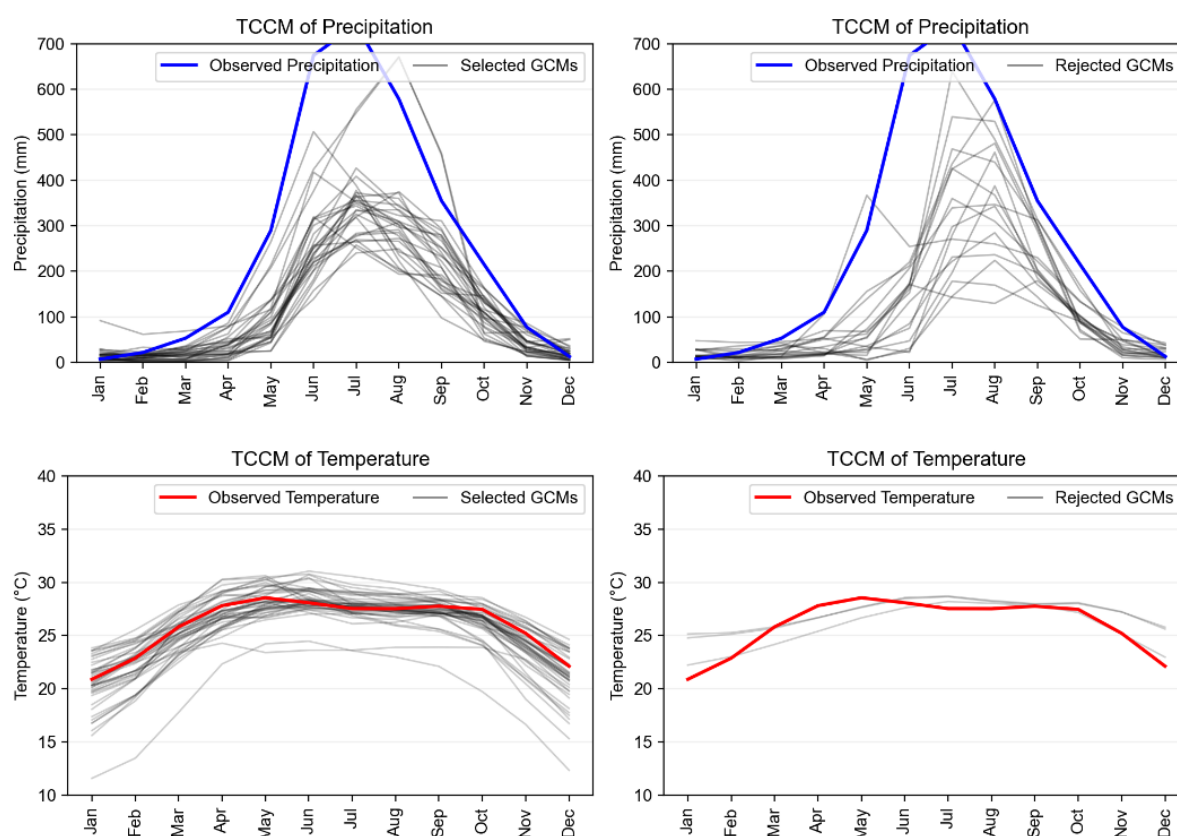
Source: The Consultant

**Figure A2-11 Monthly Precipitation Change for Different RCP Scenarios in Bangladesh in 2050s.**

### A2.2.2 Climate Change in Chattogram

#### ❖ GCMs Selection in Chattogram

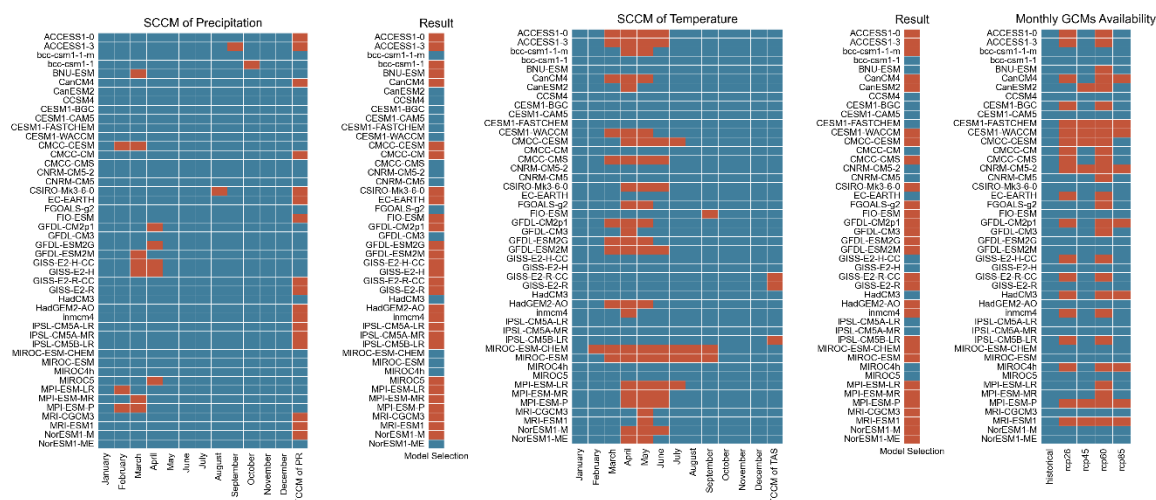
Figure A2-12 shows the selected and rejected GCMs of precipitation and temperature based on their temporal correlation with observed historical data. Considering the spatial correlation result and data availability by RCPs, 17 GCMs for precipitation and 17 GCMs for temperature were selected for further analysis as presented in Figure A2-13. Bias-correction was then applied to all GCMs to estimate future climate following each RCP.



- Selected GCM : GCMs that fall into TCCM condition
- Rejected GCM : GCMs that doesn't fall into TCCM condition

Source: The Consultant

**Figure A2-12 Result of GCMs Selection Based on TCCM in Chattogram**



Blue: Selected, Red: Not Selected

Source: The Consultant

**Figure A2-13 Result of GCMs Selection Based on TCCM, SCCM and Data Availability by RCPs in Chattogram**

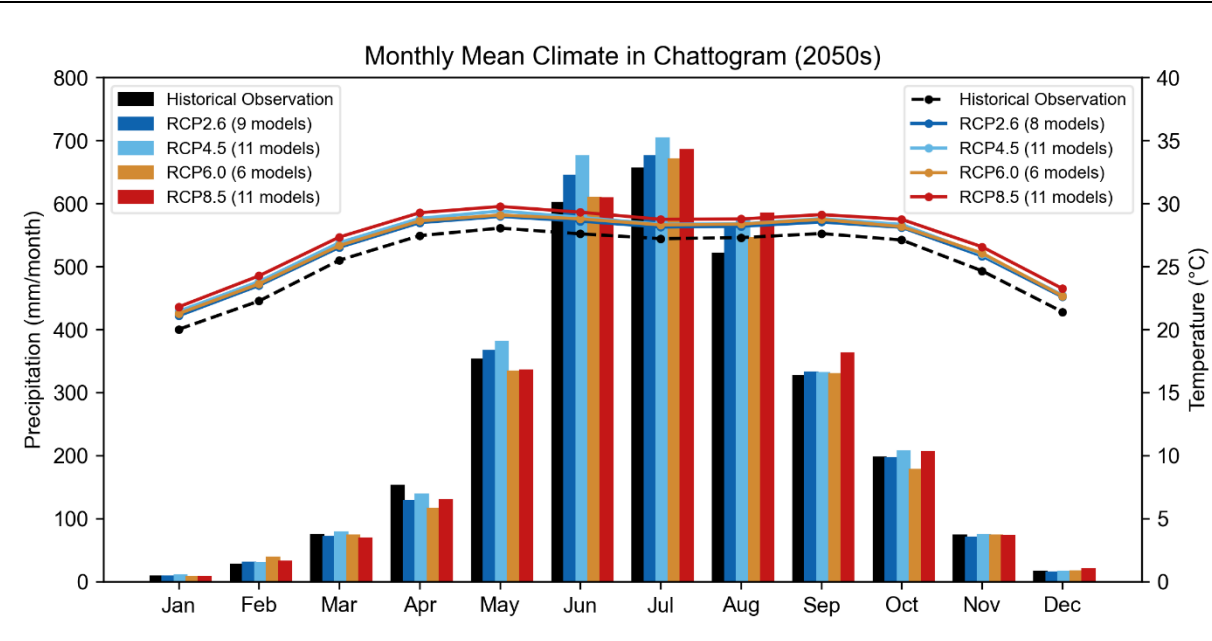
**Table A2-4 Number of Selected GCMs for Precipitation and Temperature by RCPs in Chattogram**

| Pathway | GCMs for Precipitation | GCMs for Temperature |
|---------|------------------------|----------------------|
| RCP 2.6 | 9 models               | 8 models             |
| RCP 4.5 | 11 models              | 11 models            |
| RCP 6.0 | 6 models               | 6 models             |
| RCP 8.5 | 11 models              | 11 models            |

Source: The Consultant

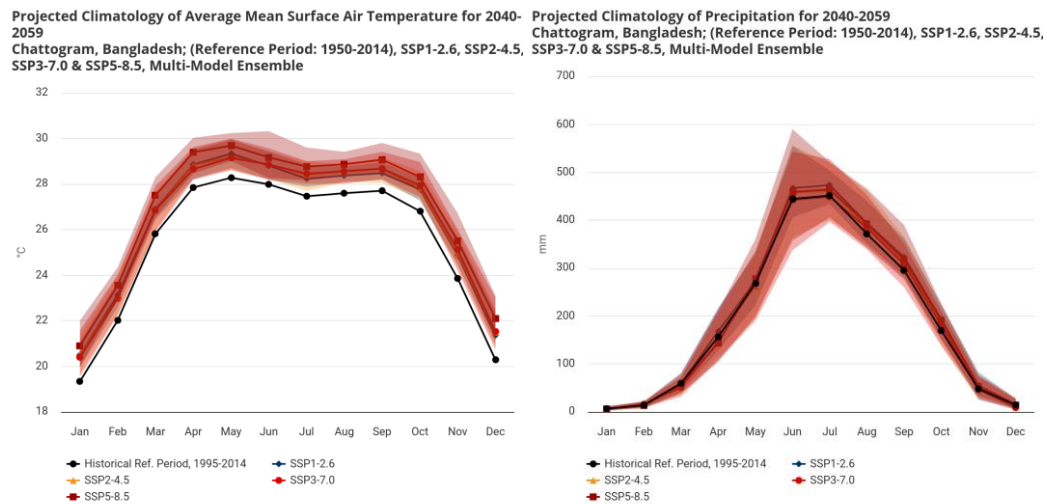
### ❖ Future Climate in Chattogram

Future monthly average mean temperature (in °C) and precipitation (in mm/month) in Chattogram were projected under CMIP5 dataset as shown in Figure A2-14. The figure shows the projected monthly climate for Bangladesh in the near future of 2050s under four RCP scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). The projection result of climate for 25 years (2038-2062) in this study shows similar result of projected climate for 20 years (2040-2059) by World Bank Climate Change Knowledge Portal as can be seen in Figure A2-15. However, the precipitation data from this analysis shows higher magnitude due to different source of historical observation dataset used by each analysis.



Source: The Consultant

**Figure A2-14 Projected Seasonal Temperature and Precipitation for the dry season (Nov-Apr) and the rainy season (May-Oct) in Chattogram Regions in 2050s.**



Source: World Bank Climate Change Knowledge Portal

**Figure A2-15 Projected Climatology of Average Mean Surface Air Temperature and Precipitation in Chattogram for 2040-2059 (20 years).**

Table A2-5 shows the result of climate change analysis for the Chattogram region. It highlights projected changes in precipitation and temperature under future climate scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5), compared to the present climate. Total annual precipitation, currently 2,999.90 mm, is projected to increase slightly under RCP2.6 (3,071.31 mm) and RCP4.5 (3,130.35 mm), but decrease under RCP6.0 (2,944.05 mm) and RCP8.5 (2,968.02 mm). The rainy season precipitation shows similar trends, with increases under RCP2.6 (2,771.55 mm) and RCP4.5 (2,804.77 mm) but slight decreases under RCP6.0 (2,621.92 mm) and RCP8.5 (2,644.14 mm). Conversely, dry season precipitation is expected to decline across all scenarios, dropping from 348.67 mm to as low as 299.76 mm under

RCP2.6. The highest precipitation month (July) shows moderate increases across all scenarios, with the largest increase under RCP4.5 (695.70 mm).

Temperature projections indicate consistent warming across all scenarios. The annual average temperature, currently 25.51°C, is projected to rise to 27.20°C under RCP8.5. Similarly, rainy season temperatures are expected to increase from 27.48°C to between 28.45°C (RCP2.6) and 29.06°C (RCP8.5). Dry season temperatures will also rise, reaching up to 25.35°C under RCP8.5. The hottest month (May) is projected to warm from 28.04°C to as high as 29.76°C under RCP8.5.

**Table A2-5 Seasonal Result of Climate Change Analysis in Chattogram**

| Season                              | Present Climate | Future Climate |          |          |          | Changing Factor |        |        |        |
|-------------------------------------|-----------------|----------------|----------|----------|----------|-----------------|--------|--------|--------|
|                                     |                 | RCP2.6         | RCP4.5   | RCP6.0   | RCP8.5   | RCP2.6          | RCP4.5 | RCP6.0 | RCP8.5 |
| Total Annual Precipitation          | 2,999.90        | 3,071.31       | 3,130.35 | 2,944.05 | 2,968.02 | 1.024           | 1.043  | 0.981  | 0.989  |
| Total Precipitation in Rainy Season | 2,651.23        | 2,771.55       | 2,804.77 | 2,621.92 | 2,644.14 | 1.045           | 1.058  | 0.989  | 0.997  |
| Total Precipitation in Dry Season   | 348.67          | 299.76         | 325.58   | 322.13   | 323.88   | 0.860           | 0.934  | 0.924  | 0.929  |
| Highest Precipitation Month (July)  | 655.09          | 690.81         | 695.70   | 673.51   | 669.80   | 1.055           | 1.062  | 1.028  | 1.022  |

| Season                              | Present Climate | Future Climate |        |        |        | Changing Factor |        |        |        |
|-------------------------------------|-----------------|----------------|--------|--------|--------|-----------------|--------|--------|--------|
|                                     |                 | RCP2.6         | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6          | RCP4.5 | RCP6.0 | RCP8.5 |
| Annual Average Temperature          | 25.51           | 26.56          | 26.80  | 26.69  | 27.20  | 1.041           | 1.050  | 1.046  | 1.066  |
| Average Temperature in Rainy Season | 27.48           | 28.45          | 28.67  | 28.57  | 29.06  | 1.035           | 1.044  | 1.040  | 1.058  |
| Average Temperature in Dry Season   | 23.55           | 24.68          | 24.92  | 24.82  | 25.35  | 1.048           | 1.058  | 1.054  | 1.077  |
| Hottest Temperature Month (May)     | 28.04           | 29.02          | 29.39  | 29.05  | 29.76  | 1.035           | 1.048  | 1.036  | 1.061  |

Source: The Consultant

The Figure A2-16 presents the results of a climate change analysis for temperature in Chattogram, highlighting present and projected future monthly temperatures under different emission scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5), as well as the corresponding temperature changes. The analysis is divided into two distinct seasons: the dry season (November to April) and the rainy season (May to October).

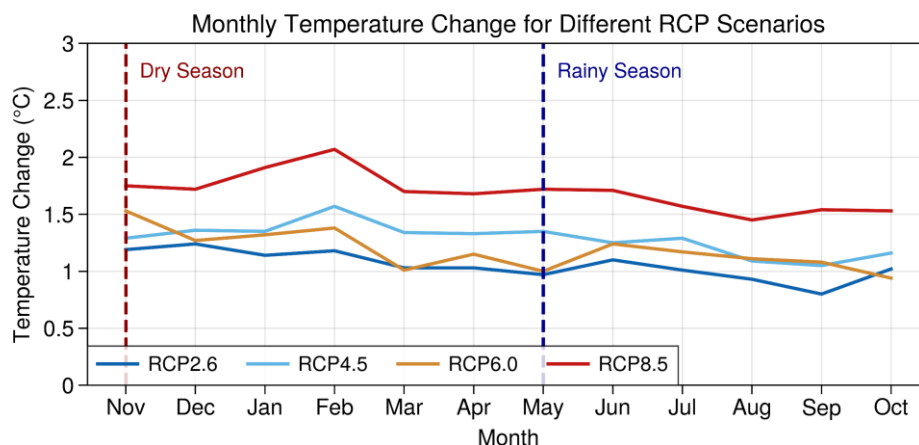
#### - **Dry Season (November to April)**

During the dry season, temperatures are projected to increase consistently across all months and emission scenarios. January, the coolest month, shows a temperature rise ranging from 1.14°C under RCP2.6 to 1.91°C under RCP8.5. February exhibits a similar trend, with an increase of up to 2.07°C under RCP8.5. March and April, which are the warmer months of the dry season, show moderate temperature increases, with April reaching up to 1.68°C under RCP8.5. These findings suggest a noticeable warming trend during the dry season, particularly under high-emission scenarios.

#### - **Rainy Season (May to October)**

In the rainy season, temperature increases are less pronounced but still significant. May, the onset of the rainy season, shows a rise of up to 1.72°C under RCP8.5. June through September experience

temperature increases ranging from 0.80°C under RCP2.6 in September to 1.71°C under RCP8.5 in June. October, marking the end of the rainy season, exhibits temperature increases of up to 1.53°C under RCP8.5. The relatively smaller increases during the rainy season compared to the dry season suggest a more moderate warming trend in this period.



| Month | Present Temperature | Future Temperature |        |        |        | Temperature Change |        |        |        |
|-------|---------------------|--------------------|--------|--------|--------|--------------------|--------|--------|--------|
|       |                     | RCP2.6             | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6             | RCP4.5 | RCP6.0 | RCP8.5 |
| Jan   | 20.01               | 21.15              | 21.36  | 21.33  | 21.92  | 1.14               | 1.35   | 1.32   | 1.91   |
| Feb   | 22.26               | 23.44              | 23.83  | 23.64  | 24.33  | 1.18               | 1.57   | 1.38   | 2.07   |
| Mar   | 25.50               | 26.52              | 26.84  | 26.51  | 27.19  | 1.03               | 1.34   | 1.01   | 1.70   |
| Apr   | 27.45               | 28.48              | 28.78  | 28.60  | 29.12  | 1.03               | 1.33   | 1.15   | 1.68   |
| May   | 28.04               | 29.02              | 29.39  | 29.05  | 29.76  | 0.97               | 1.35   | 1.00   | 1.72   |
| Jun   | 27.59               | 28.70              | 28.84  | 28.83  | 29.30  | 1.10               | 1.25   | 1.24   | 1.71   |
| Jul   | 27.21               | 28.22              | 28.50  | 28.38  | 28.77  | 1.01               | 1.29   | 1.17   | 1.57   |
| Aug   | 27.29               | 28.23              | 28.38  | 28.41  | 28.74  | 0.93               | 1.09   | 1.11   | 1.45   |
| Sep   | 27.62               | 28.41              | 28.67  | 28.69  | 29.15  | 0.80               | 1.05   | 1.08   | 1.54   |
| Oct   | 27.10               | 28.12              | 28.26  | 28.04  | 28.63  | 1.02               | 1.16   | 0.94   | 1.53   |
| Nov   | 24.65               | 25.84              | 25.95  | 26.18  | 26.40  | 1.19               | 1.29   | 1.53   | 1.75   |
| Dec   | 21.40               | 22.64              | 22.76  | 22.67  | 23.12  | 1.24               | 1.36   | 1.27   | 1.72   |

Source: The Consultant

**Figure A2-16 Monthly Temperature Change for Different RCP Scenarios in Chattogram in 2050s.**

The Figure A2-17 illustrates the results of a climate change analysis for precipitation in Chattogram, presenting current and projected future monthly precipitation levels under various emission scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) alongside the corresponding changes in precipitation. The findings are analyzed across two distinct seasons: the dry season (November to April) and the rainy season (May to October).

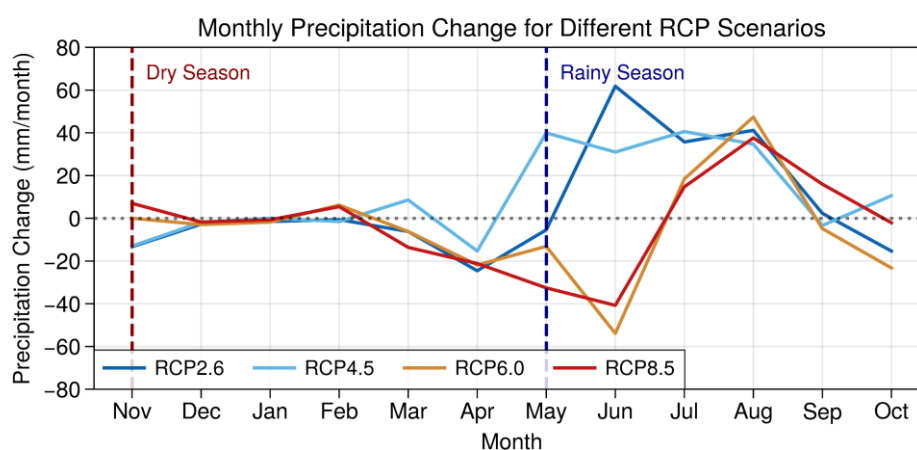
#### - Dry Season (November to April)

During the dry season, precipitation changes are mostly negative, indicating potential drying trends. January shows the most notable reduction, with precipitation decreases of up to -1.77 mm under RCP6.0. February, however, indicates a slight increase in precipitation under RCP8.5 (+5.46 mm) but reductions

under other scenarios. March and April exhibit significant declines, with April showing reductions as high as -24.56 mm under RCP2.6. These trends suggest a drier dry season overall, which could exacerbate water scarcity issues during this period.

#### - Rainy Season (May to October)

The rainy season shows mixed trends in precipitation changes, with increases in some months and decreases in others. May, the onset of the rainy season, shows a substantial reduction under RCP8.5 (-32.57 mm) but a slight increase under RCP4.5 (+39.98 mm). June and July show notable increases in precipitation under RCP2.6 and RCP4.5, with July reaching up to +40.62 mm under RCP4.5. August exhibits consistent increases across all scenarios, with a maximum increase of +47.39 mm under RCP6.0. September and October show variable trends, with September showing increases up to +15.97 mm under RCP8.5, while October experiences reductions as high as -23.25 mm under RCP6.0.



| Month | Present Precipitation | Future Precipitation |        |        |        | Precipitation Change |        |        |        |
|-------|-----------------------|----------------------|--------|--------|--------|----------------------|--------|--------|--------|
|       |                       | RCP2.6               | RCP4.5 | RCP6.0 | RCP8.5 | RCP2.6               | RCP4.5 | RCP6.0 | RCP8.5 |
| Jan   | 7.82                  | 6.32                 | 7.88   | 6.05   | 7.11   | -1.50                | 0.06   | -1.77  | -0.71  |
| Feb   | 26.71                 | 26.10                | 25.18  | 32.88  | 32.17  | -0.61                | -1.53  | 6.17   | 5.46   |
| Mar   | 73.97                 | 67.78                | 82.55  | 67.79  | 60.35  | -6.19                | 8.58   | -6.18  | -13.62 |
| Apr   | 151.91                | 127.35               | 136.58 | 130.05 | 130.74 | -24.56               | -15.33 | -21.86 | -21.17 |
| May   | 351.81                | 346.41               | 391.79 | 338.66 | 319.24 | -5.40                | 39.98  | -13.15 | -32.57 |
| Jun   | 600.86                | 662.70               | 631.87 | 546.98 | 560.11 | 61.84                | 31.01  | -53.88 | -40.75 |
| Jul   | 655.09                | 690.81               | 695.70 | 673.51 | 669.80 | 35.73                | 40.62  | 18.42  | 14.71  |
| Aug   | 520.35                | 561.53               | 555.08 | 567.74 | 557.98 | 41.18                | 34.72  | 47.39  | 37.62  |
| Sep   | 326.24                | 328.56               | 322.86 | 321.40 | 342.21 | 2.32                 | -3.38  | -4.84  | 15.97  |
| Oct   | 196.88                | 181.54               | 207.47 | 173.63 | 194.80 | -15.34               | 10.59  | -23.25 | -2.09  |
| Nov   | 73.19                 | 59.88                | 60.20  | 73.22  | 80.20  | -13.32               | -12.99 | 0.03   | 7.00   |
| Dec   | 15.07                 | 12.33                | 13.19  | 12.14  | 13.31  | -2.74                | -1.88  | -2.94  | -1.76  |

Source: The Consultant

**Figure A2-17 Monthly Precipitation Change for Different RCP Scenarios in Chattogram in 2050s.**

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## **A2.3 Key Observations in Projected Climate in Chattogram**

### **A2.3.1 Temperature Trends:**

- **General Warming:** The temperature increases across all months compared to historical observations, with RCP8.5 showing the highest increase, especially in the dry season, the average temperature could reach 29.76°C in 2050s by 1.72 °C increase from present (28.04°C).
- **Seasonal Variation:** The temperature is highest in May-June and lowest in January and December. However, temperature changes is highest in February and lowest in August.
- **Scenario Differences:** RCP8.5 consistently exhibits the highest temperatures, followed by RCP6.0 and RCP4.5, with RCP2.6 showing the smallest temperature increase.

### **A2.3.2 Precipitation Trends:**

- **Rainy Season (May-October):** The total precipitation during the rainy season is projected to show slight changes across the future scenarios. It decreases slightly under RCP2.6 (0.983 times the present) but increases under other scenarios, with the highest increase under RCP4.5 (1.022 times the present). This indicates a potential rise in rainfall intensity during the rainy season, except for a minor decline under RCP2.6.
- **Peak Precipitation:** Occurs in July, with present levels at 655.09 mm. Projected changes show increases under RCP2.6 (+35.73 mm) and RCP4.5 (+40.62 mm), while RCP6.0 (+18.42 mm) and RCP8.5 (+14.71 mm) show smaller increases.
- **Dry Season (November-April):** The dry season is projected to experience consistent decreases in precipitation across all scenarios. The total precipitation decreases by up to 4.4% (0.939 times the present) under RCP8.5, indicating a trend toward drier conditions during this period, which could exacerbate water scarcity issues in Matamuhuri River.

### **A2.3.3 Overall Climate Change Implications:**

- **Increased Extremes:** The findings suggest that Chattogram may experience more extreme rainfall during the monsoon under all future scenarios, especially under RCP2.6 and RCP4.5.
- **Warming:** The temperature rise is more pronounced under higher RCP scenarios, indicating potential heat stress in the future.

## **A2.4 Impact of Climate Change Analysis on this Project**

The climate change analysis presented in the study suggests several key impacts on water resources, particularly in relation to water supply projects in Chattogram. Here are the potential implications:

- **Higher Precipitation During Rainy Season:** The significant increase in total rainfall during the rainy season (May-October), especially under RCP4.5 scenarios from 2,651.23 mm in present level to 2,804.77 mm (1.058 times the present) indicating a higher risk of

flooding. This can overwhelm existing water discharge in Matamuhuri River, the intake source for water supply project.

- **Reduced Precipitation During Dry Season:** Despite the heavy rainfall in rainy season, the dry season (November-April) still exhibits low precipitation levels under all RCP scenarios, similar to historical trends. The total precipitation decreases by up to 0.86 times the present under RCP2.6 (from 348.67 mm to 299.76 mm). This could lead to water scarcity during these months, especially if the monsoon rains are not adequately captured and stored.
- **Higher Temperatures and Evaporation:** The projected temperature increases under all RCP scenarios. Especially under RCP8.5, the average temperature reaches up to 29.76°C (1.061 times the present temperature) in hottest month in May, which will likely lead to higher evaporation rates from reservoirs and low water flow in Matamuhuri River, reducing the effective water available for supply, particularly in January and February.

## A2.5 Data Collection and Analysis for Project Formulation as Climate Change Countermeasure Project

### A2.5.1 Outline

The Project is expected to reduce the risk of increases and decreases in river flow rates affected by climate change and ensure a stable water supply in the target areas. The implementation of the project is expected to strengthen Bangladesh's adaptability to climate change to a certain extent, and the adaptation effects of the project are estimated below.

### A2.5.2 Results of the implementation of the climate risk assessment

As part of the climate risk assessment, it was organized the "evaluation target," "climate hazards," "exposure," "vulnerability," and "climate risk." The results of the climate change assessment was described as below, and the logic for the climate risk assessment, the reasons, and the process of the study, along with the created climate risk matrix and climate risk tree.

#### (1) Determination of targets of Climate Risk Assessment

In conducting climate risk assessment and considering adaptation measures, the targets of the climate risk assessment were identified and organized based on the contents of the projects (project components, activities, etc.). For details of project components, see Main Report Chapter 6.

#### (2) Hazart

The following climate hazards were selected based on the results of the collection and analysis of related information such as past weather, disaster records, data, and future climate predictions, as well as the results of the climate change prediction analysis as mentioned in the Section above.

**Table A2.5.1 Selection of Climate Hazard**

| Selected Hazard     | H1                                                                                               | H2                                                                                                 | H3         | H4                                                                                                                                                     | H5                                                                                                             |
|---------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
|                     | Drought                                                                                          | Flood                                                                                              | Heavy Rain | Cyclone(storm)                                                                                                                                         | Hight Tide(Sea Level Rise)                                                                                     |
| Reason of Selection | Decrease of rainfall during the dry season (analysis results for the southern Chattogram region) | Increase of rainfall during the rainy season (analysis results for the southern Chattogram region) |            | The frequency of typhoons across Bangladesh is expected to increase by 40% by 2050. (Climatic Hazards in Bangladesh: A Literature Review_Masum (2019)) | Sea levels are predicted to rise at a rate of 4.7 mm per year by 2030 and 8.8 mm per year by 2100. (IPCC 2007) |

Source: JICA Survey Team

## (3) Exposure

Potential exposures that are likely to be affected by climate hazards during the project planning period in the target area were extracted as shown in the table below:

**Table A2.5.2 Potential Exposure**

| No. | Potential Exposures                                                                                                  |
|-----|----------------------------------------------------------------------------------------------------------------------|
| 1   | Water Intake Facilities (Intake Structure, Intake Channel, Sedimentation Basin, Water Intake Pump Station)           |
| 2   | Conveyance Pipeline, Water Transmission Pipeline (Buried Pipe. However, Aqueduct Bridges in river-crossing sections) |
| 3   | Reservoir                                                                                                            |
| 4   | Water Treatment Plant, Pump Station                                                                                  |
| 5   | Distribution Facilities (Elevated Type)                                                                              |
| 6   | Access Road                                                                                                          |
| 7   | Dredging Facilities (Dredging Vessel, Storage Warehouse, Vehicles, Heavy Machinery, etc.) and Disposal Area          |

Source: JICA Survey Team

In combination of the identified exposure and hazard, the "degree of impact" were assessed, and the direction of future changes in the "climate hazards" was confirmed and examined. The evaluation results are shown in the Climate Fit Matrix in next page.

## (4) Vulnerability

Based on the combination of "climate hazards" and "exposures" that should be monitored in the target project, "vulnerabilities" that may become significant in the future or that are already contributing to the business were considered and evaluated. The evaluation results are shown in the Climate Fit Matrix in next page..

**Table A2.5.3 Potential Exposure**

| No. | Exposure                                                                                                             | Vulnerability                                                                                                                                                                  |
|-----|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Water Intake Facilities (Intake Structure, Intake Channel, Sedimentation Basin, Water Intake Pump Station)           | (H1&H5) Intake will be constructed in downstream of the Matamuhuri River where saltwater intrusion may reach.<br>(H2) Intake will be located nearby river in flood prone area. |
| 2   | Conveyance Pipeline, Water Transmission Pipeline (Buried Pipe. However, Aqueduct Bridges in river-crossing sections) | (H2) Frequent damages to the bridges due to flood                                                                                                                              |
| 3   | Reservoir                                                                                                            | *(H2) Headrace channel, water transmission pipe lies will be located in flood prone area.                                                                                      |
| 4   | Water Treatment Plant, Pump Station                                                                                  | (H2) Frequent damages to the existing water supply                                                                                                                             |

|   |                                                                                                             |                                                                                                                                                                 |
|---|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
|   |                                                                                                             | facilities due to flood.                                                                                                                                        |
| 5 | Distribution Facilities (Elevated Type)                                                                     | (H2) Embankment will be constructed in flood prone area.<br>(H5) Riverbed areas with sandy deposits may experience saltwater intrusion through the groundwater. |
| 6 | Access Road                                                                                                 | (H2) Damage to existing roads from flood and road closures due to fallen trees from typhoon frequently occur.                                                   |
| 7 | Dredging Facilities (Dredging Vessel, Storage Warehouse, Vehicles, Heavy Machinery, etc.) and Disposal Area | *(H2) Water supply facilities will be constructed in flood prone area.                                                                                          |

Source: JICA Survey Team

(5) Climate risks

Based on the combination of "climate hazards" and "exposures" that should be monitored in the target business and the results of the assessment of vulnerability to events that may occur as a result, significant climate risks for the business were extracted and assessed. The assessment results are shown in the Climate Fit Matrix in next page..

(6) Climate change adaptation measures

Considering the final selected "climate risks," it was considered and organized possible measures (adaptation measures) to reduce the risks. The list of selected adaptation measures is shown in the Climate Fit Matrix. The corresponding SDGs items are also listed. In addition, based on the climate risks that are considered to be potentially significant in the future for the final selected target projects, a Climate Risk Tree was created and organized as shown in Figure A2.5.2.

|          |    | Climate Hazard                                                                                                       |                                                                                                                                       |                                                                                                                                                        |                                                                                                                                                             |                                                                                                    | Vulnerability                                                                                                                                                                             | Count of "3"                                                                                                                                                                | Climate Risk                                                                                                                                                                                                                                                                                                                                                                                                      | Potential Adaptation Options                                                                                                                                                                                                                                                                               | Corresponding SDGs items                                |
|----------|----|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
|          |    | H1                                                                                                                   | H2                                                                                                                                    | H3                                                                                                                                                     | H4                                                                                                                                                          | H5                                                                                                 |                                                                                                                                                                                           |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                            |                                                         |
|          |    | Drought                                                                                                              | Flood                                                                                                                                 | Heavy Rain                                                                                                                                             | Cyclone (Storm)                                                                                                                                             | High Tide (Sea Level Rise)                                                                         |                                                                                                                                                                                           |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                            |                                                         |
|          |    | Current Frequency                                                                                                    |                                                                                                                                       |                                                                                                                                                        |                                                                                                                                                             |                                                                                                    |                                                                                                                                                                                           |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                            |                                                         |
|          |    | Future Prediction                                                                                                    |                                                                                                                                       |                                                                                                                                                        |                                                                                                                                                             |                                                                                                    |                                                                                                                                                                                           |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                            |                                                         |
| Exposure | E1 | Water Intake Facilities (Intake Structure, Intake Channel, Sedimentation Basin, Water Intake Pump Station)           | 3↗<br>High possibility of being affected by reduced water intake levels and water quality due to reduced water volume during drought. | 3↗<br>Since the facilities are planned nearby the river, the possibility of being affected by flood is high.                                           | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 1↗<br>Possibility of being affected by cyclone, but minor.                                         | 2↗<br>Currently, the intake is planned in a location free from saltwater intrusion. However, possibility of being affected by saltwater intrusion in the future due to rising sea levels. | (H1&H5) Intake will be constructed in downstream of the Matamuhuri River where saltwater intrusion may reach. (H2) Intake will be located nearby river in flood prone area. | 2<br>(H1&H5) There are saltwater intrusion barriers, but are frequently damaged. Risk of intake stoppage because of saltwater intrusion at the intake point due to rising sea levels (H2) Damage to facilities and displacement of river sandbars due to flood is leading to malfunction of the water intake. Risk of intake malfunction because of facility damage and river sandbars displacement due to flood. | (H1&H5) Regular monitoring of salinity levels, raising the elevation of intake's mouth above the river bed, and installing backup intake pumps for extreme drought conditions. (H2) Installation of riverbank protection works. Regular maintenance dredging of the waterway in front of intake structure. | 6<br>CLEAN WATER AND SANITATION<br>13<br>CLIMATE ACTION |
|          | E2 | Conveyance Pipeline, Water Transmission Pipeline (Buried Pipe. However, Aqueduct Bridges in river-crossing sections) | 1↗<br>Possibility of being affected due to reduced water volume during drought.                                                       | 3↗<br>Since the aqueduct bridge is planned in the flood-prone area, the possibility of being affected by flood is high.                                | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 2↗<br>Possibility of aqueduct bridge being affected by cyclone.                                    | 1↗<br>Possibility of being affected by increased flood risk due to rising sea levels, but minor.                                                                                          | *(H2) Headrace channel, water transmission pipelines will be located in flood prone area.                                                                                   | 1<br>(H2) Frequent damages to the bridges due to flood Risk of failure in headrace channel and water transmission functions because of damage in aqueduct bridge.                                                                                                                                                                                                                                                 | (H2) Installation of riverbank protection works at the aqueduct bridge location and setting clearance under the bridge girder with consideration for sea level rise and flood level rise.                                                                                                                  | 6<br>CLEAN WATER AND SANITATION<br>13<br>CLIMATE ACTION |
|          | E3 | Reservoir                                                                                                            | 2↗<br>High possibility of being affected due to reduced water volume during drought.                                                  | 3↗<br>Since the facilities are planned in the flood-prone area, the possibility of being affected by flood is high.                                    | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 1↗<br>Possibility of being affected by cyclone, but minor.                                         | 2↗<br>Possibility of being affected by saltwater intrusion into the reservoir and increased flood risk due to rising sea levels.                                                          | (H2) Embankment will be constructed in flood prone area. (H5) Riverbed areas with sandy deposits may experience saltwater intrusion through the groundwater.                | 1<br>(H2) Frequent damages to the embankment due to flood. Risk of reservoir loss and failure of storage functions because of damage in reservoir embankment. (H5) Riverbed areas with sandy deposits may experience saltwater intrusion through the groundwater. Risk of decrease in water quality in the reservoir because of saltwater intrusion into the groundwater due to rise in sea level.                | (H2) Widening of the embankment cross-section and strengthening of slope protection. (H5) Installation of embankment blankets and cutoffs with consideration for sea level rise and flood level rise.                                                                                                      | 6<br>CLEAN WATER AND SANITATION<br>13<br>CLIMATE ACTION |
|          | E4 | Water Treatment Plant, Pump Station                                                                                  | 2↗<br>High possibility of being affected due to reduced water volume during drought.                                                  | 3↗<br>Since the facilities are planned in the flood-prone area, the possibility of being affected by flood is high.                                    | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 1↗<br>Possibility of being affected by cyclone, but minor.                                         | 1↗<br>Possibility of being affected by increased flood risk due to rising sea levels, but minor.                                                                                          | *(H2) Wsupply facilities will be constructed in flood prone area.                                                                                                           | 1<br>(H2) Frequent damages to the existing water supply facilities due to flood. Risk of failure in water supply functions because of damage to facilities.                                                                                                                                                                                                                                                       | (H2) Strengthening the protection against flood inundation (elevating structures, on-site drainage facilities, and provision of emergency power supply)                                                                                                                                                    | 6<br>CLEAN WATER AND SANITATION<br>13<br>CLIMATE ACTION |
|          | E5 | Distribution Facilities (Elevated Type)                                                                              | 1↗<br>Possibility of being affected due to reduced water volume during drought.                                                       | 1↗<br>Even though the facilities are planned in a flood-prone area, since it's elevated, there is a possibility of foundation being affected by flood. | 1↗<br>Even though the facilities are planned in a flood-prone area, since it's elevated, there is a possibility of foundation being affected by heavy rain. | 2↗<br>Since it's elevated, possibility of being affected by cyclone.                               | 1↗<br>Possibility of being affected by increased flood risk due to rising sea levels, but minor.                                                                                          | *(H4) Distribution facilities will be constructed in cyclone prone area.                                                                                                    | 0<br>(H4) Damage to the existing water supply facilities occurs due to cyclone. Risk of failure in water supply functions because of damage to facilities .                                                                                                                                                                                                                                                       | (H4) Strengthening facilities against cyclone (reinforcement of the foundation)                                                                                                                                                                                                                            | 6<br>CLEAN WATER AND SANITATION<br>13<br>CLIMATE ACTION |
|          | E6 | Access Road                                                                                                          | 0↗<br>No Impact.                                                                                                                      | 3↗<br>Since the facilities are planned in the flood-prone area, the possibility of being affected by flood is high.                                    | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 3↗<br>High possibility of being affected by cyclone such as fallen trees and downed utility poles. | 2↗<br>Possibility of being affected by increased flood risk due to rising sea levels, but minor.                                                                                          | *(H2) Access road will be constructed in flood and cyclone prone area.                                                                                                      | 2<br>(H2&H4) Damage to existing roads from flood and road closures due to fallen trees from cyclone frequently occur. Risk of losing access to facilities due to flood and cyclone.                                                                                                                                                                                                                               | (H2&H4) Elevate road levels, reinforce utility poles and strengthen tree planting along the roadsides. Secure alternative access routes in case of emergency.                                                                                                                                              | 13<br>CLIMATE ACTION<br>15<br>LIFE ON LAND              |
|          | E7 | Dredging Facilities (Dredging Vessel, Storage Warehouse, Vehicles, Heavy Machinery, etc.) and Disposal Area          | 0↗<br>No Impact.                                                                                                                      | 2↗<br>The planned facilities will be installed in the flood-prone area, hence there is a possibility of being affected by flood.                       | 2↗<br>Since the facilities are planned in the inundation area, there is a possibility of being affected by heavy rain.                                      | 1↗<br>Possibility of being affected by cyclone, but minor.                                         | 1↗<br>Possibility of being affected by increased flood risk due to rising sea levels, but minor.                                                                                          | *(H2&H3) Dredging facilities and disposal areas will be located nearby river in flood prone area                                                                            | 0<br>(H2) Damage and risk to the dredging facilities and disposal areas occurs due to flood and heavy rain.                                                                                                                                                                                                                                                                                                       | (H2) Maintenance of management facilities and strengthening the management system for emergency.                                                                                                                                                                                                           | 13<br>CLIMATE ACTION<br>15<br>LIFE ON LAND              |
|          |    | Count of "3"                                                                                                         | 1                                                                                                                                     | 5                                                                                                                                                      | 0                                                                                                                                                           | 1                                                                                                  | 0                                                                                                                                                                                         |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                            |                                                         |

Note 1) Hazard frequency assessment: ++ Frequently occurring thus far or at present, + Sometimes occurring thus far or at present, - Has hardly occurred thus far or at present

Note 2) Evaluation Scale for current impact levels:

3 Events and impacts that have occurred thus far have been so difficult that they cannot be addressed and handled.

2 Events and impacts that have occurred to date have been moderately difficult to manage and deal with.

1 It has not been so difficult to manage the events and impacts that have occurred thus far. The resulting impact was minor and was managed to some extent.

0 The impacts of events that have occurred to date have been negligible.

Source: Prepared by JICA Project Team based on the "JICA Climate-Fit (Adaption)"

Source: JICA Survey Team

Figure A2.18 Climate Change Matrix for Water Resources in South Chittogram Region Water Supply Project

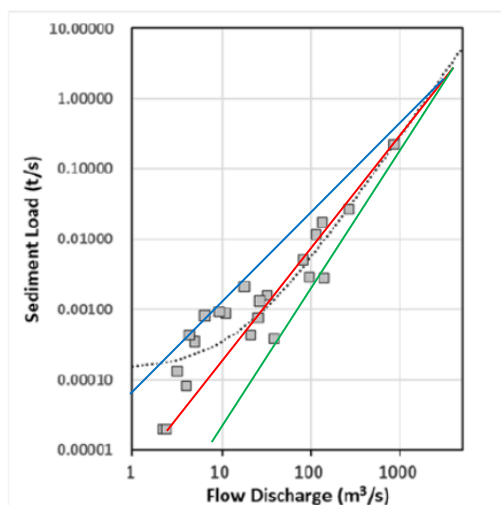


**Figure A2.19 Climate Risk Tree in South Chittogram Region Water Supply Project**

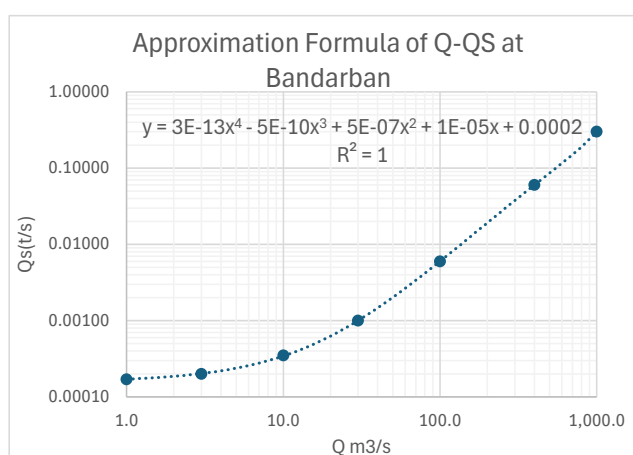
## CHAPTER A3 SEDIMENTATION INFLOW

### A3.1 Relationship between Sediment Load and Flow Discharge

There is no data for sedimentation measurement in the Matamuhuri river basin. On the other hand, there is a survey result of relationship between sediment load and flow discharge at Bandarban which was surveyed by BWDB. According to the relationship, approximation formula of Q-Qs was created as shown on Figure A3.1.1. This approximation formula is used for the estimation of sedimentation inflow in Matamuhuri river. Considering the deviation of Q-Qs plotting curve, the estimated sediment load data is calculated considering with some range (100-500%) for planning of the river facilities.



Source: JET based on data provided by BWDB



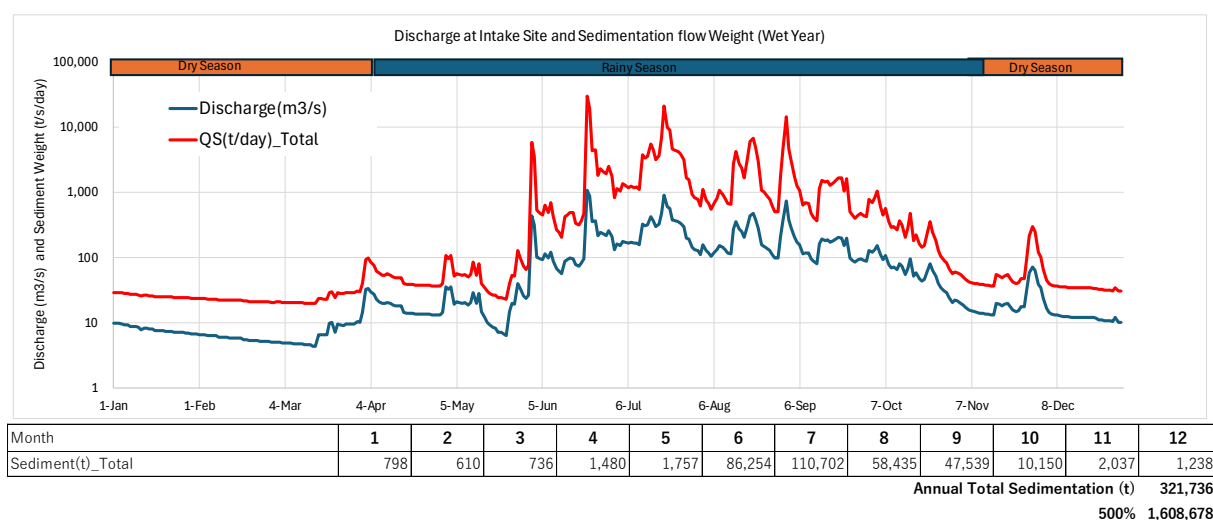
Source: JICA Survey Team

Figure A3.1.1 Approximation Formula of Q-Qs at Bandarban

### A3.2 Estimation of Annual Sedimentation to Reservoir

#### A3.2.1 Annual Sediment Load at Intake Site

By using the above approximation formula, annual sediment load at the intake site on wet season is calculated as shown below. Total sediment load was estimated as 322,000~1,610,000 ton/yr.

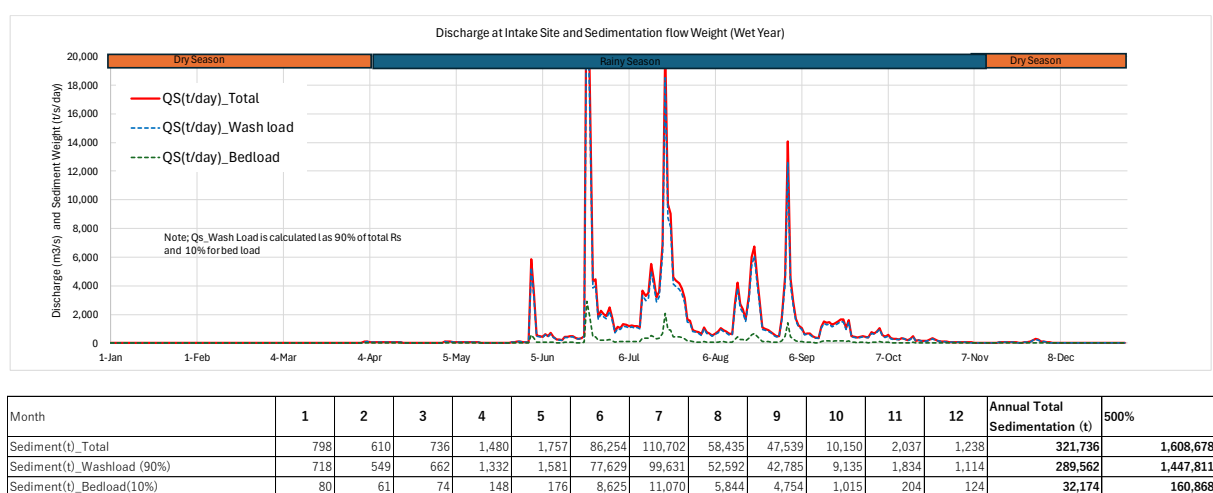


Source: JICA Survey Team

**Figure A3.2.1 Annual Sedimentation Load at Intake Site**

### A3.2.2 Annual Volume of Washload and Bedload at Intake Site

In general, it is said that out of the total sediment load of the river channel, a ratio of bed load is estimated around 10% while that of washload is 90%. According to this ratio, annual washload and bedload volume at the intake site are roughly calculated as 290,000~1,450,000ton/year and 32,000~161,000 ton/year, respectively.



Source: JICA Survey Team

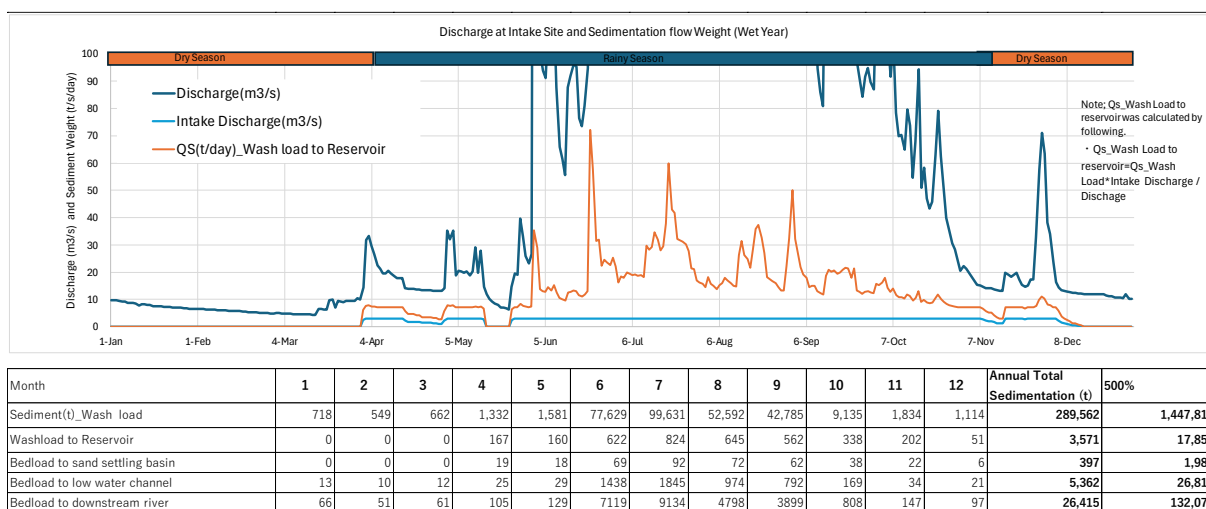
**Figure A3.2.2 Annual Washload and Bedload at Intake Site**

### A3.2.3 Annual Washload to Reservoir

While bed load flows down over river channel bed, washloads will be extracted to the intake and pass through the intake channel/sand settling basin, then eventually delivered and accumulated in the raw water reservoir. Annual washload volume to the raw water reservoir was calculated by following equation.

$$Q_s\_Washload\ to\ reservoir = Q_s\_Washload * Intake\ Discharge / River\ Discharge$$

According to this equation, annual washload to the raw water reservoir at wet season is calculated as 3,600~18,000 ton/year.



Source: JICA Survey Team

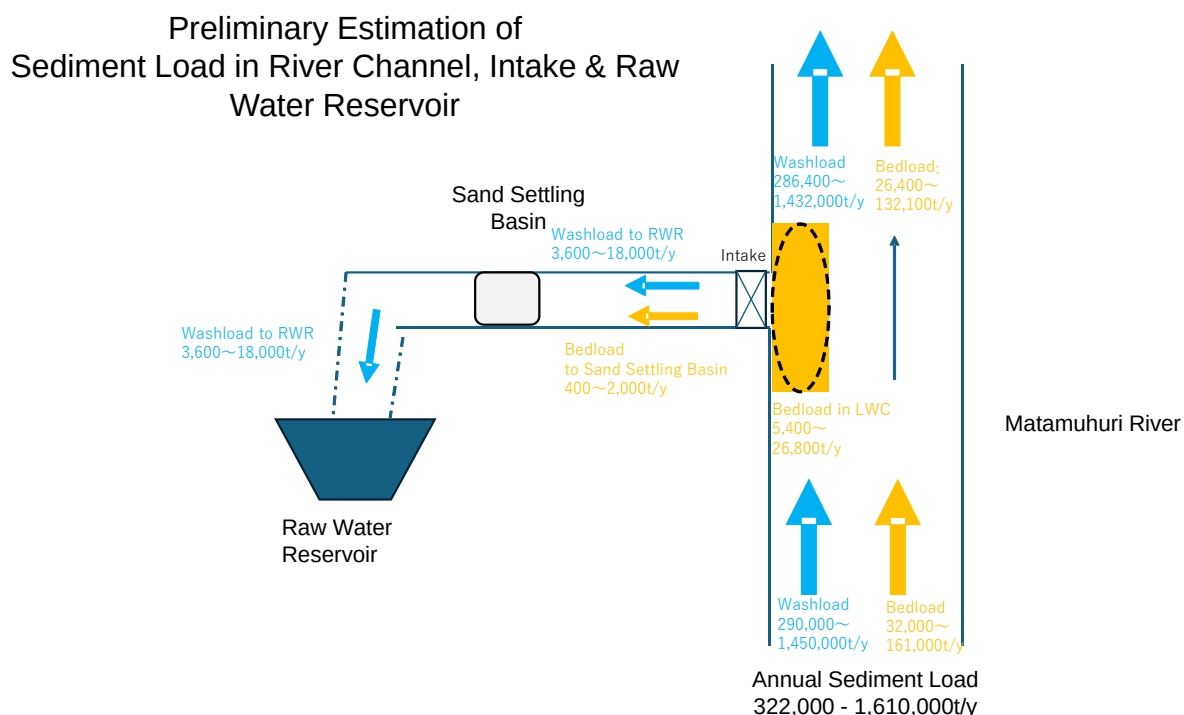
**Figure A3.2.3 Annual Washload to Reservoir**

### A3.2.4 Annual Bedload to Low Flow Channel and Sand Settling Basin

Annual bedload to the low flow channel and the sand settling basin was calculated by following equation.

$$Q_s\_Bedload\ to\ low\ flow\ channel = Q_s\_Bedload * Width\ of\ low\ flow\ channel\ (30m) / Width\ of\ river(180m) \div (5,400 \sim 26,800\ ton/year)$$

$$Q_s\_Bedload\ to\ sand\ pond = Q_s\_Bedload * (Intake\ Discharge / River\ Discharge) \div (400 \sim 2,000\ ton/year)$$



Source: JICA Survey Team

**Figure A3.2.4 Preliminary Estimation of Annual Sedimentload in River Channel, Intake and Raw Water Reservoir**

**Table A3.2.2 Preliminary Estimation of Annual Sedimentload in River Channel, Intake and Raw Water Reservoir**

| Rivre Facilitiy     | Estimation of sediment deposition* | Reamark                                    |
|---------------------|------------------------------------|--------------------------------------------|
| Sand Settling Basin | 400-2,000 ton/year                 | Mainly sand deposition                     |
| Raw Water Reservoir | 3,600-18,000 ton/year              | Mainly silt and clay depostions (washload) |

Note: The values in the above table are preliminally estimated ones based on the available and limited sediment load data in Sangu River. It is recommended to conduct sediment survey in the proposed intake site in Matamuhuri River, and review and improve the sediment load estimation in the detailed engineering stage.

### A3.2.5 Maintenance of Removal of Sediment Depositions in Low Flow Channel and Sand Settling Basin

Earth volume and spoilsite for construction works and operaion and maintenance worka in each structure is summarized below.

**Table A3.2.2 Earth Volume and Spoilsite for Construction Works and Operaion and Maintenance Works in Each Structur**

| (1) River Channel |                    |                  |
|-------------------|--------------------|------------------|
| Item              | Construction Works | During O&M Works |

|                                                 |                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                        |
|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Earth volume                                    | 41,680 m <sup>3</sup> from earth excavatiob                                                                                                                                                                                                                                                           | approx. 60,000m <sup>3</sup> /year for maintenance dredging.                                                                                                                           |
| Spoil site<br>(Location, Size)                  | To be managed by the Contractor with support for the implementing agency.                                                                                                                                                                                                                             | Dredged materials will be temporary stocked nearby intake site (around 2ha), after that the stocked materials will be hauled to the permanent spoil bank (in Palakata) and /or reused. |
| Other information                               | None                                                                                                                                                                                                                                                                                                  | At present, sand mining in the river channel is being conducted in several sites in the Matamuhuri River. There is a potential need to reuse excavated riverbed materials.             |
| <b>(2) Intake &amp; Sediment Settling Basin</b> |                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                        |
| Item                                            | Construction Works                                                                                                                                                                                                                                                                                    | During O&M Works                                                                                                                                                                       |
| Earth volume                                    | Excavation :61,000m <sup>3</sup><br>Backfill: 28,000m <sup>3</sup><br>Embankment: 8,600m <sup>3</sup>                                                                                                                                                                                                 | Approx. 220-1,100 m <sup>3</sup> /year for removal of sediment depositions from sediment settling basin                                                                                |
| Spoil site<br>(Location, Size)                  | To be managed by the Contractor with support for the implementing agency.                                                                                                                                                                                                                             | Same as maintenance dredging                                                                                                                                                           |
| Other information                               | None                                                                                                                                                                                                                                                                                                  | Same as maintenance dredging                                                                                                                                                           |
| <b>(3) Raw Water Reservoir</b>                  |                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                        |
| Item                                            | Construction Works                                                                                                                                                                                                                                                                                    | During O&M Works                                                                                                                                                                       |
| Earth volume                                    | Excavation:4,312,000m <sup>3</sup><br>Embankment: 2,750,000m <sup>3</sup>                                                                                                                                                                                                                             | Sediment volume 6,360m <sup>3</sup> /year                                                                                                                                              |
| Spoil site<br>(Location, Size)                  | Apart of excavation material can be reused as embankment material through the geological test results in DD stage.<br>Implementing agency ensures the spoil bank near the reservoir.<br>Required spoil bank maximum area is approximately 86ha by 5m height filling based on current condition data.. | permanent spoil bank is determined by implementing agency.                                                                                                                             |
| Other information                               | Generally, the residence people in low level land use want to fill up the ground level by the soil prevent from inundating by rainy season.                                                                                                                                                           |                                                                                                                                                                                        |

Source: JICA Survey Team

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## CHAPTER A4 CASE STUDY FOR DISASTER MANAGEMENT PLAN DUE TO FAILURE OF RESERVOIR EMBANKMENT

### A4.1 Outline of Case Study

BWDB suggested that the JICA Study Team (JST) should incorporate a disaster management plan, particularly for the raw water reservoir area.

They also pointed out that the JST should provide the total length of the bank protection area for the BWDB design team. This would allow the BWDB design team to review and provide their feedback on the bank protection plan.

### A4.2 Result of Case Study

#### A.4.2.1 Disasters

There are 2 types of disasters considered for the raw water reservoir:

- (1) Type 1) : disaster due to failure of reservoir embankment (earth dyke) itself, and
- (2) Type 2) : disaster due to failure of reservoir embankment caused by flooding from adjacent rivers.

#### A.4.2.2 Disaster Type 1)

The reservoir embankment (earth dyke) is designed by using the following conditions based on design standards.

(1) Design rainfall

The reservoir considers/covers 120% of 200-year rainfall, and has a spillway of which the design discharge is 120% of 200-year discharge.

(2) Stability analysis

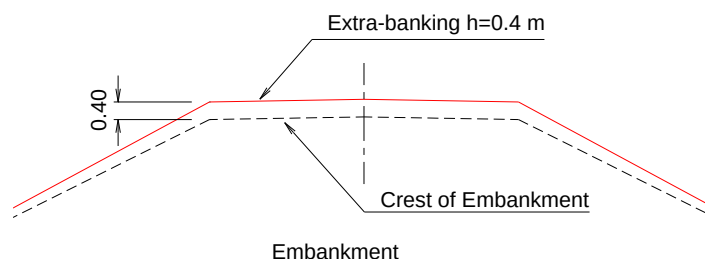
The stability analysis of the embankment has been made by using the “**Slip-circle Method**”, including flooding and seismic conditions. The stability of embankment has been confirmed through the analysis.

(3) Liquefaction

A liquefaction analysis has been also made. As the result of analysis, it is confirmed that the reservoir is not affected by liquefaction.

(4) Settlement

The settlement of embankment will occur after construction due to its soft foundation. Therefore, extra-banking in 0.4 m height is considered, as presented in the figure below.  
Embankment0.40Extra-banking h=0.4 mCrest of Embankment



Source: JICA Survey Team

**Figure A4.1 Extra-banking**

(5) Wind waves

The embankment has considered free boards (2.3 m to 2.5 m heights), which are decided based on the wave heights due to strong winds on the reservoir surface. In addition, the embankment surface is planned to be covered by concrete facing to prevent it from detrimental scouring by the strong wind waves.

In due consideration of the (1) to (5) above, the embankment of the reservoir is considered to be stable against the serious conditions such as flooding (strong rainfall), earthquake, and settlement. Hence, a disaster plan of the reservoir is not considered in the Preparatory Survey.

(6) Reference: Unexpected Risk of Embankment Breach Scenario

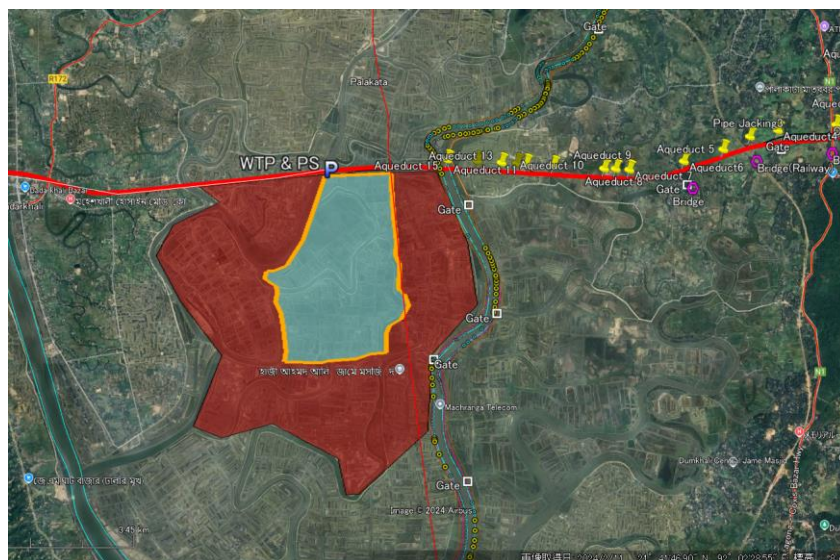
In planning a large dam, an unexpected dam break scenario is sometimes used to make downstream flood damage assumptions in an event of dam breach.

Although the proposed raw water reservoir embankment and related facilities are basically designed to be safe against floods and earthquakes up to the design safety level (design conditions), as mentioned in “**2. Disaster Type 1**” above, a rough assumption is made hereinafter about the risk assessment of a scenario in which the embankment itself breaches due to unexpected events exceeding the design conditions.

1) Assumed inundation area

It is assumed that the reservoir embankment collapses in a full water level condition, and the storage water causes flooding in surrounding areas of the reservoir. Each part of the reservoir in the figure on the next page is independent, and all parts will not collapse at the same time. If one of the parts (for instance, Reservoir No.3) collapses, 7.4 MCM of its storage water flows outward. Assuming that the topographical condition is almost flat in this area and that the average inundation depth in the flooded area is about 40 cm, about 20 km<sup>2</sup> of the area surrounded by the existing rivers and the Matarbari Port Access Road embankment would be flooded, as shown in the figure below.

Considering that most of the sediment in the reservoir is wash load, it is expected that the storage water flows down without sedimentation.



Source: JICA Survey Team

**Figure A4.2 Assumed Inundation Area in Cased of Reservoir Embankment Collapses in Full Water Level Condition,**

#### 2) Assumed flood damage risk:

The Palakata area around the reservoir is used mostly as salt fields and fish ponds with few private residences. Even if the embankment is breached, it is assumed that there will be little flooding around village areas with private residences, although the fish ponds and salt fields will be inundated in the flooded areas mentioned above.

Even if local flooding is caused, the water depth is expected to be small and the velocity of flood water is expected to be slow, so catastrophic human casualties are not likely to occur.

The above is a preliminary assessment. In the detailed design stage, it is suggested that an inundation analysis of embankment break scenario be conducted to prepare a flood hazard map and risk assessment, and local

disaster prevention plans and evacuation plans be prepared with the local communities based on this analysis.

#### **A.4.2.3 Disaster Type 2)**

If there is flooding in the adjacent river, the area around the reservoir is inundated. The design flood level of the adjacent river is EL. 4.1 m, while the designed embankment crest elevation is EL. 9.3 m. The embankment elevation is much higher than the river flooding level.

The river side slope of the embankment is covered with CC blocks to prevent it from local scouring.

So, the possibility of embankment failure due to the river flooding is quite low. If the reservoir is broken by the flooding, the areas around the reservoir are already seriously inundated as disaster. In this case, it is not necessary to make a plan of the disaster due to embankment failure.

### A4.3 Embankment Length

The embankment of the raw water reservoir is planned as in the figure below. The reservoir is divided into several parts for safety and maintenance reasons. Each part is independent from others and has a spillway, bottom drain, and access road to the reservoir inside. The total length of the embankments is approximately 11.8 km.



Source: JICA Survey Team

**Figure A4.3 Division of Raw Water Reservoir**

*Supporting Report B*  
***PRELIMINARY DESIGN OF  
PROJECT FACILITIES***

**River Training**  
**and**  
**Intake to Raw Water Reservoir**

**PREPARATORY SURVEY  
FOR  
SOUTHERN CHATTOGRAM REGION WATER SUPPLY PROJECT**

**FINAL REPORT**

**Supporting Report B: PRELIMINARY DESIGN OF PROJECT  
FACILITIES**

**< River Training and Intake to Raw Water Reservoir >**

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## **CHAPTER B6 STABILITY ANALYSIS OF RESERVOIR FACILITIES**

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## CHAPER B7 SEDIMENTATION OF REASERVOIR

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## CHAPTER B1 SEISMIC FACTOR

### 1.1 Seismic Factor

The spectral acceleration for the design earthquake is given by the following equation due to BNBC No. 6.2.34 equation

$$S_a = \frac{2}{3} \frac{ZI}{R} C_s$$

where,  $S_a$  : Design spectral acceleration (in unit of g)

$\beta$ : Coefficient used to calculate lower bound for  $S_a$ . Recommended value for  $\beta$  is 0.11

Z: Seismic zone coefficient (= 0.28 referred Figure 1.1.1)

I: Structure importance factor (=1.25, referred Table 1.1.1 to 1.1.3)

R: Response reduction factor which depends on the type of structural system (= 4.0, referred Table 1.1.4)

$C_s$ : Normalized acceleration response spectrum, which is function of structure (building) period and soil type.

$$T = C_t (h_n)^m$$

Where, T: building period (in second)

$C_t$ : Obtained in Table 1.1.6 (= 0.0466, referred Table 1.1.6)

$h_n$ : height of building in meters from foundation (= 10m)

m: Factor (= 0.9, referred Table 1.1.6)

$$T = 0.0466 (10.0)^{0.9} = 0.370 \text{ sec.}$$

From Table 1.1.7 and soil type SD, T value is TB (0.20) < T (0.37) < TC (0.8).

In this case,  $C_s$  is shown in the following equation based on BNBC-2020, Part 6, section 2.5.4.3, Table 6.2.35b

$$C_s = 2.5 S \eta$$

Where, S: Soil factor depends on site and given in Table 1.1.7 (= 1.35)

$\eta$ : Damping correction factor as a function of damping with a reference value

of  $\eta = 1$  for 5% viscous damping. (=1.0)

$$C_s = 2.5 \times 1.35 \times 1.0 = 3.375$$

$$S_a = \frac{2}{3} \times \frac{0.28 \times 1.25}{4.0} \times 3.375 = 0.197 \cong 0.2$$

Above  $S_a$  design spectral acceleration can be used as lateral seismic force coefficient due to BNBC-2020, Part 6, section 2.5.7.



Source: BNBC-2020, Part 6, section 2.5.4.3, Figure 6.2.24 Seismic zoning map of Bangladesh

**Figure 1.1.1 Seismic Zoning Map**

**Table 1.1.1 Importance Factors**

| Occupancy Category | Importance factor I |
|--------------------|---------------------|
| I, II              | 1.00                |
| III                | 1.25                |
| IV                 | 1.50                |

Note. Occupancy Category is based on Table 1.1.2.

Source: BNBC-2020, Part 6, section 2.5.5, Table 6.2.17

**Table 1.1.2 Occupancy Category of Buildings and Structures for Flood, Surge, Wind and Earthquake Loads (1/2)**

| Nature of Occupancy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Occupancy Category |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| <p>Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to:</p> <ul style="list-style-type: none"> <li>• Agricultural facilities</li> <li>• Certain temporary facilities</li> <li>• Minor storage facilities</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | I                  |
| <p>All buildings and other structures except those listed in Occupancy Categories I, III and IV</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | II                 |
| <p>Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to:</p> <ul style="list-style-type: none"> <li>• Buildings and other structures where more than 300 people congregate in one area</li> <li>• Buildings and other structures with day care facilities with a capacity greater than 150</li> <li>• Buildings and other structures with elementary school or secondary school facilities with a capacity greater than 250</li> <li>• Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities</li> <li>• Healthcare facilities with a capacity of 50 or more resident patients, but not having surgery or emergency Treatment facilities</li> <li>• Jails and detention facilities</li> </ul> | III                |
| <p>Buildings and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure, including, but not limited to:</p> <ul style="list-style-type: none"> <li>• Power generating stations<sup>a</sup></li> <li>• Water treatment facilities</li> <li>• Sewage treatment facilities</li> <li>• Telecommunication centers</li> </ul>                                                                                                                                                                                                                                                                                                                                                                           |                    |
| <p>Buildings and other structures not included in Occupancy Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                            |                    |

Source: BNBC-2020, Part VI, section 1.2.3, Table6.1.1

**Table 1.1.3 Occupancy Category of Buildings and Structures for Flood, Surge, Wind and Earthquake Loads (2/2)**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Buildings and other structures designated as essential facilities, including, but not limited to:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | IV |
| <ul style="list-style-type: none"> <li>• Hospitals and other healthcare facilities having surgery or emergency treatment facilities</li> <li>• Fire, rescue, ambulance, and police stations and emergency vehicle garages</li> <li>• Designated earthquake, hurricane, or other emergency shelters</li> <li>• Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response</li> <li>• Power generating stations and other public utility facilities required in an emergency</li> <li>• Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers,</li> <li>• Electrical substation structures, fire water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for operation of Occupancy Category IV structures during an emergency</li> <li>• Aviation control towers, air traffic control centers, and emergency aircraft hangars</li> <li>• Community water storage facilities and pump structures required to maintain water pressure for fire suppression</li> <li>• Buildings and other structures having critical national defense functions</li> </ul> |    |
| Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |    |
| <sup>a</sup> Cogeneration power plants that do not supply power on the national grid shall be designated Occupancy Category II                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |    |

Source: BNBC-2020, Part VI, section 1.2.3, Table 6.1.1

**Table 1.1.4 Response Reduction Factor**

| Seismic Force-Resisting System              | Response Reduction Factor, $R$ | System Overstrength Factor, $\Omega_o$ | Deflection Amplification Factor, $C_d$ | Seismic Design Category B             | Seismic Design Category C | Seismic Design Category D |
|---------------------------------------------|--------------------------------|----------------------------------------|----------------------------------------|---------------------------------------|---------------------------|---------------------------|
|                                             |                                |                                        |                                        | Height limit (m)                      |                           |                           |
|                                             |                                |                                        |                                        | A. BEARING WALL SYSTEMS<br>(no frame) |                           |                           |
| 1. Special reinforced concrete shear walls  | 5                              | 2.5                                    | 5                                      | NL                                    | NL                        | 50                        |
| 2. Ordinary reinforced concrete shear walls | 4                              | 2.5                                    | 4                                      | NL                                    | NL                        | NP                        |
| 3. Ordinary reinforced masonry shear walls  | 2                              | 2.5                                    | 1.75                                   | NL                                    | 50                        | NP                        |
| 4. Ordinary plain masonry shear walls       | 1.5                            | 2.5                                    | 1.25                                   | <b>18</b>                             | NP                        | NP                        |

Source: BNBC-2020, Part 6, section 2.5.5.4, Table 6.2.19

**Table 1.1.5 Site Classification Based on Soil Properties**

| Site Class | Description of soil profile up to 30 meters depth                                                                                                                               | Average Soil Properties in top 30 meters |                                   |                                             |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|-----------------------------------|---------------------------------------------|
|            |                                                                                                                                                                                 | Shear wave velocity, $\bar{V}_s$ (m/s)   | SPT Value, $\bar{N}$ (blows/30cm) | Undrained shear strength, $\bar{S}_u$ (kPa) |
| SA         | Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.                                                                          | > 800                                    | --                                | --                                          |
| SB         | Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth. | 360 – 800                                | > 50                              | > 250                                       |
| SC         | Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.                                                  | 180 – 360                                | 15 - 50                           | 70 - 250                                    |

|                |                                                                                                                                                                                                |                       |      |         |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------|---------|
| SD             | Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.                                                     | < 180                 | < 15 | < 70    |
| SE             | A soil profile consisting of a surface alluvium layer with $V_s$ values of type SC or SD and thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_s > 800$ m/s. | --                    | --   | --      |
| S <sub>1</sub> | Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index ( $PI > 40$ ) and high water content                                          | < 100<br>(indicative) | --   | 10 - 20 |
| S <sub>2</sub> | Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types SA to SE or S <sub>1</sub>                                                                  | --                    | --   | --      |

Source: BNBC-2020, Part 6, section 2.5.1, Table 6.2.13

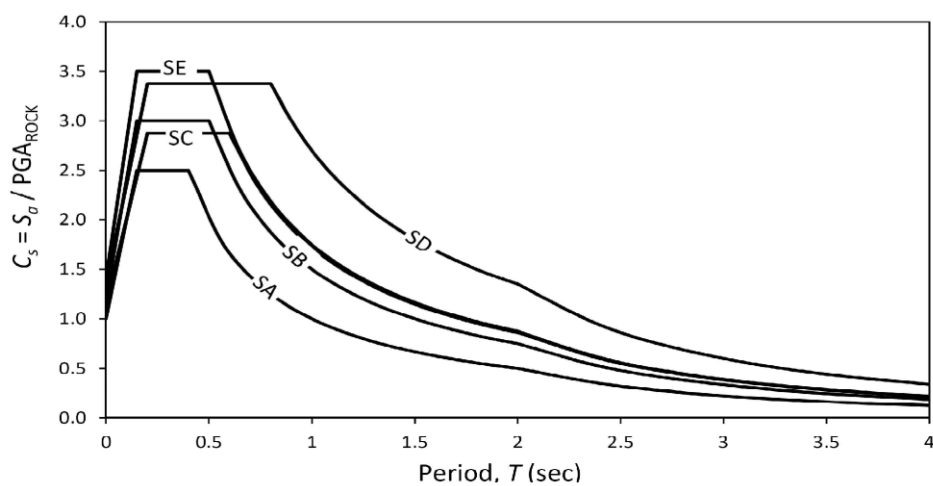
**Table 1.1.6 Value for Coefficients to Estimate Approximate period**

| Structure type                   | $C_t$  | $m$  |                                                                                                                                                                                                                          |
|----------------------------------|--------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Concrete moment-resisting frames | 0.0466 | 0.9  | Note: Consider moment resisting frames as frames which resist 100% of seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting under seismic forces. |
| Steel moment-resisting frames    | 0.0724 | 0.8  |                                                                                                                                                                                                                          |
| Eccentrically braced steel frame | 0.0731 | 0.75 |                                                                                                                                                                                                                          |
| All other structural systems     | 0.0488 | 0.75 |                                                                                                                                                                                                                          |

Source: BNBC-2020, Part 6, section 2.5.7.2, Table 6.2.20

**Table 1.1.7 Site Dependent Soil Factor  
and Other Parameters Defining Elastic Response Spectrum**

| Soil type | $S$  | $T_B(s)$ | $T_C(s)$ | $T_D(s)$ |
|-----------|------|----------|----------|----------|
| SA        | 1.0  | 0.15     | 0.40     | 2.0      |
| SB        | 1.2  | 0.15     | 0.50     | 2.0      |
| SC        | 1.15 | 0.20     | 0.60     | 2.0      |
| SD        | 1.35 | 0.20     | 0.80     | 2.0      |
| SE        | 1.4  | 0.15     | 0.50     | 2.0      |



Source: BNBC-2020, Part 6, section 2.5.4.3, Table 6.2.16

---

## CHAPTER B2 INTAKE FACILITIES

### 2.1 Condition and Function

#### 2.1.1. Basic necessary points

Basic requirements for intake are;

- Reliable amount of water intake
- Secure raw water
- Measures for a disaster and protection of environment
- Simple Operation and Maintenance
- Compliance with Laws and Standards

#### 2.1.2. Condition

The following condition was shown for preliminary design of intake

- Design inflow discharge: 2.9 m<sup>3</sup>/s
- Emergency inflow discharge: 1.7m<sup>3</sup>/s (Phase 2 inflow of Water treatment plant from raw water reservoir)
- Duration of inflow period: May to November
- Intake water level elevation: El. 1.60
- Intake inlet bottom level: El. 0.80
- Emergency inlet water level El. 0.80
- Emergency inlet bottom level El. 0.10
- Average riverbed material diameter by NODI project report: 0.2 mm to 0.3mm

### 2.2 Component of intake Facilities

The components of the intake facilities are as following;

- Inlet structure
- Stoplog
- Screen
- Conveyance box culvert from inlet structure to settling basin
- Settling basin
- Pump and pump tank
- Gates
- Manhole for drain from settling basin
- Pump control house and staff room

In addition, above, emergency intake is also set for in emergency case of water deficit based on BWDB request.

## 2.3 Location of intake

Intake can be located to 1) Beside low water channel including box culvert and 2) Beside of river bank with open access channel from low water channel edge.

As the following reasons, 1) Beside low water channel is advantage and adopted as intake location. 2) open channel shall be maintained even sedimentation is occurred or both side slope of its channel is broken in flooding.

## 2.4 Design of Intake mouth

The design of intake mouth is followed by “The Design Criteria for Water Supply Facilities, 2012, Ministry of Health, Labour and Welfare, Japan”.

The structure of the water intake mouth shall be in conformity with the following:

1. It can at all times abstract the design volume of raw water intake; earth and sand do not pile up or flow in the mouth; and its maintenance is easy.
2. Its sill level shall be 0.5 m to 1.0 m higher than that of the grit-gate.
3. The standard inflow velocity to it shall be 0.4 to 0.8 m/s.
4. Its width shall be so determined that the sill level and the inflow velocity are maintained within their standard ranges.
5. Screens shall be provided before the sluice gates.
6. A water intake apron shall be provided insofar as land is available.
7. The design water level of water intake shall be determined calculating the head loss from the intake mouth to the starting point of raw water transmission

Source: The Design Criteria for Water Supply Facilities, 2012, Ministry of Health, Labour and Welfare, Japan

Intake mouth facility is designed under the above criteria as following

### 2.4.1 Intake Elevation

As design river bed elevation by MOJI project is EL. 0.00, the intake mouth is set EL. 0.80 which is higher than 0.80 m of design river bed while the above design criteria mentions that its sill level shall be 0.5 m to 1.0 m higher than that of the grit-gate (river bed).

The emergency channel bottom elevation is 0.1 m higher than design river bed elevation EL. 0.10.

### 2.4.2 Hydraulic calculation of intake mouth

Hydraulic calculation of intake mouth is necessary for satisfied water discharge to reservoir. And effective water depth is considered from EL. 0.80 to EL.1.60, 0.80m.

## (1) Inflow loss

$$h_e = f_e \frac{V^2}{2g}$$

Where,  $h_e$ : Entrance loss (m)

$f_e$ : inflow head loss factor (= 0.25, from Guideline Manual for Land Improvement Project “Head Works”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries)

$V$ : After entrance water velocity (m/s, =  $2.9 / (2.4 \times 0.787 \times 2) = 0.767$  m/s)

$g$ : gravity (=  $9.8$  m/s<sup>2</sup>)

$$= 0.25 \frac{0.767^2}{2 \times 9.8} = 0.0075 \text{ m}$$

## (2) Screen loss

$$h_r = \beta \sin \theta \left( \frac{t}{b} \right)^{4/3} \cdot \frac{V^2}{2g}$$

Where,  $h_r$ : Screen loss (m)

$\beta$ : coefficient factor due to screen bar shape (= 2.42, rectangle)

$t$ : Bar thickness (= 0.010 m)

$b$ : Space between bar (= 0.070 m)

$\theta$ : Screen bar slope angle (= 70 degrees)

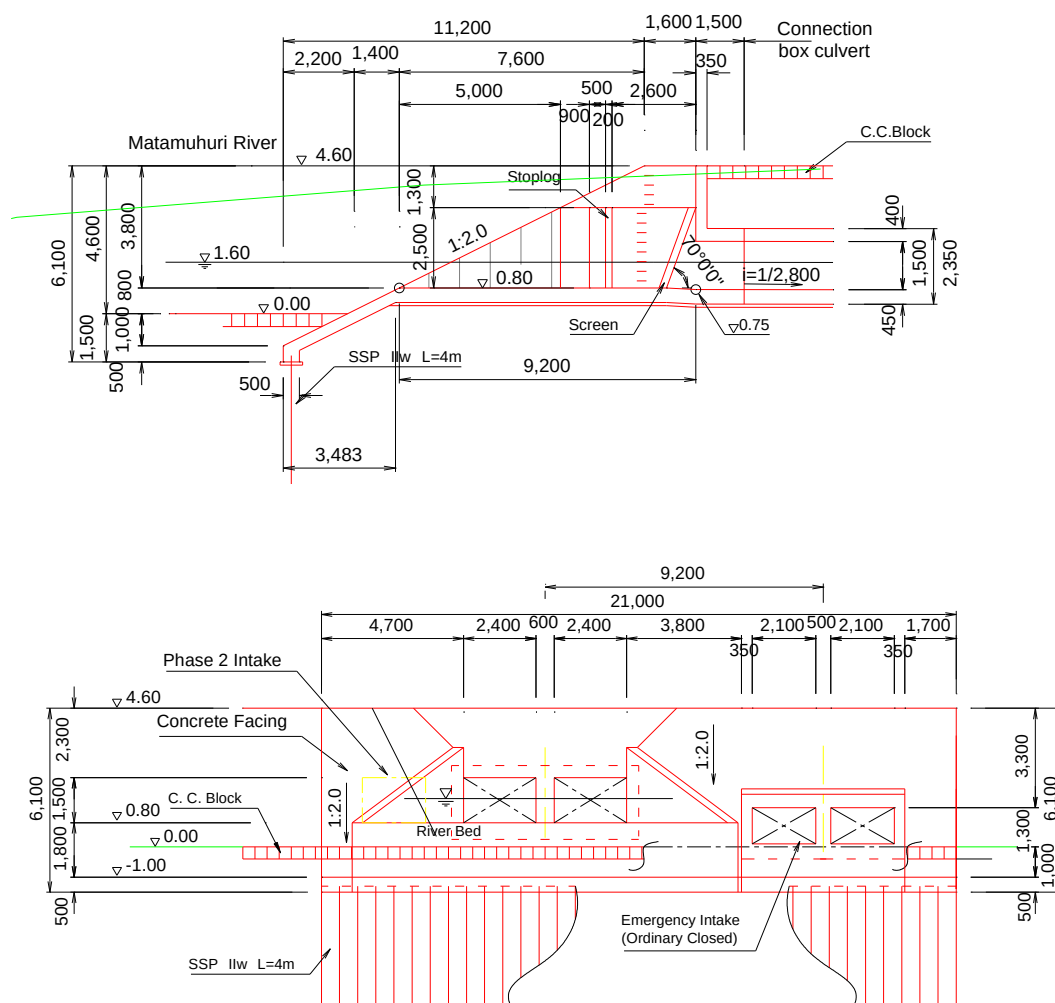
$V$ : After entrance water velocity (m/s, =  $2.9 / (2.4 \times 0.787 \times 2) = 0.767$  m/s)

$g$ : gravity (=  $9.8$  m/s<sup>2</sup>)

$$= 2.42 \sin 70 \left( \frac{0.01}{0.07} \right)^{4/3} \cdot \frac{0.767^2}{2 \times 9.8} = 0.0051 \text{ m}$$

## (3) Water surface after intake mouth

Total loss after intake mouth is  $0.0075 + 0.0051 = 0.0126$  m, and channel bottom is 0.05 m lower than entrance as shown in Figure 2.4.1.



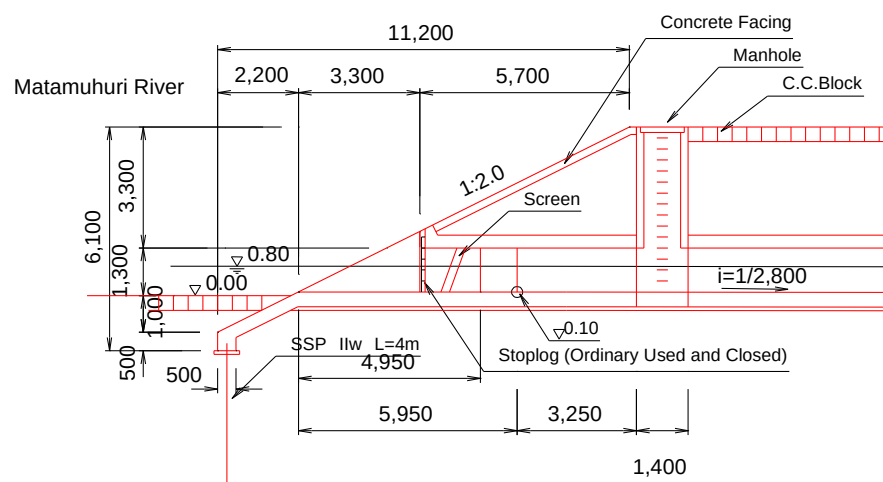
Source: JICA Survey Team

**Figure 2.4.1 Intake Front View and Profile**

#### (4) Emergency Intake Mouth

Emergency intake bottom elevation is EL. 0.10 and design water surface is EL. 0.80 that is same as elevation of intake mouth bottom.

Emergency intake mouth is set as shown in Figure 2.4.2.



Source: JICA Survey Team

**Figure 2.4.2 Emergency Intake Profile**

## 2.5 Conveyance Channel from Intake to Grit Chamber

Conveyance channel from intake to grit chamber is concrete box as following;

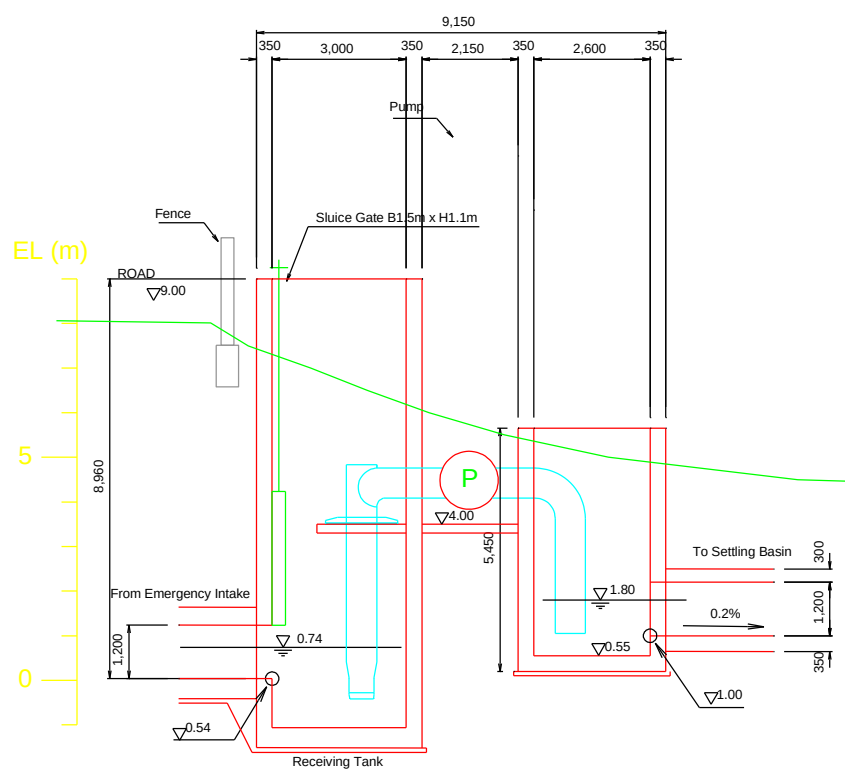
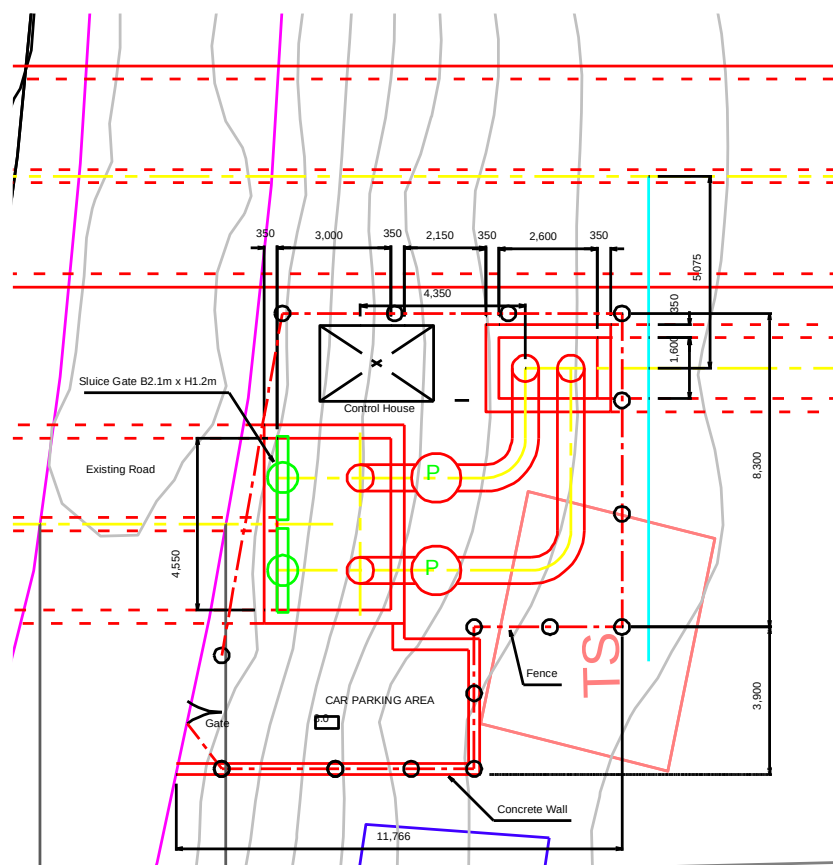
**Table 2.5.1 Conveyance channel**

|    | Item                   | Value                   | Remarks                                           |
|----|------------------------|-------------------------|---------------------------------------------------|
|    | Adopted Equation       | Manning Equation        |                                                   |
| 1) | Culvert Width x height | 2.40 m x 1.50 m         |                                                   |
| 2) | Number of Box culvert  | 2 nos.                  |                                                   |
| 3) | Culvert Slope          | 1/2,800                 |                                                   |
| 4) | Roughness Coefficient  | 0.015                   | Concrete                                          |
| 5) | Water Depth            | 0.80 m                  |                                                   |
| 6) | Flow Area              | 3.84 m <sup>2</sup>     |                                                   |
| 7) | Flow Velocity V        | 0.772 m/s               | 0.40 < V < 0.8 ok                                 |
| 8) | Discharge              | 2.964 m <sup>3</sup> /s | > Design Discharge<br>2.90 m <sup>3</sup> /s O.K. |

Source: JICA Survey Team

## 2.6 Emergency Channel

As emergency channel water level is lower than conveyance channel, the emergency pumping station is installed at existing river bank with existing road as shown in Figure 2.6.1. The channel until emergency pumping station is 2 concrete box culvert, namely Type 1 the channel after emergency pumping station is Type 2. Each box culvert is calculated by Table 2.6.1.



Source: JICA Survey Team

**Figure 2.6.1 Emergency Pumping Station**

**Table 2.6.1 Emergency channel**

|    | Item                   | Type 1                  | Type 2                  | Remarks                                           |
|----|------------------------|-------------------------|-------------------------|---------------------------------------------------|
|    | Adopted Equation       | Manning Equation        |                         |                                                   |
| 1) | Culvert Width x height | 2.10 m x 1.20 m         | 1.60 m x 1.20 m         |                                                   |
| 2) | Number of Box culvert  | 2 nos.                  | 1 no                    |                                                   |
| 3) | Culvert Slope          | 1/2,800                 | 1/500                   |                                                   |
| 4) | Roughness Coefficient  | 0.015                   | 0.015                   | Concrete                                          |
| 5) | Water Depth            | 0.70 m                  | 0.80                    |                                                   |
| 6) | Flow Area              | 1.47 m <sup>2</sup>     | 1.28 m <sup>2</sup>     |                                                   |
| 7) | Flow Velocity V        | 0.707 m/s               | 1.619 m/s               | Type 1:<br>0.40 < V < 0.8 ok                      |
| 8) | Discharge              | 2.078 m <sup>3</sup> /s | 2.072 m <sup>3</sup> /s | > Design Discharge<br>2.05 m <sup>3</sup> /s O.K. |

Source: JICA Survey Team

## 2.7 Grit Chamber

### 2.7.1 Design of Grit Chamber

Grit chamber near intake site is mentioned on The Design Criteria for Water Supply Facilities, 2012, Ministry of Health, Labour and Welfare, Japan as following;

The structure of the grit chamber shall be in conformity with the following:

1. In principle, it shall be of reinforced concrete, and be safe to buoyancy as well.
2. Its overflow rate shall be 200 to 500 mm/min as the standard.
3. The average flow velocity in the chamber shall be 2 to 7 cm/s as the standard.
4. The length of the chamber shall be computed from the effective depth, the settling velocity, average flow velocity etc.
5. The high water level of the chamber shall be lower than the design lowest water level of the intake mouth so that the design intake water volume can flow in.
6. The crown elevation of the chamber shall be set at the high water level with an allowance of 0.6 to 1 m.
7. The effective depth of the chamber shall be 3 to 4 m as the standard, and a grit deposit depth of 0.5 to 1 m shall be added.
8. A channel shall be provided in the center of the chamber bottom for the removal of sand with a slope of 1/100 in the longitudinal direction, and an inclination of 1/50 or so in the transverse direction.

#### [Interpretation]

**On the item 2.;**

.....

Besides, the retention time shall be 10 to 20 minutes of the design intake water volume as the standard.

**On the item 3.;**

Empirically assuming that the average flow velocity is 2 to 7 cm/s, the settled sand will not float and move again.

**On the item 4.;**

The length of the grit chamber shall be computed by the following formula. The standard width of the chamber shall be 1/8 to 1/3 of the length.

$$L = K \left( \frac{H}{U} \right) V$$

where,

L: Length of the chamber (m)

H: Effective depth (m)

U: Settling velocity of the sand particle to be settled (cm/s)

V: Average flow velocity in the chamber (cm/s)

K: Coefficient (safety factor) 1.5 to 2.0

Source: The Design Criteria for Water Supply Facilities, 2012, Ministry of Health, Labour and Welfare, Japan

The size of grit chamber is determined based on above standard and results shows Table 2.7.1.

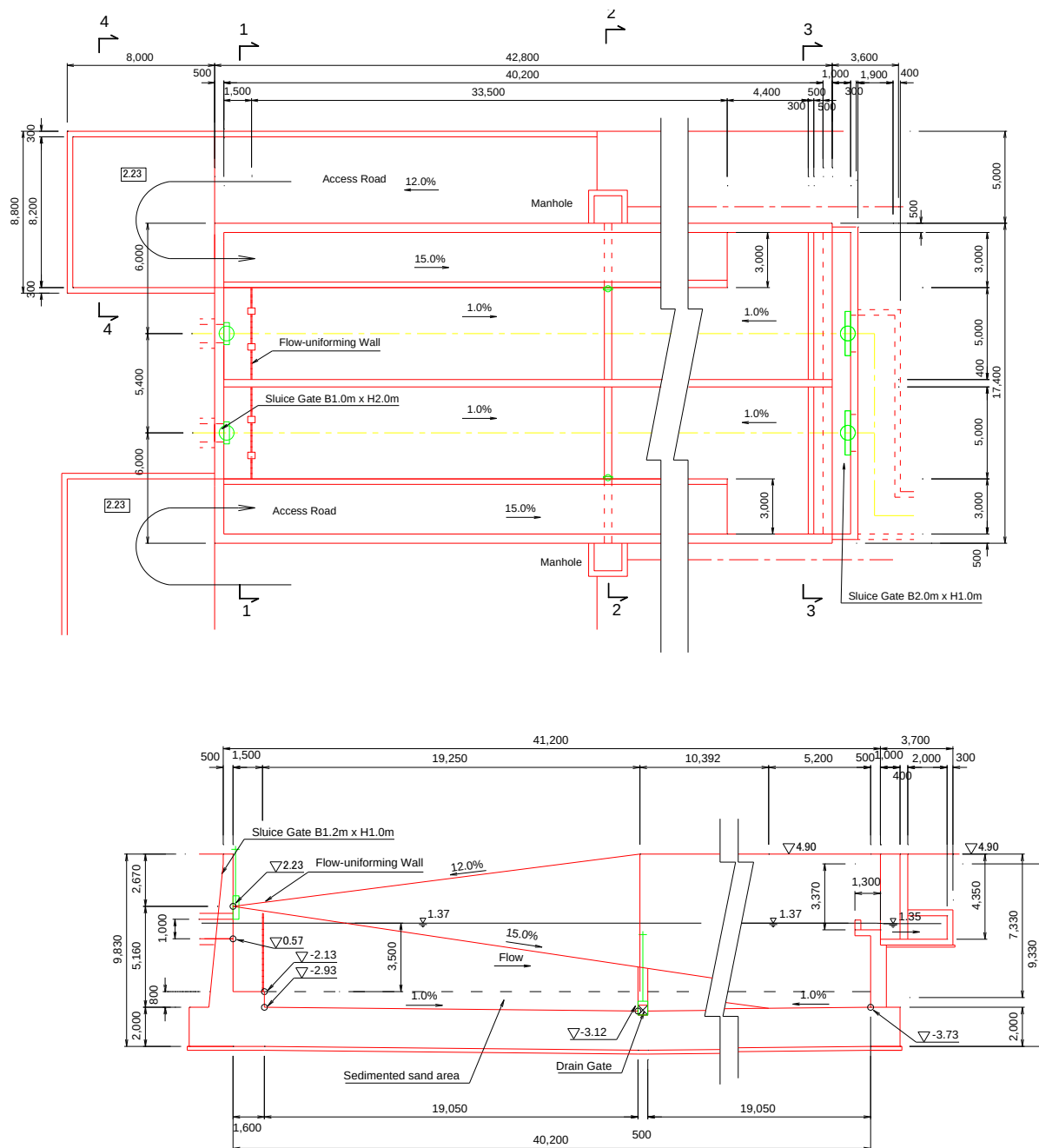
**Table 2.7.1 Grit Chamber**

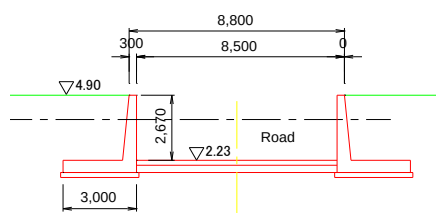
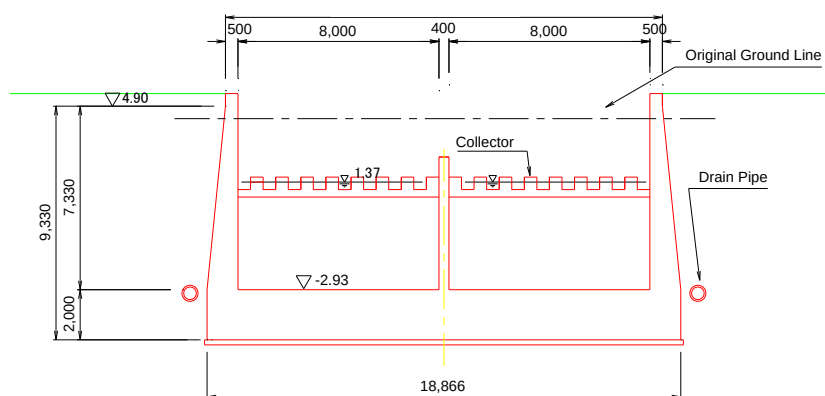
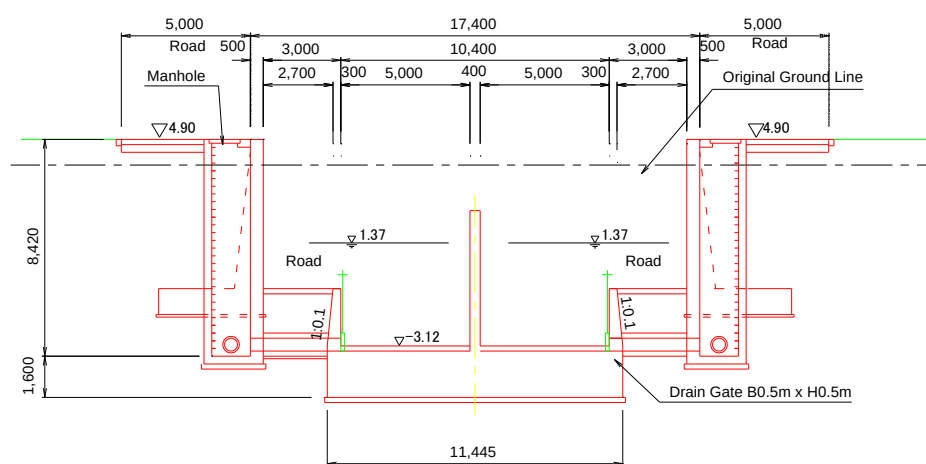
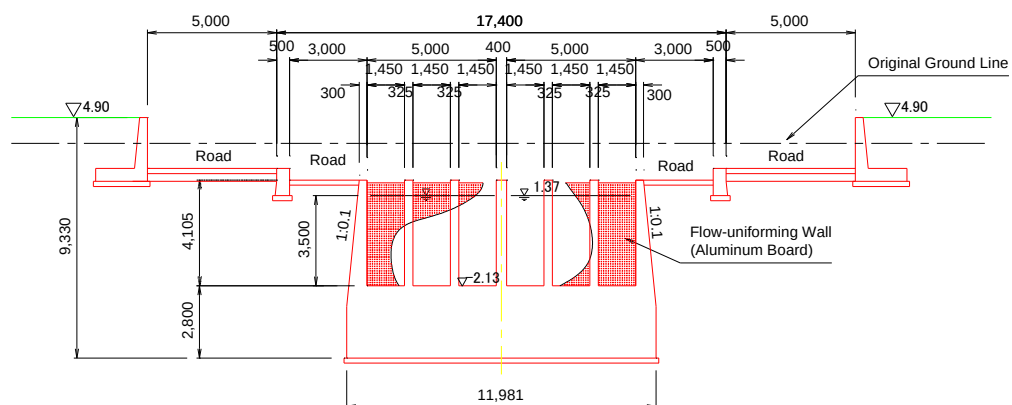
|     | Item                                  | Value                  | Design criteria/ <u>1</u> /Remarks |
|-----|---------------------------------------|------------------------|------------------------------------|
| 1)  | Design Discharge Q                    | 2.90 m <sup>3</sup> /s |                                    |
| 2)  | Width                                 | 5.0 m                  |                                    |
| 3)  | Length                                | 38.00 m                |                                    |
| 4)  | Effective Depth                       | 3.50 m                 | 3.0 m to 4.0 m                     |
| 5)  | Sediment Depth                        | 0.80 m                 |                                    |
| 6)  | Numbers                               | 3                      | 3 + 1(Standby) Total 4             |
| 7)  | Overflow Ratio                        | 305 mm/min             | 200 to 500 mm/min                  |
| 8)  | Average Flow Velocity                 | 0.055 m/s              | 0.02 to 0.07 m/s                   |
| 9)  | Settling Velocity of Sand             | 0.8 cm/s               | Design Sand Radius 0.10 mm         |
| 10) | Required Length                       | 36.25 m                | < 3) o.k.                          |
| 11) | Retention Time                        | 11.47 min.             | 10 to 20 min.                      |
| 12) | Ration of Width and Length of Chamber | 1/7.60                 | 1/8 to 1/3                         |

Source: JICA Survey Team

Note:/1: Design criteria mean The Design Criteria for Water Supply Facilities, 2012, Ministry of Health, Labour and Welfare, Japan

Grit chamber has flow straightening board made by aluminium and some gate including drain gate. As water level low and plain area around the site, the sedimented sand in grit chamber cannot be flushed out into outside by water flow. Access road leads to chamber inside and sedimented sand is moved by the trucks.





Source: JICA Survey Team

### Figure 2.7.1 Grit Chamber

#### 2.7.2 Sediment

Frequency of removing sediment is estimated by Table 2.7.2.

**Table 7.2.2 Frequency of removing sediment**

| Item                              | Value              | Remarks             |
|-----------------------------------|--------------------|---------------------|
| 1) Design income sediment weight  | 1,170 t            |                     |
| 2) Design income sediment volume  | 688 m <sup>3</sup> | 1.7t/m <sup>3</sup> |
| 3) Grit chamber sediment capacity | 463 m <sup>3</sup> | 3 grit chambers     |
| 4) Frequency of removing sediment | 1.5times/year      |                     |

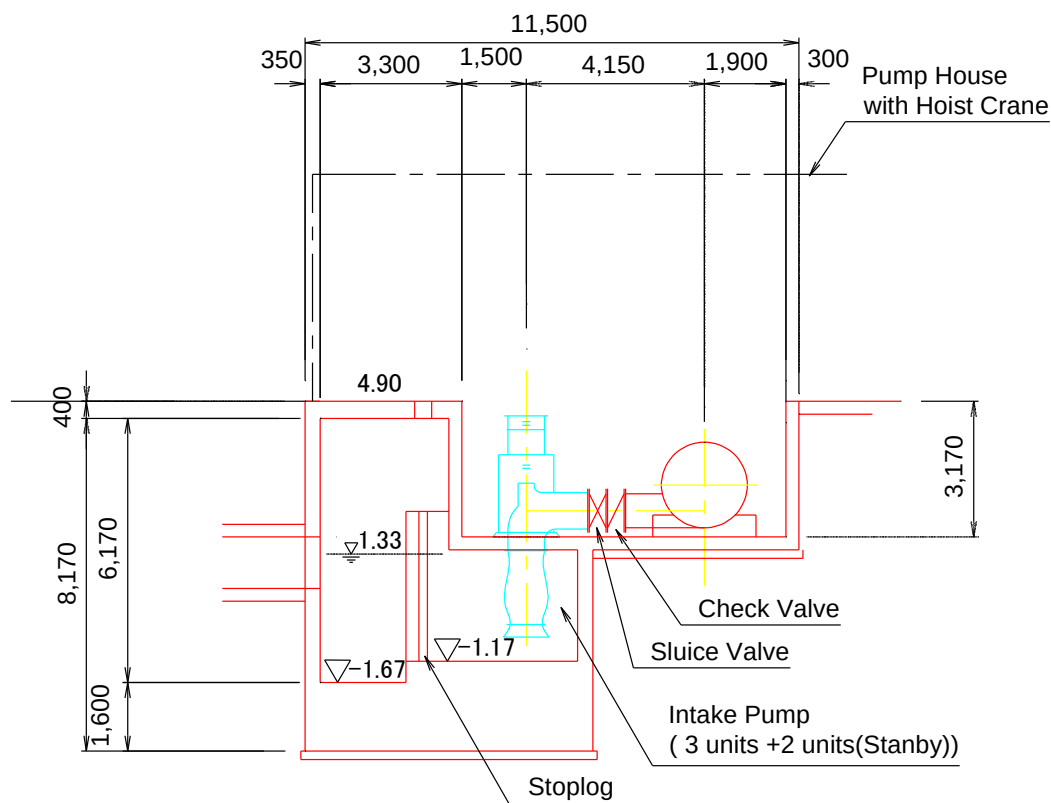
Source: JICA Survey Team

Frequency of removing sediment is 1.5times/year in case of 3 grit chamber and 1 standby grit chamber.

#### 2.8 Pumping Tank

After grit chamber, the water conveys to the raw water pipeline through pumping tank and intake pump. Pumping tank has 6 pump tanks with pumps and connecting pipeline. 6 pump tank includes 1 pump tank of Phase 2. Pumping tank is covered with the pump house with hoist crane.





Source: JICA Survey Team

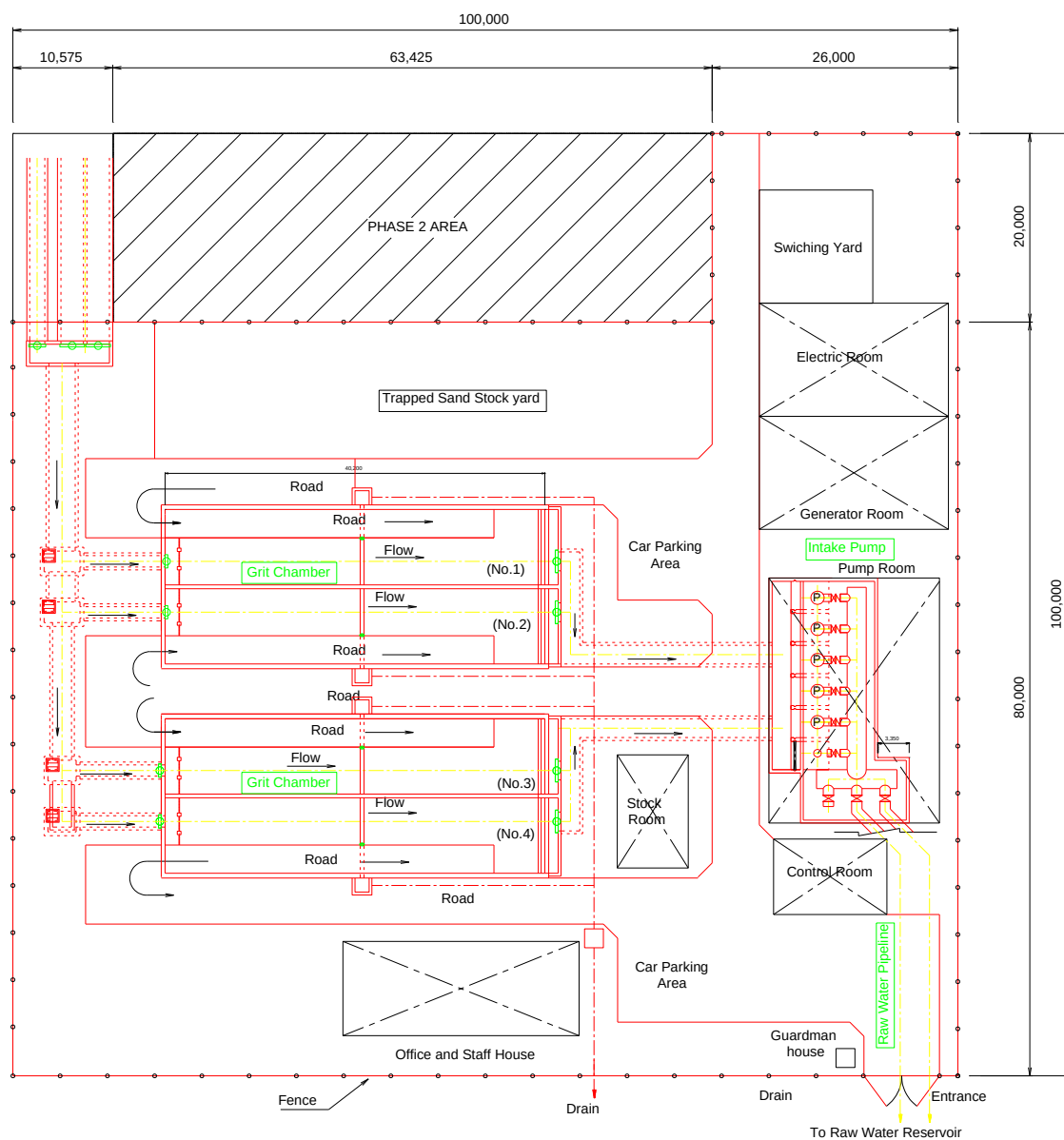
**Figure 2.8.1 Pumping Tank**

## 2.9 Layout of intake pumping station and flow diagram

Intake pumping station has not only grit chamber and pumping tank, but, related electric room, staff room and tarped sand stock yard as shown in Figure 2.9.1.

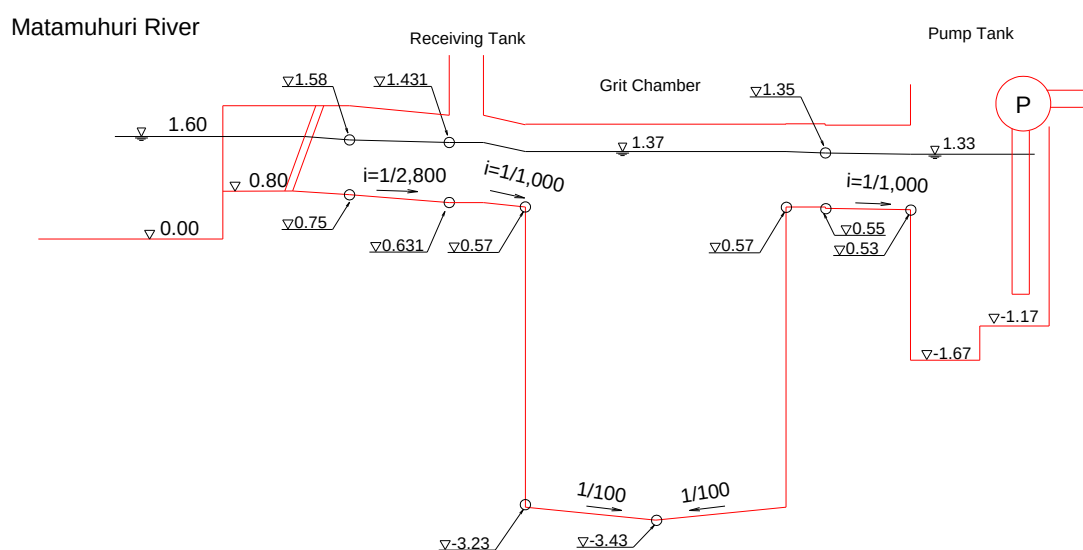
Its area is width 100 m x length 100 m including grit chamber area in Phase 2.

Flow diagram from intake to pumping tank is shown in Figure 2.9.2.



Source: JICA Survey Team

**Figure 2.9.1 Layout of intake pumping station.**



Source: JICA Survey Team

### Figure 2.9.2 Flow Diagram

## 2.10 Stability Analysis

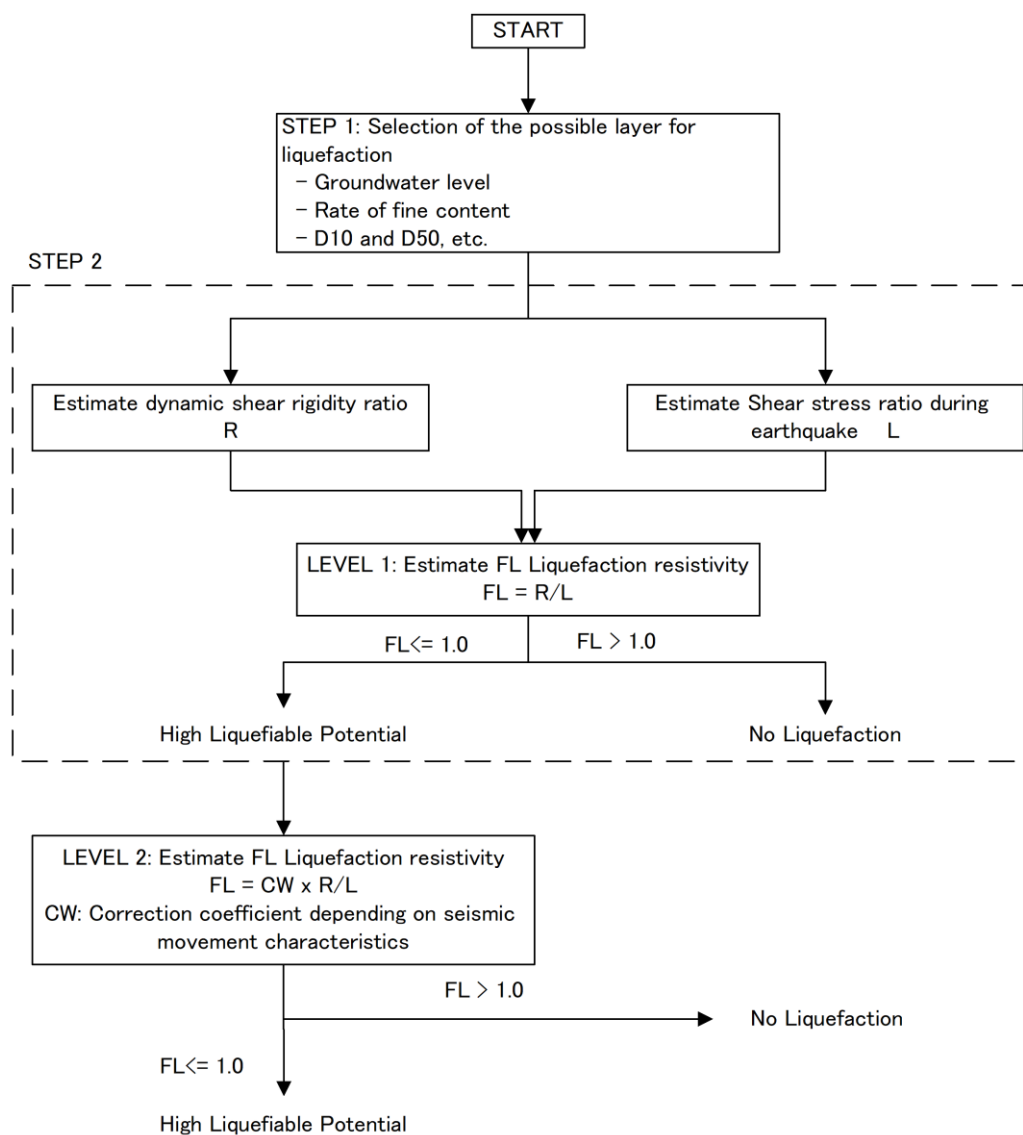
### 2.10.1 liquefaction

The two step examinations, namely STEP 1 and STEP 2, are applied for judgment of liquefiable foundation as LEVEL 1 and LEVEL 2 for the soil layer which is saturated and situated within 20m from ground surface as shown in Figure 2.10.1 based on “Specifications for Highway Bridge, Part V seismic design, Japan”.

### STEP 1

Foundation of target layer until 20 m from ground surface is considered as highly liquefiable when all of the following three conditions are applicable on the target soil layer.

- Ground water level is within 10m from ground surface.
- Fine fraction ratio ( $F_c$ ) is more than 35% and plasticity index ( $I_p$ ) is lower than 15 or  $F_c$  less than 35%.
- Mean particle diameter ( $D_{50}$ ) is lower than 10mm, and 10% particle diameter ( $D_{10}$ ) is lower than 1mm.



Source: JICA Survey Team

**Figure 2.10.1 Diagram of Liquefaction examination**

### STEP 2

Foundation of target layers that are selected by STEP 1 considered as liquefiable when value of Liquefaction Resistivity formula ( $F_L$ ) is estimated.

The possibility of the liquefaction on foundation should be check by STEP 2 based on results of laboratory tests. LEVEL 1 and LEVEL 2 are separated. When Liquefaction Resistivity is less than 1.0, the layer can be judged as liquefiable foundation at each LEVEL. Liquefaction judgments method is summarized in Table 2.10.1

**Table 2.10.1 Liquefaction Judgment Methods for STEP 2**

| STEP 2 |
|--------|
|--------|

|                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $F_L = C_W \cdot R/L$ $R = R_L$ $L = r_d \cdot k_h \cdot (\sigma_v/\sigma'_v)$ $r_d = 1.0 - 0.015x$ $\sigma_v = \gamma_{t1}hw + \gamma_{t2}(x - hw)$ $\sigma'_v = \gamma'_{t1}hw + \gamma'_{t2}(x - hw)$ |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| where:                                                                                                                                                                                                   | $F_L$ : Liquefaction resistivity<br>$R$ : Dynamic shear rigidity ratio<br>$L$ : Shear stress ratio during earthquake<br>$C_W$ : Correction coefficient depending on seismic movement characteristics<br>$R_L$ : Cyclic tri-axial strength ratio<br>$r_d$ : Reduction coefficient of depth direction during earthquake<br>$k_h$ : Design horizontal seismic intensity (See Table 2.5)<br>$\sigma_v$ : Total stress at the depth of x(m), kN/m <sup>2</sup><br>$\sigma'_v$ : Effective stress at the depth of x(m), kN/m <sup>2</sup><br>$x$ : Depth from ground surface, (m)<br>$\gamma_{t1}$ : Soil density above water surface<br>$\gamma_{t2}$ : Soil density under water surface<br>$\gamma'_{t2}$ : Soil effective density under water surface (Submerged density)<br>$hw$ : Depth to water surface depth from ground surface at x |
| Level 1 and Level 2 Type 1<br>$C_W = 1.0$<br>Liquefiable Soil: $F_L < 1.0$                                                                                                                               | Level 2 Type 2<br>$C_W = 1.0$ ( $R_L \leq 0.1$ )<br>$C_W = 3.3R_L + 0.67$ ( $0.1 < R_L \leq 0.4$ )<br>$C_W = 2.0$ ( $0.4 < R_L$ )<br>Liquefiable Soil: $F_L < 1.0$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

Source: JICA Survey Team

 $R_L$ : Cyclic tri-axial strength ratio

$$R_L = \begin{cases} 0.0882 \sqrt{(N_a/1.7)} & (N_a < 14) \\ 0.0882 \sqrt{(N_a/1.7)} + 1.6 \times 10^{-6} \cdot (N_a - 14)^{4.5} & (14 \leq N_a) \end{cases}$$

In sandy soil,

$$N_a = c_1 N_1 + c_2$$

$$N_1 = 170N / (\sigma'_v + 70)$$

$$c_1 = \begin{cases} 1 & (0\% \leq FC < 10\%) \\ (FC + 40)/50 & (10\% \leq FC < 60\%) \\ FC/20 - 1 & (60\% \leq FC) \end{cases}$$

$$c_2 = \begin{cases} 0 & (0\% \leq FC < 10\%) \\ (FC - 10)/18 & (10\% \leq FC) \end{cases}$$

**Table 2.10.2 Adopted Seismic Intensities**

| Seismic Movement          |        | Ground Classification<br>in Classification -2 due to building period |
|---------------------------|--------|----------------------------------------------------------------------|
| Level-1: Seismic Movement |        | 0.15                                                                 |
| Level-2: Seismic Movement | Type-1 | 0.35                                                                 |

|  |        |      |
|--|--------|------|
|  | Type-2 | 0.70 |
|--|--------|------|

Source: JICA Survey Team

Each layer of intake bore hole results; Intake-BH-01 to 03, is evaluated by Step 1 method. As the results of Step 1, one sample- Intake-BH-03 depth 15.0 m to 16.0 m in 10 samples has high Liquefiable Potential as shown in Table 2.10.3. Only one sample is progressed to Step 2.

**Table 2.10.3 Layer Selection by Step 1**

| Boring No.   | Depth          | Water Depth (EL. m) | Fc (%) | IP    | D50 (mm) | D10 (mm) | Evaluation  |           |             | Selection |
|--------------|----------------|---------------------|--------|-------|----------|----------|-------------|-----------|-------------|-----------|
|              |                |                     |        |       |          |          | Water Depth | FC and IP | D50 and D10 |           |
| Intake-BH-01 |                |                     |        |       |          |          |             |           |             |           |
|              | 10.00 to 10.45 | -2.1                | 93.96  | 22.49 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 12.00 to 13.00 | -2.1                | 99.12  | 20.14 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 14.00 to 15.00 | -2.1                | 99.44  | 19.53 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 18.00 to 19.00 | -2.1                | 99.54  | 16.58 | 0.05     | <0.002   | ○           | X         | ○           | X         |
| Intake-BH-02 |                |                     |        |       |          |          |             |           |             |           |
|              | 3.00 to 3.45   | -1.2                | 93.46  | 15.14 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 16.00 to 17.00 | -1.2                | 99.52  | 17.83 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 19.00 to 20.00 | -1.2                | 98.76  | 19.09 | 0.05     | <0.002   | ○           | X         | ○           | X         |
| Intake-BH-03 |                |                     |        |       |          |          |             |           |             |           |
|              | 12.00 to 13.00 | -1.2                | 99.46  | 18.67 | 0.05     | <0.002   | ○           | X         | ○           | X         |
|              | 15.00 to 16.00 | -1.2                | 92.40  | 9.62  | 0.05     | <0.002   | ○           | ○         | ○           | ○         |
|              | 18.00 to 19.00 | -1.2                | 99.20  | 15.32 | 0.05     | <0.002   | ○           | X         | ○           | X         |

Source: JICA Survey Team

As layer Intake-BH-03 15.0 m to 16.0 m is calculated by Step 2, Table 2.10.4 is obtained. Table 2.10.4 shows

- Liquefaction in case of Level 1 is not occurred or low potential
- Liquefaction in case of Level 2 Type 1 and Type 2 is high potential

**Table 2.10.4 Liquefaction Calculation by Step 2**

| Item              | Layer 15.0m-16.0 | Remarks |
|-------------------|------------------|---------|
| x                 | 15.5             |         |
| Water Depth Hw    | 1.2              |         |
| N value           | 7                |         |
| FC(%)             | 92.4             |         |
| Bulk Density      | 18.89            |         |
| Submerged Density | 9.89             |         |
| C1                | 3.620            |         |
| C2                | 4.578            |         |
| Rd                | 0.768            |         |
| $\sigma'_v$       | 164.095          |         |
| N1                | 3.280            |         |

|                |         |            |
|----------------|---------|------------|
| Na             | 16.452  |            |
| RL             | 0.27    |            |
| $\sigma_v$     | 292.795 |            |
| Level 1        |         |            |
| Kh             | 0.15    |            |
| L              | 0.21    |            |
| R              | 0.27    |            |
| Cw             | 1.0     |            |
| FL             | 1.34    | FL > 1 ok  |
| Level 2 Type 1 |         |            |
| Kh             | 0.35    |            |
| L              | 0.48    |            |
| R              | 0.27    |            |
| Cw             | 1.0     |            |
| FL             | 0.57    | FL < 1 out |
| Level 2 Type 2 |         |            |
| Kh             | 0.70    |            |
| L              | 0.96    |            |
| R              | 0.27    |            |
| Cw             | 1.58    |            |
| FL             | 0.45    | FL < 1 out |

Source: JICA Survey Team

As per this calculation, liquefaction is occurred in high possibility on Level 2 Type 1 and 2. However, countermeasure is not considered or topical treatment even implementing the countermeasure for this layer by the following reasons

- High potential layer is only one layer or thin thickness.
- This layer is not shallow layer and the layers on this layer until ground surface is not occurred.

### 2.10.2 Stability of Base Foundation

Allowable bearing capacity ( $Q_a$ ) is obtained by the ultimate bearing capacity using the safety factor shown below based on : Specifications for Highway Bridges IV Substructures, Japan.

$$q_a = \frac{Q_u}{SF}$$

SF = 3 (normal)

SF = 2 (seismic)

Ultimate bearing capacity of foundation ground is calculated with the formula below.

$$Q_u = A' \left\{ \alpha k c N_c + k q N_q + \frac{1}{2} \gamma_1 \beta B' N_r \right\}$$

Where,

$Q_u$  : Ultimate bearing capacity (kN)

$A'$  : Effective loading area on footing (m<sup>2</sup>) (Refer to following Fig. )

$\alpha, \beta$  : Shape factor of foundation as shown in the following table

**Table 2.10.5 Shape Factor of Foundation**

| Shape of Foundation  | $\alpha$     | $\beta$      |
|----------------------|--------------|--------------|
| Zonation             | 1.0          | 1.0          |
| Circle or Square     | 1.3          | 0.6          |
| Rectangle or ellipse | $1+0.3B'/L'$ | $1-0.4B'/L'$ |

Source: Specifications for Highway Bridges IV Substructures Table 10.3.3, Japan

C : Cohesion of foundation ground ( $\text{kN/m}^2$ )

q : Surcharge ( $\text{kN/m}^2$ )

$$= \gamma_2 \cdot D_f$$

$\gamma_1, \gamma_2$  : Unit weight of soil of bearing ground ( $\text{kN/m}^3$ )

$B', L'$  : Width and length of effective loading areas as shown in the following figure

$$B' = B - 2e_H$$

$$L' = L - 2e_L$$

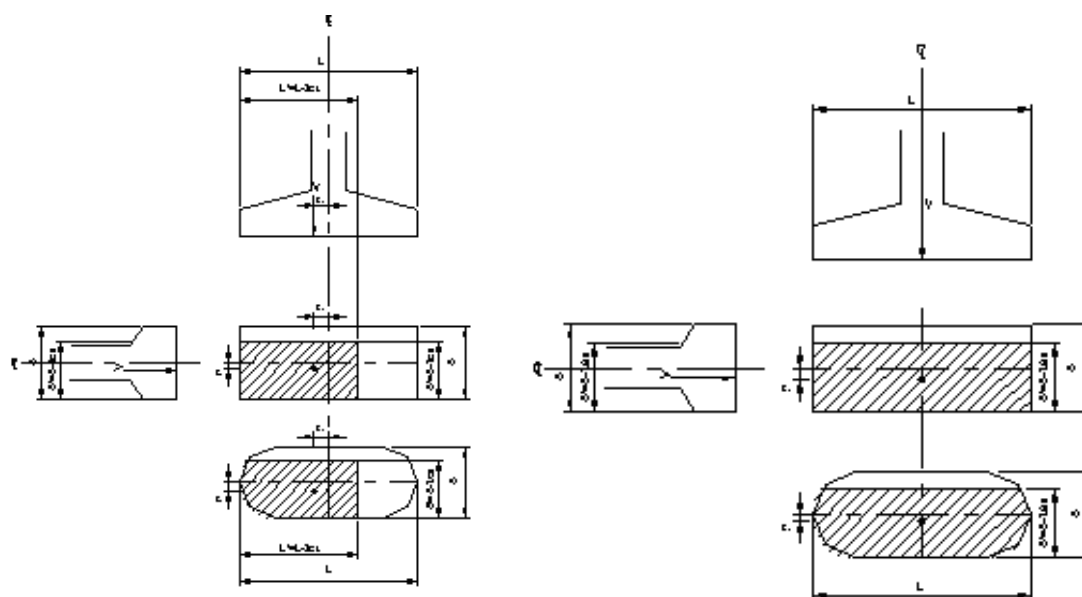
e : Distance from center of footing to point of resultant force on footing as illustrated in the following figure (m)

$D_f$  : Depth from ground surface to bottom of footing (m)

K : Coefficient  $(1+0.3 \times D_f'/B)$

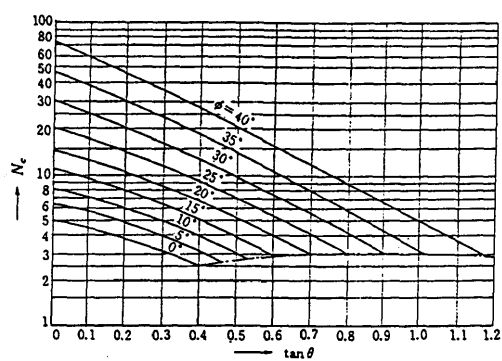
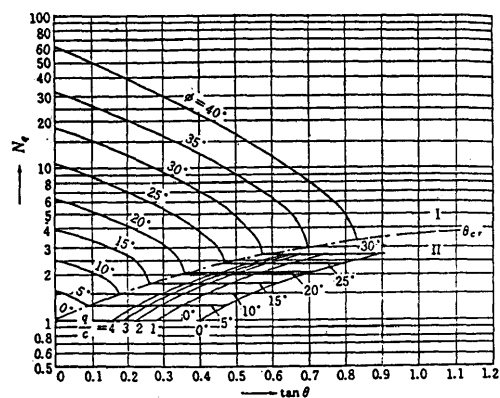
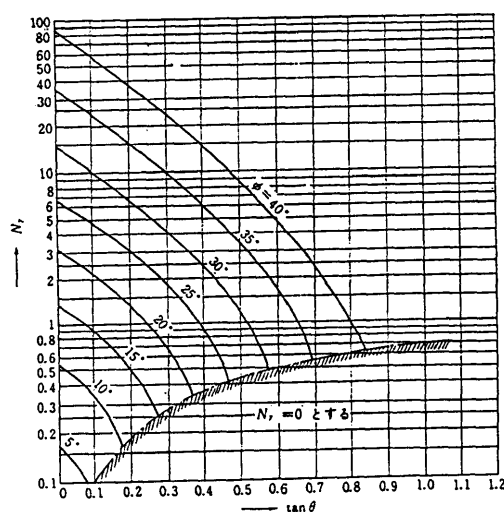
$D_f'$  : Effective embedded depth of foundation (m)

$N_c, N_q, N_r$ : Bearing capacity factors (refer to Fig. )



Source: Specifications for Highway Bridges IV Substructures Table 10.3.4, 10.3.5

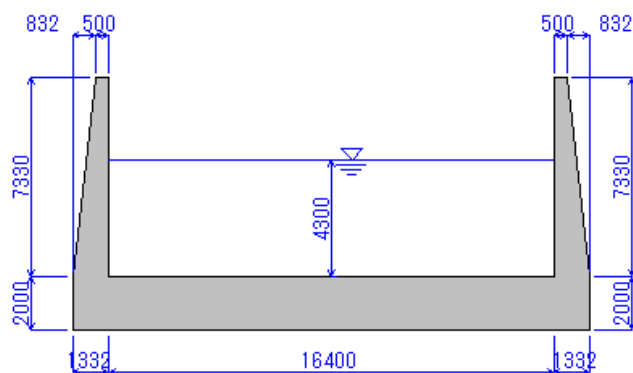
**Fig. 2.10.2 Effective Loading Area on Footing**

Graph for Bearing Capacity Factor  $N_c$ Graph for Bearing Capacity Factor  $N_q$ Graph for Bearing Capacity Factor  $N_r$ 

Source: Specifications for Highway Bridges IV Substructures Table 10.3.1, 10.3.2, 10.3.3

**Fig. 2.10.3**      **Graphs for Bearing Capacity Factor**

As per above equation, grit chamber foundation is analysed. Main figure of grit chamber is shown in Figure 2.10.4.





Source: JICA Survey Team

**Figure 2.10.4 Grit chamber Section****(1) Normal**

Active load at channel bottom is shown in Table 2.10.6

**Table 2.10.6 Active load of Grit chamber (Normal)**

| Load item           |       | Vertical load<br>V(kN/m) | Active point distance<br>x(m) | V · x<br>(kN · m/m) | Horizontal load<br>H(kN/m) | Center point Distance<br>y(m) | H · y<br>(kN · m/m) |
|---------------------|-------|--------------------------|-------------------------------|---------------------|----------------------------|-------------------------------|---------------------|
| Dead load           |       | 1185.80                  | 9.532                         | 11303.05            | 0.00                       | 0.000                         | 0.00                |
| Inside Water weight |       | 691.10                   | 9.532                         | 6587.53             | 0.00                       | 0.000                         | 0.00                |
| Earth Pressure      | Left  | 61.98                    | 0.000                         | 0.00                | 126.10                     | 3.110                         | 392.17              |
|                     | Right | 65.93                    | 18.938                        | 1248.61             | -134.13                    | 3.110                         | -417.16             |
| Total               |       | 2004.81                  | 0.000                         | 19139.19            | -8.03                      | 0.000                         | -24.99              |

Source: JICA Survey Team

Distance from origin =  $(19139.19 - 24.99) / 2004.81 = 9.534 \text{ m}$ eccentric arm  $e = 19.064 \times 0.5 - 9.534 = -0.002 \text{ m}$ 

Maxum active load in foundation

Bottom width  $L = 19.064 \text{ m}$ eccentric arm  $e \leq L/6$ 

$$q_1 = \Sigma V/L \cdot (1+6e/L) = 2004.81/19.064 \times (1+6 \times (-0.002)/19.064) = 105.09 \text{ kN/m}^2$$

$$q_2 = \Sigma V/L \cdot (1-6e/L) = 2004.81/19.064 \times (1-6 \times (-0.002)/19.064) = 105.23 \text{ kN/m}^2$$

$$\therefore q_{\max} = 105.23 \text{ kN/m}^2$$

Allowable bearing capacity ( $Q_a$ )

$$\begin{aligned}
 q_a &= 1/3(\alpha \cdot c \cdot N_c + \beta \cdot \gamma_1 \cdot B \cdot N_r + \gamma_2 \cdot D_f \cdot N_q) \\
 &= 1/3(1.0000 \cdot 38.650 \cdot 6.950 + 0.500 \cdot 18.890 \cdot 19.064 \cdot 1.460) \\
 &\quad + (8.400 \cdot 9.320 + 17.400 \cdot 0.010) \cdot 5.080 \\
 &= 310.030 \text{ kN/m}^2
 \end{aligned}$$

$$q_{\max}/q_a = 105.23 / 310.03 = 0.339 < 1.000 \quad \text{【OK】}$$

**(2) Seismic Condition**

Active load at channel bottom is shown in Table 2.10.7

**Table 2.10.7 Active load of Grit chamber (Seismic Condition)**

| Load item           |       | Vertical<br>load<br>V(kN/m) | Active<br>point<br>distance | V · x<br>(kN · m/m) | Horizontal<br>load<br>H(kN/m) | Center<br>point<br>Distance | H · y<br>(kN · m/m) |
|---------------------|-------|-----------------------------|-----------------------------|---------------------|-------------------------------|-----------------------------|---------------------|
| Dead load           |       | 1185.80                     | 9.532                       | 11303.05            | 237.16                        | 2.071                       | 491.05              |
| Inside Water weight |       | 691.10                      | 9.532                       | 6587.53             | 0.00                          | 0.000                       | 0.00                |
| Earth Pressure      | Left  | 66.88                       | 0.000                       | 0.00                | 227.61                        | 3.110                       | 707.87              |
|                     | Right | 66.88                       | 18.938                      | 1266.67             | -227.61                       | 3.110                       | -707.87             |
| Total               |       | 2010.67                     | 0.000                       | 19157.25            | 237.16                        | 0.000                       | 491.05              |

Source: JICA Survey Team

Distance from origin =  $(19157.25 + 491.05) / 2010.67 = 9.772 \text{ m}$

eccentric arm  $e = 19.064 \times 0.5 - 9.772 = -0.240 \text{ m}$

Maxum active load in foundation

Bottom width  $L = 19.064 \text{ m}$

eccentric arm  $e \leq L/6$

$$q_1 = \Sigma V/L \cdot (1+6e/L) = 2010.67/19.064 \times (1+6 \times (-0.240)/19.064) = 97.50 \text{ kN/m}^2$$

$$q_2 = \Sigma V/L \cdot (1-6e/L) = 2010.67/19.064 \times (1-6 \times (-0.240)/19.064) = 113.44 \text{ kN/m}^2$$

$$\therefore q_{\max} = 113.44 \text{ kN/m}^2$$

Allowable bearing capacity ( $Q_a$ )

$$\begin{aligned}
 q_a &= 1/3(\alpha \cdot c \cdot N_c + \beta \cdot \gamma_1 \cdot B \cdot N_r + \gamma_2 \cdot D_f \cdot N_q) \\
 &= 2/3(1.0000 \cdot 38.650 \cdot 6.950 + 0.500 \cdot 18.890 \cdot 19.064 \cdot 1.460) \\
 &\quad + 1/2 (8.400 \cdot 9.320 + 17.400 \cdot 0.010) \cdot 5.080 \\
 &= 487.199 \text{ kN/m}^2
 \end{aligned}$$

$$q_{\max}/q_a = 113.44 / 487.199 = 0.233 < 1.000 \quad \text{【OK】}$$

## CHAPER B3 DESIGN FLOOD DISCHARGE OF RAW WATER RESERVOIR

### 3.1 Standards for designing the reservoir

The following 2 standards are usually used in designing design discharge and spillway of the reservoir.

- Technical Standards of Disaster Prevention Regulation Pond, ETC., Japan River Association
- Guideline Manual for Land Improvement Project “Pond Development”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries.

Table 1.1 shows difference between both standards and Guideline Manual for Land Improvement Project “Pond Development” is adopted because this project reservoir is 1) impounding the water, 2) main function is water storage against the purpose of Technical Standards of Disaster Prevention Regulation Pond, ETC is prevented from flooding disaster.

**Table 3.1.1 Comparison table with Standards**

|                                 | a) Disaster Prevention Regulation Pond/ <u>1</u>                                                                                                                                                                                                                           | b) Pond Development/ <u>2</u>                                                                                                                                                                                                                                                                         | Adopted    |
|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 1. Design flood discharge<br>Qd | $Q_d = 1.2 \times Q_{200}$<br>$Q_{200}$ : Return period 200 years discharge (m <sup>3</sup> /s)                                                                                                                                                                            | Select 120% volume of the maximum discharge in the following A to C<br>A : Return period 200 years discharge (m <sup>3</sup> /s)<br>B : Recorded maximum discharge (m <sup>3</sup> /s)<br>C : Recorded maximum discharge in the vicinity or the value from Creager curve equation (m <sup>3</sup> /s) | b) adopted |
| 2. Duration time                | Select in the following 3 method<br>1) Kraven equation<br>2) Japan Public Works research Institute equation<br>3) Kinematic wave method                                                                                                                                    | Kinematic wave method                                                                                                                                                                                                                                                                                 | b) Adopted |
| 3. Free board height Hf of bank | Select in the following 2 method<br>$H_f \geq H_d + h_w \geq 0.6 \text{ m}$<br>$H_f \geq h_w + h_e/2$<br>$H_f$ : Free board height (Distance from NWL to Bank crest) (m)<br>$H_d$ : Design overflow depth (m)<br>$H_w$ : Wave height by wind (m)<br>$H_e$ : Wave height by | $H_f = 0.05 H_2 + (h_w \text{ or } 1.0)$<br>$H_f$ : Free board height (Distance from NWL to Bank crest) (m)<br>$H_2$ : Distance from bank base to water surface in FWL                                                                                                                                | b) Adopted |

|                                                                                   | earthquake (m)                                         |                       |              |
|-----------------------------------------------------------------------------------|--------------------------------------------------------|-----------------------|--------------|
| 4. Considering reservoir water effect in calculating design discharge of spillway | None, Inflow discharge is design discharge of spillway | Considering           | b) Adopted/3 |
| 5. Hyetograph pattern                                                             | Back focused waveform                                  | Back focused waveform | Both         |

Source: JICA Survey Team

Notes: /1 “Disaster Prevention Regulation Pond” means Technical Standards of Disaster Prevention Regulation Pond, ETC., Japan River Association.

/2 “Pond Development” means Guideline Manual for Land Improvement Project “Pond Development”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries.

/3 Inflow is only the discharge from rainfall directory at the reservoir. Discharge volume has high believability and discharge calculation can be considered with reservoir water effect.

## 3.2 Design Flood Discharge

### 3.2.1 Design Inflow

Based on Guideline Manual for Land Improvement Project “Pond Development”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries, select 120% volume of the maximum discharge in the following A to C

A : Return period 200 years discharge (m<sup>3</sup>/s)

B : Recorded maximum discharge (m<sup>3</sup>/s)

C : Recorded maximum discharge in the vicinity or the value from Creager curve equation (m<sup>3</sup>/s)

#### 1) Item A Discharge

Item A discharge adopted The Rational Method. It gives satisfactory results for small drainage catchments and is expressed as follows:

$$Q = Q_{200} \times 1.2 = C I_{200} A / 3.6 \times 1.2 \quad (1)$$

Where,

$Q$ : Item A discharge (m<sup>3</sup>/s)

$Q_{200}$ : Return period 200 years discharge (m<sup>3</sup>/s)

$C$ : Run-off coefficient.

$I_{200}$ : Return period 200 years rainfall intensity (mm/hr)

$A$ : Drainage area (Reservoir area) (km<sup>2</sup>).

It is possible to adopt 120% of  $Q_{100}$  return period 100 years discharge while  $Q_{200}$

return period 200 years is used. The duration time is obtained by Kinematic wave method as shown in the following equation and Table 3.2.1

$$T = 60 \cdot A^{0.22} \cdot f^{-0.35} \cdot r^{-0.35} \quad (2)$$

Return period 100 years rainfall equation

$$r = \frac{116.127}{t^{0.605+0.116}} \quad (3)$$

Where,

$T$  Duration time (min)

$A$ : Catchment area (km<sup>2</sup>) (= 0.525 for No1 &2, = 1.28 for No3 & 4)

$f$ : Run-off coefficient (= 1.00 reservoir area)

$r$ : Rainfall equation return period 100 years (mm/hr)

$t$  Duration time (hr)

**Table 3.2.1 Calculation of Duration time (for No. 1 & No.2)**

| T (min) | t (hr) | r (mm/hr) | T (min) | Q <sub>100</sub> (m <sup>3</sup> /s) | Remarks                    |
|---------|--------|-----------|---------|--------------------------------------|----------------------------|
| 10      | 0.1666 | 255.65    | 7.48    | 387.28                               | 10 of T is tentative value |
| 7.48    | 0.1247 | 290.50    | 8.42    | 42.36                                |                            |
| 8.42    | 0.1403 | 276.00    | 8.57    | 40.25                                |                            |
| 8.57    | 0.1428 | 273.8     | 8.59    | 39.94                                |                            |
| 8.59    | 0.1432 | 273.51    | 8.60    | 39.89                                |                            |
| 8.60    | 0.1433 | 273.46    | 8.60    | 39.88                                |                            |
| 8.60    | 0.1433 | 273.45    | 8.60    | 39.88                                | o.k.                       |

Source: JICA Survey Team

**Table 3.2.2 Calculation of Duration time (for No. 3 & No.4)**

| T (min) | t (hr) | r (mm/hr) | T (min) | Q (m <sup>3</sup> /s) | Remarks                    |
|---------|--------|-----------|---------|-----------------------|----------------------------|
| 10      | 0.1667 | 255.65    | 9.10    | 90.90                 | 10 of T is tentative value |
| 9.10    | 0.1517 | 266.66    | 8.67    | 94.81                 |                            |
| 8.67    | 0.1446 | 272.39    | 8.61    | 96.85                 |                            |
| 8.61    | 0.1435 | 273.29    | 8.60    | 97.17                 |                            |
| 8.60    | 0.1433 | 273.42    | 8.60    | 97.22                 |                            |
| 8.60    | 0.1433 | 274.45    | 8.60    | 97.23                 |                            |
| 8.60    | 0.1433 | 274.45    | 8.60    | 97.23                 | o.k.                       |

Source: JICA Survey Team

Item A discharge to reservoir is indicated by the following

**Table 3.2.3 Design Discharge by Item A discharge**

| Item                    |                  | Unit              | No.1 & No.2 | No.3 & No.4 | Remarks                      |
|-------------------------|------------------|-------------------|-------------|-------------|------------------------------|
| Catchment Area          | A                | Km <sup>2</sup>   | 0.561       | 1.414       | 1 Lot                        |
| Rainfall Intensity      | I <sub>100</sub> | mm/hr             | 273.41      | 273.41      | $116.127/(T^{0.605}+0.116)$  |
| Return Period           |                  | year              | 100         | 100         |                              |
| Rainfall Duration       | t                | hour              | 0.1433      | 0.1433      |                              |
|                         |                  | min               | 8.60        | 8.60        |                              |
| Runoff Coefficient      | C                |                   | 1.00        | 1.00        | Reservoir                    |
| 100 years Flow          | Q <sub>100</sub> | m <sup>3</sup> /s | 42.61       | 107.39      | Equation (1)                 |
| 200 years Flow          | Q <sub>200</sub> | m <sup>3</sup> /s | 51.13       | 128.87      | Q <sub>100</sub> x 1.2       |
| Item A discharge        | Q <sub>A</sub>   | m <sup>3</sup> /s | 61.35       | 154.64      | Q <sub>200</sub> x 1.2       |
| Design Inflow Discharge | Q <sub>d</sub>   | m <sup>3</sup> /s | 65.45       | 158.74      | Q <sub>A</sub> + Inflow 4.10 |

Source: JICA Survey Team

## 2) Item B discharge

There is no hourly rainfall data near the site. Item B discharge is not available.

## 3) Item C discharge

From Cox's Bazar station, the following rainfall was recorded from 2004 to 2021

3 hours maximum rainfall      122 mm/3hr = 40.67 mm/hr

Item A discharge 56.40 mm/hr (t = 3 hr) is larger than Item C discharge 40.67mm/hr (t = 3 hr). Item A discharge is adopted.

## 3.2.2 Storage Effect

As per Guideline Manual for Land Improvement Project "Pond Development", Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries, storage effect can be considered in case of large reservoir area in catchment area and these reservoirs can be adopted.

Storage effect is calculating 1) hyetograph, 2) calculating inflow hydrograph based on 1), 3) flood control calculating based on 2). 1) to 3) are calculated in next section respectively.

## 3.2.3 Hyetograph

Hyetograph adopts backward concentration method. unit time T is T = 8.60 min based on section 2.1 and calculation time is 24 hours.

Estimating rainfall I<sub>t1</sub><sup>t2</sup> time t1 to t2 can be estimated by the following.

Rainfall until t1 R<sup>t1</sup>

$$R^{t1} = \frac{116.127}{t1^{0.605} + 0.116} \times t1$$

Rainfall until  $t2$   $R^{t2}$

$$R^{t2} = \frac{116.127}{t2^{0.605} + 0.116} \times t2$$

Rainfall time  $t1$  to  $t2$   $I_{t1}^{t2}$  can estimate by difference between  $R^{t1}$  and  $R^{t2}$  and rainfall  $I_{t1}^{t2}$  is divided by the time between  $t1$  to  $t2$  as following;

$$I_{t1}^{t2} = (R^{t2} - R^{t1}) \times \frac{1}{(t2 - t1)} = \left( \left( \frac{116.127}{t2^{0.605} + 0.116} \right) \times t2 - \left( \frac{116.127}{t1^{0.605} + 0.116} \right) \times t1 \right) \times \frac{1}{(t2 - t1)}$$

Estimating rainfall

$t1 = 0.0$  hr,  $t2 = 0.1433$  hr (8.6 min)

$$I_{0.0}^{0.1433} = \left( \left( \frac{116.127}{(0.1433)^{0.605} + 0.116} \right) \times 0.1433 - \left( \frac{116.127}{(0.0)^{0.605} + 0.116} \right) \times 0.0 \right) \times \frac{1}{(0.1433 - 0.0)}$$

$$= 273.41 \text{ mm/hr}$$

$t1 = 0.1433$  hr (8.6 min),  $t2 = 0.2867$  hr (17.2 min)

$$I_{0.1433}^{0.2867} = \left( \left( \frac{116.127}{(0.2867)^{0.605} + 0.116} \right) \times 0.2867 - \left( \frac{116.127}{(0.1433)^{0.605} + 0.116} \right) \times 0.1433 \right) \times \frac{1}{(0.2867 - 0.1433)}$$

$$= 198.31 \text{ mm/hr}$$

The calculation results show Table 3.2.4.

**Table 3.2.4 Hyetograph**

| No. | Time (min) | Rainfall (mm/hr) | No. | Time (min) | Rainfall (mm/hr) | No. | Time (min) | Rainfall (mm/hr) |
|-----|------------|------------------|-----|------------|------------------|-----|------------|------------------|
| 0   | 0          | 0.00             | 60  | 516.0      | 8.81             | 120 | 1,032.0    | 14.43            |
| 1   | 8.6        | 6.76             | 61  | 524.6      | 8.864            | 121 | 1,040.6    | 14.61            |
| 2   | 17.2       | 6.79             | 62  | 533.2      | 8.914            | 122 | 1,049.2    | 14.81            |
| 3   | 25.8       | 6.81             | 63  | 541.8      | 8.966            | 123 | 1,057.8    | 15.00            |
| 4   | 34.4       | 6.84             | 64  | 550.4      | 9.018            | 124 | 1,066.4    | 15.21            |
| 5   | 43.0       | 6.86             | 65  | 559.0      | 9.071            | 125 | 1,075.0    | 15.42            |
| 6   | 51.6       | 6.89             | 66  | 567.6      | 9.125            | 126 | 1,083.6    | 15.65            |
| 7   | 60.2       | 6.91             | 67  | 576.2      | 9.180            | 127 | 1,092.2    | 15.88            |
| 8   | 68.8       | 6.94             | 68  | 584.8      | 9.236            | 128 | 1,100.8    | 16.12            |
| 9   | 77.4       | 6.97             | 69  | 593.4      | 9.292            | 129 | 1,109.4    | 16.37            |
| 10  | 86.0       | 6.99             | 70  | 602.0      | 9.350            | 130 | 1,118.0    | 16.63            |
| 11  | 94.6       | 7.02             | 71  | 610.6      | 9.409            | 131 | 1,126.6    | 16.90            |
| 12  | 103.2      | 7.05             | 72  | 619.2      | 9.468            | 132 | 1,135.2    | 17.18            |
| 13  | 111.8      | 7.08             | 73  | 627.8      | 9.528            | 133 | 1,143.8    | 17.48            |
| 14  | 120.4      | 7.10             | 74  | 636.4      | 9.590            | 134 | 1,152.4    | 17.79            |
| 15  | 129.0      | 7.13             | 75  | 645.0      | 9.653            | 135 | 1,161.0    | 18.11            |
| 16  | 137.6      | 7.16             | 76  | 653.6      | 9.716            | 136 | 1,169.6    | 18.45            |
| 17  | 146.2      | 7.19             | 77  | 662.2      | 9.781            | 137 | 1,178.2    | 18.81            |
| 18  | 154.8      | 7.22             | 78  | 670.8      | 9.847            | 138 | 1,186.8    | 19.19            |
| 19  | 163.4      | 7.25             | 79  | 679.4      | 9.914            | 139 | 1,195.4    | 19.58            |
| 20  | 172.0      | 7.28             | 80  | 688.0      | 9.982            | 140 | 1,204.0    | 20.00            |
| 21  | 180.6      | 7.31             | 81  | 696.6      | 10.052           | 141 | 1,212.6    | 20.45            |
| 22  | 189.2      | 7.34             | 82  | 705.2      | 10.123           | 142 | 1,221.2    | 20.92            |
| 23  | 197.8      | 7.37             | 83  | 713.8      | 10.195           | 143 | 1,229.8    | 21.42            |

|    |       |      |     |         |        |     |         |        |
|----|-------|------|-----|---------|--------|-----|---------|--------|
| 24 | 206.4 | 7.40 | 84  | 722.4   | 10.269 | 144 | 1,238.4 | 21.95  |
| 25 | 215.0 | 7.43 | 85  | 731.0   | 10.344 | 145 | 1,247.0 | 22.53  |
| 26 | 223.6 | 7.46 | 86  | 739.6   | 10.420 | 146 | 1,255.6 | 23.14  |
| 27 | 232.2 | 7.49 | 87  | 748.2   | 10.498 | 147 | 1,264.2 | 23.79  |
| 28 | 240.8 | 7.53 | 88  | 756.8   | 10.578 | 148 | 1,272.8 | 24.50  |
| 29 | 249.4 | 7.56 | 89  | 765.4   | 10.659 | 149 | 1,281.4 | 25.27  |
| 30 | 258.0 | 7.59 | 90  | 774.0   | 10.742 | 150 | 1,290.0 | 26.11  |
| 31 | 266.6 | 7.63 | 91  | 782.6   | 10.827 | 151 | 1,298.6 | 27.02  |
| 32 | 275.2 | 7.66 | 92  | 791.2   | 10.913 | 152 | 1,307.2 | 28.01  |
| 33 | 283.8 | 7.70 | 93  | 799.8   | 11.001 | 153 | 1,315.8 | 29.12  |
| 34 | 292.4 | 7.73 | 94  | 808.4   | 11.091 | 154 | 1,324.4 | 30.34  |
| 35 | 301.0 | 7.77 | 95  | 817.0   | 11.184 | 155 | 1,333.0 | 31.71  |
| 36 | 309.6 | 7.80 | 96  | 825.6   | 11.278 | 156 | 1,341.6 | 33.25  |
| 37 | 318.2 | 7.84 | 97  | 834.2   | 11.374 | 157 | 1,350.2 | 35.01  |
| 38 | 326.8 | 7.87 | 98  | 842.8   | 11.473 | 158 | 1,358.8 | 37.04  |
| 39 | 335.4 | 7.91 | 99  | 851.4   | 11.573 | 159 | 1,367.4 | 39.40  |
| 40 | 344.0 | 7.95 | 100 | 860.0   | 11.676 | 160 | 1,376.0 | 42.21  |
| 41 | 352.6 | 7.99 | 101 | 868.6   | 11.782 | 161 | 1,384.6 | 45.60  |
| 42 | 361.2 | 8.03 | 102 | 877.2   | 11.890 | 162 | 1,393.2 | 49.82  |
| 43 | 369.8 | 8.06 | 103 | 885.8   | 12.001 | 163 | 1,401.8 | 55.24  |
| 44 | 378.4 | 8.10 | 104 | 894.4   | 12.115 | 164 | 1,410.4 | 62.53  |
| 45 | 387.0 | 8.14 | 105 | 903.0   | 12.231 | 165 | 1,419.0 | 73.02  |
| 46 | 395.6 | 8.18 | 106 | 911.6   | 12.351 | 166 | 1,427.6 | 89.85  |
| 47 | 404.2 | 8.23 | 107 | 920.2   | 12.473 | 167 | 1,436.2 | 123.21 |
| 48 | 412.8 | 8.27 | 108 | 928.8   | 12.599 | 168 | 1,444.8 | 273.41 |
| 49 | 421.4 | 8.31 | 109 | 937.4   | 12.729 | 169 | 1,453.4 | 0.00   |
| 50 | 430.0 | 8.35 | 110 | 946.0   | 12.862 | 170 | 1,462.0 | 0.00   |
| 51 | 438.6 | 8.39 | 111 | 954.6   | 12.998 | 171 | 1,470.6 | 0.00   |
| 52 | 447.2 | 8.44 | 112 | 963.2   | 13.139 | 172 | 1,479.2 | 0.00   |
| 53 | 455.8 | 8.48 | 113 | 971.8   | 13.283 | 173 | 1,487.8 | 0.00   |
| 54 | 464.4 | 8.53 | 114 | 980.4   | 13.432 | 174 | 1,496.4 | 0.00   |
| 55 | 473.0 | 8.57 | 115 | 989.0   | 13.586 | 175 | 1,505.0 | 0.00   |
| 56 | 481.6 | 8.62 | 116 | 997.6   | 13.744 |     |         |        |
| 57 | 490.2 | 8.67 | 117 | 1,006.2 | 13.907 |     |         |        |
| 58 | 498.8 | 8.72 | 118 | 1,014.8 | 14.075 |     |         |        |
| 59 | 507.4 | 8.76 | 119 | 1,023.4 | 14.249 |     |         |        |

Source: JICA Survey Team

### 3.2.4 Inflow Hydrograph

Inflow hydrograph of No.1 and No.2 to reservoir can be estimate by using equation (1) and Table 3.2.4 while

Run-off coefficient  $f = 1.0$  ;

**Table 3.2.5 Hydrograph (No.1 & No.2 Reservoir)**

| (1) No. | (2) Minute | (3) Rainfall (mm/hr) | (4) Discharge (m <sup>3</sup> /s) | (5) Pump up Inflow | (6) Total Discharge Q <sub>200</sub> |
|---------|------------|----------------------|-----------------------------------|--------------------|--------------------------------------|
| 0       | 0.0        | 0.00                 | 0.00                              | 4.10               | 4.10                                 |
| 1       | 8.6        | 6.76                 | 1.26                              | 4.10               | 5.62                                 |
| 2       | 17.2       | 6.79                 | 1.27                              | 4.10               | 5.62                                 |
| 3       | 25.8       | 6.81                 | 1.27                              | 4.10               | 5.63                                 |
| 4       | 34.4       | 6.84                 | 1.28                              | 4.10               | 5.63                                 |
| 5       | 43.0       | 6.86                 | 1.28                              | 4.10               | 5.64                                 |
| 6       | 51.6       | 6.89                 | 1.29                              | 4.10               | 5.65                                 |
| 7       | 60.2       | 6.91                 | 1.29                              | 4.10               | 5.65                                 |
| 8       | 68.8       | 6.94                 | 1.30                              | 4.10               | 5.66                                 |
| 9       | 77.4       | 6.97                 | 1.30                              | 4.10               | 5.66                                 |

|    |       |      |      |      |      |
|----|-------|------|------|------|------|
| 10 | 86.0  | 6.99 | 1.31 | 4.10 | 5.67 |
| 11 | 94.6  | 7.02 | 1.31 | 4.10 | 5.68 |
| 12 | 103.2 | 7.05 | 1.32 | 4.10 | 5.68 |
| 13 | 111.8 | 7.08 | 1.32 | 4.10 | 5.69 |
| 14 | 120.4 | 7.10 | 1.33 | 4.10 | 5.69 |
| 15 | 129.0 | 7.13 | 1.33 | 4.10 | 5.70 |
| 16 | 137.6 | 7.16 | 1.34 | 4.10 | 5.71 |
| 17 | 146.2 | 7.19 | 1.34 | 4.10 | 5.71 |
| 18 | 154.8 | 7.22 | 1.35 | 4.10 | 5.72 |
| 19 | 163.4 | 7.25 | 1.36 | 4.10 | 5.73 |
| 20 | 172.0 | 7.28 | 1.36 | 4.10 | 5.73 |
| 21 | 180.6 | 7.31 | 1.37 | 4.10 | 5.74 |
| 22 | 189.2 | 7.34 | 1.37 | 4.10 | 5.75 |
| 23 | 197.8 | 7.37 | 1.38 | 4.10 | 5.75 |
| 24 | 206.4 | 7.40 | 1.38 | 4.10 | 5.76 |
| 25 | 215.0 | 7.43 | 1.39 | 4.10 | 5.77 |
| 26 | 223.6 | 7.46 | 1.40 | 4.10 | 5.77 |
| 27 | 232.2 | 7.49 | 1.40 | 4.10 | 5.78 |
| 28 | 240.8 | 7.53 | 1.41 | 4.10 | 5.79 |
| 29 | 249.4 | 7.56 | 1.41 | 4.10 | 5.80 |
| 30 | 258.0 | 7.59 | 1.42 | 4.10 | 5.80 |
| 31 | 266.6 | 7.63 | 1.43 | 4.10 | 5.81 |
| 32 | 275.2 | 7.66 | 1.43 | 4.10 | 5.82 |
| 33 | 283.8 | 7.70 | 1.44 | 4.10 | 5.83 |
| 34 | 292.4 | 7.73 | 1.45 | 4.10 | 5.83 |
| 35 | 301.0 | 7.77 | 1.45 | 4.10 | 5.84 |
| 36 | 309.6 | 7.80 | 1.46 | 4.10 | 5.85 |
| 37 | 318.2 | 7.84 | 1.47 | 4.10 | 5.86 |
| 38 | 326.8 | 7.87 | 1.47 | 4.10 | 5.87 |
| 39 | 335.4 | 7.91 | 1.48 | 4.10 | 5.88 |
| 40 | 344.0 | 7.95 | 1.49 | 4.10 | 5.88 |
| 41 | 352.6 | 7.99 | 1.49 | 4.10 | 5.89 |
| 42 | 361.2 | 8.03 | 1.50 | 4.10 | 5.90 |
| 43 | 369.8 | 8.06 | 1.51 | 4.10 | 5.91 |
| 44 | 378.4 | 8.10 | 1.52 | 4.10 | 5.92 |
| 45 | 387.0 | 8.14 | 1.52 | 4.10 | 5.93 |
| 46 | 395.6 | 8.18 | 1.53 | 4.10 | 5.94 |
| 47 | 404.2 | 8.23 | 1.54 | 4.10 | 5.95 |
| 48 | 412.8 | 8.27 | 1.55 | 4.10 | 5.96 |
| 49 | 421.4 | 8.31 | 1.55 | 4.10 | 5.96 |
| 50 | 430.0 | 8.35 | 1.56 | 4.10 | 5.97 |
| 51 | 438.6 | 8.39 | 1.57 | 4.10 | 5.98 |
| 52 | 447.2 | 8.44 | 1.58 | 4.10 | 5.99 |
| 53 | 455.8 | 8.48 | 1.59 | 4.10 | 6.00 |
| 54 | 464.4 | 8.53 | 1.59 | 4.10 | 6.01 |
| 55 | 473.0 | 8.57 | 1.60 | 4.10 | 6.02 |
| 56 | 481.6 | 8.62 | 1.61 | 4.10 | 6.03 |
| 57 | 490.2 | 8.67 | 1.62 | 4.10 | 6.05 |
| 58 | 498.8 | 8.72 | 1.63 | 4.10 | 6.06 |
| 59 | 507.4 | 8.76 | 1.64 | 4.10 | 6.07 |
| 60 | 516.0 | 8.81 | 1.65 | 4.10 | 6.08 |
| 61 | 524.6 | 8.86 | 1.66 | 4.10 | 6.09 |
| 62 | 533.2 | 8.91 | 1.67 | 4.10 | 6.10 |
| 63 | 541.8 | 8.97 | 1.68 | 4.10 | 6.11 |
| 64 | 550.4 | 9.02 | 1.69 | 4.10 | 6.12 |
| 65 | 559.0 | 9.07 | 1.70 | 4.10 | 6.14 |
| 66 | 567.6 | 9.13 | 1.71 | 4.10 | 6.15 |

|     |         |       |      |      |      |
|-----|---------|-------|------|------|------|
| 67  | 576.2   | 9.18  | 1.72 | 4.10 | 6.16 |
| 68  | 584.8   | 9.24  | 1.73 | 4.10 | 6.17 |
| 69  | 593.4   | 9.29  | 1.74 | 4.10 | 6.19 |
| 70  | 602.0   | 9.35  | 1.75 | 4.10 | 6.20 |
| 71  | 610.6   | 9.41  | 1.76 | 4.10 | 6.21 |
| 72  | 619.2   | 9.47  | 1.77 | 4.10 | 6.22 |
| 73  | 627.8   | 9.53  | 1.78 | 4.10 | 6.24 |
| 74  | 636.4   | 9.59  | 1.79 | 4.10 | 6.25 |
| 75  | 645.0   | 9.65  | 1.81 | 4.10 | 6.27 |
| 76  | 653.6   | 9.72  | 1.82 | 4.10 | 6.28 |
| 77  | 662.2   | 9.78  | 1.83 | 4.10 | 6.29 |
| 78  | 670.8   | 9.85  | 1.84 | 4.10 | 6.31 |
| 79  | 679.4   | 9.91  | 1.85 | 4.10 | 6.32 |
| 80  | 688.0   | 9.98  | 1.87 | 4.10 | 6.34 |
| 81  | 696.6   | 10.05 | 1.88 | 4.10 | 6.36 |
| 82  | 705.2   | 10.12 | 1.89 | 4.10 | 6.37 |
| 83  | 713.8   | 10.20 | 1.91 | 4.10 | 6.39 |
| 84  | 722.4   | 10.27 | 1.92 | 4.10 | 6.40 |
| 85  | 731.0   | 10.34 | 1.93 | 4.10 | 6.42 |
| 86  | 739.6   | 10.42 | 1.95 | 4.10 | 6.44 |
| 87  | 748.2   | 10.50 | 1.96 | 4.10 | 6.46 |
| 88  | 756.8   | 10.58 | 1.98 | 4.10 | 6.47 |
| 89  | 765.4   | 10.66 | 1.99 | 4.10 | 6.49 |
| 90  | 774.0   | 10.74 | 2.01 | 4.10 | 6.51 |
| 91  | 782.6   | 10.83 | 2.02 | 4.10 | 6.53 |
| 92  | 791.2   | 10.91 | 2.04 | 4.10 | 6.55 |
| 93  | 799.8   | 11.00 | 2.06 | 4.10 | 6.57 |
| 94  | 808.4   | 11.09 | 2.07 | 4.10 | 6.59 |
| 95  | 817.0   | 11.18 | 2.09 | 4.10 | 6.61 |
| 96  | 825.6   | 11.28 | 2.11 | 4.10 | 6.63 |
| 97  | 834.2   | 11.37 | 2.13 | 4.10 | 6.65 |
| 98  | 842.8   | 11.47 | 2.15 | 4.10 | 6.67 |
| 99  | 851.4   | 11.57 | 2.16 | 4.10 | 6.70 |
| 100 | 860.0   | 11.68 | 2.18 | 4.10 | 6.72 |
| 101 | 868.6   | 11.78 | 2.20 | 4.10 | 6.74 |
| 102 | 877.2   | 11.89 | 2.22 | 4.10 | 6.77 |
| 103 | 885.8   | 12.00 | 2.24 | 4.10 | 6.79 |
| 104 | 894.4   | 12.11 | 2.27 | 4.10 | 6.82 |
| 105 | 903.0   | 12.23 | 2.29 | 4.10 | 6.84 |
| 106 | 911.6   | 12.35 | 2.31 | 4.10 | 6.87 |
| 107 | 920.2   | 12.47 | 2.33 | 4.10 | 6.90 |
| 108 | 928.8   | 12.60 | 2.36 | 4.10 | 6.93 |
| 109 | 937.4   | 12.73 | 2.38 | 4.10 | 6.96 |
| 110 | 946.0   | 12.86 | 2.41 | 4.10 | 6.99 |
| 111 | 954.6   | 13.00 | 2.43 | 4.10 | 7.02 |
| 112 | 963.2   | 13.14 | 2.46 | 4.10 | 7.05 |
| 113 | 971.8   | 13.28 | 2.48 | 4.10 | 7.08 |
| 114 | 980.4   | 13.43 | 2.51 | 4.10 | 7.11 |
| 115 | 989.0   | 13.59 | 2.54 | 4.10 | 7.15 |
| 116 | 997.6   | 13.74 | 2.57 | 4.10 | 7.18 |
| 117 | 1,006.2 | 13.91 | 2.60 | 4.10 | 7.22 |
| 118 | 1,014.8 | 14.08 | 2.63 | 4.10 | 7.26 |
| 119 | 1,023.4 | 14.25 | 2.66 | 4.10 | 7.30 |
| 120 | 1,032.0 | 14.43 | 2.70 | 4.10 | 7.34 |
| 121 | 1,040.6 | 14.61 | 2.73 | 4.10 | 7.38 |

|     |         |        |       |      |       |
|-----|---------|--------|-------|------|-------|
| 122 | 1,049.2 | 14.81  | 2.77  | 4.10 | 7.42  |
| 123 | 1,057.8 | 15.00  | 2.81  | 4.10 | 7.47  |
| 124 | 1,066.4 | 15.21  | 2.84  | 4.10 | 7.51  |
| 125 | 1,075.0 | 15.42  | 2.88  | 4.10 | 7.56  |
| 126 | 1,083.6 | 15.65  | 2.93  | 4.10 | 7.61  |
| 127 | 1,092.2 | 15.88  | 2.97  | 4.10 | 7.66  |
| 128 | 1,100.8 | 16.12  | 3.01  | 4.10 | 7.72  |
| 129 | 1,109.4 | 16.37  | 3.06  | 4.10 | 7.77  |
| 130 | 1,118.0 | 16.63  | 3.11  | 4.10 | 7.83  |
| 131 | 1,126.6 | 16.90  | 3.16  | 4.10 | 7.89  |
| 132 | 1,135.2 | 17.18  | 3.21  | 4.10 | 7.96  |
| 133 | 1,143.8 | 17.48  | 3.27  | 4.10 | 8.02  |
| 134 | 1,152.4 | 17.79  | 3.33  | 4.10 | 8.09  |
| 135 | 1,161.0 | 18.11  | 3.39  | 4.10 | 8.16  |
| 136 | 1,169.6 | 18.45  | 3.45  | 4.10 | 8.24  |
| 137 | 1,178.2 | 18.81  | 3.52  | 4.10 | 8.32  |
| 138 | 1,186.8 | 19.19  | 3.59  | 4.10 | 8.41  |
| 139 | 1,195.4 | 19.58  | 3.66  | 4.10 | 8.49  |
| 140 | 1,204.0 | 20.00  | 3.74  | 4.10 | 8.59  |
| 141 | 1,212.6 | 20.45  | 3.82  | 4.10 | 8.69  |
| 142 | 1,221.2 | 20.92  | 3.91  | 4.10 | 8.79  |
| 143 | 1,229.8 | 21.42  | 4.01  | 4.10 | 8.91  |
| 144 | 1,238.4 | 21.95  | 4.11  | 4.10 | 9.03  |
| 145 | 1,247.0 | 22.53  | 4.21  | 4.10 | 9.15  |
| 146 | 1,255.6 | 23.14  | 4.33  | 4.10 | 9.29  |
| 147 | 1,264.2 | 23.79  | 4.45  | 4.10 | 9.44  |
| 148 | 1,272.8 | 24.50  | 4.58  | 4.10 | 9.60  |
| 149 | 1,281.4 | 25.27  | 4.73  | 4.10 | 9.77  |
| 150 | 1,290.0 | 26.11  | 4.88  | 4.10 | 9.96  |
| 151 | 1,298.6 | 27.02  | 5.05  | 4.10 | 10.16 |
| 152 | 1,307.2 | 28.01  | 5.24  | 4.10 | 10.39 |
| 153 | 1,315.8 | 29.12  | 5.44  | 4.10 | 10.63 |
| 154 | 1,324.4 | 30.34  | 5.67  | 4.10 | 10.91 |
| 155 | 1,333.0 | 31.71  | 5.93  | 4.10 | 11.22 |
| 156 | 1,341.6 | 33.25  | 6.22  | 4.10 | 11.56 |
| 157 | 1,350.2 | 35.01  | 6.55  | 4.10 | 11.96 |
| 158 | 1,358.8 | 37.04  | 6.93  | 4.10 | 12.41 |
| 159 | 1,367.4 | 39.40  | 7.37  | 4.10 | 12.94 |
| 160 | 1,376.0 | 42.21  | 7.89  | 4.10 | 13.57 |
| 161 | 1,384.6 | 45.60  | 8.53  | 4.10 | 14.33 |
| 162 | 1,393.2 | 49.82  | 9.32  | 4.10 | 15.28 |
| 163 | 1,401.8 | 55.24  | 10.33 | 4.10 | 16.50 |
| 164 | 1,410.4 | 62.53  | 11.69 | 4.10 | 18.13 |
| 165 | 1,419.0 | 73.02  | 13.65 | 4.10 | 20.49 |
| 166 | 1,427.6 | 89.85  | 16.80 | 4.10 | 24.26 |
| 167 | 1,436.2 | 123.21 | 23.04 | 4.10 | 31.75 |
| 168 | 1,444.8 | 273.41 | 51.13 | 4.10 | 65.45 |
| 169 | 1,453.4 | 0.00   | 0.00  | 4.10 | 4.10  |
| 170 | 1,462.0 | 0.00   | 0.00  | 4.10 | 4.10  |
| 171 | 1,470.6 | 0.00   | 0.00  | 4.10 | 4.10  |
| 172 | 1,479.2 | 0.00   | 0.00  | 4.10 | 4.10  |
| 173 | 1,487.8 | 0.00   | 0.00  | 4.10 | 4.10  |
| 174 | 1,496.4 | 0.00   | 0.00  | 4.10 | 4.10  |
| 175 | 1,505.0 | 0.00   | 0.00  | 4.10 | 4.10  |

Source: JICA Survey Team

Note:  $f=1.00$ ,  $A= 0.561 \text{ km}^2$

Inflow hydrograph of No.3 and No.4 to reservoir can be estimate by using equation (1) and Table 3.2.4 while Run-off coefficient  $f = 1.0$ , however, additional inflow from NO1. Or No.2 reservoir outflow shall be considered;

**Table 3.2.6 Hydrograph (No.3 & No. 4 Reservoir)**

| (1) No. | (2) Minute | (3) Rainfall (mm/hr) | (4) Discharge (m <sup>3</sup> /s) $Q_{200}$ | (5) From No1 Inflow | (6) Total Discharge $Q_{200} \times 1.2$ |
|---------|------------|----------------------|---------------------------------------------|---------------------|------------------------------------------|
| 0       | 0.0        | 0.00                 | 0.00                                        | 0.00                | 0.00                                     |
| 1       | 8.6        | 6.76                 | 3.19                                        | 0.04                | 3.87                                     |
| 2       | 17.2       | 6.79                 | 3.20                                        | 0.13                | 3.97                                     |
| 3       | 25.8       | 6.81                 | 3.21                                        | 0.25                | 4.10                                     |
| 4       | 34.4       | 6.84                 | 3.22                                        | 0.39                | 4.25                                     |
| 5       | 43.0       | 6.86                 | 3.23                                        | 0.54                | 4.42                                     |
| 6       | 51.6       | 6.89                 | 3.25                                        | 0.70                | 4.60                                     |
| 7       | 60.2       | 6.91                 | 3.26                                        | 0.87                | 4.78                                     |
| 8       | 68.8       | 6.94                 | 3.27                                        | 1.04                | 4.97                                     |
| 9       | 77.4       | 6.97                 | 3.28                                        | 1.22                | 5.16                                     |
| 10      | 86.0       | 6.99                 | 3.30                                        | 1.40                | 5.36                                     |
| 11      | 94.6       | 7.02                 | 3.31                                        | 1.58                | 5.55                                     |
| 12      | 103.2      | 7.05                 | 3.32                                        | 1.76                | 5.75                                     |
| 13      | 111.8      | 7.08                 | 3.33                                        | 1.94                | 5.94                                     |
| 14      | 120.4      | 7.10                 | 3.35                                        | 2.11                | 6.13                                     |
| 15      | 129.0      | 7.13                 | 3.36                                        | 2.29                | 6.32                                     |
| 16      | 137.6      | 7.16                 | 3.37                                        | 2.45                | 6.50                                     |
| 17      | 146.2      | 7.19                 | 3.39                                        | 2.62                | 6.68                                     |
| 18      | 154.8      | 7.22                 | 3.40                                        | 2.78                | 6.86                                     |
| 19      | 163.4      | 7.25                 | 3.42                                        | 2.93                | 7.03                                     |
| 20      | 172.0      | 7.28                 | 3.43                                        | 3.08                | 7.19                                     |
| 21      | 180.6      | 7.31                 | 3.44                                        | 3.22                | 7.35                                     |
| 22      | 189.2      | 7.34                 | 3.46                                        | 3.36                | 7.51                                     |
| 23      | 197.8      | 7.37                 | 3.47                                        | 3.49                | 7.66                                     |
| 24      | 206.4      | 7.40                 | 3.49                                        | 3.62                | 7.80                                     |
| 25      | 215.0      | 7.43                 | 3.50                                        | 3.74                | 7.94                                     |
| 26      | 223.6      | 7.46                 | 3.52                                        | 3.86                | 8.08                                     |
| 27      | 232.2      | 7.49                 | 3.53                                        | 3.97                | 8.21                                     |
| 28      | 240.8      | 7.53                 | 3.55                                        | 4.07                | 8.33                                     |
| 29      | 249.4      | 7.56                 | 3.56                                        | 4.17                | 8.45                                     |
| 30      | 258.0      | 7.59                 | 3.58                                        | 4.27                | 8.56                                     |
| 31      | 266.6      | 7.63                 | 3.59                                        | 4.36                | 8.68                                     |
| 32      | 275.2      | 7.66                 | 3.61                                        | 4.45                | 8.78                                     |
| 33      | 283.8      | 7.70                 | 3.63                                        | 4.53                | 8.88                                     |
| 34      | 292.4      | 7.73                 | 3.64                                        | 4.61                | 8.98                                     |
| 35      | 301.0      | 7.77                 | 3.66                                        | 4.69                | 9.08                                     |
| 36      | 309.6      | 7.80                 | 3.68                                        | 4.76                | 9.17                                     |
| 37      | 318.2      | 7.84                 | 3.69                                        | 4.82                | 9.26                                     |
| 38      | 326.8      | 7.87                 | 3.71                                        | 4.89                | 9.34                                     |
| 39      | 335.4      | 7.91                 | 3.73                                        | 4.95                | 9.42                                     |
| 40      | 344.0      | 7.95                 | 3.75                                        | 5.01                | 9.50                                     |
| 41      | 352.6      | 7.99                 | 3.76                                        | 5.06                | 9.58                                     |
| 42      | 361.2      | 8.03                 | 3.78                                        | 5.12                | 9.65                                     |
| 43      | 369.8      | 8.06                 | 3.80                                        | 5.17                | 9.73                                     |
| 44      | 378.4      | 8.10                 | 3.82                                        | 5.21                | 9.80                                     |
| 45      | 387.0      | 8.14                 | 3.84                                        | 5.26                | 9.86                                     |
| 46      | 395.6      | 8.18                 | 3.86                                        | 5.30                | 9.93                                     |

|     |       |       |      |      |       |
|-----|-------|-------|------|------|-------|
| 47  | 404.2 | 8.23  | 3.88 | 5.34 | 9.99  |
| 48  | 412.8 | 8.27  | 3.90 | 5.38 | 10.06 |
| 49  | 421.4 | 8.31  | 3.92 | 5.42 | 10.12 |
| 50  | 430.0 | 8.35  | 3.94 | 5.45 | 10.18 |
| 51  | 438.6 | 8.39  | 3.96 | 5.49 | 10.24 |
| 52  | 447.2 | 8.44  | 3.98 | 5.52 | 10.29 |
| 53  | 455.8 | 8.48  | 4.00 | 5.55 | 10.35 |
| 54  | 464.4 | 8.53  | 4.02 | 5.58 | 10.40 |
| 55  | 473.0 | 8.57  | 4.04 | 5.61 | 10.46 |
| 56  | 481.6 | 8.62  | 4.06 | 5.63 | 10.51 |
| 57  | 490.2 | 8.67  | 4.09 | 5.66 | 10.56 |
| 58  | 498.8 | 8.72  | 4.11 | 5.69 | 10.62 |
| 59  | 507.4 | 8.76  | 4.13 | 5.71 | 10.67 |
| 60  | 516.0 | 8.81  | 4.15 | 5.74 | 10.72 |
| 61  | 524.6 | 8.86  | 4.18 | 5.76 | 10.77 |
| 62  | 533.2 | 8.91  | 4.20 | 5.78 | 10.82 |
| 63  | 541.8 | 8.97  | 4.23 | 5.80 | 10.87 |
| 64  | 550.4 | 9.02  | 4.25 | 5.82 | 10.92 |
| 65  | 559.0 | 9.07  | 4.28 | 5.84 | 10.97 |
| 66  | 567.6 | 9.13  | 4.30 | 5.86 | 11.02 |
| 67  | 576.2 | 9.18  | 4.33 | 5.88 | 11.07 |
| 68  | 584.8 | 9.24  | 4.35 | 5.90 | 11.12 |
| 69  | 593.4 | 9.29  | 4.38 | 5.92 | 11.17 |
| 70  | 602.0 | 9.35  | 4.41 | 5.94 | 11.23 |
| 71  | 610.6 | 9.41  | 4.43 | 5.95 | 11.28 |
| 72  | 619.2 | 9.47  | 4.46 | 5.97 | 11.33 |
| 73  | 627.8 | 9.53  | 4.49 | 5.99 | 11.38 |
| 74  | 636.4 | 9.59  | 4.52 | 6.01 | 11.43 |
| 75  | 645.0 | 9.65  | 4.55 | 6.02 | 11.48 |
| 76  | 653.6 | 9.72  | 4.58 | 6.04 | 11.54 |
| 77  | 662.2 | 9.78  | 4.61 | 6.06 | 11.59 |
| 78  | 670.8 | 9.85  | 4.64 | 6.07 | 11.64 |
| 79  | 679.4 | 9.91  | 4.67 | 6.09 | 11.70 |
| 80  | 688.0 | 9.98  | 4.71 | 6.10 | 11.75 |
| 81  | 696.6 | 10.05 | 4.74 | 6.12 | 11.81 |
| 82  | 705.2 | 10.12 | 4.77 | 6.14 | 11.86 |
| 83  | 713.8 | 10.20 | 4.81 | 6.15 | 11.92 |
| 84  | 722.4 | 10.27 | 4.84 | 6.17 | 11.98 |
| 85  | 731.0 | 10.34 | 4.88 | 6.19 | 12.04 |
| 86  | 739.6 | 10.42 | 4.91 | 6.20 | 12.10 |
| 87  | 748.2 | 10.50 | 4.95 | 6.22 | 12.16 |
| 88  | 756.8 | 10.58 | 4.99 | 6.24 | 12.22 |
| 89  | 765.4 | 10.66 | 5.02 | 6.25 | 12.28 |
| 90  | 774.0 | 10.74 | 5.06 | 6.27 | 12.34 |
| 91  | 782.6 | 10.83 | 5.10 | 6.29 | 12.41 |
| 92  | 791.2 | 10.91 | 5.14 | 6.30 | 12.47 |
| 93  | 799.8 | 11.00 | 5.19 | 6.32 | 12.54 |
| 94  | 808.4 | 11.09 | 5.23 | 6.34 | 12.61 |
| 95  | 817.0 | 11.18 | 5.27 | 6.36 | 12.68 |
| 96  | 825.6 | 11.28 | 5.32 | 6.37 | 12.75 |
| 97  | 834.2 | 11.37 | 5.36 | 6.39 | 12.82 |
| 98  | 842.8 | 11.47 | 5.41 | 6.41 | 12.90 |
| 99  | 851.4 | 11.57 | 5.45 | 6.43 | 12.97 |
| 100 | 860.0 | 11.68 | 5.50 | 6.45 | 13.05 |
| 101 | 868.6 | 11.78 | 5.55 | 6.47 | 13.13 |

|     |         |       |       |      |       |
|-----|---------|-------|-------|------|-------|
| 102 | 877.2   | 11.89 | 5.60  | 6.49 | 13.21 |
| 103 | 885.8   | 12.00 | 5.66  | 6.51 | 13.29 |
| 104 | 894.4   | 12.11 | 5.71  | 6.53 | 13.38 |
| 105 | 903.0   | 12.23 | 5.77  | 6.55 | 13.46 |
| 106 | 911.6   | 12.35 | 5.82  | 6.57 | 13.55 |
| 107 | 920.2   | 12.47 | 5.88  | 6.59 | 13.64 |
| 108 | 928.8   | 12.60 | 5.94  | 6.61 | 13.74 |
| 109 | 937.4   | 12.73 | 6.00  | 6.63 | 13.83 |
| 110 | 946.0   | 12.86 | 6.06  | 6.66 | 13.93 |
| 111 | 954.6   | 13.00 | 6.13  | 6.68 | 14.03 |
| 112 | 963.2   | 13.14 | 6.19  | 6.71 | 14.14 |
| 113 | 971.8   | 13.28 | 6.26  | 6.73 | 14.24 |
| 114 | 980.4   | 13.43 | 6.33  | 6.76 | 14.35 |
| 115 | 989.0   | 13.59 | 6.40  | 6.78 | 14.47 |
| 116 | 997.6   | 13.74 | 6.48  | 6.81 | 14.58 |
| 117 | 1,006.2 | 13.91 | 6.55  | 6.84 | 14.70 |
| 118 | 1,014.8 | 14.08 | 6.63  | 6.86 | 14.82 |
| 119 | 1,023.4 | 14.25 | 6.72  | 6.89 | 14.95 |
| 120 | 1,032.0 | 14.43 | 6.80  | 6.92 | 15.08 |
| 121 | 1,040.6 | 14.61 | 6.89  | 6.95 | 15.22 |
| 122 | 1,049.2 | 14.81 | 6.98  | 6.98 | 15.36 |
| 123 | 1,057.8 | 15.00 | 7.07  | 7.02 | 15.50 |
| 124 | 1,066.4 | 15.21 | 7.17  | 7.05 | 15.65 |
| 125 | 1,075.0 | 15.42 | 7.27  | 7.08 | 15.81 |
| 126 | 1,083.6 | 15.65 | 7.37  | 7.12 | 15.97 |
| 127 | 1,092.2 | 15.88 | 7.48  | 7.15 | 16.13 |
| 128 | 1,100.8 | 16.12 | 7.60  | 7.19 | 16.31 |
| 129 | 1,109.4 | 16.37 | 7.71  | 7.23 | 16.49 |
| 130 | 1,118.0 | 16.63 | 7.84  | 7.27 | 16.67 |
| 131 | 1,126.6 | 16.90 | 7.96  | 7.31 | 16.87 |
| 132 | 1,135.2 | 17.18 | 8.10  | 7.36 | 17.07 |
| 133 | 1,143.8 | 17.48 | 8.24  | 7.40 | 17.28 |
| 134 | 1,152.4 | 17.79 | 8.38  | 7.45 | 17.51 |
| 135 | 1,161.0 | 18.11 | 8.54  | 7.50 | 17.74 |
| 136 | 1,169.6 | 18.45 | 8.70  | 7.55 | 17.98 |
| 137 | 1,178.2 | 18.81 | 8.87  | 7.60 | 18.24 |
| 138 | 1,186.8 | 19.19 | 9.04  | 7.65 | 18.50 |
| 139 | 1,195.4 | 19.58 | 9.23  | 7.71 | 18.79 |
| 140 | 1,204.0 | 20.00 | 9.43  | 7.77 | 19.08 |
| 141 | 1,212.6 | 20.45 | 9.64  | 7.83 | 19.40 |
| 142 | 1,221.2 | 20.92 | 9.86  | 7.90 | 19.73 |
| 143 | 1,229.8 | 21.42 | 10.10 | 7.97 | 20.08 |
| 144 | 1,238.4 | 21.95 | 10.35 | 8.04 | 20.46 |
| 145 | 1,247.0 | 22.53 | 10.62 | 8.12 | 20.86 |
| 146 | 1,255.6 | 23.14 | 10.91 | 8.20 | 21.28 |
| 147 | 1,264.2 | 23.79 | 11.22 | 8.28 | 21.74 |
| 148 | 1,272.8 | 24.50 | 11.55 | 8.37 | 22.23 |
| 149 | 1,281.4 | 25.27 | 11.91 | 8.47 | 22.76 |
| 150 | 1,290.0 | 26.11 | 12.30 | 8.58 | 23.34 |
| 151 | 1,298.6 | 27.02 | 12.73 | 8.69 | 23.97 |
| 152 | 1,307.2 | 28.01 | 13.20 | 8.80 | 24.65 |
| 153 | 1,315.8 | 29.12 | 13.72 | 8.93 | 25.40 |
| 154 | 1,324.4 | 30.34 | 14.30 | 9.07 | 26.23 |
| 155 | 1,333.0 | 31.71 | 14.95 | 9.22 | 27.16 |
| 156 | 1,341.6 | 33.25 | 15.67 | 9.39 | 28.20 |

|     |         |        |        |       |        |
|-----|---------|--------|--------|-------|--------|
| 157 | 1,350.2 | 35.01  | 16.50  | 9.57  | 29.37  |
| 158 | 1,358.8 | 37.04  | 17.46  | 9.77  | 30.72  |
| 159 | 1,367.4 | 39.40  | 18.57  | 10.00 | 32.28  |
| 160 | 1,376.0 | 42.21  | 19.89  | 10.25 | 34.13  |
| 161 | 1,384.6 | 45.60  | 21.49  | 10.55 | 36.34  |
| 162 | 1,393.2 | 49.82  | 23.48  | 10.89 | 39.06  |
| 163 | 1,401.8 | 55.24  | 26.04  | 11.29 | 42.53  |
| 164 | 1,410.4 | 62.53  | 29.47  | 11.78 | 47.15  |
| 165 | 1,419.0 | 73.02  | 34.42  | 12.41 | 53.71  |
| 166 | 1,427.6 | 89.85  | 42.35  | 13.25 | 64.07  |
| 167 | 1,436.2 | 123.21 | 58.07  | 14.53 | 84.22  |
| 168 | 1,444.8 | 273.41 | 128.87 | 17.63 | 172.27 |
| 169 | 1,453.4 | 0.00   | 0.00   | 19.26 | 19.26  |
| 170 | 1,462.0 | 0.00   | 0.00   | 17.82 | 17.82  |
| 171 | 1,470.6 | 0.00   | 0.00   | 16.54 | 16.54  |
| 172 | 1,479.2 | 0.00   | 0.00   | 15.41 | 15.41  |
| 173 | 1,487.8 | 0.00   | 0.00   | 14.41 | 14.41  |
| 174 | 1,496.4 | 0.00   | 0.00   | 13.51 | 13.51  |
| 175 | 1,505.0 | 0.00   | 0.00   | 12.71 | 12.71  |

Source: JICA Survey Team

Note:  $f=1.00$ ,  $A=1.414 \text{ km}^2$

### 3.3 Storage Effect Calculation

This section calculates the storage effect in case of full water volume in reservoir with return period 200 years rainfall.

#### 3.3.1 H - V curve

H (water height) – Q (reservoir volume) curve can be calculated by Table 2.6 and Table 3.3.1.

**Table 3.3.1 H-V curve in No1. & No.2 Reservoir**

| Elevation | Area (m2) | Volume (m3) | Remarks |
|-----------|-----------|-------------|---------|
| 1.0       | 427,500   | 0           |         |
| 7.0       | 521,700   | 3,084,900   |         |

Source: JICA Survey Team

**Table 3.3.2 H-V curve in No3. & No.4 Reservoir**

| Elevation | Area (m2) | Volume (m3) | Remarks |
|-----------|-----------|-------------|---------|
| 1.0       | 1,251,300 | 0           |         |
| 7.0       | 1,353,500 | 7,814,400   |         |

Source: JICA Survey Team

### 3.3.2 Overflow Discharge (Spillway)

Labyrinth crest is employed as spillway in order to saving the crest length and construction cost. Overflow discharge can be calculated by the following equation;

$$Q = C \cdot B \cdot h^{3/2} \quad (4)$$

Where,

Q: Discharge (m<sup>3</sup>/s)

C: Flow coefficient (=4.7 by Labyrinth crest)

h: Water depth from crest (m)

### 3.4 Calculation of Flood Control with Storage Effect

The equation for water depth (water height) by considering inflow, outflow and storage volume uses the following equation.

$$V(t + \Delta t) = V(t) + (I(t + \Delta t/2) - O(t + \Delta t/2)) \cdot \Delta t$$

$$I(t + \Delta t/2) = (I(t + \Delta t) + I(t)) / 2$$

$$O(t + \Delta t/2) = (O(t + \Delta t) + O(t)) / 2$$

Where,

V: Storage Volume (m<sup>3</sup>)

I: Inflow (m<sup>3</sup>/s: given value)

O: Outflow (m<sup>3</sup>/s)

$\Delta t$ : calculation time pitch (= 8.6min in here)

$$V(t + \Delta t) = V(t) + ((I(t + \Delta t) + I(t)) / 2 - (O(t + \Delta t) + O(t)) / 2) \cdot \Delta t$$

$$V(t) + I(t) / 2 \cdot \Delta t - O(t) / 2 \cdot \Delta t = V(t + \Delta t) - (I(t + \Delta t) / 2 \cdot \Delta t + O(t + \Delta t) / 2 \cdot \Delta t)$$

In above equation, left side equation is given values at all and right side is the function of water depth h only.

Suitable water depth can be obtained by above equation through try and error calculation.

Calculation results from 0.0 min to 1505 min. shows Table 3.4.2 to Table 3.4.3 and Figure 3.4.1 to Table 3.4.2, Summary of calculation shows Table 3.4.1.

**Table 3.4.1 Summary of Storage Effect calculation**

| Item                   | Unit              | No1 and No2 Reservoir | No.3 and No.4 Reservoir | Remarks |
|------------------------|-------------------|-----------------------|-------------------------|---------|
| 1) Maximum Inflow      | m <sup>3</sup> /s | 65.45                 | 172.27                  |         |
| 2) Maximum Outflow     | m <sup>3</sup> /s | 19.26                 | 46.94                   |         |
| 3) Initial water level | EL.               | 6.90                  | 6.50                    |         |
| 4) Maximum water level | EL.               | 7.210                 | 6.808                   |         |
| 3) Maximum Water Depth | m                 | 0.310                 | 0.308                   |         |

Source: JICA Survey Team

**Table 3.4.2 Summary of Storage Effect calculation in No.1 & NO.2 Reservoir**

| No. | Time (min) | Reservoir Water Level (EL.) | Inflow (m3/s) | Outflow (m3/s) | Reservoir Water Volume (m3) |
|-----|------------|-----------------------------|---------------|----------------|-----------------------------|
| 0   | 0.0        | 6.900                       | 4.10          | 0.00           | 2,800,140                   |
| 1   | 8.6        | 6.905                       | 5.62          | 0.04           | 2,802,637                   |
| 2   | 17.2       | 6.911                       | 5.62          | 0.13           | 2,805,491                   |
| 3   | 25.8       | 6.917                       | 5.63          | 0.25           | 2,808,295                   |
| 4   | 34.4       | 6.923                       | 5.63          | 0.39           | 2,811,035                   |
| 5   | 43.0       | 6.929                       | 5.64          | 0.54           | 2,813,704                   |
| 6   | 51.6       | 6.934                       | 5.65          | 0.70           | 2,816,298                   |
| 7   | 60.2       | 6.939                       | 5.65          | 0.87           | 2,818,808                   |
| 8   | 68.8       | 6.944                       | 5.66          | 1.04           | 2,821,233                   |
| 9   | 77.4       | 6.949                       | 5.66          | 1.22           | 2,823,569                   |
| 10  | 86.0       | 6.954                       | 5.67          | 1.40           | 2,825,816                   |
| 11  | 94.6       | 6.959                       | 5.68          | 1.58           | 2,827,974                   |
| 12  | 103.2      | 6.963                       | 5.68          | 1.76           | 2,830,043                   |
| 13  | 111.8      | 6.967                       | 5.69          | 1.94           | 2,832,022                   |
| 14  | 120.4      | 6.971                       | 5.69          | 2.11           | 2,833,912                   |
| 15  | 129.0      | 6.975                       | 5.70          | 2.29           | 2,835,716                   |
| 16  | 137.6      | 6.979                       | 5.71          | 2.45           | 2,837,437                   |
| 17  | 146.2      | 6.982                       | 5.71          | 2.62           | 2,839,075                   |
| 18  | 154.8      | 6.985                       | 5.72          | 2.78           | 2,840,633                   |
| 19  | 163.4      | 6.988                       | 5.73          | 2.93           | 2,842,115                   |
| 20  | 172.0      | 6.991                       | 5.73          | 3.08           | 2,843,522                   |
| 21  | 180.6      | 6.994                       | 5.74          | 3.22           | 2,844,857                   |
| 22  | 189.2      | 6.997                       | 5.75          | 3.36           | 2,846,124                   |
| 23  | 197.8      | 6.999                       | 5.75          | 3.49           | 2,847,323                   |
| 24  | 206.4      | 7.002                       | 5.76          | 3.62           | 2,848,459                   |
| 25  | 215.0      | 7.004                       | 5.77          | 3.74           | 2,849,536                   |
| 26  | 223.6      | 7.006                       | 5.77          | 3.86           | 2,850,554                   |
| 27  | 232.2      | 7.008                       | 5.78          | 3.97           | 2,851,516                   |
| 28  | 240.8      | 7.010                       | 5.79          | 4.07           | 2,852,427                   |
| 29  | 249.4      | 7.012                       | 5.80          | 4.17           | 2,853,290                   |
| 30  | 258.0      | 7.014                       | 5.80          | 4.27           | 2,854,104                   |
| 31  | 266.6      | 7.015                       | 5.81          | 4.36           | 2,854,873                   |
| 32  | 275.2      | 7.017                       | 5.82          | 4.45           | 2,855,600                   |
| 33  | 283.8      | 7.018                       | 5.83          | 4.53           | 2,856,289                   |
| 34  | 292.4      | 7.020                       | 5.83          | 4.61           | 2,856,939                   |
| 35  | 301.0      | 7.021                       | 5.84          | 4.69           | 2,857,551                   |
| 36  | 309.6      | 7.022                       | 5.85          | 4.76           | 2,858,131                   |
| 37  | 318.2      | 7.023                       | 5.86          | 4.82           | 2,858,680                   |
| 38  | 326.8      | 7.024                       | 5.87          | 4.89           | 2,859,201                   |
| 39  | 335.4      | 7.025                       | 5.88          | 4.95           | 2,859,694                   |
| 40  | 344.0      | 7.026                       | 5.88          | 5.01           | 2,860,159                   |
| 41  | 352.6      | 7.027                       | 5.89          | 5.06           | 2,860,597                   |
| 42  | 361.2      | 7.028                       | 5.90          | 5.12           | 2,861,013                   |
| 43  | 369.8      | 7.029                       | 5.91          | 5.17           | 2,861,407                   |
| 44  | 378.4      | 7.030                       | 5.92          | 5.21           | 2,861,782                   |
| 45  | 387.0      | 7.031                       | 5.93          | 5.26           | 2,862,138                   |
| 46  | 395.6      | 7.031                       | 5.94          | 5.30           | 2,862,476                   |
| 47  | 404.2      | 7.032                       | 5.95          | 5.34           | 2,862,798                   |
| 48  | 412.8      | 7.033                       | 5.96          | 5.38           | 2,863,104                   |
| 49  | 421.4      | 7.033                       | 5.96          | 5.42           | 2,863,393                   |
| 50  | 430.0      | 7.034                       | 5.97          | 5.45           | 2,863,666                   |
| 51  | 438.6      | 7.034                       | 5.98          | 5.49           | 2,863,927                   |
| 52  | 447.2      | 7.035                       | 5.99          | 5.52           | 2,864,175                   |
| 53  | 455.8      | 7.035                       | 6.00          | 5.55           | 2,864,413                   |
| 54  | 464.4      | 7.036                       | 6.01          | 5.58           | 2,864,640                   |
| 55  | 473.0      | 7.036                       | 6.02          | 5.61           | 2,864,858                   |
| 56  | 481.6      | 7.037                       | 6.03          | 5.63           | 2,865,066                   |
| 57  | 490.2      | 7.037                       | 6.05          | 5.66           | 2,865,268                   |
| 58  | 498.8      | 7.038                       | 6.06          | 5.69           | 2,865,465                   |

|     |         |       |      |      |           |
|-----|---------|-------|------|------|-----------|
| 59  | 507.4   | 7.038 | 6.07 | 5.71 | 2,865,654 |
| 60  | 516.0   | 7.038 | 6.08 | 5.74 | 2,865,835 |
| 61  | 524.6   | 7.039 | 6.09 | 5.76 | 2,866,010 |
| 62  | 533.2   | 7.039 | 6.10 | 5.78 | 2,866,178 |
| 63  | 541.8   | 7.039 | 6.11 | 5.80 | 2,866,340 |
| 64  | 550.4   | 7.040 | 6.12 | 5.82 | 2,866,497 |
| 65  | 559.0   | 7.040 | 6.14 | 5.84 | 2,866,650 |
| 66  | 567.6   | 7.040 | 6.15 | 5.86 | 2,866,801 |
| 67  | 576.2   | 7.041 | 6.16 | 5.88 | 2,866,948 |
| 68  | 584.8   | 7.041 | 6.17 | 5.90 | 2,867,089 |
| 69  | 593.4   | 7.041 | 6.19 | 5.92 | 2,867,229 |
| 70  | 602.0   | 7.042 | 6.20 | 5.94 | 2,867,367 |
| 71  | 610.6   | 7.042 | 6.21 | 5.95 | 2,867,500 |
| 72  | 619.2   | 7.042 | 6.22 | 5.97 | 2,867,630 |
| 73  | 627.8   | 7.042 | 6.24 | 5.99 | 2,867,759 |
| 74  | 636.4   | 7.043 | 6.25 | 6.01 | 2,867,887 |
| 75  | 645.0   | 7.043 | 6.27 | 6.02 | 2,868,014 |
| 76  | 653.6   | 7.043 | 6.28 | 6.04 | 2,868,140 |
| 77  | 662.2   | 7.044 | 6.29 | 6.06 | 2,868,262 |
| 78  | 670.8   | 7.044 | 6.31 | 6.07 | 2,868,384 |
| 79  | 679.4   | 7.044 | 6.32 | 6.09 | 2,868,505 |
| 80  | 688.0   | 7.044 | 6.34 | 6.10 | 2,868,625 |
| 81  | 696.6   | 7.045 | 6.36 | 6.12 | 2,868,748 |
| 82  | 705.2   | 7.045 | 6.37 | 6.14 | 2,868,870 |
| 83  | 713.8   | 7.045 | 6.39 | 6.15 | 2,868,991 |
| 84  | 722.4   | 7.045 | 6.40 | 6.17 | 2,869,111 |
| 85  | 731.0   | 7.046 | 6.42 | 6.19 | 2,869,231 |
| 86  | 739.6   | 7.046 | 6.44 | 6.20 | 2,869,353 |
| 87  | 748.2   | 7.046 | 6.46 | 6.22 | 2,869,477 |
| 88  | 756.8   | 7.046 | 6.47 | 6.24 | 2,869,600 |
| 89  | 765.4   | 7.047 | 6.49 | 6.25 | 2,869,722 |
| 90  | 774.0   | 7.047 | 6.51 | 6.27 | 2,869,846 |
| 91  | 782.6   | 7.047 | 6.53 | 6.29 | 2,869,971 |
| 92  | 791.2   | 7.047 | 6.55 | 6.30 | 2,870,098 |
| 93  | 799.8   | 7.048 | 6.57 | 6.32 | 2,870,227 |
| 94  | 808.4   | 7.048 | 6.59 | 6.34 | 2,870,357 |
| 95  | 817.0   | 7.048 | 6.61 | 6.36 | 2,870,488 |
| 96  | 825.6   | 7.049 | 6.63 | 6.37 | 2,870,620 |
| 97  | 834.2   | 7.049 | 6.65 | 6.39 | 2,870,753 |
| 98  | 842.8   | 7.049 | 6.67 | 6.41 | 2,870,887 |
| 99  | 851.4   | 7.049 | 6.70 | 6.43 | 2,871,024 |
| 100 | 860.0   | 7.050 | 6.72 | 6.45 | 2,871,165 |
| 101 | 868.6   | 7.050 | 6.74 | 6.47 | 2,871,306 |
| 102 | 877.2   | 7.050 | 6.77 | 6.49 | 2,871,450 |
| 103 | 885.8   | 7.051 | 6.79 | 6.51 | 2,871,597 |
| 104 | 894.4   | 7.051 | 6.82 | 6.53 | 2,871,746 |
| 105 | 903.0   | 7.051 | 6.84 | 6.55 | 2,871,897 |
| 106 | 911.6   | 7.052 | 6.87 | 6.57 | 2,872,051 |
| 107 | 920.2   | 7.052 | 6.90 | 6.59 | 2,872,209 |
| 108 | 928.8   | 7.052 | 6.93 | 6.61 | 2,872,371 |
| 109 | 937.4   | 7.053 | 6.96 | 6.63 | 2,872,537 |
| 110 | 946.0   | 7.053 | 6.99 | 6.66 | 2,872,706 |
| 111 | 954.6   | 7.053 | 7.02 | 6.68 | 2,872,879 |
| 112 | 963.2   | 7.054 | 7.05 | 6.71 | 2,873,055 |
| 113 | 971.8   | 7.054 | 7.08 | 6.73 | 2,873,234 |
| 114 | 980.4   | 7.054 | 7.11 | 6.76 | 2,873,415 |
| 115 | 989.0   | 7.055 | 7.15 | 6.78 | 2,873,602 |
| 116 | 997.6   | 7.055 | 7.18 | 6.81 | 2,873,793 |
| 117 | 1,006.2 | 7.056 | 7.22 | 6.84 | 2,873,988 |
| 118 | 1,014.8 | 7.056 | 7.26 | 6.86 | 2,874,190 |
| 119 | 1,023.4 | 7.056 | 7.30 | 6.89 | 2,874,397 |
| 120 | 1,032.0 | 7.057 | 7.34 | 6.92 | 2,874,610 |
| 121 | 1,040.6 | 7.057 | 7.38 | 6.95 | 2,874,829 |
| 122 | 1,049.2 | 7.058 | 7.42 | 6.98 | 2,875,052 |

|     |         |       |       |       |           |
|-----|---------|-------|-------|-------|-----------|
| 123 | 1,057.8 | 7.058 | 7.47  | 7.02  | 2,875,281 |
| 124 | 1,066.4 | 7.059 | 7.51  | 7.05  | 2,875,518 |
| 125 | 1,075.0 | 7.059 | 7.56  | 7.08  | 2,875,760 |
| 126 | 1,083.6 | 7.060 | 7.61  | 7.12  | 2,876,010 |
| 127 | 1,092.2 | 7.060 | 7.66  | 7.15  | 2,876,267 |
| 128 | 1,100.8 | 7.061 | 7.72  | 7.19  | 2,876,534 |
| 129 | 1,109.4 | 7.062 | 7.77  | 7.23  | 2,876,810 |
| 130 | 1,118.0 | 7.062 | 7.83  | 7.27  | 2,877,093 |
| 131 | 1,126.6 | 7.063 | 7.89  | 7.31  | 2,877,386 |
| 132 | 1,135.2 | 7.063 | 7.96  | 7.36  | 2,877,691 |
| 133 | 1,143.8 | 7.064 | 8.02  | 7.40  | 2,878,007 |
| 134 | 1,152.4 | 7.065 | 8.09  | 7.45  | 2,878,333 |
| 135 | 1,161.0 | 7.065 | 8.16  | 7.50  | 2,878,670 |
| 136 | 1,169.6 | 7.066 | 8.24  | 7.55  | 2,879,020 |
| 137 | 1,178.2 | 7.067 | 8.32  | 7.60  | 2,879,386 |
| 138 | 1,186.8 | 7.068 | 8.41  | 7.65  | 2,879,767 |
| 139 | 1,195.4 | 7.069 | 8.49  | 7.71  | 2,880,164 |
| 140 | 1,204.0 | 7.069 | 8.59  | 7.77  | 2,880,576 |
| 141 | 1,212.6 | 7.070 | 8.69  | 7.83  | 2,881,009 |
| 142 | 1,221.2 | 7.071 | 8.79  | 7.90  | 2,881,460 |
| 143 | 1,229.8 | 7.072 | 8.91  | 7.97  | 2,881,933 |
| 144 | 1,238.4 | 7.073 | 9.03  | 8.04  | 2,882,432 |
| 145 | 1,247.0 | 7.074 | 9.15  | 8.12  | 2,882,954 |
| 146 | 1,255.6 | 7.076 | 9.29  | 8.20  | 2,883,502 |
| 147 | 1,264.2 | 7.077 | 9.44  | 8.28  | 2,884,082 |
| 148 | 1,272.8 | 7.078 | 9.60  | 8.37  | 2,884,697 |
| 149 | 1,281.4 | 7.080 | 9.77  | 8.47  | 2,885,348 |
| 150 | 1,290.0 | 7.081 | 9.96  | 8.58  | 2,886,040 |
| 151 | 1,298.6 | 7.083 | 10.16 | 8.69  | 2,886,778 |
| 152 | 1,307.2 | 7.084 | 10.39 | 8.80  | 2,887,567 |
| 153 | 1,315.8 | 7.086 | 10.63 | 8.93  | 2,888,414 |
| 154 | 1,324.4 | 7.088 | 10.91 | 9.07  | 2,889,326 |
| 155 | 1,333.0 | 7.090 | 11.22 | 9.22  | 2,890,316 |
| 156 | 1,341.6 | 7.092 | 11.56 | 9.39  | 2,891,391 |
| 157 | 1,350.2 | 7.095 | 11.96 | 9.57  | 2,892,568 |
| 158 | 1,358.8 | 7.097 | 12.41 | 9.77  | 2,893,864 |
| 159 | 1,367.4 | 7.101 | 12.94 | 10.00 | 2,895,304 |
| 160 | 1,376.0 | 7.104 | 13.57 | 10.25 | 2,896,918 |
| 161 | 1,384.6 | 7.108 | 14.33 | 10.55 | 2,898,749 |
| 162 | 1,393.2 | 7.112 | 15.28 | 10.89 | 2,900,859 |
| 163 | 1,401.8 | 7.117 | 16.50 | 11.29 | 2,903,336 |
| 164 | 1,410.4 | 7.124 | 18.13 | 11.78 | 2,906,317 |
| 165 | 1,419.0 | 7.132 | 20.49 | 12.41 | 2,910,039 |
| 166 | 1,427.6 | 7.142 | 24.26 | 13.25 | 2,914,964 |
| 167 | 1,436.2 | 7.157 | 31.75 | 14.53 | 2,922,246 |
| 168 | 1,444.8 | 7.193 | 65.45 | 17.63 | 2,939,026 |
| 169 | 1,453.4 | 7.210 | 4.10  | 19.26 | 2,947,453 |
| 170 | 1,462.0 | 7.195 | 4.10  | 17.82 | 2,940,004 |
| 171 | 1,470.6 | 7.180 | 4.10  | 16.54 | 2,933,255 |
| 172 | 1,479.2 | 7.168 | 4.10  | 15.41 | 2,927,126 |
| 173 | 1,487.8 | 7.156 | 4.10  | 14.41 | 2,921,548 |
| 174 | 1,496.4 | 7.145 | 4.10  | 13.51 | 2,916,460 |
| 175 | 1,505.0 | 7.135 | 4.10  | 12.71 | 2,911,810 |

Source: JICA Survey Team

**Table 3.4.3 Summary of Storage Effect calculation in No.3 & NO.4 Reservoir**

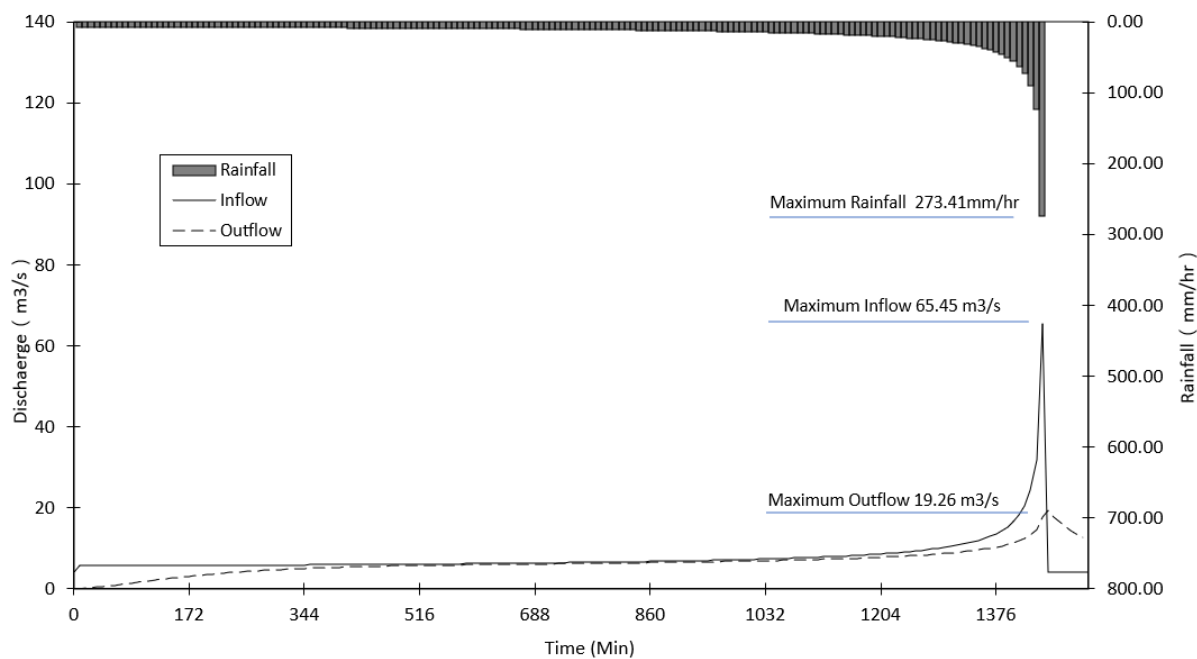
| No. | Time (min) | Reservoir Water Level (EL.) | Inflow (m3/s) | Outflow (m3/s) | Reservoir Water Volume (m3) |
|-----|------------|-----------------------------|---------------|----------------|-----------------------------|
| 0   | 0.0        | 6.500                       | 0.00          | 0.000          | 7,163,200                   |
| 1   | 8.6        | 6.501                       | 3.87          | 0.006          | 7,164,197                   |
| 2   | 17.2       | 6.502                       | 3.97          | 0.030          | 7,166,210                   |

|    |       |       |       |       |           |
|----|-------|-------|-------|-------|-----------|
| 3  | 25.8  | 6.504 | 4.10  | 0.066 | 7,168,267 |
| 4  | 34.4  | 6.506 | 4.25  | 0.112 | 7,170,376 |
| 5  | 43.0  | 6.507 | 4.42  | 0.166 | 7,172,541 |
| 6  | 51.6  | 6.509 | 4.60  | 0.229 | 7,174,766 |
| 7  | 60.2  | 6.511 | 4.78  | 0.300 | 7,177,050 |
| 8  | 68.8  | 6.512 | 4.97  | 0.379 | 7,179,390 |
| 9  | 77.4  | 6.514 | 5.16  | 0.466 | 7,181,786 |
| 10 | 86.0  | 6.516 | 5.36  | 0.561 | 7,184,235 |
| 11 | 94.6  | 6.518 | 5.55  | 0.664 | 7,186,734 |
| 12 | 103.2 | 6.520 | 5.75  | 0.774 | 7,189,278 |
| 13 | 111.8 | 6.522 | 5.94  | 0.892 | 7,191,864 |
| 14 | 120.4 | 6.524 | 6.13  | 1.018 | 7,194,485 |
| 15 | 129.0 | 6.526 | 6.32  | 1.150 | 7,197,138 |
| 16 | 137.6 | 6.528 | 6.50  | 1.289 | 7,199,817 |
| 17 | 146.2 | 6.530 | 6.68  | 1.434 | 7,202,515 |
| 18 | 154.8 | 6.532 | 6.86  | 1.585 | 7,205,229 |
| 19 | 163.4 | 6.534 | 7.03  | 1.741 | 7,207,955 |
| 20 | 172.0 | 6.536 | 7.19  | 1.903 | 7,210,684 |
| 21 | 180.6 | 6.539 | 7.35  | 2.069 | 7,213,410 |
| 22 | 189.2 | 6.541 | 7.51  | 2.240 | 7,216,132 |
| 23 | 197.8 | 6.543 | 7.66  | 2.414 | 7,218,846 |
| 24 | 206.4 | 6.545 | 7.80  | 2.592 | 7,221,543 |
| 25 | 215.0 | 6.547 | 7.94  | 2.772 | 7,224,220 |
| 26 | 223.6 | 6.549 | 8.08  | 2.955 | 7,226,876 |
| 27 | 232.2 | 6.551 | 8.21  | 3.140 | 7,229,506 |
| 28 | 240.8 | 6.553 | 8.33  | 3.326 | 7,232,105 |
| 29 | 249.4 | 6.555 | 8.45  | 3.514 | 7,234,669 |
| 30 | 258.0 | 6.557 | 8.56  | 3.702 | 7,237,196 |
| 31 | 266.6 | 6.559 | 8.68  | 3.890 | 7,239,686 |
| 32 | 275.2 | 6.561 | 8.78  | 4.078 | 7,242,134 |
| 33 | 283.8 | 6.562 | 8.88  | 4.266 | 7,244,538 |
| 34 | 292.4 | 6.564 | 8.98  | 4.453 | 7,246,896 |
| 35 | 301.0 | 6.566 | 9.08  | 4.639 | 7,249,210 |
| 36 | 309.6 | 6.568 | 9.17  | 4.824 | 7,251,477 |
| 37 | 318.2 | 6.569 | 9.26  | 5.007 | 7,253,696 |
| 38 | 326.8 | 6.571 | 9.34  | 5.188 | 7,255,865 |
| 39 | 335.4 | 6.573 | 9.42  | 5.366 | 7,257,982 |
| 40 | 344.0 | 6.574 | 9.50  | 5.543 | 7,260,049 |
| 41 | 352.6 | 6.576 | 9.58  | 5.717 | 7,262,066 |
| 42 | 361.2 | 6.577 | 9.65  | 5.888 | 7,264,033 |
| 43 | 369.8 | 6.579 | 9.73  | 6.057 | 7,265,952 |
| 44 | 378.4 | 6.580 | 9.80  | 6.223 | 7,267,822 |
| 45 | 387.0 | 6.582 | 9.86  | 6.386 | 7,269,641 |
| 46 | 395.6 | 6.583 | 9.93  | 6.546 | 7,271,410 |
| 47 | 404.2 | 6.584 | 9.99  | 6.703 | 7,273,131 |
| 48 | 412.8 | 6.586 | 10.06 | 6.857 | 7,274,806 |
| 49 | 421.4 | 6.587 | 10.12 | 7.007 | 7,276,435 |
| 50 | 430.0 | 6.588 | 10.18 | 7.155 | 7,278,019 |
| 51 | 438.6 | 6.589 | 10.24 | 7.299 | 7,279,558 |
| 52 | 447.2 | 6.590 | 10.29 | 7.440 | 7,281,052 |
| 53 | 455.8 | 6.592 | 10.35 | 7.578 | 7,282,502 |
| 54 | 464.4 | 6.593 | 10.40 | 7.713 | 7,283,910 |
| 55 | 473.0 | 6.594 | 10.46 | 7.844 | 7,285,279 |
| 56 | 481.6 | 6.595 | 10.51 | 7.973 | 7,286,608 |
| 57 | 490.2 | 6.596 | 10.56 | 8.098 | 7,287,898 |
| 58 | 498.8 | 6.597 | 10.62 | 8.221 | 7,289,152 |
| 59 | 507.4 | 6.598 | 10.67 | 8.340 | 7,290,372 |
| 60 | 516.0 | 6.599 | 10.72 | 8.457 | 7,291,557 |
| 61 | 524.6 | 6.599 | 10.77 | 8.571 | 7,292,708 |
| 62 | 533.2 | 6.600 | 10.82 | 8.682 | 7,293,827 |
| 63 | 541.8 | 6.601 | 10.87 | 8.791 | 7,294,915 |
| 64 | 550.4 | 6.602 | 10.92 | 8.897 | 7,295,973 |
| 65 | 559.0 | 6.603 | 10.97 | 9.001 | 7,297,003 |
| 66 | 567.6 | 6.604 | 11.02 | 9.102 | 7,298,006 |

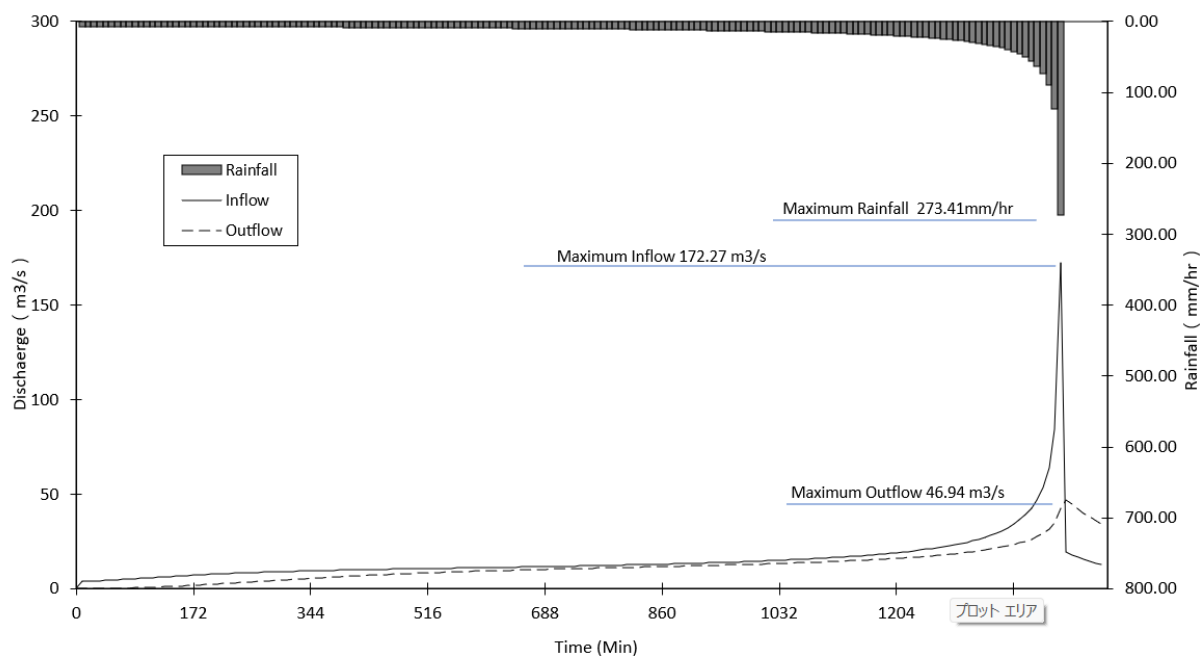
|     |         |       |       |        |           |
|-----|---------|-------|-------|--------|-----------|
| 67  | 576.2   | 6.604 | 11.07 | 9.201  | 7,298,983 |
| 68  | 584.8   | 6.605 | 11.12 | 9.298  | 7,299,935 |
| 69  | 593.4   | 6.606 | 11.17 | 9.393  | 7,300,863 |
| 70  | 602.0   | 6.606 | 11.23 | 9.486  | 7,301,771 |
| 71  | 610.6   | 6.607 | 11.28 | 9.578  | 7,302,660 |
| 72  | 619.2   | 6.608 | 11.33 | 9.667  | 7,303,528 |
| 73  | 627.8   | 6.608 | 11.38 | 9.755  | 7,304,377 |
| 74  | 636.4   | 6.609 | 11.43 | 9.841  | 7,305,206 |
| 75  | 645.0   | 6.610 | 11.48 | 9.926  | 7,306,017 |
| 76  | 653.6   | 6.610 | 11.54 | 10.009 | 7,306,813 |
| 77  | 662.2   | 6.611 | 11.59 | 10.091 | 7,307,595 |
| 78  | 670.8   | 6.611 | 11.64 | 10.171 | 7,308,360 |
| 79  | 679.4   | 6.612 | 11.70 | 10.250 | 7,309,114 |
| 80  | 688.0   | 6.613 | 11.75 | 10.328 | 7,309,854 |
| 81  | 696.6   | 6.613 | 11.81 | 10.406 | 7,310,583 |
| 82  | 705.2   | 6.614 | 11.86 | 10.482 | 7,311,301 |
| 83  | 713.8   | 6.614 | 11.92 | 10.557 | 7,312,009 |
| 84  | 722.4   | 6.615 | 11.98 | 10.631 | 7,312,708 |
| 85  | 731.0   | 6.615 | 12.04 | 10.705 | 7,313,401 |
| 86  | 739.6   | 6.616 | 12.10 | 10.779 | 7,314,086 |
| 87  | 748.2   | 6.616 | 12.16 | 10.851 | 7,314,764 |
| 88  | 756.8   | 6.617 | 12.22 | 10.924 | 7,315,437 |
| 89  | 765.4   | 6.617 | 12.28 | 10.995 | 7,316,102 |
| 90  | 774.0   | 6.618 | 12.34 | 11.067 | 7,316,762 |
| 91  | 782.6   | 6.618 | 12.41 | 11.138 | 7,317,419 |
| 92  | 791.2   | 6.619 | 12.47 | 11.209 | 7,318,073 |
| 93  | 799.8   | 6.619 | 12.54 | 11.279 | 7,318,723 |
| 94  | 808.4   | 6.620 | 12.61 | 11.350 | 7,319,374 |
| 95  | 817.0   | 6.620 | 12.68 | 11.421 | 7,320,024 |
| 96  | 825.6   | 6.621 | 12.75 | 11.492 | 7,320,673 |
| 97  | 834.2   | 6.621 | 12.82 | 11.563 | 7,321,322 |
| 98  | 842.8   | 6.622 | 12.90 | 11.635 | 7,321,972 |
| 99  | 851.4   | 6.622 | 12.97 | 11.706 | 7,322,625 |
| 100 | 860.0   | 6.623 | 13.05 | 11.779 | 7,323,279 |
| 101 | 868.6   | 6.623 | 13.13 | 11.851 | 7,323,937 |
| 102 | 877.2   | 6.624 | 13.21 | 11.924 | 7,324,598 |
| 103 | 885.8   | 6.624 | 13.29 | 11.998 | 7,325,263 |
| 104 | 894.4   | 6.625 | 13.38 | 12.073 | 7,325,934 |
| 105 | 903.0   | 6.625 | 13.46 | 12.148 | 7,326,610 |
| 106 | 911.6   | 6.626 | 13.55 | 12.224 | 7,327,290 |
| 107 | 920.2   | 6.627 | 13.64 | 12.301 | 7,327,978 |
| 108 | 928.8   | 6.627 | 13.74 | 12.379 | 7,328,674 |
| 109 | 937.4   | 6.628 | 13.83 | 12.458 | 7,329,379 |
| 110 | 946.0   | 6.628 | 13.93 | 12.538 | 7,330,092 |
| 111 | 954.6   | 6.629 | 14.03 | 12.620 | 7,330,815 |
| 112 | 963.2   | 6.629 | 14.14 | 12.703 | 7,331,550 |
| 113 | 971.8   | 6.630 | 14.24 | 12.788 | 7,332,295 |
| 114 | 980.4   | 6.630 | 14.35 | 12.873 | 7,333,051 |
| 115 | 989.0   | 6.631 | 14.47 | 12.961 | 7,333,821 |
| 116 | 997.6   | 6.632 | 14.58 | 13.050 | 7,334,605 |
| 117 | 1,006.2 | 6.632 | 14.70 | 13.142 | 7,335,402 |
| 118 | 1,014.8 | 6.633 | 14.82 | 13.235 | 7,336,213 |
| 119 | 1,023.4 | 6.633 | 14.95 | 13.330 | 7,337,040 |
| 120 | 1,032.0 | 6.634 | 15.08 | 13.427 | 7,337,885 |
| 121 | 1,040.6 | 6.635 | 15.22 | 13.526 | 7,338,748 |
| 122 | 1,049.2 | 6.635 | 15.36 | 13.629 | 7,339,632 |
| 123 | 1,057.8 | 6.636 | 15.50 | 13.733 | 7,340,534 |
| 124 | 1,066.4 | 6.637 | 15.65 | 13.841 | 7,341,457 |
| 125 | 1,075.0 | 6.638 | 15.81 | 13.951 | 7,342,403 |
| 126 | 1,083.6 | 6.638 | 15.97 | 14.065 | 7,343,374 |
| 127 | 1,092.2 | 6.639 | 16.13 | 14.181 | 7,344,369 |
| 128 | 1,100.8 | 6.640 | 16.31 | 14.301 | 7,345,390 |
| 129 | 1,109.4 | 6.641 | 16.49 | 14.425 | 7,346,440 |
| 130 | 1,118.0 | 6.642 | 16.67 | 14.553 | 7,347,519 |

|     |         |       |        |        |           |
|-----|---------|-------|--------|--------|-----------|
| 131 | 1,126.6 | 6.642 | 16.87  | 14.684 | 7,348,630 |
| 132 | 1,135.2 | 6.643 | 17.07  | 14.821 | 7,349,774 |
| 133 | 1,143.8 | 6.644 | 17.28  | 14.961 | 7,350,952 |
| 134 | 1,152.4 | 6.645 | 17.51  | 15.107 | 7,352,170 |
| 135 | 1,161.0 | 6.646 | 17.74  | 15.258 | 7,353,431 |
| 136 | 1,169.6 | 6.647 | 17.98  | 15.415 | 7,354,733 |
| 137 | 1,178.2 | 6.648 | 18.24  | 15.578 | 7,356,081 |
| 138 | 1,186.8 | 6.649 | 18.50  | 15.748 | 7,357,478 |
| 139 | 1,195.4 | 6.650 | 18.79  | 15.925 | 7,358,927 |
| 140 | 1,204.0 | 6.651 | 19.08  | 16.109 | 7,360,433 |
| 141 | 129.0   | 6.653 | 19.40  | 16.301 | 7,361,999 |
| 142 | 137.6   | 6.654 | 19.73  | 16.502 | 7,363,631 |
| 143 | 146.2   | 6.655 | 20.08  | 16.713 | 7,365,333 |
| 144 | 154.8   | 6.657 | 20.46  | 16.934 | 7,367,111 |
| 145 | 163.4   | 6.658 | 20.86  | 17.166 | 7,368,974 |
| 146 | 172.0   | 6.659 | 21.28  | 17.411 | 7,370,925 |
| 147 | 180.6   | 6.661 | 21.74  | 17.669 | 7,372,974 |
| 148 | 189.2   | 6.663 | 22.23  | 17.942 | 7,375,130 |
| 149 | 197.8   | 6.664 | 22.76  | 18.232 | 7,377,405 |
| 150 | 206.4   | 6.666 | 23.34  | 18.540 | 7,379,811 |
| 151 | 215.0   | 6.668 | 23.97  | 18.869 | 7,382,366 |
| 152 | 223.6   | 6.670 | 24.65  | 19.221 | 7,385,082 |
| 153 | 232.2   | 6.673 | 25.40  | 19.599 | 7,387,980 |
| 154 | 240.8   | 6.675 | 26.23  | 20.006 | 7,391,082 |
| 155 | 249.4   | 6.678 | 27.16  | 20.447 | 7,394,420 |
| 156 | 258.0   | 6.680 | 28.20  | 20.927 | 7,398,028 |
| 157 | 266.6   | 6.683 | 29.37  | 21.454 | 7,401,947 |
| 158 | 275.2   | 6.687 | 30.72  | 22.033 | 7,406,231 |
| 159 | 283.8   | 6.690 | 32.28  | 22.678 | 7,410,949 |
| 160 | 292.4   | 6.694 | 34.13  | 23.402 | 7,416,194 |
| 161 | 301.0   | 6.699 | 36.34  | 24.225 | 7,422,088 |
| 162 | 309.6   | 6.704 | 39.06  | 25.172 | 7,428,797 |
| 163 | 318.2   | 6.710 | 42.53  | 26.286 | 7,436,571 |
| 164 | 326.8   | 6.717 | 47.15  | 27.628 | 7,445,798 |
| 165 | 335.4   | 6.726 | 53.71  | 29.306 | 7,457,131 |
| 166 | 344.0   | 6.737 | 64.07  | 31.531 | 7,471,823 |
| 167 | 352.6   | 6.753 | 84.22  | 34.825 | 7,492,962 |
| 168 | 361.2   | 6.789 | 172.27 | 42.403 | 7,539,211 |
| 169 | 369.8   | 6.809 | 19.26  | 46.940 | 7,565,576 |
| 170 | 378.4   | 6.798 | 17.82  | 44.507 | 7,551,549 |
| 171 | 387.0   | 6.788 | 16.54  | 42.205 | 7,538,043 |
| 172 | 395.6   | 6.778 | 15.41  | 40.033 | 7,525,068 |
| 173 | 404.2   | 6.768 | 14.41  | 37.987 | 7,512,633 |
| 174 | 412.8   | 6.759 | 13.51  | 36.063 | 7,500,731 |
| 175 | 421.4   | 6.750 | 12.71  | 34.255 | 7,489,354 |

Source: JICA Survey Team



Source: JICA Survey Team

**Figure 3.4.1 Results of flood control calculation at No.1 and No.2 Reservoir**

Source: JICA Survey Team

**Figure 3.4.2 Results of flood control calculation at No.3 and No.4 Reservoir**

## CHAPTER B4 DESIGN OF SPILLWAY IN RAW WATER RESERVOIR

### 4.1 General

Spillway composes of 1) Inflow portion, 2) Channel and 3) Stilling basin. This section mentions and designs the following points:

- Overflow type and overflow depth in inflow portion
- hydraulic calculation of channel
- Stilling basin type and its size

#### 4.1.1 Condition

Spillway condition is as following;

**Table 4.1.1 Spillway Condition by Reservoir**

| Item                                       | No.1 and<br>No.2<br>Reservoir | No.3 and<br>No.4<br>Reservoir | Remarks |
|--------------------------------------------|-------------------------------|-------------------------------|---------|
| 1) Design Discharge<br>(m <sup>3</sup> /s) | 19.26                         | 46.94                         |         |
| 2) HWL                                     | EL. 6.90                      | EL.6.50                       |         |
| 3) Embankment Crest                        | EL. 9.30                      | EL. 9.30                      |         |

Source: JICA Survey Team

### 4.2 Overflow depth and overflow type

#### 4.2.1 Design Overflow Depth

Overflow depth 0.30 m is obtained as per Guideline Manual for Land Improvement Project “Pond Development”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries as following and construction cost comparison;

- Minimum water depth 0.4 m is desired in case of inflowing with driftwood and garbage in mountain side. However, this reservoir does not include driftwood and garbage. Water depth less than 0.4m can be set in this project reservoirs.
- As water depth is higher, construction cost is larger as shown in Table 4.2.1. Embankment cost is quite higher than concrete cost. Smaller water depth is advantage.

**Table 4.2.1 Comparison table by Water Depth**

Unit:10<sup>6</sup>TK

| Water<br>Depth (m) | Crest<br>Length (m) | Concrete<br>Cost | Embankme<br>nt Cost | Total | Remarks |
|--------------------|---------------------|------------------|---------------------|-------|---------|
| 0.3                | 58.16               | 0.0              | 0.0                 | 0.0   |         |

|     |       |       |      |      |  |
|-----|-------|-------|------|------|--|
| 0.4 | 32.31 | -0.22 | 2.88 | 2.66 |  |
| 0.5 | 19.39 | -0.33 | 5.75 | 5.75 |  |

Note: this cost is in case of No.3 reservoir. Water depth 0.3 m is based cost 0.0. Crest type is

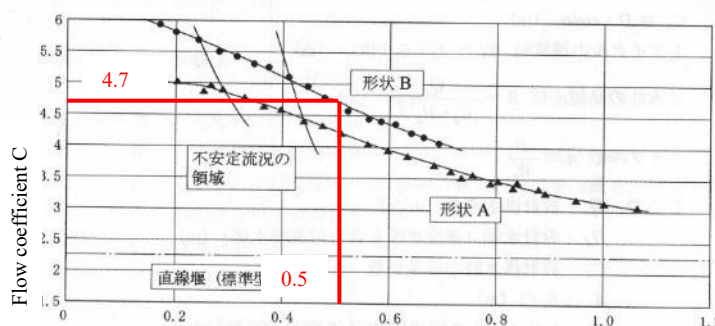
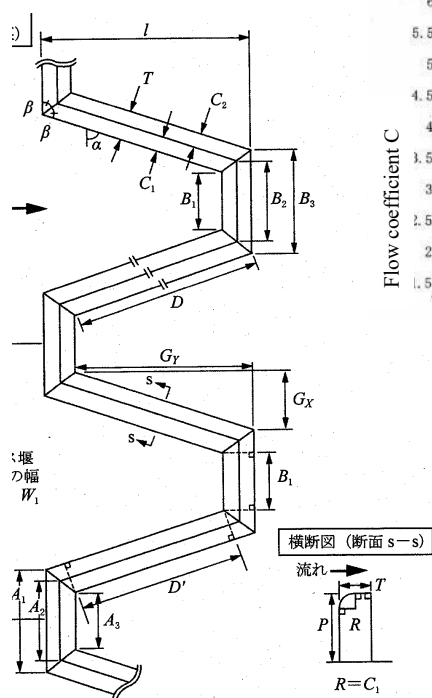
Source: JICA Survey Team

Therefore, overflow depth is 0.30 m.

#### 4.2.2 Crest Type

As crest length is so long and overflow depth is small, Labyrinth type, that is compact and simple, is selected.

(1) No.1 and No.2 reservoir



H/P

Source: Guideline Manual for Land Improvement Project  
“Pond Development”, P175

**Figure 4.2.2 C~H/P Curve**

Source: Guideline Manual for Land Improvement Project

“Pond Development”, P174

**Figure 4.2.1 Labyrinth Schematic Diagram**

(Type B)

$W/P = 3$ ,  $L/W = 4$ ,  $A/W = 0.0765$ ,  $T/P = 0.3$ ,  $R/T = 2/3$

Now,  $P = 0.6$  (m) is set.

$W = 3 \times 0.6 = 1.8$

$L = 4 \times 1.8 = 7.2$

$A = 0.0765 \times 1.8 = 0.0765 \times 1.8 = 0.1377$

$T = 0.3 \times 0.6 = 0.18$

$R = 2/3 \times 0.18 = 0.12$

$$C1 = R = 0.12 \text{ (m)}$$

$$\alpha = \cos^{-1} ((W - 4A)/(L - 4A)) = \cos^{-1} ((1.8 - 4 \times 0.1377)/(7.2 - 4 \times 0.1377)) = 79.17^\circ$$

$$\beta = 90 - \alpha / 2 = 90 - 79.17 / 2 = 50.415^\circ$$

$$l = T + ((L - 4A) / 2 + T \times \tan(\alpha / 2)) \times \sin \alpha = 0.18 + ((7.2 - 4 \times 0.1377) / 2 + 0.18 \times \tan(79.17 / 2)) \times \sin 79.17 = 3.651 \text{ (m)}$$

$$B1 = 2A = 2 \times 0.1377 = 0.275 \text{ (m)}$$

$$B2 = B1 + 2 \times C1 \times \tan(\alpha / 2) = 0.275 + 2 \times 0.12 \times \tan(79.17 / 2) = 0.474 \text{ (m)}$$

$$B3 = B1 + 2 \times T \times \tan(\alpha / 2) = 0.275 + 2 \times 0.18 \times \tan(79.17 / 2) = 0.573 \text{ (m)}$$

$$A1 = B3 = 0.573 \text{ (m)}$$

$$A2 = A1 - 2C1 \times \tan(\alpha / 2) = 0.573 + 2 \times 0.12 \times \tan(79.17 / 2) = 0.375 \text{ (m)}$$

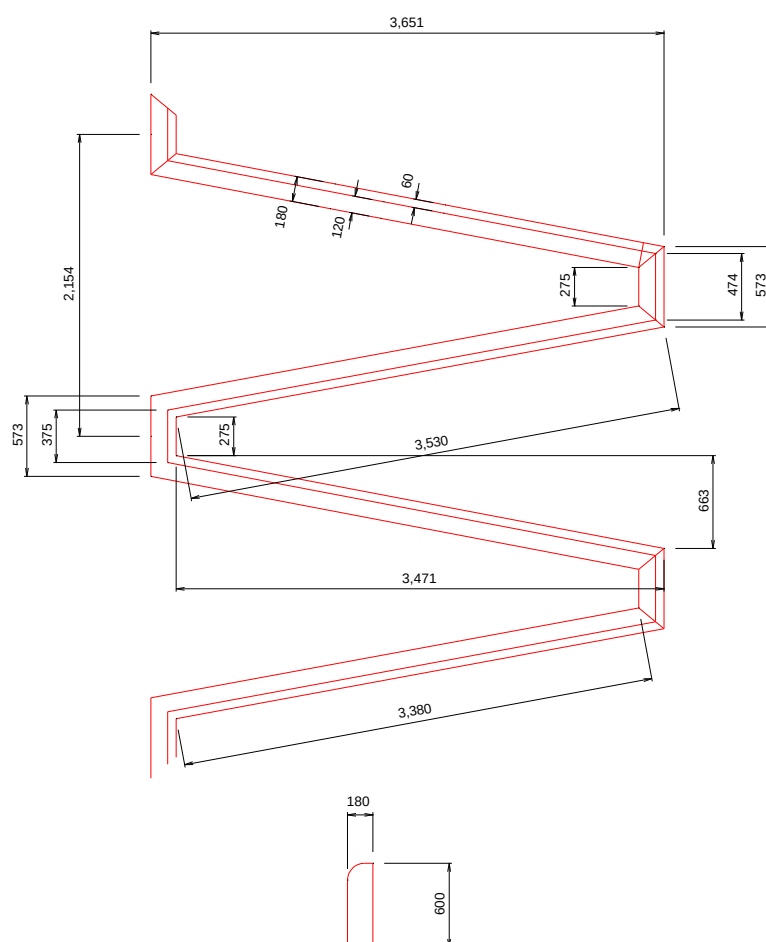
$$A3 = B1 = 0.275 \text{ (m)}$$

$$D' = (L - 4A) / 2 = (7.2 - 4 \times 0.1377) / 2 = 3.325 \text{ (m)}$$

$$D = D' + T \times \tan(\alpha / 2) = 3.325 + 0.18 \times \tan(79.17 / 2) = 3.473 \text{ (m)}$$

$$Gx = D \times \cos \alpha = 3.473 \times \cos 79.17 = 0.653 \text{ (m)}$$

$$1 \text{ cycle crest length } W1 = A3 + B3 + 2 \times Gx = 0.275 + 0.573 + 2 \times 0.653 = 2.154 \text{ (m)}$$



Source: JICA Survey Team

**Figure 4.2.3 Labyrinth Detail**

Required crest length  $B = Qd / (C Hd^{3/2})$

Where,

Qd : Design discharge (= 19.26 m<sup>3</sup>/s)

Hd: Overflow depth (= 0.310 m)

C: Flow coefficient (from Figure 2.2, = 4.7)

$$B = 19.26 / (4.7 \times 0.310^{3/2}) = 23.742 \text{ m}$$

$$\text{Cycle number } n = B / W1 = 23.742 / 2.154 = 11.02 \text{ cycle} \rightarrow 11 \text{ cycle}$$

$$\text{Crest total length } 2.154 \times 11 = 23.694 \text{ m}$$

(2) No.3 and No.4 reservoir

Crest shape is same as No.1 and No.2 type

Crest cycle and required crest length are;

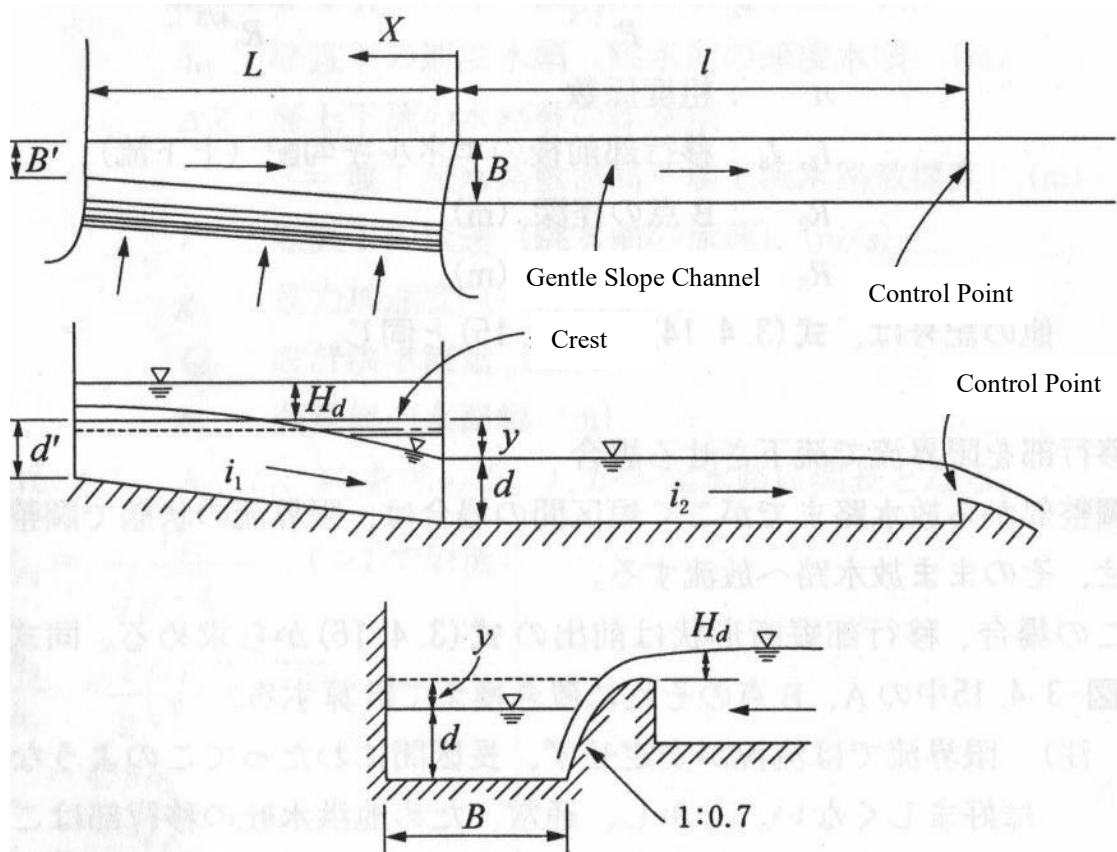
$$B = 46.94 / (4.7 \times 0.309^{3/2}) = 58.144 \text{ m}$$

$$\text{Cycle number } n = B / W1 = 58.144 / 2.154 = 26.99 \text{ cycle} \rightarrow 27 \text{ cycle}$$

$$\text{Crest total length } 2.154 \times 27 = 58.158 \text{ m}$$

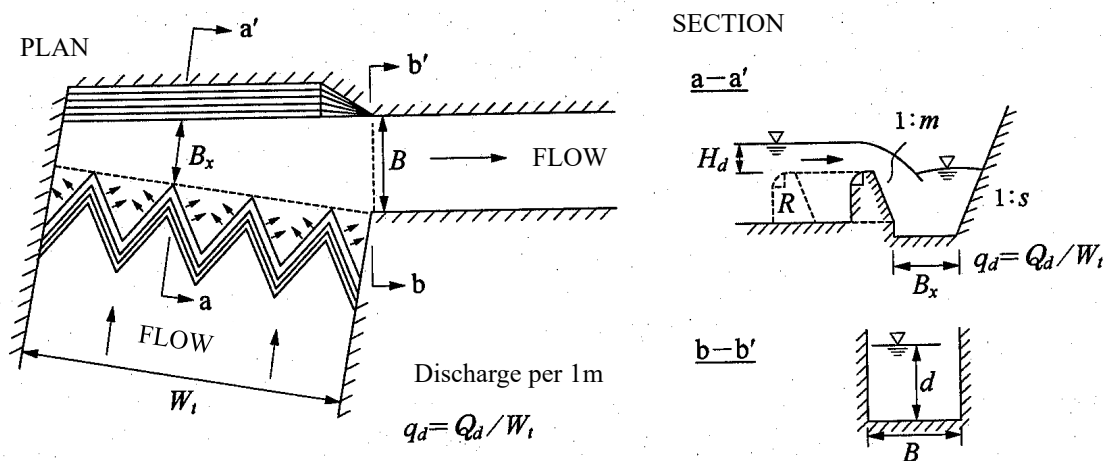
**4.3 Transition Channel****4.3.1 Side Channel**

As crest length is long while settling basin width is small, side channel type is selected as upper transition channel as shown in Figure 4.3.1.



Source: Guideline Manual for Land Improvement Project "Pond Development", P72

**Figure 4.3.1 Side channel**



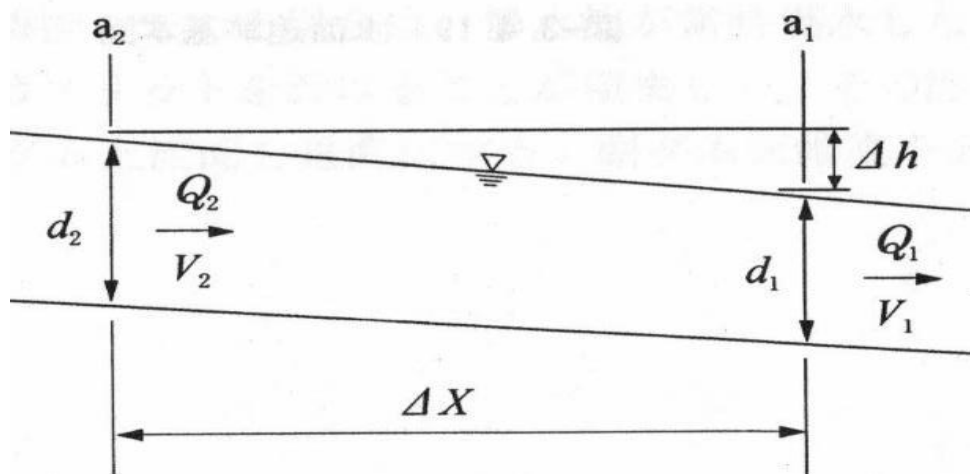
Source: Guideline Manual for Land Improvement Project "Pond Development", P74

**Figure 4.3.2 Transition channel with Labyrinth Crest**

Design condition for side channel shows next from Guideline Manual for Land Improvement Project "Pond Development"

- 1) Side wall slope in overflow side 1:0.7 is desirable. Opposite side wall slope generally is to be more than 1:0.5 slope.
- 2) Side wall bottom slope  $i_1$  shall be  $i_1 \leq 1/13$ .
- 3) Ratio of bottom width  $B$  and water depth  $d$   $d/B = 0.5$  is desirable.

- 4) Flude number  $Fr$  at end of side channel end shall be  $Fr < 0.5$ . Recommendable number is  $Fr = 0.44$ .
- 5) Water surface in side channel shall be less than  $1 / 2.5$  of overflow depth at crest.
- 6) Connection channel to side channel shall be gentle slope under 4) condition.
- 7) The calculation of water surface in side channel is to estimate from downstream end to upstream end by using the motion equation as following equation and figure;



Source: Guideline Manual for Land Improvement Project "Pond Development", P72

**Figure 4.3.3 Calculation Section**

$$\Delta h = \frac{Q_1 \times (V_1 + V_2)}{g \times (Q_1 + VQ_2)} \times \left( \Delta V + \frac{q \times V_2 \times \Delta X}{Q_1} \right)$$

Where,  $\Delta h$ : Water rising up depth during  $\Delta X$  distance (m)

$Q_1$ : Discharge at a1 section (m<sup>3</sup>/s)

$Q_2$ : Discharge at a2 section (m<sup>3</sup>/s)

$V_1$ : Water Velocity at a1 section (m/s)

$V_2$ : Water Velocity at a2 section (m/s)

$q$ : Unit length overflow discharge (m<sup>3</sup>/s/m)

$\Delta V$ :  $V_1 - V_2$  (m/s)

$G$ : gravity (9.8m/s<sup>2</sup>)

Calculation is assuming  $\Delta h$  and try and error method.

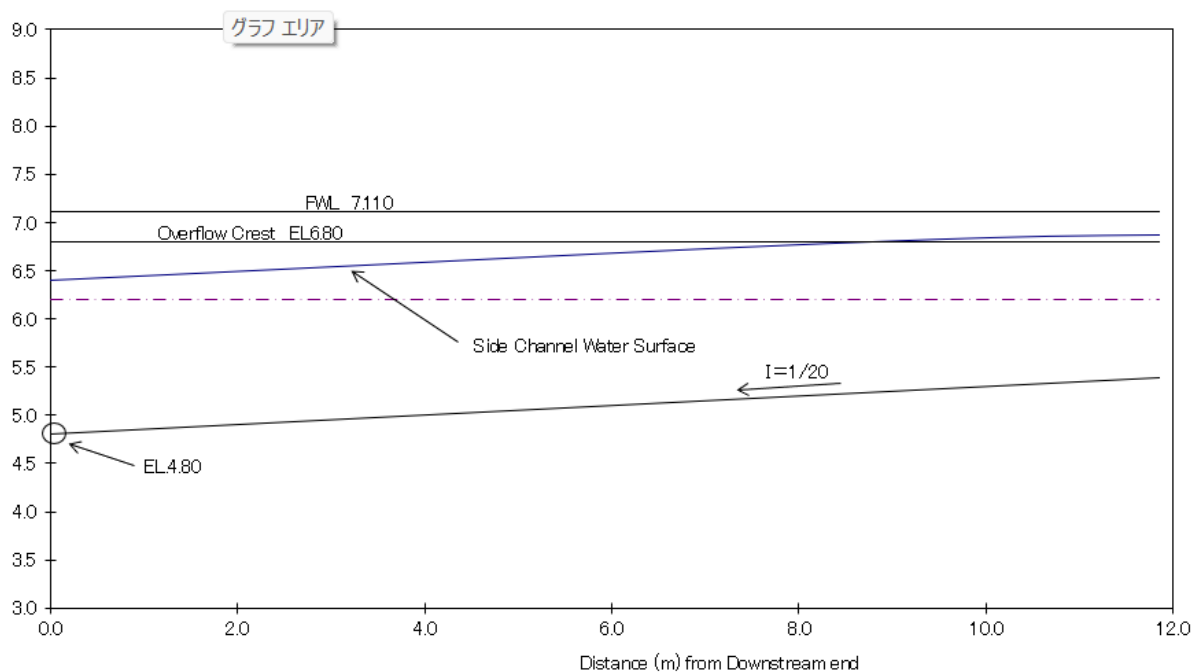
Each Condition and calculation results shows Table 4.3.1 and calculation sheets are Table 4.3.2 and Table 4.3.3. Discharge value is 50% of design discharge because this side channel has two side channel and one connection channel at connecting point of both side channel or T shape channel.

**Table 4.3.1 Side Channel Design Condition**

|  | No.1 and No.2<br>Reservoir | No.3 and No.4<br>Reservoir | Remarks |
|--|----------------------------|----------------------------|---------|
|--|----------------------------|----------------------------|---------|

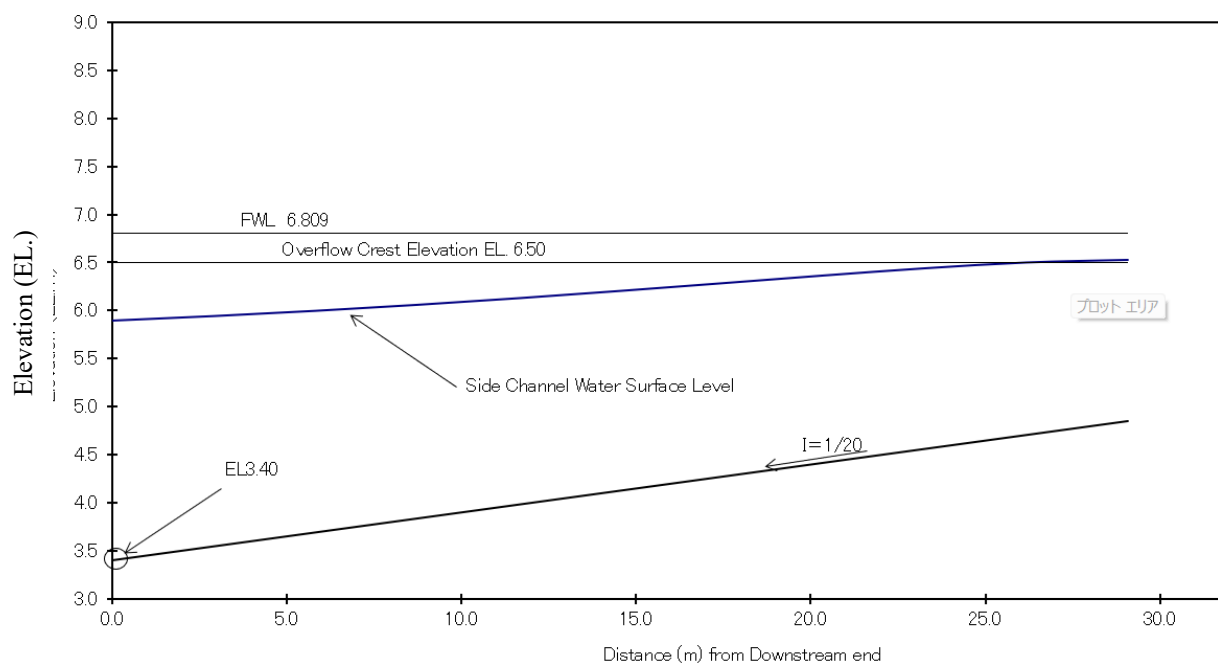
|                                                       |              |              |                     |
|-------------------------------------------------------|--------------|--------------|---------------------|
| 1) Crest length (m)                                   | 23.694       | 58.158       |                     |
| 2) Crest El.                                          | 6.80         | 6.50         |                     |
| 3) Overflow Depth (m)                                 | 0.310        | 0.309        |                     |
| 4) Top El. of overflow side wall                      | 6.20         | 5.90         |                     |
| 5) Design Discharge (m <sup>3</sup> /s)               | 9.63 (19.26) | 3.47 (46.94) | 0: Design discharge |
| 6) Unit discharge q (m <sup>3</sup> /s/m)             | 0.813        | 0.807        |                     |
| 7) Bottom Width at Downstream End (m)                 | 3.20         | 4.50         |                     |
| 8) Bottom Width at Upstream End (m)                   | 1.60         | 2.50         | 8) $\approx$ 7)/2   |
| 9) Bottom Elevation (EL.)                             | 4.80         | 3.40         |                     |
| 10) Channel Slope                                     | 1/20         | 1/20         | < 1/13              |
| 11) Maximum Water Surface Level (EL.) at Side Channel | 6.87         | 6.53         |                     |

Source: JICA Survey Team



Source: JICA Survey Team

**Figure 4.3.4 Calculated Water Surface at Reservoir No.1 and No.2**



Source: JICA Survey Team

**Figure 4.3.5 Calculated Water Surface at Reservoir No.3 and No.4**

Table 4.3.2 Calculation Sheet of Side Channel Water Surface at No.1 and No.2 Reservoir

|   | ①Acc.<br>Distanc<br>e | ②Unit<br>distanc<br>e | ③Botto<br>m El. | ④ $\Delta h'$ | ⑤Water<br>Surface<br>EL. | ⑥Water<br>Depth<br>(m) | ⑦Botto<br>m Width<br>(m) Bx | ⑧Sectio<br>n Area | ⑨Qx   | ⑩V    | ⑪Q1+<br>Q2 | ⑫Q1/<br>g/⑪ | ⑬V1<br>+v2 | ⑭ $\Delta v$<br>=V1<br>-v2 | ⑮qv<br>2 $\Delta x$<br>/Q1 | ⑯⑮<br>+⑭ | ⑰ $\Delta h =$<br>⑫ $\times$ ⑬ $\times$<br>⑯ |
|---|-----------------------|-----------------------|-----------------|---------------|--------------------------|------------------------|-----------------------------|-------------------|-------|-------|------------|-------------|------------|----------------------------|----------------------------|----------|----------------------------------------------|
| 0 | 0.0                   |                       | 4.80            |               | 6.40                     | 1.60                   | 3.200                       | 5.120             | 9.630 | 1.881 | -          | -           | -          | -                          | -                          | -        | -                                            |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.2000        | 6.60                     | 1.74                   | 3.040                       | 5.292             | 8.667 | 1.638 | 18.297     | 0.054       | 3.519      | 0.243                      | 0.164                      | 0.407    | 0.0769                                       |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.0769        | 6.48                     | 1.62                   | 3.040                       | 4.918             | 8.667 | 1.762 | 18.297     | 0.054       | 3.643      | 0.118                      | 0.176                      | 0.295    | 0.0577                                       |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.0577        | 6.46                     | 1.60                   | 3.040                       | 4.859             | 8.667 | 1.784 | 18.297     | 0.054       | 3.664      | 0.097                      | 0.178                      | 0.276    | 0.0542                                       |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.0542        | 6.45                     | 1.60                   | 3.040                       | 4.849             | 8.667 | 1.787 | 18.297     | 0.054       | 3.668      | 0.093                      | 0.179                      | 0.272    | 0.0536                                       |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.0536        | 6.45                     | 1.59                   | 3.040                       | 4.847             | 8.667 | 1.788 | 18.297     | 0.054       | 3.669      | 0.093                      | 0.179                      | 0.272    | 0.0535                                       |
| 1 | 1.2                   | 1.2                   | 4.86            | 0.0535        | 6.45                     | 1.59                   | 3.040                       | 4.847             | 8.667 | 1.788 | 18.297     | 0.054       | 3.669      | 0.093                      | 0.179                      | 0.271    | 0.0535                                       |
| 2 | 2.4                   | 1.2                   | 4.92            | 0.0535        | 6.51                     | 1.59                   | 2.880                       | 4.575             | 7.704 | 1.684 | 16.371     | 0.054       | 3.472      | 0.104                      | 0.187                      | 0.291    | 0.0547                                       |
| 2 | 2.4                   | 1.2                   | 4.92            | 0.0547        | 6.51                     | 1.59                   | 2.880                       | 4.578             | 7.704 | 1.683 | 16.371     | 0.054       | 3.471      | 0.106                      | 0.187                      | 0.293    | 0.0549                                       |
| 2 | 2.4                   | 1.2                   | 4.92            | 0.0549        | 6.51                     | 1.59                   | 2.880                       | 4.579             | 7.704 | 1.683 | 16.371     | 0.054       | 3.471      | 0.106                      | 0.187                      | 0.293    | 0.0549                                       |
| 2 | 2.4                   | 1.2                   | 4.92            | 0.0549        | 6.51                     | 1.59                   | 2.880                       | 4.579             | 7.704 | 1.682 | 16.371     | 0.054       | 3.471      | 0.106                      | 0.187                      | 0.293    | 0.0549                                       |
| 3 | 3.6                   | 1.2                   | 4.98            | 0.0549        | 6.56                     | 1.59                   | 2.720                       | 4.313             | 6.741 | 1.563 | 14.445     | 0.054       | 3.246      | 0.119                      | 0.195                      | 0.315    | 0.0556                                       |
| 3 | 3.6                   | 1.2                   | 4.98            | 0.0556        | 6.56                     | 1.59                   | 2.720                       | 4.315             | 6.741 | 1.562 | 14.445     | 0.054       | 3.245      | 0.120                      | 0.195                      | 0.315    | 0.0557                                       |
| 3 | 3.6                   | 1.2                   | 4.98            | 0.0557        | 6.56                     | 1.59                   | 2.720                       | 4.315             | 6.741 | 1.562 | 14.445     | 0.054       | 3.245      | 0.120                      | 0.195                      | 0.316    | 0.0557                                       |
| 3 | 3.6                   | 1.2                   | 4.98            | 0.0557        | 6.56                     | 1.59                   | 2.720                       | 4.315             | 6.741 | 1.562 | 14.445     | 0.054       | 3.245      | 0.120                      | 0.195                      | 0.316    | 0.0557                                       |
| 4 | 4.7                   | 1.2                   | 5.04            | 0.0557        | 6.62                     | 1.58                   | 2.560                       | 4.052             | 5.778 | 1.426 | 12.519     | 0.055       | 2.988      | 0.136                      | 0.204                      | 0.340    | 0.0558                                       |
| 4 | 4.7                   | 1.2                   | 5.04            | 0.0558        | 6.62                     | 1.58                   | 2.560                       | 4.052             | 5.778 | 1.426 | 12.519     | 0.055       | 2.988      | 0.136                      | 0.204                      | 0.340    | 0.0558                                       |
| 4 | 4.7                   | 1.2                   | 5.04            | 0.0558        | 6.62                     | 1.58                   | 2.560                       | 4.052             | 5.778 | 1.426 | 12.519     | 0.055       | 2.988      | 0.136                      | 0.204                      | 0.340    | 0.0558                                       |
| 4 | 4.7                   | 1.2                   | 5.04            | 0.0558        | 6.62                     | 1.58                   | 2.560                       | 4.052             | 5.778 | 1.426 | 12.519     | 0.055       | 2.988      | 0.136                      | 0.204                      | 0.340    | 0.0558                                       |
| 4 | 4.7                   | 1.2                   | 5.04            | 0.0558        | 6.62                     | 1.58                   | 2.560                       | 4.052             | 5.778 | 1.426 | 12.519     | 0.055       | 2.988      | 0.136                      | 0.204                      | 0.340    | 0.0558                                       |
| 5 | 5.9                   | 1.2                   | 5.10            | 0.0558        | 6.68                     | 1.58                   | 2.400                       | 3.791             | 4.815 | 1.270 | 10.593     | 0.056       | 2.696      | 0.156                      | 0.212                      | 0.367    | 0.0551                                       |
| 5 | 5.9                   | 1.2                   | 5.10            | 0.0551        | 6.68                     | 1.58                   | 2.400                       | 3.789             | 4.815 | 1.271 | 10.593     | 0.056       | 2.696      | 0.155                      | 0.212                      | 0.367    | 0.0551                                       |
| 5 | 5.9                   | 1.2                   | 5.10            | 0.0551        | 6.68                     | 1.58                   | 2.400                       | 3.789             | 4.815 | 1.271 | 10.593     | 0.056       | 2.697      | 0.155                      | 0.212                      | 0.367    | 0.0551                                       |
| 5 | 5.9                   | 1.2                   | 5.10            | 0.0551        | 6.68                     | 1.58                   | 2.400                       | 3.789             | 4.815 | 1.271 | 10.593     | 0.056       | 2.697      | 0.155                      | 0.212                      | 0.367    | 0.0551                                       |
| 6 | 7.1                   | 1.2                   | 5.16            | 0.0551        | 6.73                     | 1.57                   | 2.240                       | 3.527             | 3.852 | 1.092 | 8.667      | 0.057       | 2.363      | 0.179                      | 0.218                      | 0.397    | 0.0532                                       |
| 6 | 7.1                   | 1.2                   | 5.16            | 0.0532        | 6.73                     | 1.57                   | 2.240                       | 3.523             | 3.852 | 1.093 | 8.667      | 0.057       | 2.364      | 0.177                      | 0.219                      | 0.396    | 0.0531                                       |
| 6 | 7.1                   | 1.2                   | 5.16            | 0.0531        | 6.73                     | 1.57                   | 2.240                       | 3.523             | 3.852 | 1.093 | 8.667      | 0.057       | 2.364      | 0.177                      | 0.219                      | 0.396    | 0.0531                                       |
| 7 | 8.3                   | 1.2                   | 5.21            | 0.0531        | 6.78                     | 1.57                   | 2.080                       | 3.258             | 2.889 | 0.887 | 6.741      | 0.058       | 1.980      | 0.207                      | 0.222                      | 0.428    | 0.0495                                       |
| 7 | 8.3                   | 1.2                   | 5.21            | 0.0495        | 6.78                     | 1.56                   | 2.080                       | 3.251             | 2.889 | 0.889 | 6.741      | 0.058       | 1.982      | 0.205                      | 0.222                      | 0.427    | 0.0493                                       |
| 7 | 8.3                   | 1.2                   | 5.21            | 0.0493        | 6.78                     | 1.56                   | 2.080                       | 3.251             | 2.889 | 0.889 | 6.741      | 0.058       | 1.982      | 0.205                      | 0.222                      | 0.427    | 0.0493                                       |
| 8 | 9.5                   | 1.2                   | 5.27            | 0.0493        | 6.83                     | 1.55                   | 1.920                       | 2.982             | 1.926 | 0.646 | 4.815      | 0.061       | 1.535      | 0.243                      | 0.215                      | 0.458    | 0.0430                                       |

|    |      |     |      |        |      |      |       |       |       |       |       |       |       |       |       |       |        |
|----|------|-----|------|--------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| 8  | 9.5  | 1.2 | 5.27 | 0.0430 | 6.82 | 1.55 | 1.920 | 2.969 | 1.926 | 0.649 | 4.815 | 0.061 | 1.537 | 0.240 | 0.216 | 0.456 | 0.0430 |
| 8  | 9.5  | 1.2 | 5.27 | 0.0430 | 6.82 | 1.55 | 1.920 | 2.969 | 1.926 | 0.649 | 4.815 | 0.061 | 1.537 | 0.240 | 0.216 | 0.456 | 0.0430 |
| 9  | 10.7 | 1.2 | 5.33 | 0.0430 | 6.86 | 1.53 | 1.760 | 2.693 | 0.963 | 0.358 | 2.889 | 0.068 | 1.006 | 0.291 | 0.179 | 0.470 | 0.0322 |
| 9  | 10.7 | 1.2 | 5.33 | 0.0322 | 6.85 | 1.52 | 1.760 | 2.674 | 0.963 | 0.360 | 2.889 | 0.068 | 1.009 | 0.289 | 0.180 | 0.469 | 0.0322 |
| 9  | 10.7 | 1.2 | 5.33 | 0.0322 | 6.85 | 1.52 | 1.760 | 2.674 | 0.963 | 0.360 | 2.889 | 0.068 | 1.009 | 0.289 | 0.180 | 0.469 | 0.0322 |
| 10 | 11.8 | 1.2 | 5.39 | 0.0322 | 6.88 | 1.49 | 1.600 | 2.388 | 0.000 | 0.000 | 0.963 | 0.102 | 0.360 | 0.360 | 0.000 | 0.360 | 0.0132 |
| 10 | 11.8 | 1.2 | 5.39 | 0.0132 | 6.87 | 1.47 | 1.600 | 2.357 | 0.000 | 0.000 | 0.963 | 0.102 | 0.360 | 0.360 | 0.000 | 0.360 | 0.0132 |

Source: JICA Survey Team

Table 4.3.3 Calculation Sheet of Side Channel Water Surface at No.3 and No.4 Reservoir

|   | ①Acc.<br>Distanc<br>e | ②Unit<br>distanc<br>e | ③Botto<br>m El. | ④Δh'   | ⑤Wate<br>r<br>Surface<br>EL. | ⑥Wate<br>r Depth<br>(m) | ⑦Botto<br>m Width<br>(m) Bx | ⑧Sectio<br>n Area | ⑨Qx    | ⑩V    | ⑪Q1+<br>Q2 | ⑫Q1/<br>g/(⑪) | ⑬V1<br>+v2 | ⑭Δv=<br>V1-v2 | ⑮qv<br>2Δx/Q1 | ⑯⑮<br>+ ⑭ | ⑰Δh=<br>⑫×⑬×<br>⑯ |
|---|-----------------------|-----------------------|-----------------|--------|------------------------------|-------------------------|-----------------------------|-------------------|--------|-------|------------|---------------|------------|---------------|---------------|-----------|-------------------|
| 0 | 0.0                   |                       | 3.40            |        | 5.90                         | 2.50                    | 4.500                       | 11.250            | 22.658 | 2.014 | -          | -             | -          | -             | -             | -         | -                 |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.2000 | 6.10                         | 2.55                    | 4.275                       | 10.921            | 20.392 | 1.867 | 43.050     | 0.054         | 3.881      | 0.147         | 0.179         | 0.326     | 0.0679            |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.0679 | 5.97                         | 2.42                    | 4.275                       | 10.356            | 20.392 | 1.969 | 43.050     | 0.054         | 3.983      | 0.045         | 0.189         | 0.234     | 0.0500            |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.0500 | 5.95                         | 2.40                    | 4.275                       | 10.280            | 20.392 | 1.984 | 43.050     | 0.054         | 3.998      | 0.030         | 0.190         | 0.221     | 0.0474            |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.0474 | 5.95                         | 2.40                    | 4.275                       | 10.268            | 20.392 | 1.986 | 43.050     | 0.054         | 4.000      | 0.028         | 0.190         | 0.219     | 0.0470            |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.0470 | 5.95                         | 2.40                    | 4.275                       | 10.267            | 20.392 | 1.986 | 43.050     | 0.054         | 4.000      | 0.028         | 0.191         | 0.218     | 0.0469            |
| 1 | 2.9                   | 2.9                   | 3.55            | 0.0469 | 5.95                         | 2.40                    | 4.275                       | 10.266            | 20.392 | 1.986 | 43.050     | 0.054         | 4.000      | 0.028         | 0.191         | 0.218     | 0.0469            |
| 2 | 5.8                   | 2.9                   | 3.69            | 0.0469 | 5.99                         | 2.30                    | 4.050                       | 9.327             | 18.126 | 1.943 | 38.519     | 0.054         | 3.930      | 0.043         | 0.207         | 0.250     | 0.0531            |
| 2 | 5.8                   | 2.9                   | 3.69            | 0.0531 | 6.00                         | 2.31                    | 4.050                       | 9.352             | 18.126 | 1.938 | 38.519     | 0.054         | 3.925      | 0.048         | 0.207         | 0.255     | 0.0540            |
| 2 | 5.8                   | 2.9                   | 3.69            | 0.0540 | 6.00                         | 2.31                    | 4.050                       | 9.356             | 18.126 | 1.937 | 38.519     | 0.054         | 3.924      | 0.049         | 0.206         | 0.255     | 0.0541            |
| 2 | 5.8                   | 2.9                   | 3.69            | 0.0541 | 6.00                         | 2.31                    | 4.050                       | 9.356             | 18.126 | 1.937 | 38.519     | 0.054         | 3.924      | 0.049         | 0.206         | 0.255     | 0.0541            |
| 3 | 8.7                   | 2.9                   | 3.84            | 0.0541 | 6.06                         | 2.22                    | 3.825                       | 8.488             | 15.861 | 1.869 | 33.987     | 0.054         | 3.806      | 0.069         | 0.224         | 0.293     | 0.0606            |
| 3 | 8.7                   | 2.9                   | 3.84            | 0.0606 | 6.06                         | 2.23                    | 3.825                       | 8.512             | 15.861 | 1.863 | 33.987     | 0.054         | 3.801      | 0.074         | 0.223         | 0.297     | 0.0615            |
| 3 | 8.7                   | 2.9                   | 3.84            | 0.0615 | 6.06                         | 2.23                    | 3.825                       | 8.516             | 15.861 | 1.862 | 33.987     | 0.054         | 3.800      | 0.075         | 0.223         | 0.298     | 0.0616            |
| 3 | 8.7                   | 2.9                   | 3.84            | 0.0616 | 6.06                         | 2.23                    | 3.825                       | 8.516             | 15.861 | 1.862 | 33.987     | 0.054         | 3.800      | 0.075         | 0.223         | 0.298     | 0.0617            |
| 4 | 11.6                  | 2.9                   | 3.98            | 0.0617 | 6.12                         | 2.14                    | 3.600                       | 7.714             | 13.595 | 1.762 | 29.455     | 0.055         | 3.625      | 0.100         | 0.241         | 0.341     | 0.0680            |
| 4 | 11.6                  | 2.9                   | 3.98            | 0.0680 | 6.13                         | 2.15                    | 3.600                       | 7.737             | 13.595 | 1.757 | 29.455     | 0.055         | 3.620      | 0.105         | 0.241         | 0.346     | 0.0688            |
| 4 | 11.6                  | 2.9                   | 3.98            | 0.0688 | 6.13                         | 2.15                    | 3.600                       | 7.740             | 13.595 | 1.757 | 29.455     | 0.055         | 3.619      | 0.106         | 0.241         | 0.347     | 0.0689            |

|    |      |     |      |        |      |      |       |       |        |       |        |       |       |       |       |       |        |
|----|------|-----|------|--------|------|------|-------|-------|--------|-------|--------|-------|-------|-------|-------|-------|--------|
| 4  | 11.6 | 2.9 | 3.98 | 0.0689 | 6.13 | 2.15 | 3.600 | 7.740 | 13.595 | 1.756 | 29.455 | 0.055 | 3.619 | 0.106 | 0.241 | 0.347 | 0.0689 |
| 4  | 11.6 | 2.9 | 3.98 | 0.0689 | 6.13 | 2.15 | 3.600 | 7.740 | 13.595 | 1.756 | 29.455 | 0.055 | 3.619 | 0.106 | 0.241 | 0.347 | 0.0689 |
| 5  | 14.5 | 2.9 | 4.13 | 0.0689 | 6.20 | 2.07 | 3.375 | 6.998 | 11.329 | 1.619 | 24.924 | 0.056 | 3.375 | 0.138 | 0.259 | 0.396 | 0.0745 |
| 5  | 14.5 | 2.9 | 4.13 | 0.0745 | 6.21 | 2.08 | 3.375 | 7.017 | 11.329 | 1.615 | 24.924 | 0.056 | 3.371 | 0.142 | 0.258 | 0.400 | 0.0750 |
| 5  | 14.5 | 2.9 | 4.13 | 0.0750 | 6.21 | 2.08 | 3.375 | 7.019 | 11.329 | 1.614 | 24.924 | 0.056 | 3.371 | 0.142 | 0.258 | 0.400 | 0.0751 |
| 5  | 14.5 | 2.9 | 4.13 | 0.0751 | 6.21 | 2.08 | 3.375 | 7.019 | 11.329 | 1.614 | 24.924 | 0.056 | 3.371 | 0.142 | 0.258 | 0.400 | 0.0751 |
| 6  | 17.4 | 2.9 | 4.27 | 0.0751 | 6.28 | 2.01 | 3.150 | 6.330 | 9.063  | 1.432 | 20.392 | 0.057 | 3.046 | 0.182 | 0.275 | 0.457 | 0.0789 |
| 6  | 17.4 | 2.9 | 4.27 | 0.0789 | 6.29 | 2.01 | 3.150 | 6.342 | 9.063  | 1.429 | 20.392 | 0.057 | 3.043 | 0.185 | 0.274 | 0.459 | 0.0792 |
| 6  | 17.4 | 2.9 | 4.27 | 0.0792 | 6.29 | 2.01 | 3.150 | 6.342 | 9.063  | 1.429 | 20.392 | 0.057 | 3.043 | 0.185 | 0.274 | 0.459 | 0.0792 |
| 7  | 20.4 | 2.9 | 4.42 | 0.0792 | 6.37 | 1.95 | 2.925 | 5.696 | 6.797  | 1.193 | 15.861 | 0.058 | 2.622 | 0.236 | 0.286 | 0.522 | 0.0798 |
| 7  | 20.4 | 2.9 | 4.42 | 0.0798 | 6.37 | 1.95 | 2.925 | 5.697 | 6.797  | 1.193 | 15.861 | 0.058 | 2.622 | 0.236 | 0.286 | 0.522 | 0.0798 |
| 7  | 20.4 | 2.9 | 4.42 | 0.0798 | 6.37 | 1.95 | 2.925 | 5.698 | 6.797  | 1.193 | 15.861 | 0.058 | 2.622 | 0.236 | 0.286 | 0.522 | 0.0798 |
| 8  | 23.3 | 2.9 | 4.56 | 0.0798 | 6.45 | 1.88 | 2.700 | 5.082 | 4.532  | 0.892 | 11.329 | 0.061 | 2.085 | 0.301 | 0.285 | 0.586 | 0.0748 |
| 8  | 23.3 | 2.9 | 4.56 | 0.0748 | 6.44 | 1.88 | 2.700 | 5.069 | 4.532  | 0.894 | 11.329 | 0.061 | 2.087 | 0.299 | 0.286 | 0.585 | 0.0747 |
| 8  | 23.3 | 2.9 | 4.56 | 0.0747 | 6.44 | 1.88 | 2.700 | 5.068 | 4.532  | 0.894 | 11.329 | 0.061 | 2.087 | 0.299 | 0.286 | 0.585 | 0.0747 |
| 9  | 26.2 | 2.9 | 4.71 | 0.0747 | 6.52 | 1.81 | 2.475 | 4.471 | 2.266  | 0.507 | 6.797  | 0.068 | 1.401 | 0.387 | 0.243 | 0.630 | 0.0601 |
| 9  | 26.2 | 2.9 | 4.71 | 0.0601 | 6.50 | 1.79 | 2.475 | 4.435 | 2.266  | 0.511 | 6.797  | 0.068 | 1.405 | 0.383 | 0.245 | 0.628 | 0.0600 |
| 9  | 26.2 | 2.9 | 4.71 | 0.0600 | 6.50 | 1.79 | 2.475 | 4.435 | 2.266  | 0.511 | 6.797  | 0.068 | 1.405 | 0.383 | 0.245 | 0.628 | 0.0600 |
| 10 | 29.1 | 2.9 | 4.85 | 0.0600 | 6.56 | 1.71 | 2.250 | 3.840 | 0.000  | 0.000 | 2.266  | 0.102 | 0.511 | 0.511 | 0.000 | 0.511 | 0.0266 |
| 10 | 29.1 | 2.9 | 4.85 | 0.0266 | 6.53 | 1.67 | 2.250 | 3.764 | 0.000  | 0.000 | 2.266  | 0.102 | 0.511 | 0.511 | 0.000 | 0.511 | 0.0266 |

Source: JICA Survey Team

**4.3.2 Channel after Side Channel**

The channel after side channel is determined by maintaining the uniform flow of subcritical flow and ununiform flow portion.

(1) Channel of from Side Channel End to 6.0 m downstream

Side channel end to 6.0 m down portion is adopted in uniform flow by using Manning equation as shown in Table 4.3.4.

**Table 4.3.4 Hydraulic Calculation of Side Channel End to 6.0m Downstream Portion**

|                                                   | No.1 and No.2<br>Reservoir | No.3 and No.4<br>Reservoir | Remarks          |
|---------------------------------------------------|----------------------------|----------------------------|------------------|
| 1) Design Discharge (m <sup>3</sup> /s)           | 19.26                      | 46.94                      |                  |
| 2) Channel Length (m)                             | 6.458                      | 6.00                       |                  |
| 3) Water Surface Elevation at<br>Side Channel End | 6.20                       | 5.90                       |                  |
| 4) Channel Width (m)                              | 4.00                       | 5.00                       |                  |
| 5) Design Water Depth (m)                         | 1.60                       | 2.50                       |                  |
| 6) Channel slope                                  | 1/410                      | 1/420                      |                  |
| 7) Manning Rough coefficient                      | 0.015                      | 0.015                      | Casting Concrete |
| 8) Calculated Velocity (m/s)                      | 3.044                      | 3.775                      |                  |
| 9) Calculated Discharge (m <sup>3</sup> /s)       | 19.482                     | 47.188                     | 9) > 1) ok       |

Source: JICA Survey Team

(2) Downstream Channel from 6.0m downstream of Side Channel End

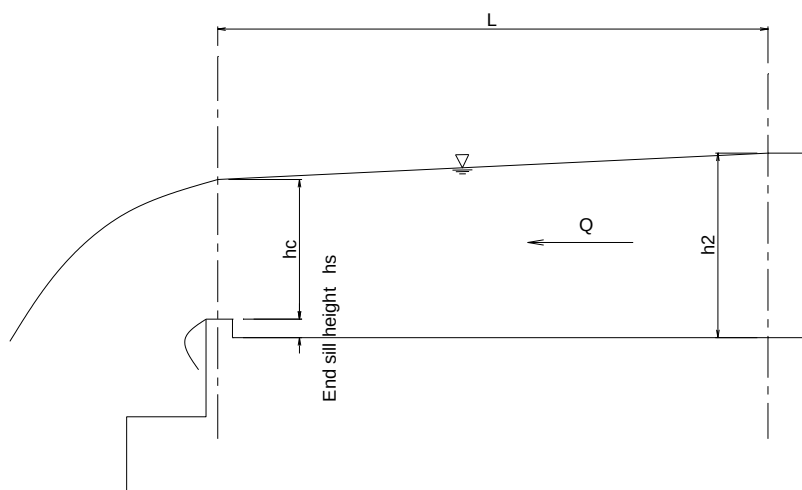
This portion is 5.0 m between settling basin at downstream side and gentle slope channel 6.0 m as shown in previous section.

This portion channel dimension can be obtained by ununiform flow calculation. The results of calculation are shown in Table 4.3.5.

**Table 4.3.5 Hydraulic Calculation of Downstream Channel**

|                                                   | No.1 and<br>No.2<br>Reservoir | No.3 and No.4<br>Reservoir | Remarks                                                        |
|---------------------------------------------------|-------------------------------|----------------------------|----------------------------------------------------------------|
| 1) Design Discharge (m <sup>3</sup> /s)           | 19.26                         | 46.94                      |                                                                |
| 2) Channel Length (m) L                           | 5.00                          | 5.00                       |                                                                |
| 3) Channel Width (m)                              | 4.00                          | 5.00                       |                                                                |
| 4) Upstream end Elevation                         | 4.784                         | 3.386                      | Bottom Elevation at 6.0<br>m downstream of<br>connecting point |
| 5) Upstream End Water Depth<br>h <sub>2</sub> (m) | 1.60                          | 2.50                       | From section 3.2.1                                             |
| 6) Downstream End water<br>Depth (m)              | 1.332                         | 2.087                      | Critical Depth h <sub>c</sub>                                  |
| 7) Manning Rough coefficient                      | 0.015                         | 0.015                      | Casting Concrete                                               |
| 8) End Sill Height (m)                            | 0.144                         | 0.115                      |                                                                |

Source: JICA Survey Team



Source: JICA Survey Team

**Figure 4.3.9 Downstream Channel from 6.0m downstream of Side Channel End**

#### 4.4 Settling Basin

The step structure was selected by the following reasons as settling basin structure of spillway;

- the step structure always has the energy absorbing function although water level at outside varies.
- Structure is not complex and not used with special materials nor special tools.
- Structure length is not long and large area, and doesn't have the structure of occurring the sedimentation.

Detailed calculation for size is shown in the following equation with step height  $d$  and horizontal length  $l$  sourced by hydraulics formulas (Japan Society of Civil Engineers 1999 edition), P265,

$$h_{wc}/d > 1.06 - 0.465 \, d/l$$

where,  $h_{wc}$ : critical depth (m)

$$h_{wc} = ((Qd/B)^2/g)^{1/3}$$

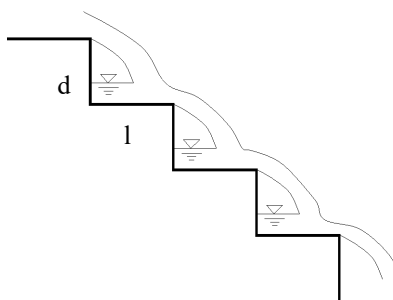
where;  $Qd$ : Design discharge (m<sup>3</sup>/s)

$B$ : step width (m)

$g$ : Gravitational acceleration (= 9.8 m/s<sup>2</sup>)

$d$ : Step height (m)

$l$ : Horizontal length (m)



Source: JICA Survey Team

**Figure 4.4.1 Step Structure**

The calculation of step structure is shown in the below;

**Table 4.4.1 Calculation of Step dimensions of spillway**

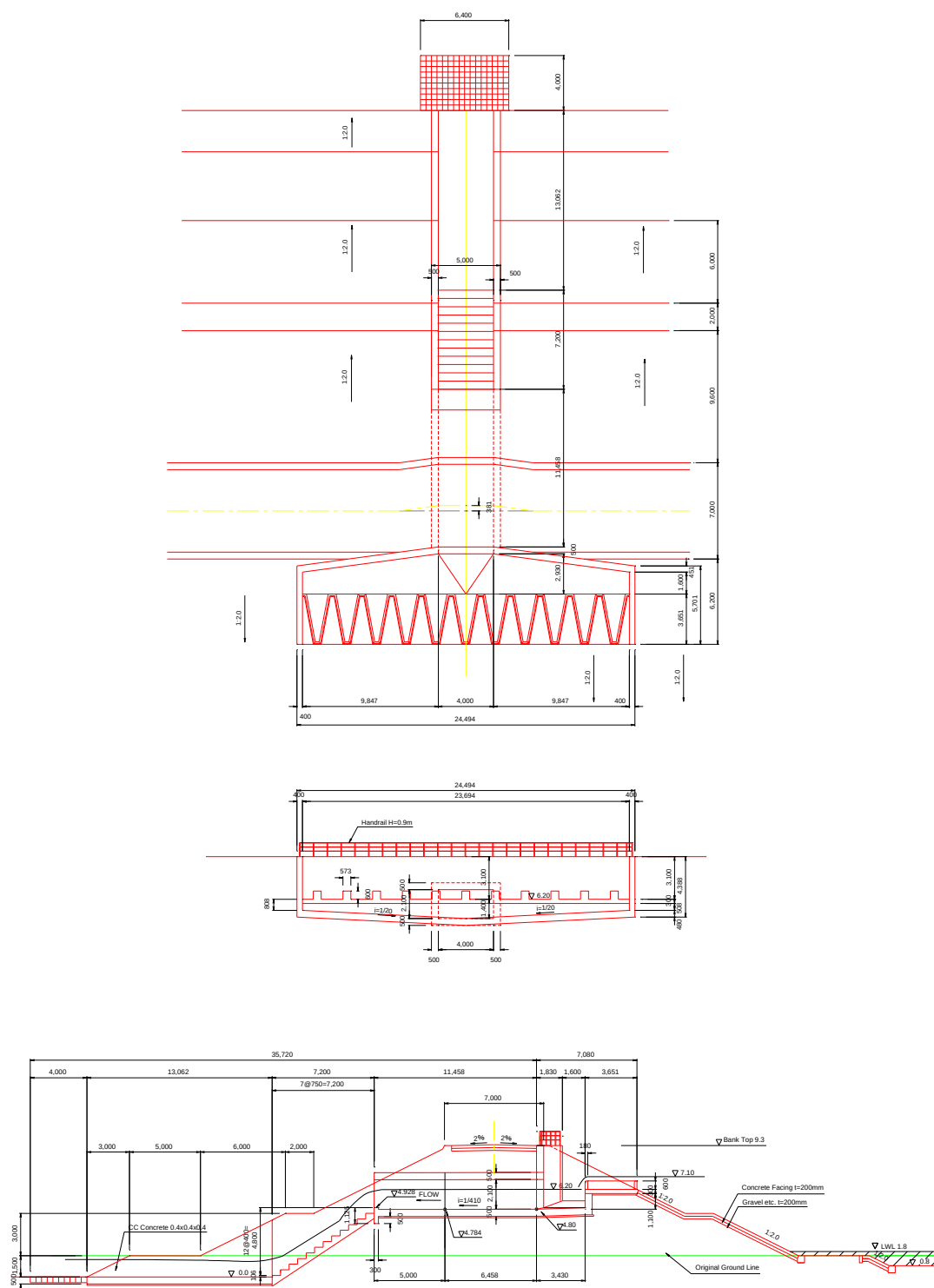
| Item                    | Qd<br>(m <sup>3</sup> /s) | B<br>(m) | Hwc<br>(m) | d<br>(m) | l<br>(m) | (a)<br>(m) | Hwc > (a) | Remarks |
|-------------------------|---------------------------|----------|------------|----------|----------|------------|-----------|---------|
| No.1 and No.2 Reservoir | 19.26                     | 4.00     | 1.332      | 0.40     | 0.60     | 0.300      | OK        |         |
| No.1 and No.2 Reservoir | 46.94                     | 5.00     | 2.087      | 0.50     | 0.75     | 0.375      | OK        |         |

Note:  $(a) = (1.06 - 0.465 \frac{d}{l}) \times d$

Source: JICA Survey Team

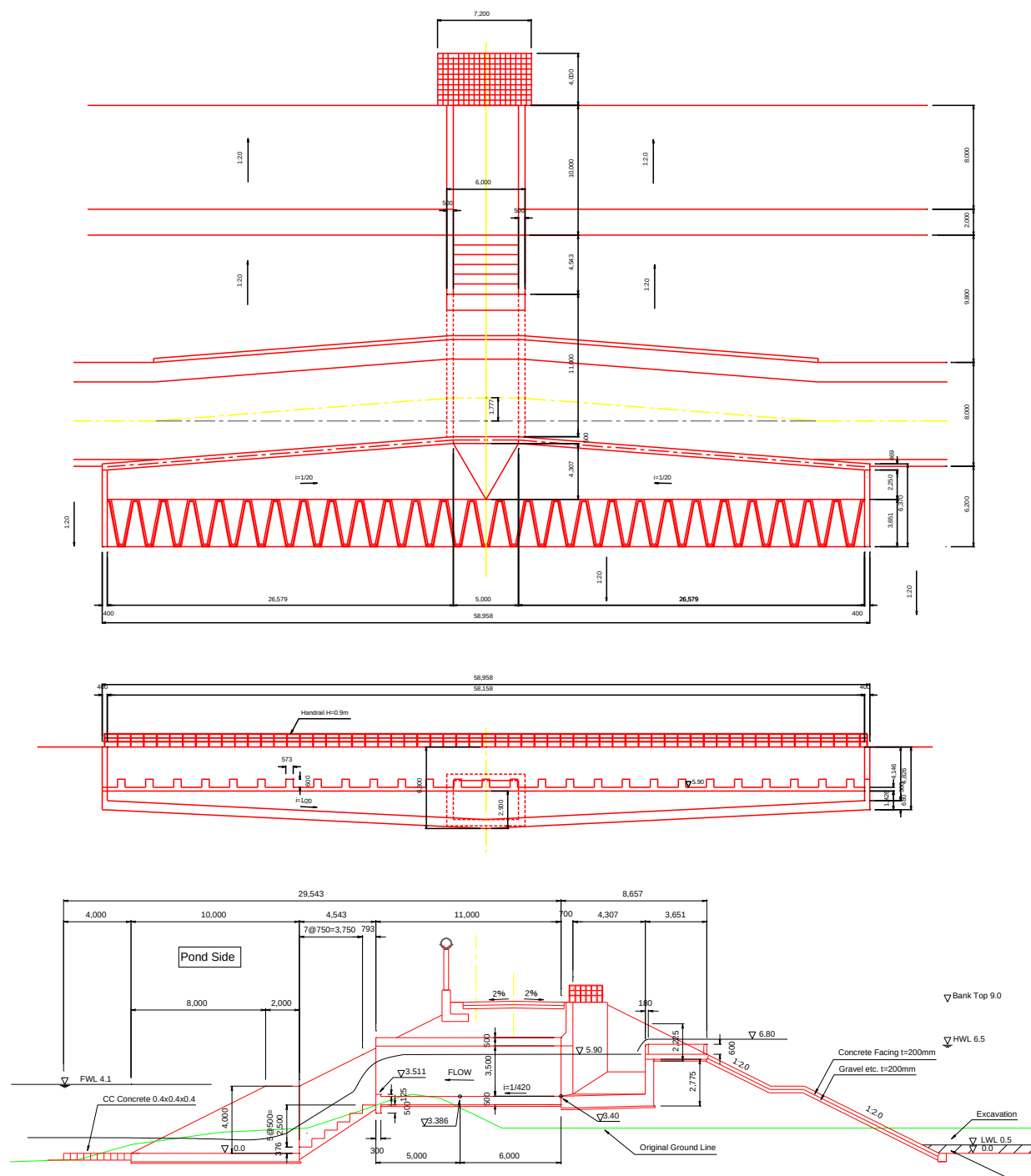
## 4.5 Spillway Feature

Until previous section, 2 spillways; No.1 & No.2, and No.3 & No.4 are designed and these main features are shown in Figure 4.5.1 and 4.5.2.



Source: JICA Survey Team

**Figure 4.5.1 Spillway of No.1 and No.2**



Source: JICA Survey Team

Figure 4.5.2 Spillway of No.3 and No.4

## CHAPTER 5 STABILITY ANALYSIS FOR RESERVOIR

### EMBANKMENT BY SLIP CIRCLE METHOD

#### 5.1 Purpose and Condition

Stability analysis is carried out by slip-circle method. Typical one sections is analyzed.

The purpose of this stability analysis is to confirm the safety of the weak foundation for the raw water reservoir embankment. Design condition of the stability analysis is set as follows;

- Geological conditions are obtained by N-value of bore holes, the results of soil test and site investigations.
- Required Safety factor is more than 1.2.
- As soil condition is not good from some geological test results, the layer of mechanical improved soil is set if necessary.
- Stability analysis by slip-circle method basically follows “Guideline Manual for Land Improvement Project “Pond Development”, Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries”.
- Slip lines that slide only the embankment body are not covered because the purpose of this stability analysis is to confirm the foundation stability.

#### 5.2 Slip-Circle Method

Embankment safety is evaluated by the safety factor. Safety factor can be estimate by the following equation.

Minimum safety factor against slope failure calculated by the slip-circle method:

$$SF = \frac{\Sigma\{CL + (N - U)\tan \phi\}}{\Sigma(T)}$$

Where,

SF : Safety factor

N : Normal forces acting on slip circle of each slice (kN/m)

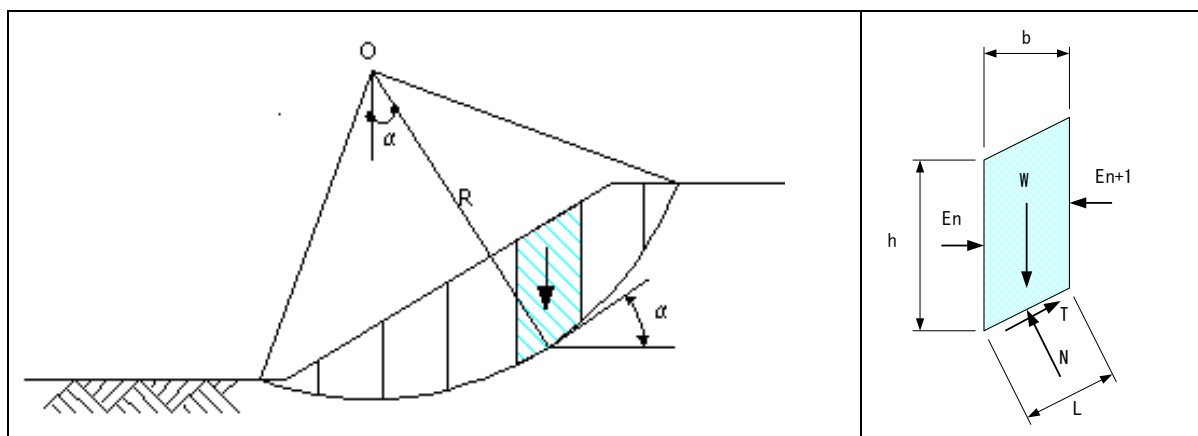
T : Tangential force acting on slip circle of each slice (kN/m)

U : Pore pressure acting slip circle of each slice (kN/m)

$\phi$  : Angle of internal friction of materials on slip circle of each slice (degree)

C : Cohesion of materials on slip circle of each slice (kN/m<sup>2</sup>)

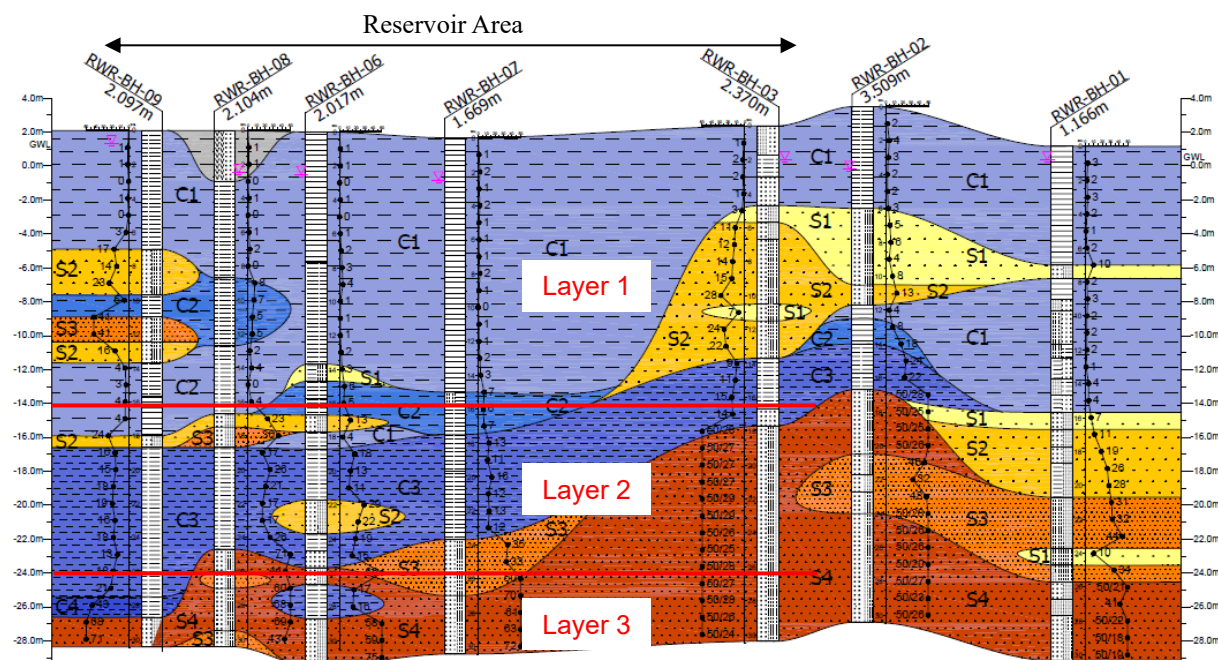
L : Arc length of circle of each slice (m)



Source: JICA Survey Team

Figure 5.2.1 Forces Acting on Each Slice

### 5.3 Modeled Cross Section for Analysis



Source: JICA Survey Team

Figure 5.3.1 Soil Profile in Reservoir

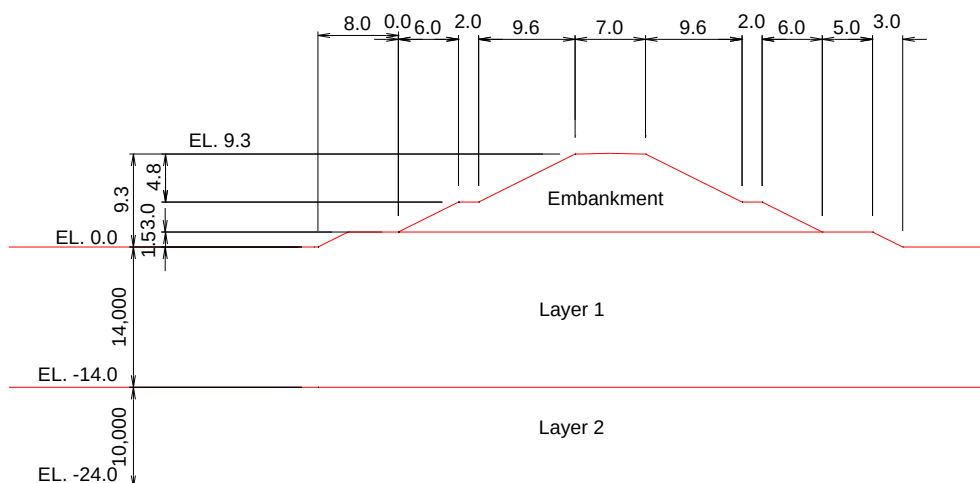
From the geological investigation results such as N values, soil test and soil profile, the soil foundation layer can be classified into 3 layer as indicated Table 5.3.1.

Table 5.3.1 Foundation Layer

| Layer No. | N-value      | Depth                  | Remarks   |
|-----------|--------------|------------------------|-----------|
| 1         | 1 to 6       | El. 2 to El. -14.0     |           |
| 2         | 7 to 26      | El. -14.0 to El. -24.0 |           |
| 3         | More than 35 | Less than El.-24.0     | Hard soil |

Source: JICA Survey Team

Under the analysis, Layer 3 can be hard soil or be deemed fixed area. Considered foundation layer is layer 1 and layer 2 only as shown in Figure 5.3.2



Source: JICA Survey Team

### Figure 5.3.2 Analysis section

## 5.4 Design Parameter

#### 5.4.1 Soil Design Parameter

From Bore hole RWR-BH-03, 06, 07, 08 and 09 that is in the raw water reservoir and a part of RWR-BH-02, the results of soil test; Table 5.4.1 is obtained.

**Table 5.4.1 Soil test results on each layer**

| Layer     | Depth (m) | Water Content, $w_n$ | Wet Density, $\gamma_t$ | Undrained Shear Strength Parameters(UU) |          | Drained Shear Strength Parameters(CU) |          |
|-----------|-----------|----------------------|-------------------------|-----------------------------------------|----------|---------------------------------------|----------|
|           |           |                      |                         | $c_u$                                   | $\phi_u$ | $c_d$                                 | $\phi_d$ |
|           |           | (%)                  | (kN/m <sup>3</sup> )    | (kPa)                                   | (deg.)   | (kPa)                                 | (deg.)   |
| Layer 1   |           |                      |                         |                                         |          |                                       |          |
| RWR-BH-06 |           |                      |                         |                                         |          |                                       |          |
| UD-03     | 9.0-10.0  | 36.49                | 17.65                   |                                         |          | 26.34                                 | 12.36    |
| RWR-BH-07 |           |                      |                         |                                         |          |                                       |          |
| UD-03     | 12.5-13.0 | 45.51                | 17.18                   |                                         |          | 10.67                                 | 35.19    |
| RWR-BH-08 |           |                      |                         |                                         |          |                                       |          |
| UD-02     | 4.0-5.0   | 43.3                 | 16.93                   |                                         |          | 13.05                                 | 19.40    |
| RWR-BH-09 |           |                      |                         |                                         |          |                                       |          |
| UD-01     | 2.0-3.0   | 38.74                | 18.10                   | 13.13                                   | 0        | 15.69                                 | 27.71    |
|           |           |                      |                         |                                         | Average  | 16.44                                 | 23.67    |
| Layer 2   |           |                      |                         |                                         |          |                                       |          |
| RWR-BH-02 |           |                      |                         |                                         |          |                                       |          |
| UD-05     | 13.5-14.0 | 30.42                |                         | 113.46                                  | 0        |                                       |          |
| RWR-BH-03 |           |                      |                         |                                         |          |                                       |          |
| UD-02     | 14.5-15.0 | 22.61                |                         |                                         |          | 24.46                                 | 19.67    |
| UD-03     | 15.5-16.0 | 21.04                | 17.54                   | 67.52                                   | 0        |                                       |          |
| RWR-BH-09 |           |                      |                         |                                         |          |                                       |          |
| UD-04     | 17.5-18.0 | 41.24                |                         | 40.62                                   | 0        |                                       |          |
|           |           |                      |                         |                                         |          |                                       |          |
|           |           |                      | Average                 | 73.8667                                 | 0        |                                       |          |

Source: JICA Survey Team

Design parameter is shown in Table .

**Table 5.4.2 Design Parameters for Soil Layer in Reservoir Area**

| Layer No.     | Wet Density          | Saturated Density    | C                    | $\phi$   | Source                            |
|---------------|----------------------|----------------------|----------------------|----------|-----------------------------------|
|               | (kN/m <sup>3</sup> ) | (kN/m <sup>3</sup> ) | (kN/m <sup>2</sup> ) | (Degree) |                                   |
| Embankment    | 18.0                 | 9.0                  | 0.0                  | 30.0     | Sand / <u>1</u>                   |
| Layer 1       | 17.33                | 8.33                 | 16.44                | 23.67    | From Soil test results mean value |
| Layer 2       | 17.54                | 8.54                 | 73.87                | 0.0      | From Soil test results mean value |
| Improved soil | 19.0                 | 10.0                 | 250.0                | 0.0      | / <u>2</u>                        |

Note: /1 Based on Guidelines of Earth Works of Wall, 2013, Japan road association, Japan/ 2 Standard allowable shear stress value based on Guidelines of flexible Sluiceway, Japan

Source: JICA Survey Team

**5.4.2 Active load**

Active load, vehicle load is affected on the embankment crest. Active load is 10kN/m on crest only. Active load is considered in normal case only in all case.

### 5.4.3 Water Level in embankment

Water level in embankment is bottom of embankment basically because embankment surface is covered with water proof sheet in case of normal time and flooding time.

## 5.5 Calculation case and results

### 5.5.1 Calculation Cases

Calculation cases and their condition are shown in Table 5.5.1.

**Table 5.5.1 Calculation Case**

| Case | Condition               | Seismic Condition | Water level (EL.) | Active load | Calculation slope |
|------|-------------------------|-------------------|-------------------|-------------|-------------------|
| 1    | Normal full water level | -                 | 6.5               | 100%        | Both side         |
| 2    | Seismic condition       | 100% (=0.2)       | 6.5               | -           | Both side         |
| 3    | Flooding                | -                 | 6.8               | -           | Reservoir side    |
| 4    | After just completion   | 50% (=0.1)        | 1.5               | -           | Reservoir side    |

Source: JICA Survey Team

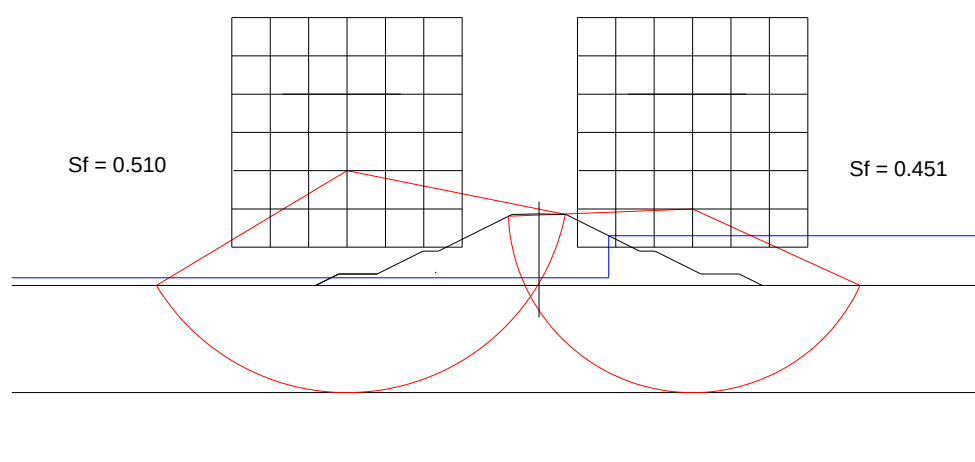
### 5.5.2 Stability Analysis of Original Embankment

At first, analysis the original condition without soil improvement is shown in Table 5.5.2 and Figure 5.5.1. its value is quite far from stable safety factor 1.2. It means that embankment need soil improvement in foundation.

**Table 5.5.2 Calculation results of original condition**

| Case            | Water level | Side  | Resistance Moment | Active Moment | Safety Factor |
|-----------------|-------------|-------|-------------------|---------------|---------------|
| 2   HWL Seismic | EL. 6.5     | Right | 24,090.1          | 53,381.7      | 0.451 < 1.2   |
| 2   HWL Seismic | EL. 6.5     | Left  | 37,332.8          | 73,181.8      | 0.510 < 1.2   |

Source: JICA Survey Team

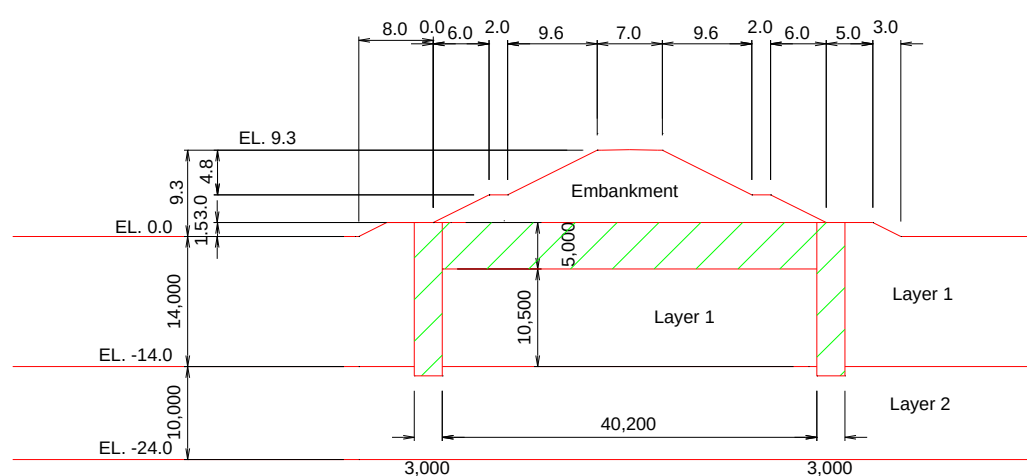


Source: JICA Survey Team

**Figure 5.5.1 Results of Original Condition****5.5.3 Stability Analysis by Modified section**

As section 5.5.2 indicates original section is quite far from stable section, embankment foundation needs soil improvement. Soil improvement can separate 2 methods mainly, namely 1) consolidation drain method or soil compaction method, and 2) soil mixing method. 1) construction cost is cheaper than 2). 2) of effect is higher than 1). 2) soil mixing method is selected as soil improvement method after try and error carried out as shown in Figure 5.5.2.

The embankment stability is kept by Figure 5.5.2 section through slip-circle method and Table 5.5.3.

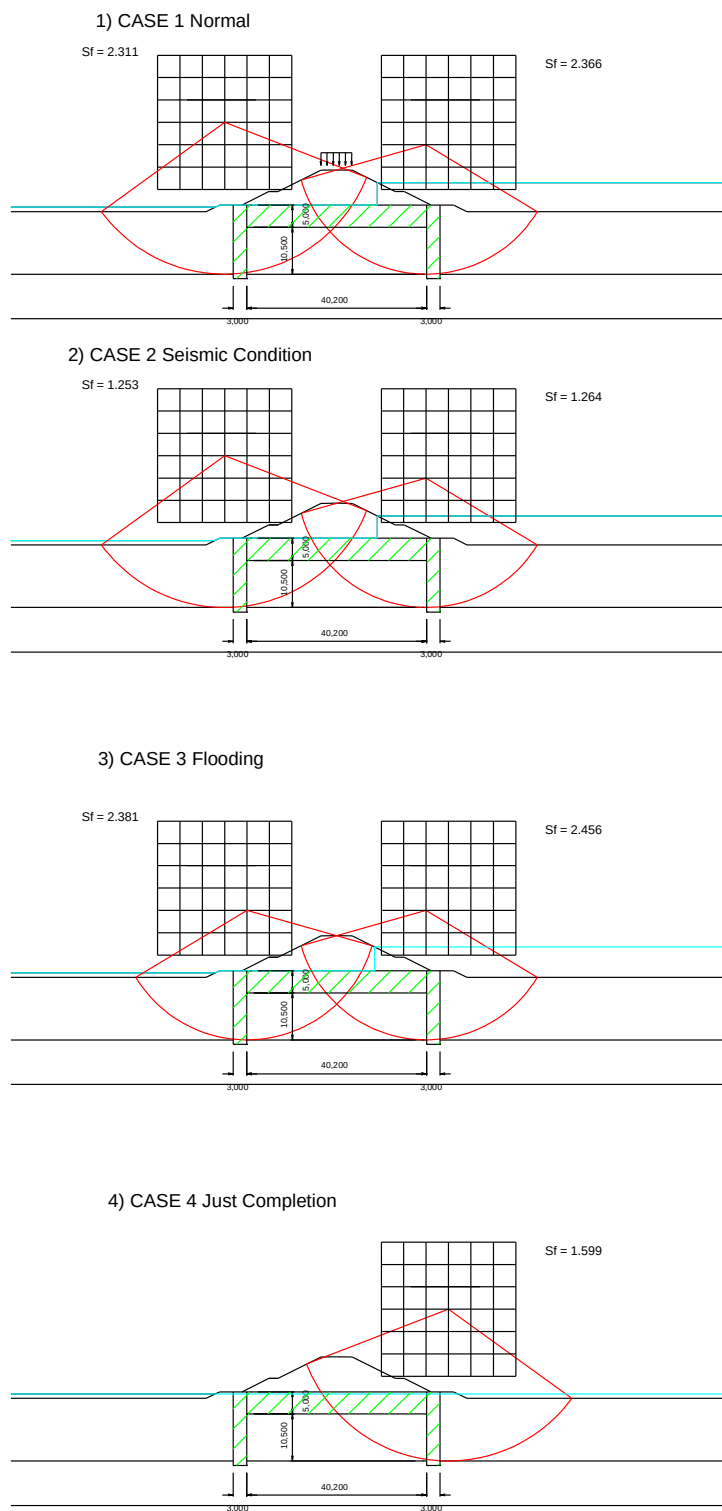


Source: JICA Survey Team

**Figure 5.5.2 Calculation results****Table 5.5.3 Calculation results of modified condition**

| Case |                       | Water level | Side  | Resistance Moment (kNm) | Active Moment (kNm) | Safety Factor  |
|------|-----------------------|-------------|-------|-------------------------|---------------------|----------------|
| 1    | HWL Normal            | EL. 6.5     | Right | 100,384.3               | 42,430.6            | 2.366 > 1.2 ok |
|      |                       | EL. 6.5     | Left  | 126,002.0               | 54,524.8            | 2.311 > 1.2 ok |
| 2    | HWL Seismic           | EL. 6.5     | Right | 96,639.7                | 76,438.2            | 1.264 > 1.2 ok |
|      |                       | EL. 6.5     | Left  | 122,018.3               | 97,354.9            | 1.253 > 1.2 ok |
| 3    | FWL Normal            | EL. 6.8     | Right | 99,155.7                | 40,379.8            | 2.456 > 1.2 ok |
|      |                       | EL. 6.8     | Left  | 106,946.5               | 44,914.1            | 2.381 > 1.2 ok |
| 4    | Just after Completion | EL. 1.0     | Right | 126,703.8               | 79,233.6            | 1.599 > 1.2 ok |

Source: JICA Survey Team



Source: JICA Survey Team

**Figure 5.5.3 Results of stability analysis**

#### **5.5.4 Soil Improvement**

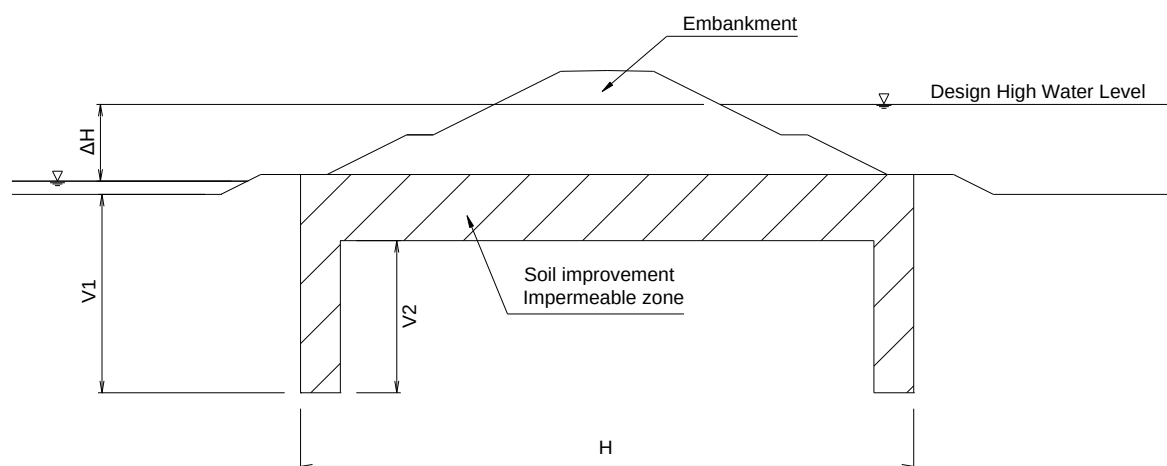
Soil improvements of soil mixing method are many methods by the contractors and materials. These method has some patents by the contractor and some mixing material are difficult to use by the fact that these materials are not in Bangladesh market or difficult to import or quite expensive.

Soil improve method in detail is necessary to be studied by detailed design stage based on sufficient geological data implement in detailed design stage. And soil improve method may be provided by performance base, not specification base in bidding document.

## CHAPTER B6 SEEPAGE AND SETTLEMENT

### 6.1 Seepage/Piping Analysis

For relatively impervious embankments, where seepage or piping is more likely to occur under the structure, seepage analysis according to the Lane's Creep Theory shall be conducted by Guideline Manual for Land Improvement Project "Head Works", Rural Development Bureau, Ministry of Agriculture, Forestry, and Fisheries.



Source: JICA Survey Team

**Figure 6.1.1 Model of Creep Distance**

$$C \leq \frac{(\sum H)/3 + \sum V}{\Delta H}$$

Where:

C : Creep Ratio (See table 6.1.1, =8.5)

H : Horizontal path length (m)

V : Vertical path length (m)

h : Hydraulic head or the difference between inside and outside water level(m)

**Table 6.1.1 Creep Ratio**

| Material                             | Ratio |
|--------------------------------------|-------|
| very fine sand or silt               | 8.5   |
| fine sand                            | 7.0   |
| medium sand                          | 6.0   |
| coarse sand                          | 5.0   |
| fine gravel                          | 4.0   |
| medium gravel                        | 3.5   |
| coarse gravel including cobbles      | 3.0   |
| boulders with some cobbles and grave | 2.5   |

| Material                  | Ratio |
|---------------------------|-------|
| soft clay                 | 3.0   |
| medium clay               | 2.0   |
| hard clay                 | 1.8   |
| very hard clay or hardpan | 1.6   |

Source: Design Guideline for Flexible Sluiceway 7.13 Shielding Wall Design

2 way; the reservoir to the river side and the river side to the reservoir are calculated and these calculation results shows Table 6.1.2.

From Table 6.1.2, it is confirmed that seepage is safety.

**Table 6.1.2 Seepage analysis by lane's creep theory**

| Flow Case                  | Reservoir to River | River to Reservoir | Remarks |
|----------------------------|--------------------|--------------------|---------|
| 1) $\Delta H$ (m)          | $6.8 - 0.0 = 6.8$  | $4.1 - 0.5 = 3.6$  |         |
| 2) $V1$ (m)                | 16.5               | 16.5               |         |
| 3) $V2$ (m)                | 11.5               | 11.5               |         |
| 4) $H$ (m)                 | 46.2               | 46.2               |         |
| 5) $C$                     | 8.5                | 8.5                |         |
| 6) $\Sigma H/3 + \Sigma V$ | 71.4               | 71.4               |         |
| 7) 6)/ 1)                  | 10.5               | 19.83              |         |
| 8) Evaluation              | 7) > 5) ok         | 7) > 5) ok         |         |

Source: JICA Survey Team

## 6.2 Salt water intrusion to reservoir

As adjacent river to the reservoir is brackish water region, it is concerned that salty water enters the reservoir that is quite harmful for drinking water. However, salty water is difficult to enter the reservoir by the following reasons

- Water elevation El. 0.5 to 6.5 in the reservoir is higher than river water level MSL.0.0 that is mean river water level.
- As embankment is covered with water proof sheet, the water from the river to the reservoir cannot enter.
- In case that the river salty water to the reservoir through foundation reaches the bottom of the reservoir. However, it is difficult for the salty water to penetrate the reservoir due to gentle hydraulic gradient by soil improvement column and difference in specific density between salt water and fresh water.

## 6.3 Consolidation Settlement

Consolidation settlement is examined on the basis of the result of soil investigation by BNBC 2020, Part VI, 3.10.5, equation 6.3.39:

$$S_c = \frac{C_c H}{1+e_0} \log \frac{\sigma'_0 + \sigma'_p}{\sigma'_0}$$

Where,

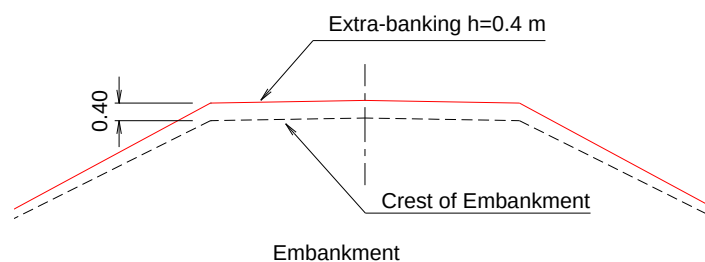
- $S_c$  : Total consolidation settlement (m)  
 $C_c$  : Compression index of soil  
 $H$  : Thickness of compressive layer (m)  
 $e_0$  : Initial void ratio  
 $\sigma'_0$  : Initial effective stress of midpoint of the layer (m<sup>2</sup>/kN)  
 $\sigma'_p$  : increase in effective stress of midpoint of the layer due to embankment (m<sup>2</sup>/kN)

**Table 6.3.1 Consolidation settlement**

| Item           |                                                    | Remarks               |
|----------------|----------------------------------------------------|-----------------------|
| 1) $C_c$       | 0.37                                               | From soil test result |
| 2) $e_0$       | 1.06                                               | From soil test result |
| 3) $H$         | 20.5 m                                             | EL. -3.5 to EL. -24.0 |
| 4) $\sigma'_0$ | $15.25 \times 17.33 = 264.28$<br>kN/m <sup>2</sup> |                       |
| 5) $\sigma'_p$ | $9.3 \times 19 = 176.70$ kN/m <sup>2</sup>         |                       |
| 6) $S_c$       | 0.819 m                                            |                       |

Source: JICA Survey Team

Total consolidation settlement 0.82 m is estimated. However, usually half of 0.82 m consolidation settlement is done during construction. 0.40m extra-banking is considered in embankment as shown in Figure 6.3.1.



Source: JICA Survey Team

**Figure 6.3.1 Extra-Banking**

## 6.4 Liquefaction

The study procedure of liquefaction is same as section 2.10.1. however, only Level 1 for liquefaction is studied because reservoir embankment is mainly soil that is easy recovery and small damage even if liquefaction occurs.

Step 1 of liquefaction for RWR-BH-03, 06, 07, 08, and 09 is examined for 27 samples as shown in Table 6.4.1.

Table 6.4.1 Layer Selection by Step 1

| Boring No. | Depth          | Water Depth (EL. m) | Fc (%) | IP    | D50 (mm) | D10 (mm) | Evaluation  |           |             | Selection |
|------------|----------------|---------------------|--------|-------|----------|----------|-------------|-----------|-------------|-----------|
|            |                |                     |        |       |          |          | Water Depth | FC and IP | D50 and D10 |           |
| RWR-BH-03  |                |                     |        |       |          |          |             |           |             |           |
|            | 2.50 to 3.00   | -2.6                | 98.56  | 25.20 | 0.007    | <0.0013  | ○           | x         | ○           | x         |
|            | 15.50 to 16.00 | -2.6                | 96.64  | 20.95 | 0.035    | <0.0013  | ○           | x         | ○           | x         |
| RWR-BH-06  |                |                     |        |       |          |          |             |           |             |           |
|            | 3.00 to 3.45   | -2.5                | 99.26  | 28.67 | 0.006    | <0.0013  | ○           | x         | ○           | x         |
|            | 4.00 to 5.00   | -2.5                | 97.36  | 25.32 | 0.008    | <0.0013  | ○           | x         | ○           | x         |
|            | 6.00 to 7.00   | -2.5                | 98.96  | 34.16 | 0.006    | <0.0013  | ○           | x         | ○           | x         |
|            | 9.00 to 10.00  | -2.5                | 98.06  | 19.82 | 0.010    | <0.0013  | ○           | x         | ○           | x         |
|            | 12.00 to 12.45 | -2.5                | 89.22  | 14.39 | 0.032    | <0.0013  | ○           | ○         | ○           | ○         |
|            | 20.00 to 20.45 | -2.5                | 84.10  | 12.51 | 0.022    | <0.0013  | ○           | ○         | ○           | ○/1       |
| RWR-BH-07  |                |                     |        |       |          |          |             |           |             |           |
|            | 2.50 to 3.00   | -2.5                | 99.68  | 25.52 | 0.006    | <0.0013  | ○           | x         | ○           | x         |
|            | 4.50 to 5.00   | -2.5                | 99.70  | 26.60 | 0.005    | <0.0013  | ○           | x         | ○           | x         |
|            | 8.00 to 8.45   | -2.5                | 97.12  | 29.42 | 0.007    | <0.0013  | ○           | x         | ○           | x         |
|            | 12.50 to 13.00 | -2.5                | 99.64  | 27.03 | 0.006    | <0.0013  | ○           | x         | ○           | x         |
|            | 14.50 to 15.00 | -2.5                | 96.94  | 25.84 | 0.005    | <0.0013  | ○           | x         | ○           | x         |
|            | 17.00 to 17.45 | -2.5                | 94.42  | 12.60 | 0.006    | <0.0013  | ○           | ○         | ○           | ○         |
|            | 22.00 to 22.45 | -2.5                | 88.70  | 18.83 | 0.016    | <0.0013  | ○           | x         | ○           | x         |
| RWR-BH-08  |                |                     |        |       |          |          |             |           |             |           |
|            | 2.00 to 3.00   | -2.5                | 96.36  | 50.63 | 0.007    | <0.0013  | ○           | x         | ○           | x         |
|            | 4.00 to 5.00   | -2.5                | 98.30  | 23.17 | 0.014    | <0.0013  | ○           | x         | ○           | x         |
|            | 7.00 to 8.00   | -2.5                | 98.28  | 20.65 | 0.014    | <0.0013  | ○           | x         | ○           | x         |
|            | 10.00 to 11.00 | -2.5                | 97.04  | 15.43 | 0.029    | <0.0013  | ○           | x         | ○           | x         |
|            | 13.00 to 13.45 | -2.5                | 93.16  | 20.14 | 0.012    | <0.0013  | ○           | x         | ○           | x         |
|            | 20.00 to 20.45 | -2.5                | 85.90  | 10.84 | 0.039    | <0.0013  | ○           | ○         | ○           | ○/1       |
| RWR-BH-09  |                |                     |        |       |          |          |             |           |             |           |
|            | 2.50 to 3.00   | -0.8                | 99.48  | 24.26 | 0.005    | <0.0013  | ○           | x         | ○           | x         |
|            | 6.50 to 7.00   | -0.8                | 89.26  | 16.43 | 0.012    | <0.0013  | ○           | x         | ○           | x         |
|            | 105.0 to 11.00 | -0.8                | 99.72  | 21.56 | 0.007    | <0.0013  | ○           | x         | ○           | x         |
|            | 15.00 to 15.45 | -0.8                | 99.28  | 22.89 | 0.005    | <0.0013  | ○           | x         | ○           | x         |
|            | 17.50 to 18.00 | -0.8                | 97.76  | 25.40 | 0.007    | <0.0013  | ○           | x         | ○           | x         |
|            | 22.00 to 22.45 | -0.8                | 98.26  | 20.06 | 0.007    | <0.0013  | ○           | x         | ○           | x         |

Note:/1 As its layer depth is more than 20 m, this layer is just reference while the adaptable layer for liquefaction is depth less than 20 m.

Source: JICA Survey Team

Step 2 for selected layer is calculated as shown in Table 6.4.2.

**Table 6.4.2 Liquefaction Calculation by Step 2**

| Boring No.        | RWR-BH-06                        |                  | RWR-BH-07        | RWR-BH-08        | Remarks   |
|-------------------|----------------------------------|------------------|------------------|------------------|-----------|
|                   | 12.0-12.45                       | 20.0-20.45       | 17.0-17.45       | 20.0-20.45       |           |
| x                 | 15.5                             | 20.2             | 17.2             | 20.2             |           |
| Water Depth Hw    | 1.2                              | 2.5              | 2.5              | 2.5              |           |
| N value           | 1                                | 13               | 7                | 26               |           |
| FC(%)             | 89.22                            | 84.10            | 94.42            | 85.90            |           |
| Bulk Density      | 16.65                            | 16.65            | 17.20            | 16.93            |           |
| Submerged Density | 7.65                             | 7.65             | 8.2              | 7.93             |           |
| C1                | 3.461                            | 3.205            | 3.721            | 3.295            |           |
| C2                | 4.401                            | 4.117            | 4.690            | 4.217            |           |
| Rd                | 0.768                            | 0.697            | 0.742            | 0.697            |           |
| $\sigma'_v$       | 129.375                          | 177.03           | 163.54           | 182.686          |           |
| N1                | 0.518                            | 5.439            | 3.253            | 10.729           |           |
| Na                | 6.195                            | 21.548           | 16.794           | 39.567           |           |
| RL                | 0.17                             | 0.33             | 0.28             | 3.88             |           |
| $\sigma_v$        | 258.075                          | 336.33           | 295.84           | 341.986          |           |
| Level 1           |                                  |                  |                  |                  |           |
| Kh                | 0.15                             | 0.15             | 0.15             | 0.15             |           |
| L                 | 0.23                             | 0.20             | 0.20             | 0.20             |           |
| R                 | 0.17                             | 0.33             | 0.28             | 3.88             |           |
| FL                | 0.73                             | 1.65             | 1.38             | 19.84            | FL > 1 ok |
| Selection/Remarks | High<br>liquefiable<br>potential | Not<br>available | Not<br>available | Not<br>available |           |

Source: JICA Survey Team

As per this calculation, liquefaction at Layer 12.0-12.45 in RWR-BH-06 is occurred in high possibility on Level 1. However, countermeasure is not considered or topical treatment even if implementing the countermeasure for this layer by the following reasons

- High potential layer is only one layer (1 sample) and thin thickness under 23 samples being checked. Therefore, its liquefaction is quite local phenomenon.
- This layer is not shallow layer
- . Even occurring the liquefaction in reservoir bottom that is almost area of reservoir area, it is not damaged for reservoir function.

## CHAPTER B7 SEDIMENTATION OF RESERVOIR

### 7.1 Sediment at Raw Water Reservoir

From main report chapter 5, wash load sediment comes from intake site 10,800t/year

It is assumed that the wash load is trapped in first reservoir; No.1 and No.2.

Sediment yield or volume is quite fluctuated by river flow volume and/or year. Therefore, safety factor is considered. Estimated sediment removing frequency is shown in Table 7.1.1.

**Table 7.1.1 Sediment moving frequency.**

| Item                                 | Value                  | Remarks                   |
|--------------------------------------|------------------------|---------------------------|
| 1) Income sediment weight            | 10,800 t               |                           |
| 2) Income sediment volume            | 6,360 m <sup>3</sup>   | 1.7t/m <sup>3</sup>       |
| 3) Water reservoir sediment capacity | 810,000 m <sup>3</sup> |                           |
| 4) Safety factor                     | 5.0                    |                           |
| 5) sediment removing frequency       | 25.5 year/time         | $5) = 3) / (2) \times 4)$ |

Source: JICA Survey Team

As the results of calculation, 25.5year/time is obtained, however, finally the reservoir sediment capacity will be determined by the comparison with embankment sediment capacity height cost of embankment and sediment removing cost on detailed design stage.