JAPAN INTERNATIONAL COOPERATION AGENCY

CENTRO DE REHABILITACION DE MANABI (CRM)
THE REPUBLIC OF ECUADOR

THE DETAILED DESIGN STUDY ON THE WATER TRANSMISSION SCHEMES FOR CHONE-PORTOVIEJO RIVER BASINS

FINAL REPORT
VOLUME III
MAIN REPORT
(ANNEX I)

1.DESIGN CRITERIA
2.HYDROLOGICAL STUDY
3.WATER TRANSMISSION PLAN

MARCH [illegible]

NIPPON KOEI CO., LTD.
TOKYO, JAPAN

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FINAL REPORT

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FINAL REPORT

MAIN REPORT - GENERAL CONTENTS

ABBREVIATION

Ecuadorian Institutions

CEDEGE	:	Committee for Guayas River Basin Development
CETUR	:	Ecuadorian Corporation for Tourism
CLIRSEN	:	Integrated Center for Remote Sensing Survey
CONADE	:	National Development Council
CPC	:	Chamber of Shrimp Producer
CRM	:	Manabi Rehabilitation Center
DIGMER	:	Directorate General of Merchant Marine
DINAC	:	National Directorate of Valuation and Cadastre
DINAF	:	National Directorate of Forestry
DITURIS	:	Directorate of Tourism
EMAPAM	:	Municipal Enterprise of Potable Water and Sewerage of Manta
ESPOL	:	Polytechnic Littoral College
GOE	:	Government of Ecuador
IEOS	:	Ecuadorian Institute of Sanitary Works
IERAC	:	Ecuadorian Institute for Agrarian Reform
IGM	:	Geographic Military Institute
INAMHI	:	National Institute of Meteorology and Hydrology
INEC	:	National Institute of Statistics and Census
INECEL	:	Ecuadorian Institute for Electrification
INEFAN	:	Ecuadorian Institute of Forestry and Natural Areas
INEN	:	Ecuadorian Institute of Standards
INERHI	:	Ecuadorian Institute of Water Resources
INIAP	:	Institute of Agricultural Investigations
INOCAR	:	Military Oceanographic Institute
JRH	:	Jipijapa and Pajan Board of Water Resources
MAG	:	Ministry of Agriculture and Livestock
MICIP	:	Ministry of Industry, Commerce, Integration and Fishery
MOP	:	Ministry of Public Works and Communications
PFI	:	Institutional Reinforcement Planning Unit of CRM

PHIMA	:	Integrated Water Resources Development Plan of Manabi
PMRC	:	Management Program of Coastal Resources

International or Foreign Institutions

ACI	:	American Concrete Institute
ASCE	:	American Society of Civil Engineers
ASTM	:	American Society for Testing and Materials
CAF	:	Corporación Andina de Fomento
CEPIS	:	Panamerican Center for Sanitary Engineering and the Environment
CIDIAT	:	Interamerican Center for Integrated Development of Water and Land
FAO	:	Food and Agriculture Organization of the United Nations
IDB/BID	:	Interamerican Development Bank
IEC	:	International Electrotechnical Commission
JEC	:	Japanese Electrotechnical Committee
JICA	:	Japan International Cooperation Agency
JIS	:	Japanese Industrial Standards
OAS/OEA	:	Organization of American States
OECF	:	Overseas Economic Cooperation Fund of Japan
SCS	:	Soil Conservation Service of USDA
UNDP	:	United Nations Development Program
USA	:	United States of America
USAID	:	United States Agency for International Development
USDA	:	United States Department of Agriculture
WHO	:	World Health Organization of the United Nations

Technical Terms

A.C.	:	Alternating Current
ACSR	:	Aluminum Cable Steel Reinforced
BOD	:	Biochemical Oxygen Demand
COD	:	Chemical Oxygen Demand

D.C.	:	Direct Current
DO	:	Dissolved Oxygen
EC/CE	:	Electrical Conductivity
EIA	:	Environmental Impact Assessment
EMMP	:	Environmental Management and Monitoring Plan
FEM	:	Finite Element Method
F.M.	:	Finess Modulus
F/S	:	Feasibility Study
FWL	:	Flood Water Level
GPS	:	Global Positioning System
H	:	Horizontal
HWL	:	High Water Level
IEE	:	Initial Environmental Examination
IPM	:	Integrated Pest Management
LACAT	:	Program for Warm Tropical Lakes
LWL	:	Low Water Level
MOL	:	Minimum Operating Level
NATM	:	New Austrian Tunneling Method
PLC	:	Power Line Carrier
RWL	:	Reservoir Water Level
SPT	:	Standard Penetration Test
ST	:	Station
T-N	:	Total Nitrogen
T-P	:	Total Phosphorus
TRMS	:	Transbasin and Reservoir Management System
TSS	:	Total Suspended Solid
V	:	Vertical
ZEM	:	Special Zone for Management

Economic Terms and Others

CIF	:	Cost Insurance and Freight

EIRR	:	Economic Internal Rate of Return
FC	:	Foreign Currency
FIRR	:	Financial Internal Rate of Return
FOB	:	Free on Board
GDP	:	Gross Domestic Product
GRP	:	Gross Regional Product
IVA	:	Sales Tax or Value Added Tax
LC	:	Local Currency
NGO/ONG	:	Non Governmental Organization

ABBREVIATION OF MEASURES

Length

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre
masl	=	metre above sea level
EL.	=	elevation

Area

ha	=	hectare
m^2	=	square metre
km^2	=	square kilometre

Volume

l, lit	=	litre
Kl, Klit	=	kilolitre
l/s	=	litre per second
m^3	=	cubic metre
m^3/s, cms	=	cubic metre per second
m^3/min	=	cubic metre per minute
m^3/hr	=	cubic metre per hour
MCM, mcm	=	million cubic metre
m^3/d, cmd	=	cubic metre per day

Weight

mg	=	milligram
mg/l	=	milligram per litre
meq/l	=	milli-equivalent per litre
g	=	gram
kg	=	kilogram
t, ton	=	ton
t/y	=	ton per year
MT	=	metric ton

Time

sec	=	second
min	=	minute
hr, HR	=	hour
d	=	day
yr	=	year

Money

S/.	=	Ecuadorian Sucres
¥	=	Japanese Yen
US$	=	U. S. Dollars

Energy

Kcal	=	Kilocalorie
KW, Kw	=	kilowatt
MW, Mw	=	megawatt
KWh, Kwh	=	kilowatt-hour
GWh, Gwh	=	gigawatt-hour
V	=	volt
KV	=	kilovolt
KVA	=	kilovolt ampere
MVA	=	megavolt ampere
Hz	=	Hertz

Others

%	=	percent
°	=	degree
'	=	minute
"	=	second
°C	=	degree Celsius
MD, md	=	man-day
mil.	=	million
NO. Nos	=	number
pers.	=	person
Umho	=	micromho
ppt	=	parts per thousand
ppm	=	parts per million
ppb	=	parts per billion
l/h/d	=	litre per person per day
g/c/d	=	gram per capita per day
LS	=	lump sum
MPN	=	most probable numbers
O&M	=	Operation and Maintenance
p.a.	=	per annum
rpm	=	revolutions per minutes

ANNEX 1

DESIGN CRITERIA

THE DETAILED DESIGN
ON
THE WATER TRANSBASIN SCHEMES
FOR
CHONE-PORTOVIEJO RIVER BASINS

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1. CIVIL WORKS

1.1 General

1.1.1 Introduction

This design criteria aims to present the design concept, the design conditions and procedures to be applied in the basic and detailed design of the civil works for the Water Transbasin Schemes for Chone-Portoviejo River Basins. It also presents the standard procedures and methods for making design calculations to be executed in more effective and time saving.

This report covers;

(1) Waterway
- (i) Diversion Tunnels
- (ii) Head Tank
- (iii) Severino Open Channel with Siphons and Inspection Roads
- (iv) Inlet and Outlet of Diversion Tunnel

(2) Severino Pumping Station and Penstock Pipe

(3) Access Road

(4) Hydromechanical Equipment

(5) Electrical Equipment,

(6) Transmission Line

1.1.2 Standard to be Applied

The standard to be applied to the civil works are basically the ASTM, AASHTO, JIS, Bureau of Reclamation/United States, Department of the Interior, etc.

1.2 Design Data

The design values to be used for the design of structures are listed hereinafter, however they are subject to change if otherwise specified in the drawing or directed by the Engineer

1.2.1 Dead Load

	Material		Unit weight (tf/m^3)
1.	Concrete, reinforced		2.4
2.	Concrete, plain		2.3
3.	Concrete, cement mortar		2.0
4.	Reinforced steel bar		7.85
5.	Rolled structural steel		7.85
6.	Embankment, or backfill materials		1.65
	Rock	(wet)	1.7 ~ 1.9
		(saturated)	1.8 ~ 2.0
	Sand and gravel	(wet)	1.8
		(saturated)	2.0
	Earth	(wet)	1.8
		(saturated)	2.0
	Random	(wet)	1.8
		(saturated)	2.0
7.	Water		1.0

1.2.2 Earthquake Force

Earthquake force acting on the structure is calculated by the following formula:

$$K = Kh \cdot G$$

Where,
- K : horizontal force in ton
- G : dead load of structure in ton
- Kh : earthquake coefficient (= 0.15)

1.2.3 Wind Load

Wind load is assumed to work on towers of transmission line.

1.2.4 Physical Value of Material

(1) Internal Friction Angle and Cohesion

		Internal friction angle (degree)	MaterialCohesion (tf/m^2)
1.	Embankment		
	Rock or sand & gravel	35	0
	Earth	30	2
2.	Backfilling		
	Free drain backfill	35	0
	Random backfill	25	0

(2) Friction Coefficient

	Material	Friction Coefficient
1.	Concrete to concrete	0.65
2.	Concrete to fresh rock	0.65
3.	Concrete to weathered rock	0.50
4.	Concrete to earth or sand and gravel	0.40

(3) Coefficient of Elasticity

(i) Reinforcement calculation

Modulus of elasticity, concrete	$Ec = 1.4 \times 10^5$ kgf/cm^2
Modulus of elasticity, steel	$Es = 2.1 \times 10^6$ kgf/cm^2
Modulus ratio	n (= Es/Ec) = 15

(ii) Analysis of elastic deflection and internal force

	Concrete			Steel	
f28 (kgf/cm^2)	Ec (10^5kgf/cm^2)	Gc (10^5kgf/cm^2)	υ	Es (10^6kgf/cm^2)	n
210	2.35	1.00	0.2	2.1	8.94

Where, f28 : compressive strength of 28-day age

Gc : modulus of rigidity; $Gc = Ec/2\,(1 + \upsilon)$

υ : Poisson's ratio

1.2.5 Design Stress

(1) Design Stress

(i) Concrete

Class of Concrete	Compressive Strength (kgf/cm^2)
A	250
B	210
C	210
D	210
E	180
F	210
G	140
H	140
Shotcrete	210

(iii) Steel

Yield tensile stress : 4,200 kgf/cm^2

(iii) Foundation

Condition	Bearing Capacity (tf/cm^2)
1. Earth	10
2. Sand & gravel	30
3. Weathered rock	50
4. Rock	Depending on geotechnical condition

1.2.6 Safety Factor of Stability

Loading Condition	Sliding	Overturning
1. Normal	4.0	1.2 (middle third)
2. Extreme	2.0	1.1 (middle third)

1.2.7 Roughness Coefficient

Material	Structure	Roughness coefficient
1. Concrete	Waterway	0.014
2. Steel	Penstock	0.012
3. Earth	River channel	0.030-0.035

1.2.8 Slope of Cut and Embankment

(1) Slope of Open Cut

Material	Slope	Description
1. Fresh Rock	1:0.5	for permanent slope without slope protection
	1:0.3	for permanent slope with slope protection or temporary or backfilled slope
2. Weathered Rock	1:0.5	for permanent slope with slope protection
	1:0.8	for permanent slope without slope protection
	1:0.5	for temporary or backfilled slope
3. Common	1:1.0	for permanent slope
	1:0.5	for temporary or backfilled slope

Note: A berm of 1.5 m. wide shall be provided at 7.5 or 8.0 intervals in height in cut slope.

(2) Slope of Embankment

Material	Slope
1. Earth, Selected	1: 0.5
2. Earth, Random	1: 1.8
3. Common	1: 2.0

Note: A berm of 2.0 m. wide shall be provided at 5.0 m. intervals in height in embankment slope.

1.3 Basic Design Concept

1.3.1 Waterway

Waterway is composed of diversion tunnels, Severino head tank and Severino open channel to divert the water from Daule-Peripa reservoir to La Esperanza and Poza Honda reservoirs.

(i) Daule-Peripa ~ La Esperanza Diversion Tunnel
(ii) Severino Head Tank
(iii) Severino Open Channel
(iv) La Esperanza ~ Poza Honda Diversion Tunnel
(v) Poza Honda ~ Mancha Grande Diversion Tunnel

(1) Diversion Tunnels

(a) Economic Diameter

Head loss of the diversion tunnels depends on their diameters. As diameter are enlarged, head loss is decreased. On the other hand, the enlargement of diameter of them increases their construction costs.

The optimal diameter of each diversion tunnel is defined as one having the minimum sum of the annualized value of cost and annualized value of water supply benefit. Then, the optimal diameter is examined by comparison of annualized cost and benefit.

(b) Alignment

The alignments of the diversion tunnels are designed to connect the inlets and outlets by the shortest route, considering topographic and geological conditions.

(c) Type

The diversion tunnels are of non-pressure type forming the horseshoe shape.

(d) Rock supporting system

The supporting system surrounding the diversion tunnels are designed taking into account the geological investigation and tunnel structural analysis results.

(e) Structural design

The diversion tunnel is lined with concrete. The concrete lining should endure internal water pressure and external pressure.

(2) Severino Head Tank

Severino head tank is located at 150m south of proposed Severino pump house, beginning point of Severino open channel. The head tank is connected to penstock end, so as not to affected high velocity flow from the penstock. The location of head tank is examined considering hydraulic requirement and the geological and topographic conditions as well as structural features in the detailed design.

(3) Severino Open Channel

A 6.4 km long open channel having trapezoidal section of concrete lining, connects the head tank to Caña Dulce inlet (inlet of La Esperanza ~ Poza Honda diversion tunnel located at Caña Dulce) along the gently undulated land. This open channel transports the maximum discharge of $16m^3$/sec to Poza Honda reservoir.

Five (5) shipons are identified on the whole Severino open channel route.

Inspection road is provided on the mountain side of the open channel. This road has functions of inspecting a condition of transbasin flow in the open channel and repairing for its facilities.

(4) Inlets and Outlets of Diversion Tunnels

Inlets and outlets are provided at following locations. Those inlets and outlets of the diversion tunnels consist of gate, stoplog, valve, approach, retaining wall, etc.

(i) Conguillo inlet : Inlet of Daule-Peripa ~ La Esperanza diversion tunnel located on Conguillo river in Daule-Peripa reservoir.

(ii) Membrillo outlet : Outlet of Daule-Peripa ~ La Esperanza diversion tunnel located on Membrillo river in La Esperanza reservoir.

(iii) Caña Dulce inlet : Inlet of La Esperanza ~ Poza Honda diversion tunnel located at Caña Dulce.

(iv) Los Cuyuyes outlet : Outlet of La Esperanza ~ Poza Honda diversion tunnel located upper reach of Poza Honda reservoir.

(v) Poza Honda inlet : Inlet of Poza Honda ~ Mancha Grande diversion tunnel in Poza Honda reservoir.

(vi) Mancha Grande outlet : Outlet of Poza Honda ~ Mancha Grande diversion tunnel located at Mancha Grande river.

1.3.2 Severino Pumping Station

Proposed Severino Pumping Station is located at 10 km southeast of La Esperanza dam which will be completed in 1996.

Pump house is plan to construct in the reservoir of La Esperanza dam. Thus, this structure has to examine uplift and water pressure to be acted.

1.3.3 Access Roads

(1) Route

The purpose of access roads is to provide access into the project area and to the specific work locations.

The access roads comprise of:

(i) Conguillo Access Road (permanent, 6 m wide),

(ii) El Guasmo Access Road (temporary, 4 m wide),

(iii) Membrillo Outlet Access Road (permanent, 6 m wide),

(iv) Severino Access Road (permanent, 6 m wide),

(v) Caña Dulce Inlet Access Road (permanent, 6 m wide),

(vi) Los Cuyuyes Access Road (permanent, 6 m wide),

(vii) La Seca Access Road (temporary, 4 m wide) and

(viii) Poza Honda Access Road (permanent, 6 m wide).

Routes of the above access roads are mentioned in Subsection 4.5 of Main Report.

(2) Road design

The function of the roads as well as its anticipated traffic loading is of relevance for the selection of the standards to be applied. The long term function of the roads will be provided good all weather access to this hilly region for the permanent access roads, except two temporary access road.

1.4 Design Criteria

1.4.1 Waterway

1.4.1.1 Diversion Tunnel

(1) Tunnel Structural Analysis for Inlet and Outlet Structure

The strucutal anlysis for the inlet structures and the transition parts at the tunnel inlet and outlet are carried out by frame analysis according to the Ecuadorian Building Code.

(a) Design Conditions

The design conditions to be used for the structural analysis are as follows;

(i) Design values

<Design values of bedrock>

- Daule-Peripa ~ La Esperanza diversion tunnel

Inlet side

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	20,000	kgf/cm^2
Poisson's ratio (ν)	0.2	
Internal friction angle (ϕ)	40.0	degree
Cohesion (C)	5.0	kgf/cm^2

Outlet side

Unit weight (γ)	1.7	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.25	
Internal friction angle (ϕ)	35.0	degree

Cohesion (C)	2.5	kgf/cm^2

- La Esperanza ~ Poza Honda diversion tunnel

Inlet side

Unit weight (γ)	2.0	tf/m^3
Elasticity modulus (Er)	20,000	kgf/cm^2
Poisson's ratio (ν)	0.2	
Internal friction angle (ϕ)	40.0	degree
Cohesion (C)	5.0	kgf/cm^2

Outlet side

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.25	
Internal friction angle (ϕ)	35.0	degree
Cohesion (C)	2.5	kgf/cm^2

- Poza Honda ~ Mancha Grande diversion tunnel

Inlet side

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.2	
Internal friction angle (ϕ)	30.0	degree
Cohesion (C)	2.0	kgf/cm^2

Outlet side

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.25	
Internal friction angle (ϕ)	30.0	degree
Cohesion (C)	2.0	kgf/cm^2

<Design values of concrete>

Unit weight of reinforced concrete	2.4	tf/m^3
Elasticity modulus of concrete (Ec)	235,000	kgf/cm^2
Elasticity modulus of reinforcing bar (Es)	2,100,000	kgf/cm^2
Design compressive strength of concrete ($\sigma 28$)	210	kgf/cm^2
Tensile strength of reinforcing bar (fy)	4,200	kgf/cm^2

(ii) Design Loads

The design loads to be considered for the each structure are as follows;

<Daule-Peripa ~ La Esperanza diversion tunnel>

<u>Conguillo inlet structure, inlet tunnel</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr) + Water pressure(Pw)

<u>Conguillo inlet structure, inlet shaft</u>

Case 1 : Bedrock pressure(Pr) + Water pressure(Pw)

<u>Conguillo tunnel inlet (tunnel transition part)</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr) + Water pressure(Pw)

<u>Membrillo tunnel outlet (tunnel transition part)</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr)+ Water pressure(Pw)

Case 2 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr) + Water pressure(Pw) + Backfill grout pressure(Pg)

<La Esperanza ~ Poza Honda diversion tunnel>

Caña Dulce inlet culvert

Case 1 : Wc + Earth pressure(Pe) + Pw

Caña Dulce tunnel inlet

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

Los Cuyuyes tunnel outlet (tunnel transition part)

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

<Poza Honda ~ Manch Grande diversion tunnel>

Poza Honda inlet structure, inlet culvert

Case 1 : Wc + Pe + Pw

Poza Honda inlet structure, inlet tunnel

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

Poza Honda inlet structure, inlet shaft

Case 1 : Pr + Pw

Poza Honda tunnel inlet (tunnel transition part)

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

Mancha Grande tunnel outlet (tunnel transition part)

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

(iii) Bedrock pressure

The maximum lateral bedrock pressure acting on the lining concrete at the tunnel inlet and outlet is given by the following Terzaghi's theory.

$Prh = Ka \cdot (Prv + \gamma \cdot Ht)$

where, Prh : leteral bedrock pressure(tf/m)
Ka : coefficient of lateral bedrock pressure
Ka : $\tan^2 (45 - \phi / 2)$
ϕ : internal friction angle of bedrock
Prv : vertical bedrock pressure(tf/m)
γ : unit weight of bedrock(tf/m^3)
Ht : excavation height of tunnel(m)

(iv) Spring constant of bedrock

The bedrock surrounding the tunnel resist together with the concrete lining against the internal and outer pressure. The resistant force by bedrock is incorporated into the calculation as spring constant.

The spring constant is given by the following formula.

$K = A \cdot E / L$

where, K : spring constant(t/m)
A : area subject to a spring(m^2)
E : elasticity modulus of bedrock(tf/m^2)
L : unit length of a spring(m)

(v) Load factor

The structure and structural members shall be designed to get design stress in all sections, at least equal to the required stress calculated for factored loads and the forces in combination as stipulated in Chapter 9 of the Ecuadorian Building Code.

The load factor to be applied for each load is as follows;

Dead load	1.4
Bedrock pressure	1.7
Water pressure	1.4

Earth pressure 1.7
Backfill grout pressure 1.4

Based on the design conditions mentioned above, the structural analysis was carried out by using computer program, SAP 90 (Authorized computer program in Ecuador).

(b) Required Reinforcing Bar Areas

The required reinforcing bar areas for each section are conducted from the following formulas.

(i) Minimum required reinforcing bar area

$As = 0.0033 \cdot b \cdot d = (14/fy) \cdot b \cdot d$

where, As : minimum required reinforcing bar area(cm^2)
b : width of section(cm)
d : effective depth of section(cm)
fy : specified yield strength(4,200kgf/cm^2)

(ii) Maximum reinforcing bar area

$$As = 0.75 \bullet P_b = 0.75 \bullet \beta 1 \bullet \frac{fc}{fy} \bullet \frac{6,115}{fy + 6,115} \bullet d \bullet b$$

$a = As \cdot fy / (0.85 \cdot f'c \cdot b)$

$\phi Mu = 0.85 \cdot As \cdot fy (d - a/2)$
or
$\phi Mu = (As \cdot fy \cdot d \cdot (1 - 0.59 \cdot fy / f'c)$

$A's = 0.5\ As$

where, ϕ : stress reduction factor
Mu : factored moment in the section
f'c : specified compressive stress of concrete(kgf/cm^2)

Required area of compressive reinforcing bar
$Pu \,.\, e'/\phi = 0.85 \cdot f'c \cdot a \cdot b \cdot (d - c/2) + A's \cdot fy \cdot (d - d')$

where, Pu : total axial load

c : distance of extreme compression fiber to the neutral axis

d' : distance of extreme compression fiber to centroid of compression reinforcing bar

$$f'c = 6{,}120 \cdot (\frac{d-c}{c})$$

Pu = 0.85 · f'c · a · b + A's · fy - As · f's

Required area of tensile reinforcing bar

m = fy / (0.85 · f'c)

$$Pu = 0.85 \cdot fc \cdot b \cdot d \cdot (-(\frac{e'}{d} - 1) + (\frac{e'}{d} - 1)^2 + 2 \cdot m \cdot (1 - \frac{d'}{d}))$$

(iii) Shear stress

The design of cross sections subject to shearing is based on the following formulas.

$Vc = 0.85 \,.\, 0.53 \,.\, f'c^{1/2} \,.\, d \,.\, b$

where, Vc : shear nominal strength(kgf/cm^2)

If V > Vc

Required area of diagonal bars : Av

$Av / \phi = (V - Vc) / (f'y \cdot \sin \alpha)$

Required area of stirrups : Avs

$Avs / \phi = (V - Vc) \cdot e / (fy \cdot d)$

(iv) Longitudinal reinforcing bars

As = 0.00125 · b · d

(2) Tunnel Structural Analysis for Lining

The structural analysis for the tunnel Lining of three diversion tunnels are carried out by FEM analysis.

(a) Design Conditions

The design conditions to be used for the FEM analysis are as follows;

(i) Design values

Following design values of base rock are adopted for Daule-Peripa ~ La Esperanza and Poza Honda diversion tunnels.

		Case A-1	Case A-2	Case A-3	Case A-4
1.	Overburden (m)	60	140	250	320
2.	Elastic Modulus E (kgf/cm^2)	10,000	20,000	20,000	22,000
3.	Cohesion C (kgf/cm^2)	2.5	5.0	5.0	5.0
4.	Internal Friction Angle (degree)	35	40	40	40
5.	Unit Weight (t/m^3)	1.7	1.8	1.8	1.8
6.	Poisson's Ratio	0.25	0.2	0.2	0.2
7.	Creep				
	α	0.50	0.5	0.5	0.5
	β (5 days loading)	0.016	0.033	0.033	0.036
8.	Initional Stress				
	a) Vertical σy (t/m^2)	1/ 102	2/ 252	3/ 450	4/ 576
	b) Horizontal σx (t/m^2)	1/ 71	2/ 176	3/ 315	4/ 403

1/ $\sigma y = 1.7\ t/m^3 \times 60\ m = 102\ t/m^2$

1/ $\sigma x = \lambda \cdot \sigma y = 0.7 \times 102\ t/m^2 = 71\ t/m^2$

2/ $\sigma y = 1.8\ t/m^3 \times 140\ m = 252\ t/m^2$

2/ $\sigma x = \lambda \cdot \sigma y = 0.7 \times 252\ t/m^2 = 176\ t/m^2$

3/ $\sigma y = 1.8\ t/m^3 \times 250\ m = 450\ t/m^2$

3/ $\sigma x = \lambda \cdot \sigma y = 0.7 \times 450\ t/m^2 = 315\ t/m^2$

4/ $\sigma y = 1.8\ t/m^3 \times 320\ m = 576\ t/m^2$

4/ $\sigma x = \lambda \cdot \sigma y = 0.7 \times 576\ t/m^2 = 403\ t/m^2$

For the Poza Honda ~ Mancha Grande diversion tunnel, following design values are adopted for the analysis.

		Case B-1	Case B-2
1.	Overburden (m)	60	300
2.	Elastic Modulus E (kgf/cm^2)	10,000	20,000
3.	Cohesion C (kgf/cm^2)	2.0	5.0
4.	Internal Friction Angle (degree)	30	40
5.	Unit Weight (t/m^3)	1.8	2.0
6.	Poisson's Ratio	0.25	0.2
7.	Creep		
	α	0.50	0.5
	β (5 days loading)	0.016	0.033
8.	Initional Stress		
	a) Vertical σy (t/m^2)	1/ 108	2/ 600
	b) Horizontal σx (t/m^2)	1/ 76	2/ 420

1/ $\sigma y = 1.8\ t/m^3 \times 60\ m = 108\ t/m^2$

$\sigma x = \sigma x = \lambda \bullet \sigma y = 0.7 \times 108 = 76\ t/m^2$

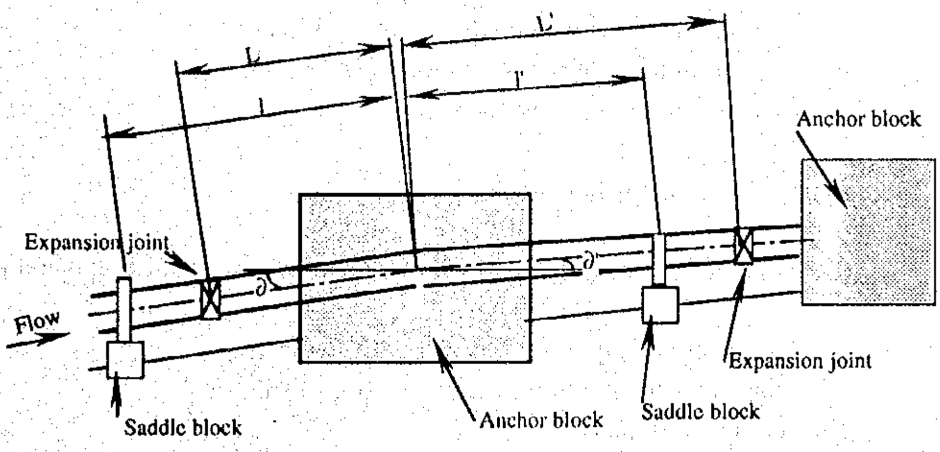
2/ $\sigma y = 2.0\ t/m^3 \times 300\ m = 600\ t/m^2$

$\sigma x = \sigma x = \lambda \bullet \sigma y = 0.7 \times 600\ t/m^2 = 420\ t/m^2$

1.4.1.2 Anchor Block

(1) Method of Stability Analysis

(a) Definition of variables



∂ : vertical angle of upstream pipe axis (degree)

∂' : vertical angle of downstream pipe axis (degree)

ϕ : vertical intersection angle between upstream and downstream pipe axes

$\phi = \partial - \partial'$ (degree)

θ : horizontal intersection angle between upstream and downstream pipe axes (degree)

L : pipe length between I.P of anchor block and upstream expansion joint (m)

L' : pipe length between I.P of anchor block and downstream expansion joint (m)

l : pipe length between I.P of anchor block and upstream adjacent saddle pier (m)

l' : pipe length between I.P of anchor block and downstream adjacent saddle pier (m)

D : inside diameter of penstock pipe (m)

A : inside sectional area of penstock pipe (m^2)

t : thickness of upstream penstock pipe (m)

t' : thickness of downstream penstock pipe (m)

H : design head at I.P of anchor block (m)

He : design head at upstream expansion joint (m)

He' : design head at downstream expansion joint (m)

Q : maximum pumping discharge (m^3/sec)

s : weight of upstream penstock pipe shell per 1 m (t/m)
$s = \pi \bullet D \bullet t \bullet rs$

s' : weight of downstream penstock pipe shell per 1 m (t/m)
$s' = \pi \bullet D \bullet t' \bullet rs$

rs : density of steel =7.85 (t/m^3)

w : weight of contained water in pipe per 1 m (t/m)

c : friction coefficient between pipe shell and saddle (=0.25)

f : friction coefficient between water and steel (=0.02)

fe : friction force of expansion joint per 1 m = 0.7 (t/m)

wc : unit weight of plain concrete =2.3 (t/m^3)

(b) Acting Force on Anchor Block

(i) Thrust perpendicular to pipe axis due to dead weight of pipe and water in pipe

for upstream pipe $W = 1/2 \bullet (w+s) \bullet l \bullet \cos\partial$
for downstream pipe $W' = 1/2 \bullet (w+s') \bullet l' \bullet \cos\partial'$
component force

Force	x-direction	y-direction	z-direction
W	$W \bullet \sin\partial$	0	$-W \bullet \cos\partial$
W'	$W' \bullet \sin\partial' \bullet \cos\theta$	$-W' \bullet \sin\partial' \bullet \sin\theta$	$-W' \bullet \cos\partial'$

(ii) Thrust along pipe axis due to dead weight of pipe

for upstream pipe $P_1 = s \cdot L \cdot \sin\partial$
for downstream pipe $P_1' = s' \cdot L' \cdot \sin\partial'$
component force

Force	x-direction	y-direction	z-direction
P_1	$-P_1 \cdot \cos\partial$	0	$-P_1 \cdot \sin\partial$
P_1'	$-P_1' \cdot \cos\partial' \cdot \cos\theta$	$-P_1' \cdot \cos\partial' \cdot \sin\theta$	$-P_1' \cdot \sin\partial'$

refer to Figure 1.1

(iii) Thrust due to friction of water in pipe

for upstream pipe $P_2 = (2 \cdot f \cdot Q^2/g \cdot \pi \cdot D^3) \cdot L$
for downstream pipe $P_2' = (2 \cdot f \cdot Q^2/g \cdot \pi \cdot D^3) \cdot L'$
component force

Force	x-direction	y-direction	z-direction
P_2	$P_2 \cdot \cos\partial$	0	$P_2 \cdot \sin\partial$
P_2'	$P_2' \cdot \cos\partial' \cdot \cos\theta$	$-P_2' \cdot \cos\partial' \cdot \sin\theta$	$P_2' \cdot \sin\partial'$

refer to Figure 1.1

(iv) Centrifugal force acting on bend point

due to vertical bend $P_v = 2 \cdot v^2/g \cdot A \cdot \sin(\phi/2)$
due to horizontal bend $P_h = 2 \cdot v^2/g \cdot A \cdot \sin(\theta/2)$
component force

Force	x-direction	y-direction	z-direction
P_v	$-P_v \cdot \sin(\phi/2)$	0	$P_v \cdot \cos(\phi/2)$
P_h	$P_h \cdot \sin(\theta/2)$	$P_h \cdot \cos(\theta/2)$	0

refer to Figure 1.1

(v) Thrust due to inner pressure acting on expansion joint

for upstream pipe $P_3 = He \cdot \pi \cdot D \cdot t$
for downstream pipe $P_3' = He' \cdot \pi \cdot D \cdot t'$

component force

Force	x-direction	y-direction	z-direction
P_3	$P_3 \cdot \cos\partial$	0	$P_3 \cdot \sin\partial$
P_3'	$P_3' \cdot \cos\partial' \cdot \cos\theta$	$-P_3' \cdot \cos\partial' \cdot \sin\theta$	$P_3' \cdot \sin\partial'$

refer to Figure 1.1

(vi) Unbalanced force due to water pressure acting on bend point

due to vertical bend $P_{rv} = 2 \cdot H \cdot A \cdot \sin(\phi/2)$

due to horizontal bend $P_{rh} = 2 \cdot H \cdot A \cdot \sin(\theta/2)$

component force

Force	x-direction	y-direction	z-direction
P_{rv}	$-P_{rv} \cdot \sin(\phi/2)$	0	$P_{rv} \cos(\phi/2)$
P_{rh}	$P_{rh} \cdot \sin(\theta/2)$	$P_{rh} \cdot \cos(\theta/2)$	0

refer to Figure 1.1

(vii) Thrust due to temperature change

for upstream pipe $F = F_1 + F_2$

for downstream pipe $F' = F_1' + F_2'$

- Thrust due to friction of supporting point

for upstream pipe $F_1 = c \cdot (w+s) \cdot (L - l/2) \cdot \cos\partial$

for downstream pipe $F_1' = c \cdot (w+s') \cdot (L' - l'/2) \cdot \cos\partial'$

- Thrust due to friction of expansion joint

for upstream pipe $F_2 = fe \cdot \pi \cdot (D+2t)$

for downstream pipe $F_2' = fe \cdot \pi \cdot (D+2t')$

component force

Force	x-direction	y-direction	z-direction
F	$F \cdot \cos\partial$	0	$-F \cdot \sin\partial$
F'	$F' \cdot \cos\partial' \cdot \cos\theta$	$-F' \cdot \cos\partial' \cdot \sin\theta$	$F' \cdot \sin\partial'$

refer to Figure 1.1

(viii) Dead weight of anchor block

$W_A = wc \cdot V$ V : concrete volume of anchor block

(iv) Seismic force

$F = F_{WA} + F_p$

$F_{WA} = K_h \cdot W_A$ $F_p = K_h \cdot [(w+s) \cdot l/2 + (w+s') \cdot l'/2]$

K_h : coefficient of horizontal earthquake (= 0.15)

(c) Check of Safety

(i) Safety for overturning

The safety for overturning can be confirmed by the following equation.

$e = |B/2 - \Sigma M / \Sigma V| \quad < B/6$

where, e : eccentricity of resultant force on base measured from center of base

B : base length of anchor block

ΣM : total moment

ΣV : total vertical force

(ii) Safety for sliding

$Fs = \Sigma V \cdot \lambda / \Sigma H \quad > 2.0$

where, Fs : safety factor

ΣH : total horizontal force

λ : friction coefficient of concrete and foundation = 0.65

(iii) Safety for bearing capacity

$\sigma max = \Sigma V / A \cdot (1 \pm 6 \cdot e/B) < qa$

where, σmax : maximum compressive stress

A : area of base

qa : bearing capacity of foundation

1.4.1.3 Severino Head Tank

The Sevarino Head Tank is divided into two separate lines by partition wall in consideration of operation and maintenance of the transbasin system.

(1) Structural Analysis

(a) Structural calculation

The structural analysis of frame were made by applying the SAP90 computer program, (Structural Analysis Program), that use the "Finite Element Method". This program represent the research work conducted at the University of California, Berkeley, by Professor Edward L. Wilson.

(b) Loading condition

The structural analysis were made for the loading conditions of the following four cases.

Case 1 : the tanks is empty without earthquake effect.

Case 2 : the one side of the tank is filled with water at HWL and the other is empty without earthquake affect.

Case 3 : the both side of the tank is filled with water and earthquake effect is not taken account.

Case 4 : the both side of the tanks is also filled with water and earthquake effect is taken into consideration.

1.4.2 Severino Pumping Station

(1) Preliminary Consideration of Structural System

(a) Structural System

To determine the structural system of pump house substructure, following are considered and analyzed for the finalization of design:

i) Stabilize the structure against great hydrostatic and earth pressure.
ii) Minimize the deflection of structure for overhead traveling crane.
iii) Consider the stress against temperature change before and after completion of structure.

To the above subject, following consideration and analysis were made and employed for the detailed design.

(b) Frame structural system

To minimize the concrete volume and stabilize against great hydraulic and earth pressure acting on the structure, frame structural system was employed and designed instead of wall structural system or other system. Frame structural system also gives advantage to minimize the deflection of column for crane girder. Therefore, at the top of substructure, roof beams ridged with columns are employed.

(c) Measure against crack of concrete and temperature force

To prevent objectionable intermediate crack in concrete generated by temperature change and heat of hydration, the expansion joint is provided between No. 3 and No. 4 pumping units. The contraction joint gives advantage to relieve tensile stress induced by shrinkage and heat of hydrant. To keep the watertighyness, PCV waterstop is provided. Reinforcement for shrinkage and temperature stress is also provided. To check the stress induced by temperature change and confirm the stability against cracks generated by stress (moment, shearing, etc.) structural analysis and calculation are made.

(2) Stability Analysis

(a) General

Pump house building is divided into two blocks by expansion joint, i.e., transformer yard side block and erection by side block.

The structural stability is analyzed to assure safety against overturning, sliding, floating, and bearing capacity of foundation rock. The following three cases are included in the stability analysis:

Case - I: After completion of construction

The external forces acting on the substructure include dead load, minimum hydrostatic pressure by reservoir water, earth pressure at rest by backfill, surcharge pressure and uplift.

Case - II : Normal Condition

Pump station complete and operating without earthquake effects:

The external forces acting on the substructure include dead load, maximum hydrostatic pressure by reservoir water, earth pressure at rest by backfill, groundwater pressure, surcharge pressure ad the uplift.

Case - III : Seismic Condition

Pump station complete and operating with earthquake:

In addition to the external forces in Case- II, earth quake load is considered.

(b) Structural model

The pump house is divided into two blocks, i.e., transformer yard side machine bay and erection bay side machine bay. These blocks are built on sound rock foundation and each block is nearly symmetrical structure. The stability analysis is carried out for the transformer yard side block taking into consideration of symmetrical structure model. The structural model for the stability analysis is shown in Design of Pump House Substructure, Design Calculation Report.

(c) Stability Analysis

External forces acting on substructure such as earth pressure, hydrostatic pressure and uplift pressure and their center of gravity are calculated as below.

Stability analysis of the structure is made based on self-weight and the external forces calculated. The following criterion are adopted in the stability analysis.

Overturning	=	Σ v.x / Σ H.y
Sliding	=	(Σ W-U).f + C.A. / Σ H
Bearing Capacity	=	V/B.L (1 ± 6 e/L)
Floating	=	Σ W/U

Where,	ΣV	=	Sum of vertical forces
	ΣH	=	Sum of horizontal forces
	x	=	distance from reference line to center of gravity
	y	=	distance from reference line to center of gravity
	ΣW	=	sum of vertical forces except up-lift
	U	=	Uplift
	f	=	Coefficient of friction between concrete and foundation rock (0.65)
	C	=	Cohesion between concrete and foundation rock ($50 t/m^2$)

A = Area of base on foundation
e = eccentricity
B = width of foundation
L = length of foundation

Allowable minimum factors of safety are as follows:

Loading Conditions	Overturning	Sliding	Flotation
Case I, III	1.1	2.0	1.1
Case II	1.2	4.0	1.2

(i) Loading condition

Case I : After Completion of Construction
Case II : Normal Condition
Case III : Seismic Condition

(ii) Lateral Earth Pressure

$$P = \gamma_t \cdot Ka \cdot h_l$$

where, γ_t = 1.8 tf/m^3
Ka = 0.5
h_l = depth of earth (m)

(3) Structural Design

(a) Structural analysis of frame

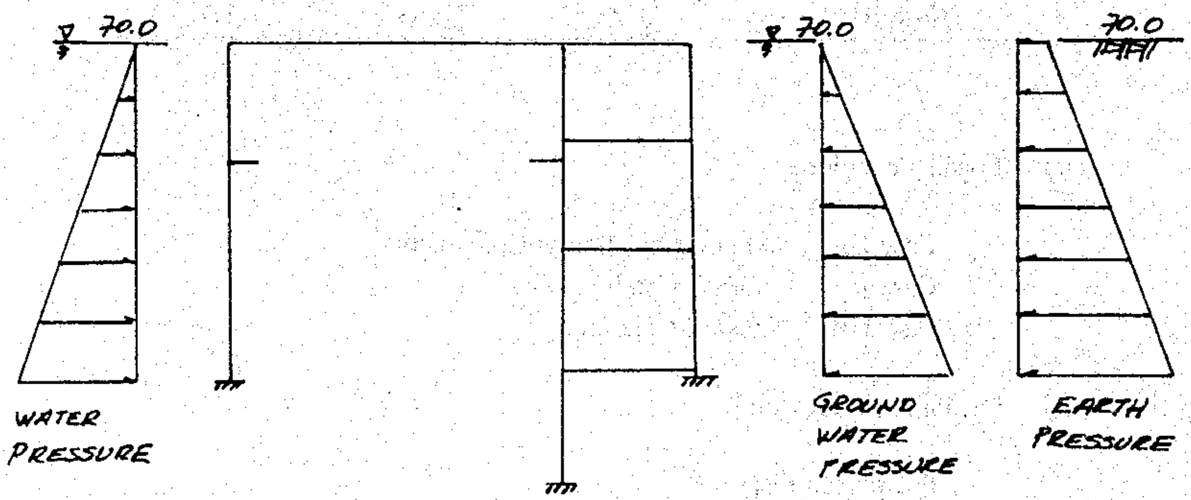
(i) Frame model

In analyzing the stress of respective structural members f the pump house, was made applying the SAP90 computer program, (Structural Analysis Program), that use the Finit Element Method. This program represent the research work conducted at the University of California, Berkeley, by Professor Edward L. Wilson.

(ii) Loading condition

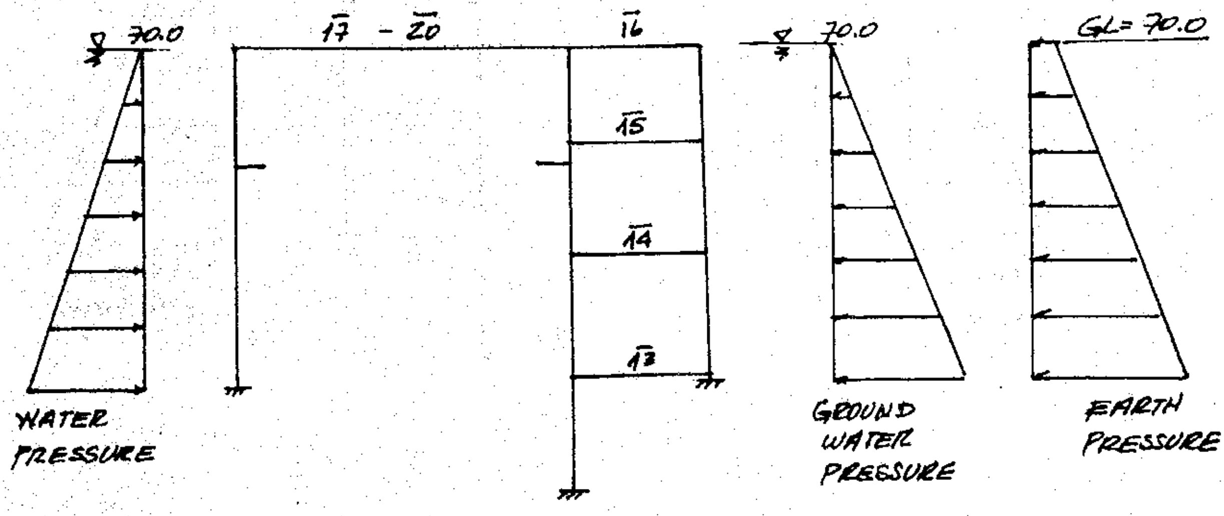
Loading condition of six cases are shown below figures as stated in 3.2.1.

Case - I Normal condition

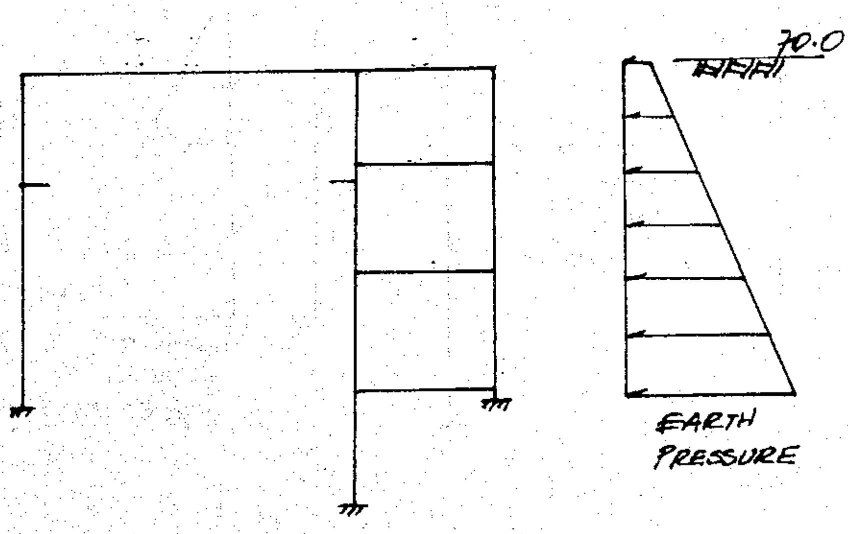


Case - II & III   Temperature change

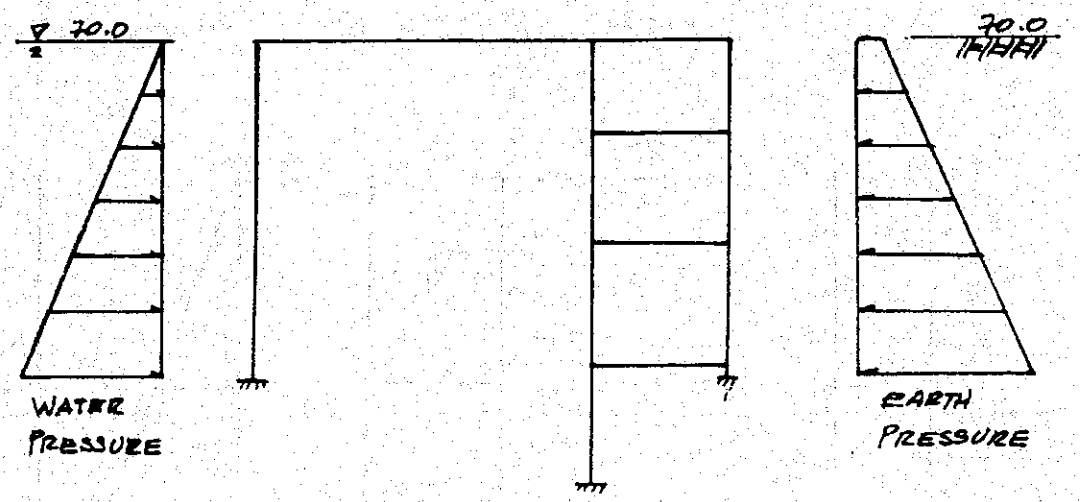
Under sudden 10°C increase (Case-II) and decrease (Case-III), eight members shown on the following figure are analyzed.



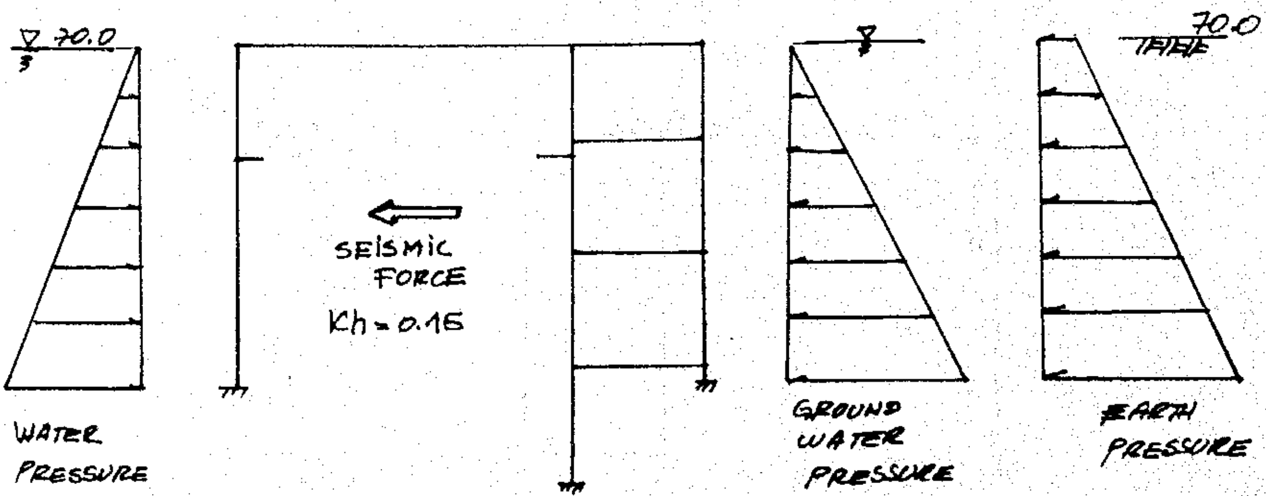
Case - IV   Completion time - 1 (Just before completion)



Case - V Completion - 2 (After completion)



Case - VI Seismic condition



1.4.3 Severino Open Channel

(1) Structural Design

Severino open channel has trapezoidal cross section in principal, and it will be lined with concrete in order to reduce their maintenance works. Typical cross section and procedure for determination of the cross section elements are explained below.

(a) Bottom width-water depth ratio (B/h)

Open channel bottom width-water depth ratio (B/h) is usually 1/1 to 2/1. While, B/h in the most effective hydraulic cross section which wetted perimeter becomes minimum, is 1/1.2 in the open channel side slope of 1:1 or 1/1.64 in 1:1.5 side slope. In this open channel, the section is trapezoidal with a side slope gradient of 1:12, that is the most hydraulically efficient and economical section having a maximum flow volume with a minimum wetted perimeter.

(b) Side slope

Inside slope of the open channel is 1(V): 1.2 (H).

If the excavation depth from the ground surface to the open channel crest is deeper than 3.0 meters, a berm having a width of 1.0 meters should be provided at every 3.0 meters in height.

Outside slope of the open channel is as follow;

Open channel	Outside Slope (V : H)
Embankment height, less than 5 m	1 : 1.5
Embankment height, over 5 m	1 : 1.5 with berm of 1.5m wide

Note: The side slope of the open channel depends upon the characteristic of materials to be used for open channel construction and also on height of open channel embankment. The inside and outside slopes specified above is determined based on the experience of the consultant and the investigation results of the existing projects in Ecuador and is confirmed by stability analysis on the basis of the results of soil tests of clayey soil and silty soil, which cover most of the Project area and are easily obtained along canal routes. According to the results of analysis, canal embankment clayey and silty soils are safe against sliding (Refer to the Design Calculation Report).

(c) Thickness of lining

Thickness of lining is 15 cm.

The thickness of lining is usually 6 to 12 cm. In Babahoyo Project in Ecuador, the thickness of lining in the major canals is 10 cm in case of the side slope of 1(v):1.5 (H) and J. Calle Project, 15 cm with the side slope of 1(V):0.5 (H). Lining thickness of 15 cm is adopted for this open channel.

(d) Freeboard

Freeboard provides for a open channel water surface higher than normal which may be caused by (i) sedimentation in the channel, (ii) temporary miss-operation of water supply, (iii) excess flows caused by storm run-off entering the open channel, (iv) additional water level resulting from a rougher friction coefficient than used for design, and (v) waves produced by wind or surges which accompany sudden changes in flow. Taking the above into account, the freeboard for open channel should be determined based on the following equation (derived from Design Criteria for Irrigation and Drainage and Land Reclamation Project by Ministry of Agriculture, Forestry and Fishery of Japan);

$$Fb = 0.05\,h + hv + s$$

where,

Fb : freeboard (m)
h : design water depth (m)
hv : velocity head (m)
s : 0.10 m

The freeboard estimated by the above equation is that for the lining, and the freeboard of open channel embankment should be determined by adding 30 cm to the freeboard obtained by the above equation.

(e) Radius of horizontal curve of open channel

Radius of horizontal curve of open channel should be more than 5-8 times the water surface width at design water level.

(2) Hydraulic Calculation

(a) Flow formula

Manning (Strickler) formula should be employed for hydraulic calculation of open channel. The formula is as follows:

$$Q = A\,V$$

$$V = 1/n\; R^{2/3}\; I^{1/2}$$

where,

Q: design discharge (m^3/s)
V: mean water velocity (m/sec)
n: roughness coefficient of Manning formula
R: hydraulic radius (m) = A/P
A: flow area (m^2)
P: wetted perimeter (m)
I: hydraulic gradient of open channel

(b) Roughness coefficient

Roughness coefficients (n) used in the Manning (Stricker) formula are as follows;

Material of canal	Roughness coefficient
Concrete lining	0.015
Concrete	0.015

(c) Velocities of open channel flow

Unless otherwise specified, design velocity should be determined within the following allowable ranges.

(unit: m/s)

Material of Wetted Perimeter	Allowable velocity Min.	Allowable velocity Max.
Concrete lining	0.5	1.5
Concrete (thick)	0.5	3.0

Allowable minimum velocity should be decided so as not to cause sedimentation and weed growing in the wetted perimeter as much as possible. Generally it is recognized that the velocity more than 0.7 m/sec prevents weed growing and that 0.45 m/sec to 0.9 m/sec prevent the sedimentation of wash load.

(d) Head loss calculation

In hydraulic design of hydraulic structures such as open channel, culverts, siphons, etc., the following head losses are considered.

(i) Friction loss (hf)
(ii) Transition losses;
- Gradual contraction (hgc)
- Gradual enlargement (hge)
- Sudden contraction (hsc)
- Sudden enlargement (hse)

(iii) Head loss at trash-rack (ht)
(iv) Head loss at inlet (hi)
(v) Head loss at bend (hb)

These losses can be calculated as follows;

(i) Friction loss (hf)

$$hf = \{(nV)^2/R^{4/3}\}\ L$$

where,

hf: friction loss (m)
L: length of open channel (m)
V: mean water velocity (m/sec)
R: hydraulic radius (m)
n: roughness coefficient

(ii) Transition

Transition should be provided so as to smoothly connect a channel to a structure or to reduce the head losses at the structure. If the open channel has little surplus water head to convey water or the design velocity can not be more than 0.7 m/sec, or open channel will connect to a siphon, a straight warp type of transition having a diagonal angle to the flow direction less than 12.5 degrees is provided.

The length of the straight warp type transition should not be less than the length calculated by the following formula:

L = (Wu - Wd)/2 tan T

where,

- L: length of transition (m)
- Wu: width of water surface in open channel (m)
- Wd: width of water surface in flume, conduit or closed transition (m)
- T: angle of transition = 12.5 °

- Gradual contraction (hgc)

hgc = fgc (hvd - hvu) + L Im

hgcw = hgc + (hvd - hvu)

where,

- hgc: head loss due to gradual contraction (m)
- hgcw: change of water level due to gradual contraction (m)
- fgc: coefficient of loss, as straight warped type of transition
- hvd: velocity head after gradual contraction (m)
- hvu: velocity head before gradual contraction (m)
- L: length of transition (m)
- Im: mean hydraulic gradient, = (Iu + Id)/2
- Iu: hydraulic gradient before gradual contraction
- Id: hydraulic gradient after gradual contraction

- Gradual enlargement (hge)

hge = fge (hvu - hvd) + L Im

hgew = hge + (hvu - hvd)

where,

- hge: head loss due to gradual enlargement
- hgew: change of water level (m)
- fge: coefficient; as straight warp type of transition is taken
- hvu: velocity head before enlargement (m)
- hvd: velocity head after enlargement (m)

L: length of transition (m)
Im: mean hydraulic gradient = (Iu + Id)/2
Iu: hydraulic gradient of upstream channel
Id: hydraulic gradient of downstream channel

- Sudden contraction (hsc)

hsc = fsc hvd

hscw = hsc + (hvd - hud)

where,

hsc: head loss due sudden contraction (m)
fsc: coefficient of loss due to sudden contraction (see following table)
hvd: velocity head after contraction (m)
hscw: change of water level due to sudden contraction (m)
hud: velocity head before contraction (m)

Dd/Du	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
fsc	0.50	0.50	0.49	0.49	0.46	0.43	0.21	0.38	0.29	0.07	0.0

Du: Diameter before contraction (m)
Dd: Diameter after contraction (m)

- Sudden enlargement (hse)

hse = fse hvu

hsew = hse + hvd - hvu

where,

hse: head loss due to sudden enlargement (m)
fse: coefficient = $(1 - au/ad)^2$
hvu: velocity head before enlargement (m)
hsew: change of water level (m)
hvd: velocity head after enlargement (m)
Au: flow area before enlargement (m)
Ad: flow area after enlargement (m)

(iii) Head loss at trash-rack (ht)

Head loss due to screen should be three (3) times the head loss calculated by Kirschmer formula.

$ht = fr\ hvu$
$fr = b \sin q\ (t/b)^{4/3}$
$htw = ht + hvd - hvu$

where,

- ht: head loss at trash-rack (m)
- htw: change of water level due to screen loss (m)
- hvu: velocity head at just upstream channel (m)
- b: coefficient to be determined according to shape of element bars.
- q: angle with floor (degree)
- b: clear space between bars (m)
- t: thickness of bars (m)

(iv) Head loss at inlet (hi)

$hi = fi\ hvd$

where,

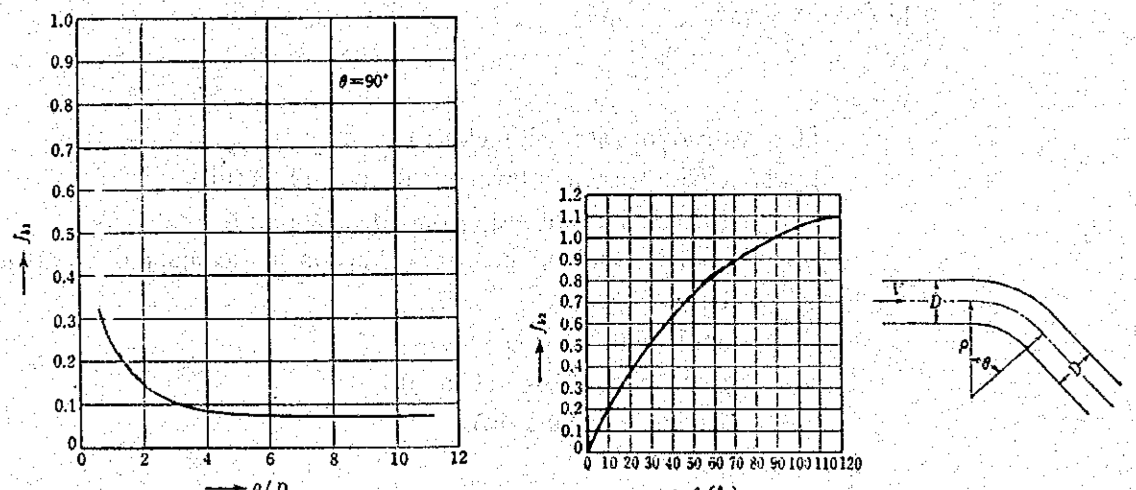
- hi: head loss at inlet (m)
- fi: coefficient to be determined according to shape of entrance
  - bell-mouthed circular 0.1
  - bell-mouthed rectangular 0.2
  - ordinary 0.5
- hvd: velocity head in downstream channel (m)

(v) Head loss at bend (hb)

$hb = fb1\ fb2\ hv$

where,

- hb: head loss due to bend (m)
- fb1, fb2: coefficient as shown below
- hv: velocity head in conduit (m)



(a) f_{b1} (θ=90°) (b) f_{b2}

1.4.4 Access Road

1.4.4.1 General

The access roads have several functions and the followings are basic design concepts on the detailed design of the roads;

(a) The access roads will be used for transportation of construction materials and excavated materials during the main construction period,

(b) Semi-trailers are able to pass through the access roads to mobilize and demobilize equipment, machines, plants, and instruments,

(c) The access roads could be used for a local community and a maintenance of the projects facilities after completion of the construction,

(d) The access roads are classified into 2 types, permanent access roads which will be used during and after construction, and temporary access roads which will be used during construction only ,

(e) Pavement will be made only for the permanent access roads and no pavement is applied to temporary access roads.

(f) The Contractor shall maintain and improve the road including the pavement during construction and shall hand over as designed to the Client after completion of the Project,

(g) To be basically in conformity with Ecuadorian standards "Manual de Diseño de Carreteras, Ministerio de Obras Publicas y Communicaciones" (Main Road Standard) and "Manual de Diseño de Caminos Vecinales, MOP-1985, Ministerio de Obras Publicas y Communicaciones" (Secondary Road Standard), and

(h) American Association of State Highway and Transportation Officials (AASHTO), Japanese Standard and Richtlinien Fur die Anlage von Landstras (German Standard, RAL) are referred in case some items in the Ecuadorian standard are insufficient for the criteria to be applied to the Project.

Based on the design concepts above, about 55 km in total length of the access roads are required for the Project consisting of the following 8 parts;

(i) Conguillo Access Road

Permanent access road to be newly constructed connecting from the existing road at Buenaventura to Conguillo Inlet through Membrillo village and its total length is about 22.6 km.

(ii) El Guasmo Access Road

Temporary access road to be newly constructed to El Guasmo Work Adit branching off Conguillo Access Road and its length is about 1.6 km in total.

(iii) Membrillo Outlet Access Road

Temporary access road to be newly constructed branching off Conguillo Access Road to Membrillo Outlet and its total length is about 0.4 km.

(iv) Severino Access Road

Permanent access road to be newly constructed connecting from the existing road at Piedra Azul to Severino Pumping Station through Bijagual and its total length is about 9.3 km. The road connects to Severino Inspection Road near Bijagual.

(v) Caña Dulce Inlet Access Road

Temporary access road to be newly constructed to Caña Dulce Inlet branching off Severino Access Road at Bijagual and its total length is about 2.7 km.

(vi) Los Cuyuyes Access Road

Permanent access road to be newly constructed connecting from the existing Poza Honda dam to Los Cuyuyes Outlet and its total length is about 12.6 km.

(vii) La Seca Access Road

Temporary access road to be newly constructed branching off Los Cuyuyes Access Road at La Mercedes No.1 village to La Seca Work Adit and its total length is about 3.8 km.

(viii) Poza Honda Inlet Access Road

Permanent access road to be newly constructed to Poza Honda Inlet branching off Los Cuyuyes Access Road and its length is about 0.7 km in total.

Location of each access road is shown in Figure 1.2.

Canuto Access Road is the existing road connecting to Conguillo Access Road at Buenaventura from Canuto, which has an important role for the Project although the detailed design of the road is out of our scope of works. The road will be used during and after construction of the Daule-Peripa ~ La Esperanza Transbasin Scheme such as Conguillo Inlet, Membrillo Outlet, the diversion tunnel connecting the inlet and outlet and their associated facilities.

1.4.4.2 Geometric Design

(1) Geometric Standards

Class 5 stated in MOP Standard is applied to the access roads with a design speed of 30 km/hour. Class 4 is applied to the inspection road and design speed of 30 km/hour is also proposed. However it could be judged that the manual is not covered in details on the criteria to be directly applied to the Project. Therefore each item of the geometric design is studied to define the criteria for the Project based on MOP and Province Standards as explained hereunder.

The proposed geometric design criteria are shown below;

Standard		Class 4, 5
Design Speed (km/hour)		30
Horizontal Alignment	Min. Curve Radius (m)	30 (15)
	Min. Curve Length (m)	40
	Min. Curve Radius without Inverse Cant (m)	80
Longitudinal Alignment	Max. Longitudinal Gradient (%)	7.0 (8.0~10.0)
	Min. Curve Radius, crest shape (m)	250
	Min. Curve Radius, sag shape (m)	250
	Min. Curve Length (m)	25
Cross Section	Standard Crossfall (%)	4.0
	Max. Superelevation Runoff	1/75
	Min. Superelevation Runoff	1/300
Max. Combined Grade (%)		11.5 (12.5)
Min. Sight Distance (m)		30

Note : values in ( ) are in exceptional case.

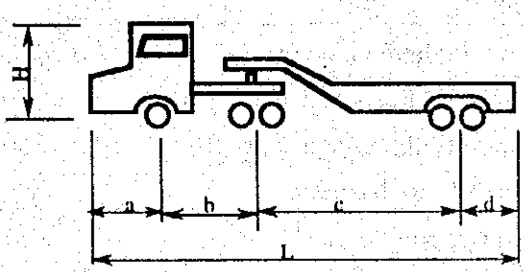
Road width of 6.0 m is determined for the permanent access roads so that vehicles on both ways can pass each other. Layby is not required. Road width of the temporary access road is set at 4.0 m in view of their temporary usage during construction.

(2) Design Vehicles

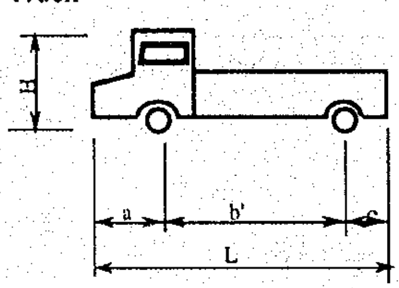
Semi-trailer and truck are selected as design vehicle for the access road. Dimensions of the design vehicles are referred to the Main Road Standard (MOP-001-E) and are shown below;

Vehicle	Length (m) L	Width (m) W	Height (m) H	Front Over-hang (m) a	Front (m) b	Axial Distance between Wheel Base (m) b'	Rear (m) c	Rear Over-hang (m) d	Min. Turning Radius (m) Rmin
Semi-trailer	16.78	2.59	4.12	0.92	5.49		9.15	0.61	13.72
Truck	9.15	2.59	4.12	1.22		6.10		1.83	12.81

Semi-trailer



Truck



(3) Horizontal Alignment

(a) Minimum horizontal curve radius

Minimum horizontal curve radius of 30 m is established for a design speed of 30 km/hour in the Secondary Road Standard. However, it is proposed to apply 15 m to the minimum horizontal curve radius for the access roads of the Project considering that minimum turning radii are 13.72 m for semi-trailer and at 12.81 m for truck, respectively, and from their functional, economical and constructional points of view.

(b) Minimum curve length

In general, minimum curve length is determined under the following conditions;

(i) not to cause difficulty on handling to driver,

(ii) to be less than some value established by a standard in alteration of centrifugal acceleration on curve section, and

(iii) to prevent illusion which it seems to be smaller curve radius than actual one in case intersectional angle (IA) is relatively small.

In this design criteria, condition (i) above is used to determine minimum curve length taking into consideration of a function of the roads. Minimum curve length is defined as follows;

$$L = t \cdot V$$

where, L : minimum curve length (m)
t : time passing through curve section (sec)
V : design speed (m/sec)

Empirically (t) is taken at 6 sec as a minimum value in order not to cause difficulty on handling through curve section, therefore

$$L = 6 \cdot 30 \cdot 1{,}000 / 3{,}600 = 50 \text{ m}$$

(c) Widening of carrigeway on curve section

On curve section, front and rear wheels of vehicle pass through different locus . It is therefore required to be wider carrigeway on curve section than that in straight section. The widening of carrigeway is determined as follows;

$$e = B - b$$

where, e : widening of carrigeway on curve section (m)
B : width of vehicle in handling on curve section (m)
for semi-trailer $B = Rw + 1.295\ \sqrt{Rc^2 - 124.811}$
for truck $B = Rw + 1.295\ \sqrt{Rc^2 - 53.582}$
Rw : radius of outer curve (m)
for semi-trailer $Rw = \sqrt{(\sqrt{Rc^2 - 41.088} + 1.295)^2 + 41.088}$
for truck $Rw = \sqrt{(\sqrt{Rc^2 - 41.088} + 1.295)^2 + 53.582}$
Rc : radius along center line of each lane (m)
b : width of lane (m)

The following table shows the results of estimation using the above formula. The estimated widening are round up at every 25 cm on account of design and construction of curve section. In case the estimated widening is less than 20 cm, it could be judged that the widening is not required.

Widening e (m)	Curve Radius R (m)	
	Permanent Access Road (Road Width : 6.0 m, Design Vehicle : Semi-trailer)	Temporary Access Road (Road Width : 4.0 m, Design Vehicle : Semi-trailer)
1.75	$R < 16$	-
1.50	$16 \leq R < 18$	-
1.25	$18 \leq R < 21$	
1.00	$21 \leq R < 25$	
0.75	$25 \leq R < 31$	$R \leq 16$
0.50	$31 \leq R < 42$	$16 \leq R < 18$
0.25	$42 \leq R$	$18 \leq R < 21$

(d) Standard Crossfall

Standard crossfall is determined depending on kinds of pavement as shown below, referring to the Province Standard.

$i = 2.5$ % for asphalt pavement

$i = 4.0$ % for crushed stone pavement and non-pavement

(e) Superelevation

(i) Maximum superelevation

Maximum superelevation is determined at 8.0 %, referring to the Secondary Road Standard.

(ii) Minimum curve radius without inverse cant

<in case standard crossfall : 4 %>

This value is determined based on the following formula.

$Re = V^2 / (127 \cdot (i + f))$

where,

Re : minimum curve radius of inverse cant (m)
V : design speed (= 30 km/hour)
i : superelevation (= -0.04)
f : coefficient of friction due to sideslip (=0.15)

therefore,

$Re = 30^2 / (127 \cdot (-0.04+0.15)) = 64.4 = 65$ m

Coefficient of friction due to sideslip (f) is defined at 0.16 in Secondary Road Standard, which is the maximum value specified in AASHTO. However the coefficient is determined at 0.15 in this criteria taking into consideration of a comfortable handling.

<in case standard crossfall : 2.5 %>

The value is determined based on the same formula as case (a), but the following values are applied to the estimation.

i : superelevation (= -0.025)
f : coefficient of friction due to sideslip (=0.044)

therefore,

$Re = 30^2 / (127 \cdot (-0.025+0.044)) = 373.0 = 380$ m

(iii) Superelevation on curve section

Superelevation on curve section could be determined not to cause lateral force to driver, that is, the case of f = 0 in the above formula, therefore;

$Rm = Va^2 / (127 \cdot im)$

where,

Rm : curve radius not to cause lateral force to driver (m)
Va : running speed (= 28 km/hour)
im : superelevation

(Rm) are estimated based on the above formula for each (im) as shown in the following table.

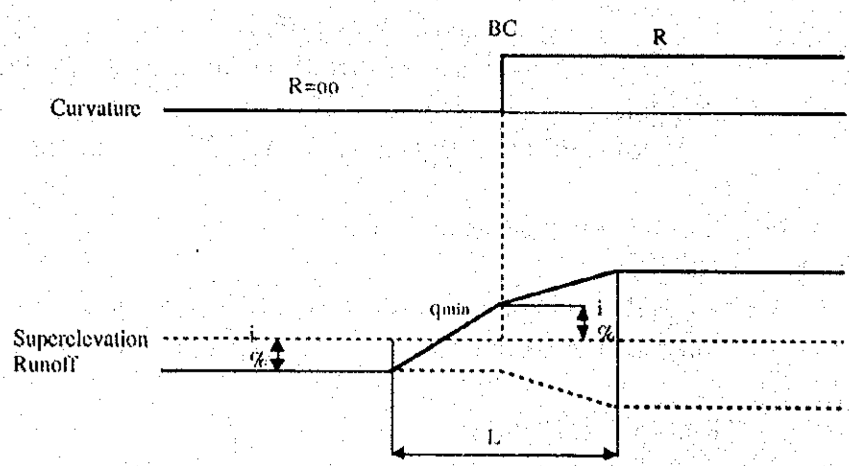
Super-elevation (%)	Curve Radius ; Ra (m)
8	Ra ≤ 40
7	40 ≤ Ra < 60
6	60 ≤ Ra < 80
5	80 ≤ Ra < 110
4	110 ≤ Ra < 150
3	150 ≤ Ra < 190
2.5	190 ≤ Ra < 380

(iv) Superelevation runoff

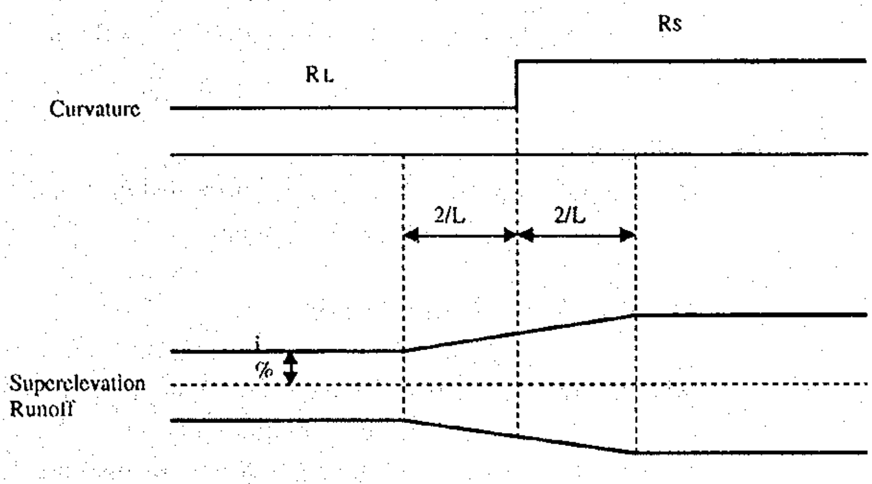
Superelevation runoff is determined at 1/75 at a maximum (q min) and at 1/300 at a minimum referring to AASHTO, RAL and Japanese Standard.

Sharps of superelevation runoff are determined as shown below, considering the maximum and the minimum rate of superelevation runoff determined.

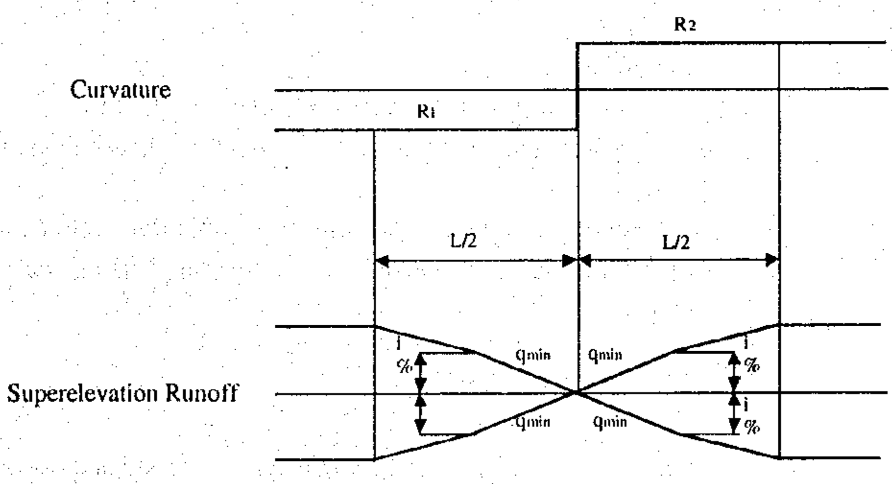
<in case of straight section - curve section>



<in case of curve section - curve section>



<in case of S-sharp curve section>



(v) Attainment of superelevation

Attainment of superelevation is made in a length which is determined for superelevation runoff.

(f) Sight distance

(i) Basic conditions

Basic conditions are shown below to determine sight distance.

- sight distance required for stopping
  - height of driver's eye : 1.15 m
  - height of object : 0.15 m

- sight distance required for outstripping
  - height of driver's eye : 1.15 m
  - height of vehicle to be outstripped : 1.37 m

(ii) Sight distance

According to the conditions above, sight distance required for stopping is determined using the following formula.

$$D = V / 3.6 \cdot t + V^2 / (2 \cdot g \cdot f \cdot 3.6^2)$$

where, D : Sight distance required for stopping (m)
V : design speed (= 30 km/hour)
f : friction coefficient between tire and road surface (=0.44)
t : reaction time (= 2.5 sec)
g : acceleration of gravity (= 9.8 m/sec²)

therefore,

$$D = 0.694 \cdot 30 + 0.00394 \cdot 30^2 / 0.44 = 29.9 \text{ m}$$

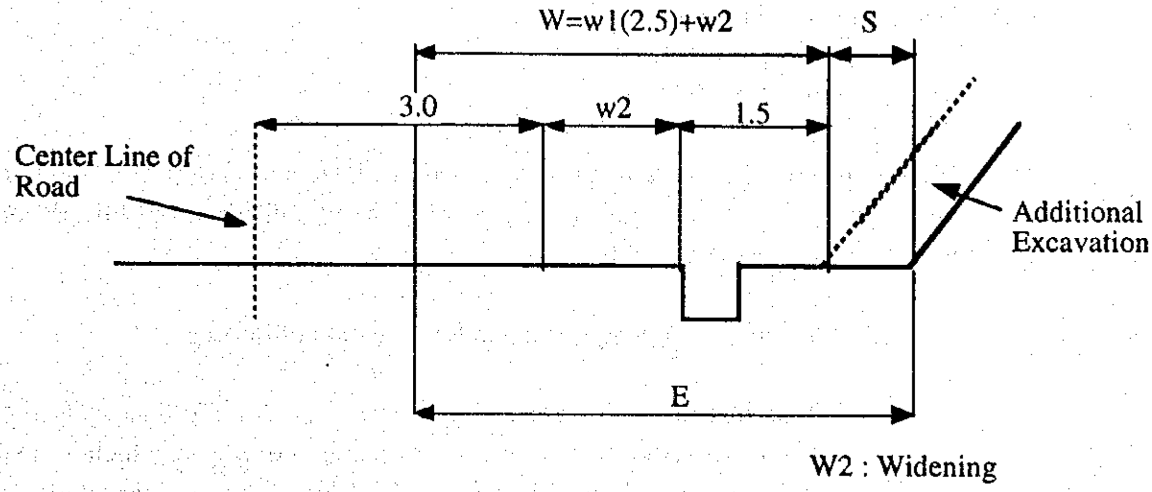
Sight distance required for stopping is determined at 30 m.

To secure the sight distance estimated on curve sections, distances between center of road and obstacle are determined using the formula as shown below.

$$E = D^2 / 8R$$

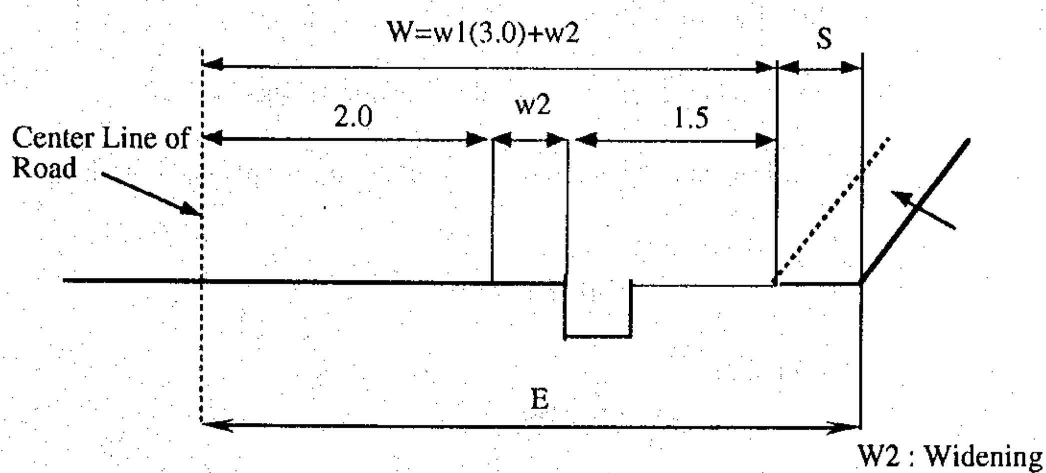
where, E : distances between center of road and obstacle to secure sight distance(m)
D : sight distance (=30 m)
R : horizontal curve radius (Min. 30 m for V = 30 km/h)

<Permanent Access Road>



D (m)	R (m)	E (m)	w1 (m)	w2 (m)	W (m)	S (m)
30	30	3.75	2.5	0.75	3.25	0.50

<Temporary Access Road>



D (m)	R (m)	E (m)	w1 (m)	w2 (m)	W (m)	S (m)
30	30	3.75	3.00	0.00	3.00	0.75

Therefore, widening to secure the sight distance is not required for the both permanent and temporary access roads.

(4) Longitudinal Alignment

(a) Length of Vertical Curve

Minimum vertical curve length is determined in consideration of (i) transition of impact due to change of vertical gradient, (ii) securing of sight distance and (iii) prevention of visual illusion, as explained below.

(i) Vertical curve length required for transition of impact

At points of turning vertical gradient, it is required that vertical curve is inserted between two gradients for transition of impact which is created due to the turning of vertical gradient. In general, the transition curve length is empirically determined using the following formula.

$$L = V^2 \cdot (i_1 - i_2) / 360$$

where, L : vertical curve length (m)
V : design speed (=30 km/hour)
(i_1-i_2) : absolute value of difference between vertical gradients (%)

therefore, $L = 2.5 \cdot (i_1 - i_2)$

(ii) Vertical curve length required for securing sight distance

Vertical curve length to secure sight distance is defined as follows;

- for crest

$$L = D^2 \cdot (i_1 - i_2) / 398$$

- for sag

$$L = D^2 \cdot (i_1 - i_2) / 2692$$

where, L : vertical curve length (m)
D : sight distance (=30 m)
(i_1-i_2) : absolute value of difference between vertical gradients (%)

therefore, $L = 2.3 \cdot (i_1 - i_2)$ for crest curve portion and

$L = 0.3 \cdot (i_1 - i_2)$ for sag curve portion.

Maximum value is selected among 3 lengths estimated above as the minimum vertical curve length, that is $L = 2.5 \cdot (i_1 - i_2)$.

(iii) Prevention of visual illusion

In case $(i_1 - i_2)$, absolute value of difference between vertical gradients, is too small, the minimum vertical curve length is estimated very short and causes visual illusion which seems to be sudden bending alignment. Therefore the minimum vertical curve length shall be more than a value which is empirically determined as length passing through within 3 seconds.

Therefore, L = 30 km/hour • 3 sec./ 3600 sec. = 25 m

Minimum vertical length is, therefore, determined as follows;

$$L = 2.5 \cdot (i_1 - i_2)$$

where, L : minimum vertical curve length (m), and more than 25 m
$(i_1 - i_2)$: absolute value of difference between vertical gradients (%)

(b) Radius of vertical curve

Vertical curve is generally expressed as approximate formula to circular curve as shown below.

$$Lr = R \cdot (i_1 - i_2) / 100$$
$$R = 100 \cdot Lr / (i_1 - i_2)$$

where, R : radius of vertical curve
Lr : vertical curve length (m)
$(i_1 - i_2)$: absolute value of difference between vertical gradients (%)

Minimum radius of vertical curve is determined when minimum vertical curve length is employed to input the minimum vertical curve length, $L = 2.5 \cdot (i_1 - i_2)$ in Lr of the above formula as calculated below;

$$R = 100 \cdot 2.5 \cdot (i_1 - i_2) / (i_1 - i_2) = 250 \text{ m}$$

(c) Longitudinal gradient

Longitudinal gradients are defined as shown in the table below, based on Province Standard.

Max. Longitudinal Gradient	normal case	7.0 %		
	exceptional case	8.0 %	Max. Length	1,000 m
		9.0 %		
		10.0 %		500 m
Min. Longitudinal Gradient		0.5 %		

(5) Combined Gradient

Gradient on road surface consists of crossfall or superelevation and longitudinal gradient and their combination gradient is always the most rapid one. The direction of the combination gradient corresponds to a surface flow direction.

The combination gradient is estimated by the following equation.

$$S = \sqrt{i^2 + j^2}$$

where, S : combination gradient (%)
i : crossfall or superelevation (%)
j : longitudinal gradient (%)

Maximum combination gradient is determined at 11.5 % based on the maximum longitudinal gradient of 8.0 % and the maximum superelevation of 8.0 % as estimated below.

$$S = \sqrt{8.0^2 + 8.0^2} = 11.3\% = 11.5\%$$

However, maximum combination gradient for special cases is defined at 12.5 % in consideration of exceptional conditions.

(6) Typical Cross Sections

The proposed typical cross sections are determined based on slope gradients for embankment and excavation judging from technical and economical points of view, pavement design and drainage design. Typical cross sections are classified into 4 types for the access roads and 2 types for the inspection roads as shown in Figures 1.3 and 1.4.

(a) Embankment slope

slope : 1 (V): 1.5 (H)

berm : 2.0 m in width at every 5 m in height

(b) Excavation slope

Two (2) kinds of excavation slope are considered depending on geological conditions as follows;

Geological condition	Slope		
Soil	1	:	1.0
weathered and hard rock	1	:	0.5

berm : 2.0 m in width at every 8 m in height

(c) Side Ditch

Side ditch is provided along foot of an excavated slope and a longitudinal gradient is determined as same as a gradient of road.

Size and type of the ditches will be determined based on "Drainage Design Criteria" set forth in Subsection 1.4.4.4 of this paper.

(d) Pavement

Thickness of each layer of pavement structure is determined based on a CBR value in subgrade portion referring to Province Standard and Japanese Standard as stated in Subsection 1.4.4.3 of this paper.

1.4.4.3 Pavement Design

As it was mentioned in Subsection 1.4.4.1, pavement shall be used in the permanent and temporary access roads as well as the inspection roads of the Project.

(i) Road with granular surface without surfacing for traffic demands up to 100 cars per day, for inspection roads.

(ii) Roads with granular surface without surfacing, placed over a layer of subgrade with selected material, for traffic demands of about 250 vehicles per day, for temporary and permanent access roads.

(1) CBR Design Value

The soil classification, climatic conditions and humidity regime prevailing in the subsoil allow the most appropriate selection of representative values of design bearing values (CBR) for a homogeneous section of the road.

(2) Design Method

For determining the thickness of each one of the layers, the following steps shall be taken:

(a) Traffic analysis to get the accumulated number of axle repetitions equivalent to 18 Kip (thousand pound) during the construction period.

(b) Soil analysis and estimate of the bearing value of the subgrade to obtain the CBR design values.

(c) Study of the material sources for pavement available in the Project area; which shall determine and locate the adequate material sources to comply with the requirements.

(d) Usage of curves and design concepts as stipulated in the section VI of the Design Manual of Access Roads, 1984 established by the Ministry of Public Works of Ecuador, to fix the design thickness f the pavement.

(3) Determination of Thickness

Three specific cases shall be considered for determining the thickness of each of the layers in accordance with the CBR value assumed for the subgrade.

(i) When CBR is equal to 3 % or less.

(ii) When CBR is between 3 and 12 percent.

(iii) When CBR is largest than 12%.

(a) Inspection

According to the Fig. VI-7 of aforementioned 1984 Manual of MOP:

Case A :	Design CBR: $\leq$ 3 %	
	Number of equivalent axle repetitions:	37,000
	Total thickness of granular material with CBR larger than 30:	32 cm
	It is assumed	35 cm (compacted in two layers < 20cm)
Case B :	Design CBR: > 3% $\leq$ 12%	
	Number of equivalent axle repetitions:	37,000
	Total thickness of granular material with CBR larger than 30:	18 cm
	It is assumed	20 cm
Case C :	Design CBR: > 12%	
	Number of equivalent axle repetitions:	37,000
	Total thickness of granular material with CBR larger than 30:	12.5 cm
	It is assumed	15 cm

(b) Permanent and temporary access roads

According to the Fig. VI-8 of aforementioned 1984 Manual of MOP:

Case A :	Design CBR: $\leq$ 3 %	
	Number of equivalent axle repetitions:	100,000
	Total thickness of granular material with CBR larger than 60:	15 cm
	Thickness of material of subgrade improvement with CBR = 12:	35 cm
	Total thickness of pavement	50 cm
Case B :	Design CBR: > 3% and $\leq$ 12%	
	Number of equivalent axle repetitions:	100,000
	Total thickness of granular material with CBR larger than 60:	15 cm
	Thickness of material of subgrade improvement with CBR = 12:	20 cm
	Total thickness of pavement	35 cm