PART B
STUDY GUIDELINE
ON
SOIL SURVEY AND LAND EVALUATION

&

PART 1- C
DESIGN GUIDELINE
ON
HYDRAULIC STRUCTURE
GATES

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER RESOURCES

PROCEDURAL GUIDELINES FOR STUDY OF SMALL & MEDIUM SCALE IRRIGATION PROJECTS IN ETHIOPIA

PART B

STUDY GUIDELINE ON SOIL SURVEY AND LAND EVALUATION

CONTINENTAL CONSULTANTS

Tel. 62 55 78 Fax 251 1 62 55 79
P.O.Box 22640
E-mail cc@telecom.net.et
Addis Ababa, Ethiopia

August, 2002

IN ASSOCIATION WITH

CONCERT ENGINEERING AND CONSULTING ENTERPRISE P.L.C (CECE)

ENGINEERS WATER RESOURCES & AGRICULTURAL DEVELOPMENT PLANNERS

P.O.BOX 6064 TEL. 627660 FAX 627690
ADDIS ABABA E-mail coneng@ telecom.net.et
ETHIOPIA

FOREWORD

This production was initiated and prepared under the auspicious of the Ministry of Water Resources of the federal democratic Republic of Ethiopia. Its purpose is to give counsel to the practicing professionals in the small and medium scale irrigation development and affiliated water resources engineering planning, study, surveys, explorations, design, field and laboratory tests, construction materials investigation and geotechnical designs and treatments. It can also be used as a baseline for further update and revision.

This guideline represents an advice of good practice and therefore takes the form of recommendations. Compliance with it does not confer immunity from relevant statutory and legal requirements.

The document is prepared by CONTINENTAL CONSULTANTS (CC) in association with (CECE). It covers the following components relevant to the study of small and medium scale irrigation projects: -

GUIDELINES

HYDRO METEDROLOGY (PART A)

☞ **SOIL SURVEY AND LAND EVALUATION (PART B)**

IRRIGATION AGRONOMY (PART C)

ENGINEERING GEOLOGY (PART D -1)

GEO-TECHNICAL ENGINEERING (PART D - 2)

IRRIGATION (PART E)

HEADWORKS (PART F)

SOCIOLOGY (PART G)

ENVIRONMENTAL IMPACT ASSESSMENT (PART H)

FINANCIAL AND ECONOMIC ANALYSIS (PART I)

TABLE OF CONTENT

Acronyms and Abervations

API:	Aerial Photo Interpretation
AWC:	Available Water Capacity
EARO:	Ethiopian Agricultural Research Organization.
EEC:	European Economic Commission
ESRDF:	Ethiopian Social Rehabilitation and Development Fund
EU	European Union
EVDSA:	Ethiopian Valleys Development Study Authority
FAO:	Food and Agriculture Organization of The UN
FC	Field Capacity
HC:	Hydraulic Conductivity
IFAD:	International Fund for Agricultural Development
IR:	Infiltration Rate
L MU:	Land Management Unit
LU:	Land Mapping Unit
MOA:	Ministry of Agriculture
MOWR:	Ministry of Water Resources
MSF:	Ministry of State Farms
NGO :	Non Governmental Organization
NMSA:	National Meteorological Service Agency
PWP:	Permanent Wilting Point
SMU:	Soil Mapping Unit
UNDP:	United Nations Development Program
UNESCO:	United Nations Education Science and Cultural Organization
WB:	World Bank
WRDA:	Water Resources Development Authority

1. INTRODUCTION

1.1. Study Background

Ethiopia has an estimated 3.7 million hectares of irrigable land and only about 5% is currently developed. This has shown that, the contribution of the irrigation sub sector to the national economy is very low. One of the constraints restricting this development is the low national capacity in irrigation project study and design. The Ministry of Water Resources has identified this short fall and initiated the preparation of procedural Guidelines, Criteria and manuals for study of medium and small scale irrigation projects. The Soil and Land Evaluation guideline is one of the multi disciplinary subjects prepared under this assignment.

Knowledge of the soils with in a potential irrigable area is essential for economic and technical reasons. The high cost of development of irrigated agriculture requires justification by assessment of the risks and benefits, and the design of the irrigation scheme itself is dependent on detailed knowledge of the soils within the irrigable area.

Soil survey and land classification are generally accepted essential preliminaries to invest in irrigation development.

By carrying out a systematic soil survey, in which, all important surface and sub - surface characteristics of individual soil bodies are mapped, the findings can be used, not only for irrigation development projects, but also in the planning of many different forms of land use and management practices.

Soil surveyor has to identity significant differences with in the soil body, so as to enable him demarcate those areas which for all practical use and management purposes are uniform. Moreover, soil survey should interpret the significance of the constraints mapped in terms of different combinations of irrigation methods, types of crops and cropping pattern, methods of management which seem to be physically, socially and economically relevant.

Changes associated with the introduction of irrigation are generally much greater than those under rainfed agriculture, and accurate prediction requires a correspondingly wider and sounder knowledge of the soils and substrata.

Site characteristics such as topography, land use land cover, vegetation, stones, flooding, termite mounds and other surface feature are very important aspects in considering the feasibility of irrigation development, since they influence the cost and/or physical possibility of land improvement.

Knowledge of soil physical characteristics helps to create a favorable environment for plant growth and crop production.

Acquisition of chemical data provides awareness about plant nutrient availability which helps in efficient fertilizer management. All the above soil data will be used in soil and land classification in which relatively uniform management is possible to adopt.

Irrigation planning requires a high degree of precision of soil boundary location, while the accuracy of economic studies required to attract capital from international investment agencies, necessitates fairly detailed knowledge of the distribution of different kinds of soils, their suitability for irrigated agriculture and then land development requirements and limitations, in all command areas.

Precision in soil type and soil boundaries is related to mapping scale, the density of soil observations, sampling for laboratory analysis, filed testing on really representative sites. This guidelines will discuss each of the above under the different chapters here in under.

1.2. Objective Of The Study

The Objective of the agricultural soil study is to establish guidelines, standards and criteria's of soil survey, classification, correlation, mapping, land evaluation for study of medium and small scale irrigation projects in Ethiopia.

Moreover methodologies for field testing, laboratory analysis and interpretation of results will be established.

1.3. Pervious Soil Survey and Land Evaluation Studies

Modern irrigation development in the country started in the 1930s along the Awash river by local and international entrepreneurs. The soil survey and Land evaluation studies and design of most of these schemes were mostly carried out by foreign experts with limited participation of local experts. The different foreign experts used soil survey criteria's and procedures of their own country. Later on, after a basic steps has been taken to create and gradually build local capacity in water resource development planning, guidelines and procedures prepared by international agencies like FAO have been used. Besides international financing agencies such as FAO/UNDP, IFAD, WB, ADF ..etc. have tried to help the water sector by recruiting and assigning consultants to the respective institutions. The consultants have tried to prepare guidelines and manuals. Review of these materials has indicated that most of them have some limitations in application for Soil survey and land evaluation of irrigation projects in Ethiopia.

1.4. Scope of the Study

- Review and discussion of the existing guideline, procedures, standards and criteria's prepared by international and bilateral organization
- Review and discussion of pervious procedures, guidelines, criteria's prepared by national institutions such as EVDSA, WRDA, MOA and ESRDF
- Investigate standards for soil and land classification including soil correlation for irrigation projects
- Prepare soil survey methodology for study and investigation of small scale projects.
- Prepare soil data analysis, evaluation and mapping procedures for irrigation projects
- Prepare soil laboratory testing procedures and interpretation of results
- prepare methodologies and criteria's for assessment of chemical properties, physical properties and hydrodynamic(IR., HC , AWC) properties
- Investigate procedures for application of fertilizer and soil amendments
- Investigate land evaluation criteria and guide lines for irrigated agriculture
- Prepare methodology for investigation of soil and water conservation
- Prepare the soil survey and land evaluation Procedural guide line

1.5. Methodology of the Study

The preparation of Soil Survey and land evaluation guideline has been started with defining the scope of the assignment thoroughly investigating the requirement of the TOR and Technical proposal.

International guidelines, bulletins, publications prepared by FAO-UNDIP-ISRIC, International Soil Science Society(ISSS), International Institute for Land Reclamation and Improvements (ILRI), International Soil Management and Research Center (ISMRC) .etc were reviewed and materials found relevant have been extracted.

Moreover guidelines prepared for national use in soil survey by developing and developed countries like India, USA, Canada, UK, Australia, Newezeland, French, Turkey , EU etc. have been reviewed and related part of the materials were taken.

Besides Semidetailed and Detailed Irrigation Project Studies conducted for Water Resources Authority, Ethiopian Valleys Development Studies Authority, Ministry of Water Resources and Ministry of Agriculture (for small scale) in the last two –three decades have been reviewed.

2. LEVELS OF SOIL SURVEY

The levels of soil survey are differentiated in purpose, intensity, scale of mapping. In general the following soil survey stage rare distinguished.

2.1. Synthesis

Synthesis is a compilation of soil maps based on abstraction from other surveys plus, where gaps in coverage render it necessary inferences from different source. Scale is usually, 1: 2,000,000 or smaller. The FAO World Soil map and Agro-ecological map of 1: 5,00,000, MOA/FAO, 1984; Soil Association map at 1: 2,000,000, CCTA 1:5,000,000 Soil map of Africa, EEC Soil map of Europe at 1: 2, 500,000 and most other regional and sub-regional maps are all belongs to this type. This type of map is helpful as a fundamental and applied teaching aid and also best for display as a mapping of natural resource atlas. Moreover, it helps as an immediate source to answer inquires from international organizations in planning technical proposals or requesting financial assistance. The mapping units are the higher categories of international or any national soil orders or its associations. This level of study have limited use for irrigation development planning.

2.2. Exploratory

Exploratory (very low intensity survey), is conducted to provide land and soil information of other wise unknown regions. It is a preliminary identification of areas for development and these days largely restricted to areas with serious problems, usually in terms of physiographic or group of physiographic arrangements. It is a tool to make a plan for sectoral development say agriculture, forestry, rangeland, wildlife in countries like Ethiopia where there remains still large undeveloped areas. It can provide a basis for more detailed study. Exploratory surveys are mapped at a scale of 1: 1,000,000 - 1: 500,000. Soil and Geomorphology map of Ethiopia at scale of 1 : 1 000 000 is a typical example. Mapping units are soil great groups, suborders, orders/class, units and associations.

2.3. Reconnaissance

Reconnaissance (low intensity survey) is a resource inventory of large area at a small scale of 1: 100,000 - 1: 500,000 with the aim of identifying an area for development plan of main land use types such as rainfed, irrigation, pasture, rangeland etc. that are physically possible with in a large region of an area of the country. In relation to irrigation, these maps can only serve pre - investment purposes, to identify potentially suitable areas for irrigation with in which more intensive mapping is required. River basin master plan soil and land use survey and maps are categorized in here. The mapping units are soil sub - orders, series, geomorphic units and soil associations.

2.4. Semi-detailed

Semi-detailed (medium intensity survey) is to identity specific areas largely earmarked as suited to specific forms of agricultural development (say) irrigation at a mapping scale of 1: 25,000 - 1: 100,000. These serves as a guide in pre - investment decision, by identifying project areas with in which expenditure on more intense studies and implementation appears to be justified. Several prefeasibility studies were conducted by Ethiopian Valleys Development Authority, Ministry of Water Resources and Regional governments. Mapping units are soil series, associations and complexes of soil classes.

2.5. Detailed

Detailed (high intensity survey) is conducted at a mapping scale of 1: 10,000 - 1: 25,000 with the objective of investment feasibility studies of fairly potential development areas for a specific purposes. Thus enable planners and users to make decision in further steps to be taken, either implementing or go for best alternative use of other wise potential area. It is an adequate basis for planning irrigation implementation only if the soils are very uniform with in which it is not necessary to know the `` **exact** `` location of soil boundaries, such as areas where only sprinkler, drip irrigation and very simple drainage measures are considered and in area where the existing structure are such that the possibility of layout changes for irrigation based on soil information is limited. Several feasibility studies were conducted by Ethiopian Valleys Development Studies Authority, Ministry of Water Resources and Regional governments and most of them are ready for implementation. Koga irrigation project is a typical example.

2.6. Intensive

Intensive (very high intensity survey) is conducted at a scale of 1: 5,000 - 1: 10,000 intended to plan the implementation of farming enterprise usually of areas where complex soil problems requiring precise recommendation. For example plantation management, an irrigation layout requiring sub-surface drainage or intensive irrigated farm requiring plantation management. Moreover, this level of intensity is used to delineate research centers, demonstration and pilot farms with in an irrigation project. The scale is detailed enough to delineate phases of soil series and specific crop related parameters such as salinity, sodicity, toxicity effects ... etc. At this intensity level, every soil boundary should be checked in the filed and the level of dependence on API is minimal.

It should be noted that at each successive stage, recommendations on the areas deserving further investigations and the intensity of filed observations required in the next stage should be given, in explicit terms.

The guidelines and b
asic survey procedures for all level of survey are similar except for observation densities, type of parameters evaluated, scale of mapping ... etc. In general, the more intensive are the mapping units, the more detailed are the measurements of the parameters and normally the more specific is the purpose of the survey. The use of aerial photos or satellite imagery is correspondingly reduced with increasing scale and intensity of survey and depend more on actual data

In all the above levels of study discussed, there is as such no clear cut standard observation density than range of standards. It varies from 0. 25 - 5 per cm^2 of map scale. The actual observation density should depend on the survey objectives, the mapping scale, the homogeneity of the area, the experience of the surveyor, the quality of API or remote sensing and base map obtained (See Table 1).

Table 1:Scale and Density of Observation for different soil survey levels and purposes.

No	Level of Survey	Range of Scale	Typical scale	Density of observation	*Minimum size delination(ha)	Purposes	Remarks
1	Synthesis	1: 2000 000 & smaller	1: 200 000	None	101,000	world and continental planning	not useful
2	Exploratory	1:1 000 000 to 1:500 000	1: 1000 000	Variable	4,000	National atlas, National resource inventory at national/regional levels,	limited use
3	Reconnaissance	1: 100 000 to 1:500 000	1: 250 000	1 per 200- 400 ha but usually less	1 000	regional land use planning, tentative project location	can be skipped if 2 is done well
4	Semi detail	1: 25 000 to 100 000	1: 50 000	1per 15 to 50 ha	40.5	agricultural advisory work, project planning, irrigation surveys	can be skipped if 3 is done in more detail
5	Detail	1; 25, 000 to 1:10 000	1: 10, 000	1 per 5 to 15 ha	0.4	project implementation	can be skipped if 4 is done in more detail
6	V. intensive	1: 10 000 to 1 : 5 000	1: 5 000	1 per 2.5 to 5 ha	0.1	Special purpose	

* Minimum size delineation is taken as $6mm^2$

3. SOIL SURVEY PLANNING

3. 1. Per - Filed Activities

i. **Maps and Data collection:** Collection of maps, aerial photographs, satellite imageries and data's, existing national, regional and local topographic map at the scale of 1: 50,000 and 1: 250,00 are very essential to get first hand information. Paired aerial photos display the area of study in a three dimensional and synoptic view and are there fore an excellent tool in soil survey. Aerial photos from Ethiopian mapping Agency and other government and non-government organizations who have retained for their own use, should be obtained before survey started. Scale, date and season of flight are very important. Satellite imageries are useful in small scale soil survey. Pervious studies and relevant documents on soil survey, land resources, Agriculture and studies on Integrated Rural Development by government institutions and NGOS are very useful at least for survey planning Other data's on access, settlement pattern, climate and local environmental conditions need to be collected. Information's on the socio -economic, cultural systems, religious and any special condition of the inhabitants, security situation and risks are important in soil survey work and logistic planning. For example knowing the rainy seasons will help us to plan our survey in dry season.

ii. **Equipment and transport** : the leader and the soil survey team should ensure that necessary equipment have been acquired, before filed work begins. The types of filed equipment needed will normally be determined by the purpose and intensity level of the project, by the nature of the terrain, and to some extent by personal preference. Some items are used in virtually all conventional soil surveys, whilst others are required for special investigation. The number of equipment's depends on the number of survey teams with some spares in case of damage and loss. The survey team requires A - 4 wheel drive vehicles adopted to the terrain. The vehicle should be supplied with full range of spare parts. Radio communication should be mounted at least on one vehicles and at head office for frequent communication. In remote areas camping equipment, food and kitchen items, water and fuel tankers are very essential(see Table 2.)

Table 2. Check list of filed equipment for soil survey.

Basic items	Remarks
Augers (Screw, Dutch, Jarret and Barrel types).	
Strong spades of varying width, Shovel	
Pickaxes, mattock or crowbar	
Broad-bladed knife or trowel	
Geological hammer	
Filed note book, Camera and Video camera for recording	
Pit description guide lines	
Map Legends	
Pencils (including photo marker)	
Map case and/or clip board	
Tape measure	
Pocket stereoscope	
GPS	
Munsell soil color chart	
Water bottle	
Acid bottle	
Hand lens	
Plastic pail or water carrier	
Clinometer or Abney level	
Sample bags, ties and labels	
Kubiena boxes	
Monolith trays	
Core sampling equipment	
First aid Kit	
Filed compass	
Calorimetric filed PH kit or portable pH meter.	
EC meter	
Infiltration Test (set equipment) and water barrels	
Hydraulic conductivity (set equipment)	
Water sampler	
Stone samplers	
Others as deemed necessary	

iii. **Preparation of Base Maps**: Preparation of base maps to be used in the field and preliminary delineation of soil from Aerial photograph interpretation has to be done in office. The base maps has to be prepared from existing topomaps, API and other pervious studies. They should normally be at least twice larger than the intended publication scale and sufficiently detailed to enable sampling points and mapped boundaries to be located accurately in relation to topographic and other visible features.

As API plays significant role in soil survey, suitable scale photo covering the area need to be obtained and interpreted at the preparatory stage. If new photography is commissioned, the cost is considerably greater and orders may need to be placed well in advance, particularly if the objective is to obtain photos at a specific times of the year (wet/dry season, at planting/after harvest..etc) when soil difference are most likely to be revealed.

iv. **Preparation of work plan, manpower and survey organization.**

The work plan for all activities in office, filed and laboratory analysis need to be scheduled on bar charts possibly on daily, weekly, monthly and annual basis. The responsible expert for each activities has to be assigned

The survey team should be organized at head office and filed level. As far as possible the survey should be organized to allow each survey and his team to operate independently. With in a team assign responsibilities for specific technical/ administrative operations to individuals and make sure individual TOR and job description are carefully designed to avoid overlaps and get effective out put. Daily routines including departure and return times has to be fixed. The Omo Ghibe River Basin Integrated Master Plan and other master plan studies survey organization which were also adopted in subsequent master plans could be an example for soil survey organization of large scale irrigation projects.

3. 2. Field Activities

The main part of activities in filed is checking identified soil classes and boundaries to be mapped, the mapping legend and actual relations between soil properties and land forms or surface feature, shown on the preliminary base. This has to be followed by auger observation, pit description and sampling, special tests such as HC and IR.

Provisional filed soil maps have to be prepared to check if there is any data gaps and complete before leaving for head office.

3. 3. Post-filed Activities

- Submission of the samples to certified soil testing laboratories
- Compilation and analysis of field soil description data's
- Analysis of laboratory results
- Final soil classification and mapping
- Land evaluation for irrigation
- Land evaluation for selected crops
- Assessment of soil and water conservation aspects
- Investigation of soil problems and recommendation of management options

4. AERIAL PHOTO INTERPRETATION AND REMOTE SENSING TECHNOLOGY FOR SOIL SURVEY

4.1. General

API are used in soil survey for preparation of base map, to plan field operation, for interpretation of soil boundaries and to find your way about in the field and to locate observation sites and peculiar feature. API can not be a substitute for field work. It may however, enable work in the filed to be reduced, better planned or other wise rendered more effective output. API are not used to actually identify soil types, rather to locate changes in the land form and surface patterns that may be related to differing soil properties, with boundaries of mapable soil units. Aerial photographs are an image of the land surface on which difference in surface reflectance of light appears differences in tone, texture, pattern, shape, relief ... etc.

4.2. Scale and Coverage of the Aerial Photographs

Paired aerial Photographs display the area of study in a three dimensional and synoptic view and are therefore an excellent tool in the study of land use and soil survey.

The aerial photographs are available in the country at different scale ranging from 10,000 to 60,000. During interpretation scale and interrelationship of the ground features have to be thoroughly investigated (see Table 3).

The major equipment essential for interpretation is a good mirror stereoscope. A moving table and x3 binoculars are desirable, whilst an interpretoscope zooms stereoscope or similar instrument will be a luxury but simply all the job if available.
A moving table allows different parts of the view to be brought under binocular view without disturbing stereoscope alignment

Table 3. Aerial Photographs Scales and coverage

Level of survey	Scale	Area covered by one whole print (km^2)	Working* area on one print (km^2)	Number of prints per $100km^2$	Ground equiv. of 1mm(m)	Ground equv. of 1 cm (2)(ha)
Very large	1:5 000	1.3	0.8	240	5	0.25
large	1:10 000	5.2	3.3	60	10	1
	1:20 000	21	13	15	20	4
Medium	1: 25 000	33	21	10	25	6.25
	1:30 000	47	30	7	30	9
	1:40 000	84	53	4	40	16
Small	1:50 000	131	84	2.4	50	25
Land sat	1:1000000	34 000	20 000	0.005	100	10 000

Source: David Dent and A. Young, 1981

** The working are is that covered by a single print after omitting overlp with adjacent runs and with next but one prints in a run i.e. the area on which boundaries are drawn on.*

4.3. Aerial Photo Interpretation Techniques

Stereoscopic view of aerial photos give a 3 D of an object. API uses the following techniques to identify the characteristics of land and soils.

Tone: is the shade of gray, ranging from black to white.

For example: - rock out crop and bare soil exhibited by light tone, wet soil is darker than dry soil, water will be very dark unless turbid, high objects such as trees, houses are reflecting shadow, mottling spots are darker than the normal surface ..etc.

Texture: is the fine pattern of tone contrast.

For example: - bare mad flats give a smooth texture, forest canopy is reflected by moderately rough texture and most crops have characteristics texture.

Pattern: is a spatial differential arrangement of an object. It is a regular variation in ton at a scale in which an individual element can be seen.

For example:- orchards, badlands, termite mounds, cultivation, fallow land and shifting cultivation creates different observable pattern than the default areas.

Shape : is individual appearance and should be assumed accordingly.

Size: is identifiable object in relation to scale of photo and again should be assumed accordingly.

Site: is topographic or geographic location and are important in the identification of features.

Note that, interpretation must be based on what can be seen, such as land forms vegetation and land use. However the usefulness depends on how clearly the relationship between these visible features and soil types can be established in the filed.

4.4. Aerial Photo Interpretation Features

Features which can usually be readily identified and delineated by stereoscopic examination of aerial photographs for soil survey and land evaluation include.

Vegetation: in undisturbed conditions changes may be due to different plant associations, growing in different soil types, or slight variation in species composition, plant vigor resulting from different moisture conditions in adjacent soil. Note that, the better understanding that the surveyor has of the physiology and ecology of vegetation the more skilled he will be in using it as an indicator of soil type.

Land system /geomorphic unit: is ranging from major sub-continental to the parts of a single slope facets such as foot slopes, summit, hills, mountains and structural such as shield areas, down warped basin, dissected fold mountains or coastal plains, plateaus, alluvial plains, pediments, peneplains, volcanic cones, calderas, lava flows, craters. These features serve as a setting especially in small and medium scale intensity survey.

Relief units: include drainage pattern such as multibasin (radial, centrifugal ... etc.,), freely developed (denderitic, parallel ... etc.) structurally developed (annular, trellis ... etc.), gullies (u, v, shaped, ... etc.), streams (intermittent or dry, ... etc.), slope (shape, angle aspect and orientation), rivers and its type, micro-relief (gilgai, vertic, crack, salt encrustation)

Land use/land cover : cultivated, pasture, forest, plantations, orchards, rangeland, wood land, urban or villages. The coincidence of land use boundaries with soil boundaries is generally low, land use being a complex feature that depends on physical as well as socio-economic factors.

4.5. Other Remote Sensing Techniques

The other remote sensing techniques such as satellite imageries of various types, ground penetrating radar's ..etc. and GIS techniques are useful, especially on small scale land use and soil survey. In River basin integrated master plan projects, MSS satellite images have been significantly used for soil and land use mapping at the scale of 1:250 000, 1 : 500 000 and 1:1 million. The use of satellite imagery has opened up a new possibility in soil survey, that of producing same sort of map of the whole of a large country in no more a few man months. Geomorphology and soil map and Soil Association map of Ethiopia were used mainly satellite interpretation. Detailed discussion on satellite imageries are found less important, since its application in large scale mapping, especially for irrigation development is limited.

All remote sensing systems are only valid if and only if the soil/land units mapped from them, can be related to land and soil types on the ground.

5. SOIL SURVEY AND MAPPING METHODS

5. 1. Soil survey method

There are different methods of obtaining soil data in soil survey.

i. **Compilation and/or remote sensing interpretative survey**. Whilst all other methods are used in field soil data collection and API, this system is entirely based on compilation and synthesis of pre-existing soil and land resource data combined with imageries of different types and scale such as MSS, TMS, Spot ..etc with out any or at best minimal ground truthing. This method is used for national or regional soil mapping by generalization of the soil nature and its application for irrigation is limited.

ii. **Free survey**: is a method where filed observation are suited purposively to check or plot boundaries in accordance with a pre determined mapping legend from API or any per-existing source or in best following preliminary field studies.

i.e. based on the available information, past experience and API, the surveyor uses his judgment in the objective of the survey to locate auger and profile observation points.

Whenever this method is used, the preliminary investigation either from API or filed checking is the most critical part, since itself demands both methodical investigation and skilled judgment on the part of the surveyor, whilst its quality or effectiveness largely determines the utility of the survey as a whole. On statistical grounds even a preliminary free survey should consist of essentially a form of a stratified sample blocks, and that soil observation sites should be randomly located. But practical considerations dictate that they should be near tracks or pre-existing traverse lines and any access routes. This leads to bias in sampling. The greatest advantage of this system is that in making general purpose surveys of moderate intensity, an experienced surveyor can map soil units with fewer observations or more precise units with the same number of observation than grid survey. In irrigation development planning it is best used at reconnaissance and possibly semidetailed stage.

iii. **Traverse survey**: is the systematic location of soil observation points along accurately located traces. It does not necessarily imply that the traces are arranged in the form of a parallel grid, or even that they are straight throughout their length. The position of individual traverses likely to yield the most informative observations, are often determined by a preliminary study of aerial photographs. This type of technique is used in semi - detailed surveys and in densely vegetated or featureless terrain. Sampling points along traverses are not necessarily at regular distances, rather depend on changes in surface features. This technique is well applied for irrigation projects.

iv. **Grid surveys**: are based on regularly spaced pre-determined sampling points of geographically known or cultural features on the base map. It is usually used at high or very high intensity levels for special purpose surveys like irrigation and drainage design, farm enterprise management planning, in which the usefulness of air photo interpretation demands precise plotting of sites. Grid surveys are also used in areas where soil changes have little or no external ground expression or where overall access is difficult such as in tropical forest, semi arid dense bush and grasslands or large tracts of flood plains and swamp. Soil boundaries are drawn by joining points of equal value of a specific property or where general purpose classes are defined, between points at which dissimilar soils occur. As the cost of laying particularly grids is high, partially in dense vegetation, traces prepared for topographic survey should preferably be used as a base line in irrigation surveys.

The limitations of grid survey is that, there being same degree of spatial dependence between sampling points, to the extent that, the soil in most unsampled places is generalized and represented by the soil at the nearest sampling point. Besides in bad terrain's and dense vegetation where even, a foot access is a problem preparing trace lines will be a problem. A soil surveyor can over come this problem by cutting " W" or inverted " W" to enable pick the soil variability in between fixed grid lines. This has been effectively used in feasibility study of Gelana Irrigation Project.

Grid survey is used in irrigation, for large scale mapping and special purpose surveys like drainage, salinity/sodicity, toxicity ..etc.

v. **Physiographic survey:** is survey techniques where mapped boundaries are based on external features of the soil landscape perceived by systematic API and other remote sensing interpretations of the local land form, drainage Pattern, catena/topo sequence, natural vegetation or land cover aided by geological and geomorphological information. Mapping is performed by delineating a physiographic unit sufficient to incorporate main soil variation. This method takes advantage of pedological correlation of soils under an auspices of soil forming factors, similar land forms and relief, geology and parent material, vegetation and land use. Field observations are made not to locate boundaries, but to identify or describe the soils with in each mapping unit. The limitation of this method is that, physiographic units which can be identified and mapped on their external expression contain more than one type of soil and many areas, such as flood plains posses insignificant physiographic external expressions of either land forms or spatial variations in soil types.

This method has been widely used for reconnaissance or low intensity survey or low intensity survey aimed at assessing the potential of the land resources in undeveloped areas. Soil and Geomorphology map of Ethiopia (1984) prepared by FAO and the then, land use planning department of the MOA is a typical example.

vi. **Sample area Survey:** one or more carefully chosen representative locations are selected in the survey area, taking care that all main physiographic and geological formations and other features are included. These relatively small areas are surveyed in detail at a scale of say 1: 10,000 when the final publication scale of the soil map covering the whole area is to be 1:100,000. These detailed soil maps of the sample area provide the basic information on the landscape, geology-soil correlation that enable the whole survey area to be easily interpolated. This method requires more time and highly specialized personnel. Theoretically the resulting soil map is said to be accurate than grid or other methods. However its application in Ethiopia is absent and further recommendation requires pretesting.

Table.4. Summary of Application of Soil Survey Methods and Techniques.

No	Survey Technique	Application in irrigation
1	Compilation and/or remote sensing interpretative survey	Not applicable
2	Free survey	At reconnaissance and semi detail
3	Traverse survey	used in conjunction with 4
4	Grid surveys	well suited to use
5	Physiographic survey	at reconnaissance and exploratory
6	Sample area survey	its experience in irrigation planning is absent and should be used cautiously.

5. 2. Soil Observation, Sampling and Testing

Soil observation are made for different purposes. For observations intended to characterize soil units, observations and descriptions should be made in soil profile. The depth of the profile should be 2 meters or to an impenetrable layer. To check drainage, up to 3 ms and another 2m auguring will describe permeability of the soil. The pit is sampled for laboratory analysis and stepped for soil core sampling using core rings. In core sampling the cylinder has to be about 5-7.5 cm long and 5- 7.5 cm diameter.

Routine auger description to the depth of 150 - 200 cm helps in delineating and checking the boundaries. Composite samples from the soil surface (25cm) are collected for fertility assessment. A number of random samples (approximately 200gm each) are collected from each uniform unit and are mixed together. Table 5 shows soil observation sampling and testing required for different analysis and interpretation.

Table. 5. Soil Observation, Sampling and Testing.

Nature of observation & sampling	Nature of test	Required depth (m)	Remarks
Soil Pit	Morphology, physical and chemical characteristics of the soil profile	2	Disturbed soil samples of about 2 kg collected from each horizon
Auger boring	Routine soil observation	1.5-2.0	Observation of physical characteristics, CaCo3, PH & EC
Deep boring	drainage study	2-5	Groundwater, impermeable layers/hard pans & salinity are recorded
Shallow pit	Locate soil boundaries and characterize soil variability	1	By using sharp spade to dig, rooting condition, color, texture, structure are described and samples may be taken if required
Road and gully cuts	Identify the nature of parent material and disturbed soils	As deep as the road and gully cut	Sampling is taken rarely if the profile is undisturbed and need arise for testing of disturbed soil
Infiltration Rate	Soil moisture relationship	Saturated soil	3 sets of double ring inflitrometers
Permeability	Drainablity classes	2-3	Invers auger hole, float apparatus and recording tape are required.
Undisturbed soil core	Bulk density, 0.33, 15 bar	at selected horizon	Determination of AWC
Composite	Fertilizer	Surface 25cm	Determination of important micro/macro elements
Plant leaf and/or Tissue	leaf/tissue analysis	representative specimen	micro nutrient/toxicity indication
fragmented Rock/stone		Surface/ horizon	Determination of the nature of parent material

4.3. Attaining Observation Density

The actual number of observation density depends as discussed above mainly on the complexity of the soil and objective of the survey.

The number of augers should be determined as per the scale. However 10% of the observation has to be profile description and sampling for laboratory analysis. Each soil mapping units need to be represented at least by 2 - 3 soil profiles.

Infiltration and hydraulic conductivity shall be done for each soil types and/ or soil mapping units at the same location with representative profiles.

At reporting stage summary table has to be prepared to show how the study attained or not attained (including reasons) the observation density (see Table 6).

Table 6. Format for Summary of Soil Observation

1 Soil Mapping Unit	2 Area surveyed (ha)	3 No of Auger hole	4 No of Pits	5 Total obs. (3+4)	6 Obs. density (5/2)	7 %Auger obs.	8 % Pit obs.	Other tests	
								No of IR	No of HC
SMU1									
SMU2									
SMU3									
SMU4									
SMU5									
...etc									
Total	x	x	x	x	x	x	x	x	

5.4 Soil Mapping Unit Types

Simple mapping unit: is a soil pattern in which a boundary delineation's consist dominantly of a single soil type or very similar to it. In soil nature it is very difficult to get a uniform mapping unit. The mapping units are important as it serves as a basis for describing and predicting soil behavior. One has to bear in mind that, a typical soil mapping unit includes an unknown amount of variation usually said to be insignificant in respect to management of the soil. Hence in delineating the boundary of the mapping unit in irrigation, a surveyor has to concentrate on important boundary lines such as permeability, salinity/sodicity, slope, stoniness etc. instead of looking for the uniformity of the soil.

Soil complexes mapping units: are compound map units consisting of two or more dissimilar (contrasting) components and other components similar to them that occur in a regularly repeating pattern and are too small to set apart at that particular mapping scale. Its application in irrigation development planning is limited as the mixed complex soil may create devastating impact

Soil associations mapping units: are different soil types that occur together on the same parent material and differ in characteristics related to local variations. The dominant soil is extensively described and mapped. In irrigation most of the time the mapping unit types are soil associations. An associated mapping unit can be a soil series, phases, polypedon, group of soil properties, landform (slope), drainage pattern and others as preferred by the soil surveyor.

Soil consociation mapping units: are soil map units in which all boundary delineations consist dominantly of a single component or components very similar to it.

Other Soil Mapping units: For practical soil and land management purposes any mappable land and soil characteristics can be used as a mapping unit. The most common ones are, soil type/ units, sub units, series , phases, variants. Moreover individual or group of soil properties and limitations such as stoniness, permeability, salinity- sodicity, acidity, fertility. .etc can be mapped as a soil mapping unit within the intended objective. Significant land characteristics such as slope, landform, drainage pattern, catena , microclimate, vegetation.. etc can be used as a soil and/or land mapping unit, each independently.

Land Units(LU): is mapped area of land with specific similar characteristics in one of the land features such as physiography, local geology, external land characteristics such as micro climate, land form, land use land cover, drainage pattern and .etc. Land unit is mapped at exploratory and reconnaissance level and at preliminary survey stage from API and topo maps in semidetail and detail irrigation studies. Identification of the land units will help the soil survey process as it facilitates with the base map to locate the grid /traverse pattern.

5.5. Soil Map Legend

The objective of a map is to present an overview of an area, to highlight the main variables and to act as an information synthesizing mechanism. It presents a group of areas which are similar in their primary characteristics and characterize their spatial variation and relationship to each other.

Maps can be represented as points, lines and polygons. A soil map is a polygon and termed as discussed above, a soil mapping unit. The data on the map is explained by soil mapping legend. For each soil symbol on the map, the map legend should include a brief explanation of the most significant soil characteristics represented, interms designed to be informative not only to the soil scientists but also to the widest possible range of users.
On basic soil map relating to high and very high intensity survey it is often convenient to use a two or three symbol to designate each soil mapping unit. For example the Legend to soil map of Weiyb irrigation project can be:-
VK11: Kubsa soil serious, strongly calcareous with slope 4-7%, Rhudic phase
VW22: Weyib soil serious, moderately calcareous, gentle slope (2- 3%), phreatic Phase
VW25: Goro soil serious, nearly flat (slope < 1%), Sodic phase

5.6. Description of Soil Mapping Units

Under this section each soil mapping units, have to be described in more detail both in discussion and tabular form. Land Characteristics such as, local geology/ lethology, parent material, landform , land use land cover, stoniness and rock out crops, status of soil erosion, surface features such as crusting, gilgai, termite mounds have to be discussed.

Moreover soil physical and chemical properties of the soil mapping units should explicitly discussed. The land and soil management practices to be adopted for each SMU need to be given(See Table.7)

Last but not least the soil mapping unit description should be supported by putting in place, brief Representative Soil Profile description.

Table.7. Format for Summary of Soil Mapping Unit Description.

Soil Type	Soil unit	SMU	Area (ha)	Land form	Slope	Type of mapping unit	main & associated soils	Brief description	Soil limitation	Mangmt. required	Irr. & crop suitability
A	A	SMU1									
B	B	SMU2									
C	C	SMU3									
B	D	SMU4									
E	E	SMU5									
etc	..etc	...etc									
		Total									

6. DESCRIPTION OF THE LAND CHARACTERISTICS

Land characteristics gives a basic land and soil information and helps in identifying and classifying soils and delineate boundaries. Moreover the land characteristics concerns with surface features affecting the physical feasibility and/or related cost to develop the land for irrigated agriculture.

Criteria's for description of each land characteristics given from mainly in this guideline are mainly FAO Soil Profile description guideline 1990, and USDA soil Survey Manual, 1994, Booker Tropical Soil Manual and others as relevant.

6. 1. Landform and Topography

Land form: refers to the shape of the land surface in which the soil observation is made

The major landforms and the recommended codes are: Mountain (MO), Hill (HI), Upland (UP) , Plain (PL), Plateau (PT), Basin (BA), Valley (VA).

The second level of the land forms are: Alluvial plain (AP), Lacustrine Plain (LP), Peneplain (PN), Pediment (PE), Volcano (VO), Dune field (DU), Delta (DT) and Playa (PY)

Physiographic position: is the relative position of the site with in the land element. It affects the hydrological conditions of the site (external drainage, which may be interpreted as being predominantly water receiving, water shedding or neither of these.

Characterization of Position in undulating to mountainous terrain Includes: Crest(CR), Upper slope(UP), Middle slope(MS), Lowerslope(LS) and Bottom land(BO). On the other hand flat or almost flat areas, are described as: higher part(HI), Intermediate part (IN), Lower part (LO) and Bottom/drainage line (BL).

Land Element: describe the geomorphology of the immediate surrounding of the site. Some examples are: Interfluve(IF), Valley (VA), valley floor (VF), Channel (CH), Levee (LE), Terrace (TE), Flood Plain (FP), Lagoon(LA), Pan (PA), Caldera (CA), Depression (DE), Dune (DU), Longitudinal dune(LD), Interdunal depression(ID), Slope (SL), Ridge (RI) and Beach ridge(BR).

Topography: - topographic features which have a special bearing on irrigation suitability are slope, micro relief, macro relief and the position of that specific tract of land.

Slope: - soil slope is normally measured by hand levels such as Abney level or clinometer and expressed in terms of percentage. It includes actual slope in percentage, length, shape and exposure.

Flat(F): 0- 0.5 %, Almost flat (A): 0.5 -2 %, Gently undulating (G): 2 - 5 %, Undulating (U): 5 -10%, Rolling (R): 10 - 15%, Hilly (H): 15- 30 %, Steeply dissected (S): > 30 % with moderate range of elevation and Mountainous (M): >30% with great range of elevation .

The approximate shape of the slope(i.e. straight, concave, convex, terraced and complexor irregular) has to also measured in meters. The direction of the slope north, south, east west etc. has to also known.

Micro-relief: refers to minor surface undulations and irregularities of the surface, with differences in height between crest and trough of 4 - 5cm, in plains or 4- 5m in areas of wind blown sand. Irregularities of the soil surface may be formed by different processes, such as erosion or deposition by water, wind or gravity, solution (sink holes), swelling and shrinkage (gilgail /cracks) or man more (contour terracing, dikes, ditches) ... etc. Micro-relief determines land leveling /grading, cut and fill and earth moving during development. Average cut and fill requirement of 7.5 cm with earth moving of 375m^3 /ha is considered to be light. However average cut and fill of 15 cm, 30 cm and Earth moving of 750 and 1500 m^3/ha is categorized under medium and heavy grading requirements. The soil survey has to classify his soil accordingly and give to the irrigation engineer for cost estimate and land development planning.

Macro-relief: is uncorrectable shapes and forms and dictates filed size. It also determines the method of irrigation. For maximum production with a minimum labor requirement, irrigated fields as large as, 8 ha (is very favorable), 3.6 ha (is favorable) 2 ha (is moderately favorable) and 1 ha (is unfavorable) field size for irrigation development. For maximum production with a minimum labor requirement and use of machinery, irrigated field blocks should be large and the irrigation's system runs long and strait to avoid erosion and less maintenance. The more complex is the topography the less desirable is gravity irrigation. Sprinkler and drip irrigation is suited to this type of terrain.

Position of the tract of land: areas of land rising several meters above adjacent land should be delineated on the map for ease of identification and location. Any decision to exclude them from irrigation would make later in consultation with the engineers and economists. Moreover small tract of land isolated from the major irrigable area, regardless of the quality of land are usually uneconomic to include in an irrigation scheme if they are remote from the sources of water or drainage outlet. They are again have to be excluded after completion of the survey and mapping with the consultation of irrigation engineer and economist.

6. 2. Natural Vegetation and Land Use.

Vegetation types: such as grassland, forestry, woodland, etc. have to be identified. Botanical names of plants should also be given (use common names or local names, if botanical species names are not available in the filed, but find the botanical names later in the office). Besides its relevance in soil type identification, land clearing and removal cost, also depends on size, density and type of vegetation.

Land use: identify nature of land use and land management practices.

Farming system: principal crops grown (kind, varieties, rotations and yields, use of irrigation, contour cultivation, use of organic or inorganic fertilizer ... etc.

6. 3. External Drainage

Overflow hazards due to external drainage from rivers or stream channels or surface run-off from higher uplands often influence the use, management and development costs of affected portions of an irrigation project. External drainage class described as:

Ponded (P) where none of the water added to the soil escapes as runoff on site.
Very slow(VS), Slow(S), Moderate (MO), Rapid(R), Very rapid(R) depending on how fast the rainfall move rapidly over the surface of the soil.

6.4. Internal Drainage

The internal drainage of the soil profile is a combination of two features i.e. the period when the soil is saturated or very wet and the rate of water movement through the soil. A more specific condition of drainage should there fore be distinguished between the existing or recent conditions of wetness and the rate at which water can move through the soil (vertically or laterally) expressed as permeability or hydraulic conductivity. Hydraulic conductivity is measured in field for selected representative profiles (see section 9).

The internal drainage or permeability of a soil profile can be estimated by saturation with bottles of water and observation of the rate of movement in each layer. However the result has to be correlated with the texture and measured hydraulic conductivity at a later stage before giving recommendation

The rate of estimation is: extremely slow (ES), Very slow (VS), slow (S), Moderately slow (MS), Moderately rapid (MR), Rapid(R) and Very Rapid(VR).

6.5. Flooding

Flooding, or temporary inundation, is described according to estimated frequency, duration and depth. At most sites it is difficult to assess flooding accurately. Information may be obtained from recording past events or discussion with local people.

Moreover flooding is often determined from surface sedimentation, debris, transported stones, cobbles, and injuries to trees and vegetations by sedimentation.

Flooding can be measured by frequency of occurrence: daily, weekly, fortnightly, monthly, quarterly, annually, biannually, every 3,4,5,10, 20,..etc. years. Duration implies the time elapsed for an hour, 2,3,4, 5 ..Etc. hours, for < one day, 1- 15 days, 15- 30 days, 30 - 90 days, 90 - 180 days, 90 - 180 days, 180 - 360 days and continuously flooded.

6. 6. Stoniness and Rock out Crops.

The occurrence of surface coarse fragments causes hindrance to cultivation. The coarse fragments should be described as follow
None (0%), Very few (0 - 2%), Few (2 - 5 %), Common (5 - 15 %), Many (15 - 40 %), Abundant (40 - 80 %), Dominant > 80 %.

The size of the stones is as follow.

Fine gravel	0.2 - 0.6 cm
Medium gravel	0.6 - 2 cm
Coarse gravel	2 - 6 cm
Stones	6 - 20 cm
Boulders	20 - 60 cm
Large boulders	> 60 cm

USDA describes quantitatively unlike FAO which characterizes rock out crops qualitatively. Accordingly, rock out crops or rockiness refers to the relative proportion of bedrock exposures, either rock out crops, or patches of soil to thin over bedrock for use. This will limit the use of modern mechanized agricultural equipment.

Class 0: have no rocks or very few rocks of < 2%

Class 1: fairly rocky, sufficient bed rock exposure 35 - 100m apart and 2- 10 % to interfere with tillage.

Class 2: Rocky: sufficient bed rock exposure 10 – 35m apart and cover 10-25% and make tillage of intertilled crops impracticable.

Class 3: Very rocky, exposure 3.5 m -10 m apart and cover 25 - 50 % . Use of all machinery is impracticable.

Class 4: Extremely rocky: exposures L 3.5 m apart and cover 50 - 90 % . Use of all/or any machinery is impracticable.

Class 5: Rock out crops: more than 90% of the land is exposed.

6. 7. Status of Soil Erosion.

Erosion is the wearing away of the earth's surface by the forces of water and wind. Erosion is constructive as well as destructive. Erosion when ended with sedimentation is constructive while accelerated erosion is destructive. The Natural erosion is an important process in soil development. Hence erosion status has to be given.

Main categories of erosion are: No evidence of erosion (N), Wind erosion (W), Aeolian erosion or deposition (A), Mass movement, land slides and similar phenomena(M), Not known (NT)

Types of erosion and deposition are: sheet erosion (WS), Rill erosion (WR), Gully erosion (WG), Tunnel erosion (WT), Deposition by water (WD), water and wind erosion (WA), Wind erosion (AD), Wind erosion and deposition (AM), Shifting sands (AS), Salt deposition (AZ).

In soil survey the degree of accelerated erosion is described as:
None: No evidence of erosion.
Slightly eroded: Some evidence of damage to surface horizons, originally biotic functions are largely intact.
Moderate: clear evidence of removal of surface horizons, original biotic functions partly destroyed.
Severe: Surface horizons completely removed and sub surface horizons exposed. Original biotic functions largely destroyed.
Extreme: substantial removal of deeper subsurface horizons (Bad Lands)
The period of activity of accelerated erosion or deposition described as: Active at present (A), Active in recent past 50 - 100 years (R), Active in historical times (H), period of activity not known (N), accelerated and natural erosion not distinguished (x).

6. 8. Depth of Water Table.

The sign of water able and depth to water table and water table fluctuation range should be inferred by recording the presence of surface gleying and high chroma mottles. Gley colors and the presence of high chroma mottles are indicative of the presence of water table at shallow depth some time during the year. The classes are: very shallow (0-25 cm), shallow (25- 50 cm), moderately deep(50- 100cm), deep(100-150cm), very deep(>150 cm)

6. 9. Termite mounds

Termite mounds that are sufficiently large and compact to interfere with cultivation, down grades the suitability of land for irrigation. A coverage of < 2% may be disregarded but more than 2% will not only restrict the productive area, but also hinder the cultivation practices and also the field lay out.

6.10. Humans and Animal Influences

Some large and small animals made heaves and dug holes. Human influences disturb soil and at times form micro and macro surfaces. These are clearing and disposal of vegetation, terracing and bunding ..Etc. The degree, extent and time of activities have to be described with observed effects.

6. 11. Settlement and Infrastructure.

Existing settlement and infrastructure such as roads, schools, clinic, market places and others near by the survey area, are important and need to be recorded. The distance and their activities as relevant to the study have to be observed. Soils in home steads/villages may be disturbed by organic waste and debris, roads cut may buried an original soil, construction of schools, clinics, religious centers and other building complexes affects the soil due to earth moving works.

6. 12. Climate.

The climate conditions such as rainfall, temperature, humidity, wind speed, sunshine hours, radiation ... etc. has to be described. Soil temperature should also be measured.

6. 13. Surface crusting , Cracking and Gilgai

Surface crusting is formed after the top soil dries out. The crusts may inhibit germination, reduce infiltration and increase runoff.

The attributes of surface sealing consistency and thickness of the crust.

Thickness: None (N), Thin < 2 mm, Medium(F) 2- 5 mm, Thick(C) 5- 20 mm and Very thick(V) > 20 mm

Consistency: Slightly hard(S), Hard(H), Very hard(V) and, Extremly hard(E)

Surface cracks develops in shrink- swell, clay rich soil after they dry out. The average depth, width and distance from each other have to be described.

The width classes are: Fine (F) < 1cm, Medium(M) 1- 2 cm, Wide(W) 2- 5 cm, very wide (V) 5 - 10 cm, extremely wide >10 cm

The distance between cracks are: Very closely spaced (C) < 0.2 m apart, Closely spaced (D) 0.2 - 0.5 m apart, Moderately spaced (M) 0.5 - 2.0 m apart, widely spaced (W) 2- 5 m apart and very widely spaced (V) > 5 m.

The width and height of the gilgai has to also recorded. Note that the wider and deep cracking and gilagai formation is a characteristics of very heavy clay vertisols.

6. 14 . Crevassing

Crevassing develops on stratified alluvial soils, where water enters the soil through cracks and sink holes and rapidly erodes coarse textured layers in the soil profile causing the soil above to collapse. This exacerbates the problem of land degradation by providing means for runoff to enter the soil and increase erosion rate.

6. 15 Local geology and parent material.

The local geology has to be analyzed from regional geology and geomorpholgical Patterns. Geological time and periods have to also be discussed.

The identification of local geology will determine whether a general specific definition and description of the parent material and there by soil formation can be extrapolated. .

The parent material of the area is an indicative of some soil types and management practices. Basically there are two groups of parent material, namely; unconsolidated materials mostly sediments and/ or weathering material overlying the hard rocks which they have been derived. There are also transitional materials which have been transported or colluviated.

Major unconsolidated materials are Aeolian deposits (AU), Lacustrine deposits (LA), Fluvial deposits (FL), Alluvial deposits (AL), Volcanic ash (VA), Pyroclastic deposit (PY), Colluvial deposits (CO), In situ weathered (We) and Saporolite (SA)

The major types of rocks are : Granite (GR), gneiss (GN), Quartzite (QZ), Schist(SC), Andesite (AN), gabbro (GA), Basalt (BT), Dolerite (DO), Volcanic rock(VO), Lime stone (LI), Dolomite (LM), Sand stone (SA),Marl(MA), Conglomerate (CO), Tuff (TU), pyroclastic rock(PY), Evaporite(EV) and last but not least Gypsum rock (GY)

6.16.Other Surface Characteristics

A number of other surface characteristics, such as the occurrence of salts, bleached sand, litter, manure, worm casts and paths, cloddiness, puddling etc shall be recorded as they have significant influence in irrigation and water management .

7. SOIL PHYSICAL AND PROFILE CHARACTERISTICS

7.1. General

Soil physical properties have a great influence on planning and design of irrigation projects. For a better understanding of soil, water relation, it is very important to determine the soil physical properties, which are of importance in irrigation. However, full documentation of all the physical soil characteristics may be necessary as it is useful to other disciplines concerned with planning and may be needed to consider alternative development possibilities if irrigation is shown to be unfeasible.

The Rating for each of soil Physical properties have been given as taken from FAO, USDA, Booker Tropical Soil Survey manual and other materials given in reference.

7. 2. Effective Soil Depth.

The depth of soil that can be effectively exploited by plant roots is an important criterion in selecting land for irrigation as it also affects water storage capacity. Ratings is as follows.

Depth	Ratings	Remarks
< 30 cm	very shallow	suitable for grasses
30 - 50cm	shallow	close attention of crop management is required
50 - 100cm	moderately deep	suitable for most crops
100 - 150	deep .	good for most crops
> 150cm	very deep	ideal for most crops in well drained soil.

7. 3. Soil Color and Color Mottling.

Soil color is one of the most obvious and easily determined features of the soil and is easily seen. Soil color can often be related to the soils specific chemical, physical and biological properties. For example, black soil color usually indicates the presence of organic matter or manganese oxides, or both. Red colors indicate the presence of free iron oxides, which is common in well-oxidized soils. Up on the removal of free iron under reduced conditions, a gray or bluish gray color will develop in the soil indicating presence of high water table, in some instances relict soil colors **i.e.** those inherited from the initial materials persist in the soil. Color is composed of three measurable variables namely: Hue, value and chroma.

Hue: is the dominant spectral color and is related to wavelength of light.
Value: is a measure of degree of darkness or lightness of the color and is related to the total amount of light reflected by the soil.
chroma: is a measure of the purity or strength of spectral color.
These three variables have been combined in to a book of standard colors (munsell color chart) that covers the range of colors, normally found in soils. In the munsell soil color chart, the various hues are arranged vertically and the units of chroma are arranged horizontally on a page.

Since soil color is moisture dependent, especially with respect to color value, it is necessary to record the moisture status at the time the soil color is described. It is practical to describe the moist color of the soil after applying enough water to the soil when an additional drop of water does not have any influence on the soil color. If the soil under observation is dry, however, both dry and moist colors should be recorded (e.g. 10YR $^4/_4$, dry, 10YR $^4/_3$, moist).

Color mottling: the presence of color mottling in a soil profile is of great importance in determining the soil drainage characteristics and genesis should be carefully described. when mottles are abundant with no predominant matrix color, list all the colors (munsel colors) and identify their relative percentage with the word " variegated " .

Abundance: few (< 2%), common (2 - 20%), many (> 20%).

Size :fine (< 5mm), medium (5 - 15mm), coarse (> 15mm).

Contrast: faint (indistinct, needs close examination), distinct (the mottles are readily seen), prominent (conspicuous mottles are obvious and mottling is one of the out standing features of the horizon).

Sharpness: sharp (knife - edge boundaries), clear (color transition < 2mm) diffuse (color transition extends over 2mm).

7. 4. Soil Texture

Refers to the relative proportions of sand, silt and clay in a mass of soil. Soil texture influences such soil qualities as infiltration, moisture and nutrient retention, drainage, workability and susceptibility to erosion.

The United State Department of Agriculture(USDA) use the following size separates for the < 2mm soil & mineral material.

Very coarse sand	2. 0 - 1. 0 mm
Coarse sand	1. 0 - 0. 5 mm
Medium sand	0. 5 - 0. 25 mm
Fine sand	0. 25 - 0. 10 mm
Very fine sand	0. 10 - 0. 05 mm
Silt	0. 05 - 002 mm
Clay	< 0 - 002 mm

Soil of all textural classes, except coarse sand, are irrigable if proper methods are used. Composition of different textural classes are shown in Table 8.

Table. 8. Composition of different textural classes.

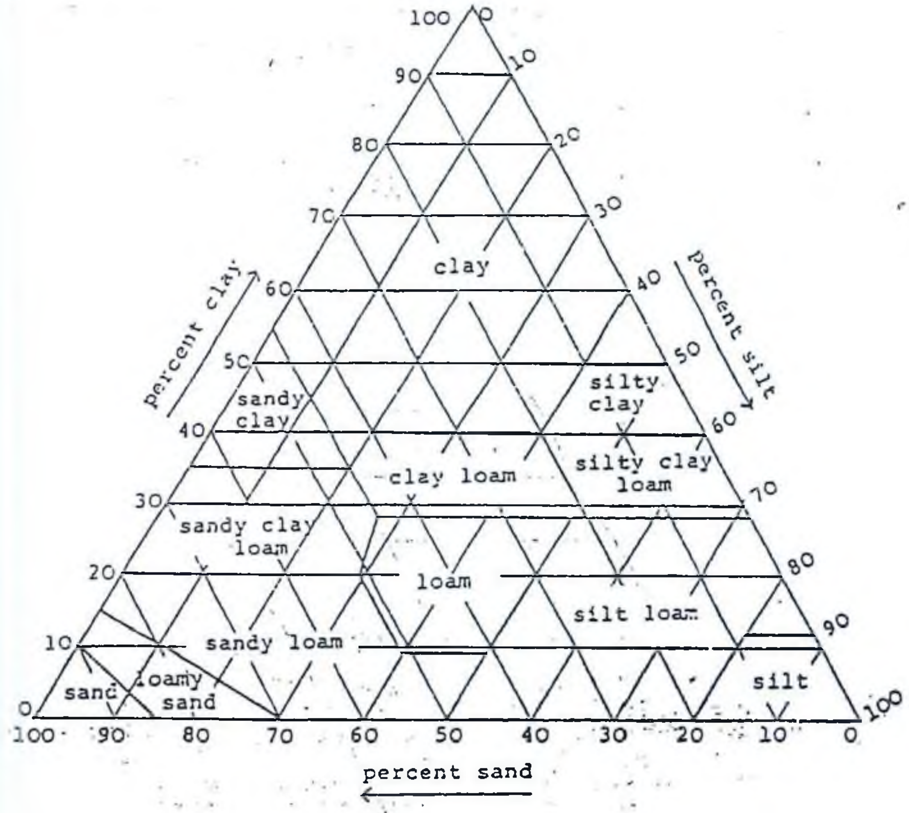
No	Class	Sand	Silt	Clay	Remarks
1	Sand	> 85	< 15	< 10	Very poor, very dry
2	Loamy sand	70 - 90	< 30	< 15	Very poor, very dry
3	Sandy loam	45 - 85	< 50	< 20	Poor water retention
4	Loam	< 52	28 - 50	8 - 28	ood water retention, Good drainage, fertile and productive, Good for irrigation
5	Clay loam	< 45	15 - 52	28 - 40	Ditto 4
6	Silty clay	< 20	40 - 60	40 - 60	Difficult to cultivate poorly drained, fertile and good for dry crops.
7	Clay	< 45	< 40	> 40	Ditto 6

Alternatively the proportions of sand, silt and clay in the various textural classes are indicated in the textural triangles shown in figure.1.

The texture classes are. Sand (S), Loamy Sand (LS), Sandy Loam (SL), Loam (L), Slit (S), Silt Loam (ZL), Clay Loam (CL), Sandy Clay Loam (SCL), Silty Clay Loam (ZCL), Sandy Loam (SL), Silty Clay (ZC), and Clay (C).

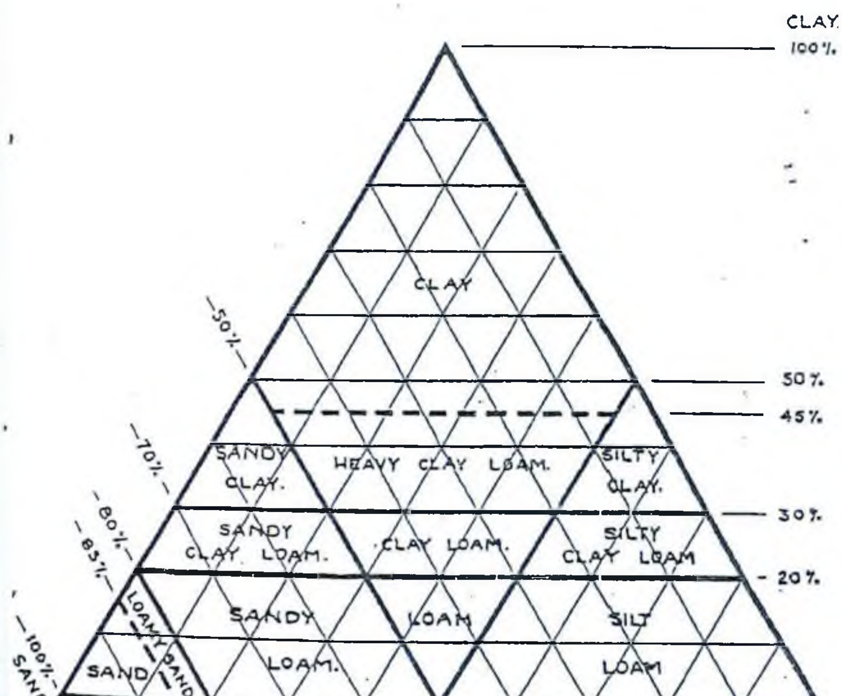
In case of gravely soils, prefix gr. shall be added before the textural symbol.
e.g. gr. SL. (gravely sandy loam).

Figure. 1. Soil Textural Triangle



KEY TO SOIL CLASSES.

SHOWING PERCENTAGES OF SAND, SILT AND CLAY IN EACH SOIL CLASS.



Modified Chart from DAVIS & BENNETT. U.S.D.A. Circ. 39.

Laboratory determination of texture is made by sieve analysis. Finger assessment of soil texture is a common practice by all agriculturists in field. The following description and making use of the flow diagram should assist the surveyor in the filed.

i. **Moist cast test:** compress some moist soil by clenching it in your hand. If the soil heads together (forms a cast), then the strength of the cast by tossing it from hand to hand. The more durable it is, the more clay is present.

ii. **Ribbon test:** moist soil is rolled in to a cigarette shape and then squeezed out between the thumb and forefinger to form the longest and thinnest ribbon possible. The length of the ribbon, its thickness and cohesiveness are used in determining the soil textural class.

iii. **Fell test**

Graininess test: soil is rubbed between thumb and fingers to assess the percentage of sand. Sand fells grainy.

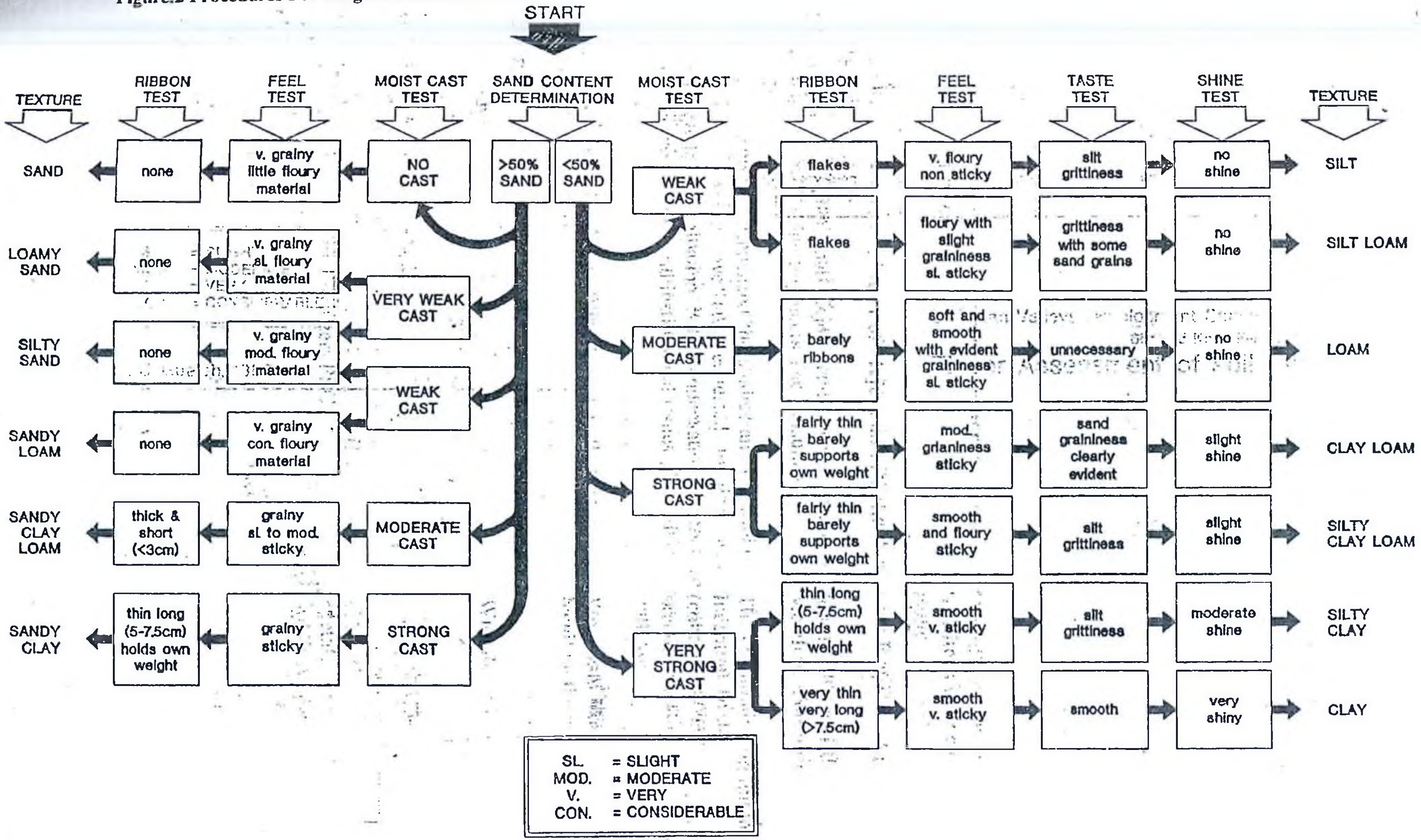
Dry fell test: in grainy soils, those with high sand content, soil is rubbed in the palm of the hand to dry it and to separate and estimate the size of the individual sands particles. The sand particles are then allowed to fall out of the hand and the amount of the finer material (silt and clay) remaining is noted.

Stickiness test: soil is wetted and compresses between the thumb and fore finger. Degree of stickiness is determined by noting how strongly it adheres to the thumb and fore finger up on release and how much it stretches.

iv. **Taste test:** a small amount of soil is worked between front teeth. Sand is distinguished as individual grains which grit sharply against the teeth. Silt particles are identified as a general fine grittiness, but individual grains can not be identified. Clay particles have no grittiness.

V. **Shine test :** a small amount of moderately dry soil is rolled in to a ball and rubbed once or twice against a hard, smooth object such as a knife blade. A shine on the ball indicates clay in the soil. For detail texture identification see figure.2.

Figure.2 Procedures For Finger Assessment of soil texture.



7. 5. Soil Structures.

Soil structures refers to the natural organization (aggregation) of soil particles in to discrete soil units (peds) which are separated from each other by persistent surfaces of weakness. Soil structure has a very important role in irrigation development and management. The potential of any soil for the growth of plants and its response to management depends as much on its structure as on its fertility.

In the filed soil structure is described based on their shape and arrangement, their size and distinctiveness and durability of the peds. Shape and arrangement of the peds is designated as the type of soil structure, size of peds as class and degree of distinctness as grades.

i. Structure type

Platy: the units are flat and plate like. They are generally oriented in soils horizontally, a special form lenticular platy structure is recognized for plates that are thickest in the middle and thin toward the edges.

Prismatic: the individual units are bounded by flat rounded vertical faces units are distinctly longer vertically and the faces are typically casts or molds of adjoining units. Vertices are angular or subrounded. The tops of the prisms are some what indistinct and normally flat.

Columnar: the units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast are very distinct and normally rounded.

Blocky: The units are block like or polyhedral. They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Typically, blocky structural units are nearly equidimensional but grade to prisms and to plates. The structure is described as angular blocky if the faces intersect at relatively sharp angles, as sub angular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded.

Granular: the units are approximately spherical or polyhedral and are bounded by carved or very irregular face that are not casts of adjoining peds.

Massive: no structural units observed

ii. Structure grade

Grade describes the distinctness of units. Three classes are used.

Weak: the units are barely observable in place. When gently disturbed, the soil material parts in to a mixture of whole and broken units and much material that exhibits no planes of weakness.

Moderate: the units are well formed and evident in undisturbed soil. When disturbed, the soil material parts in to a mixture of mostly whole units, some broken units and materials that is not in units.

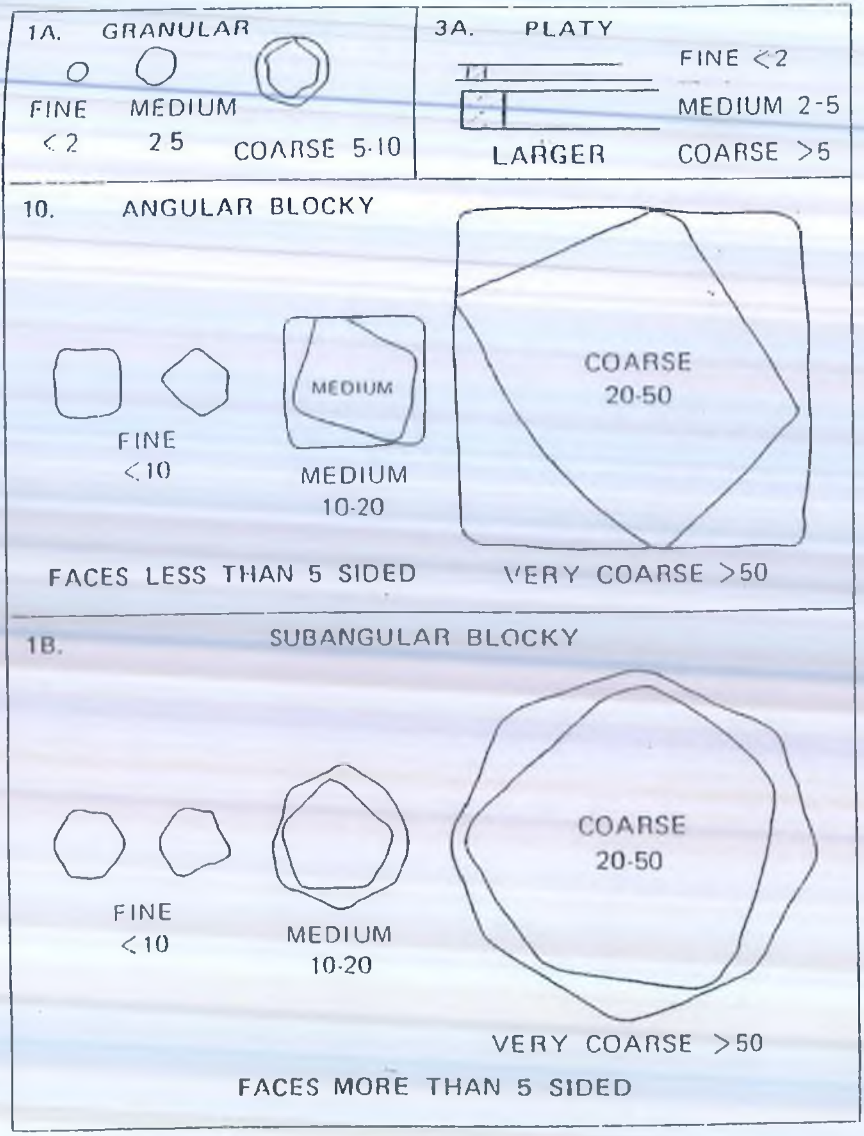
Strong: the units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed the soil material separates mainly in to whole units. Peds have distinctive surface properties.

iii. **Sizes of soil structure**

Five classes are employed. Very fine, fine medium, coarse and very coarse. The size of limits of the classes differ according to the shape of the units(see Table.9.).

Table .9. **Size Classes of Soil Structure.**

Size classes	Platy (mm)	Prismatic & Columnar (mm)	Blocky (mm)	Granular (mm)	Remarks
Very Fine	< 1	< 10	< 5	<1	
Fine	1 - 2	10 - 20	5 - 10	1 - 2	
Medium	2 - 5	20 - 50	10 - 20	2 - 5	
Coarse	5 - 10	50 - 100	20 - 50	5 - 10	
Very Coarse	> 10	> 100	> 50	> 10	



Types, kinds, and classes of soil structure.

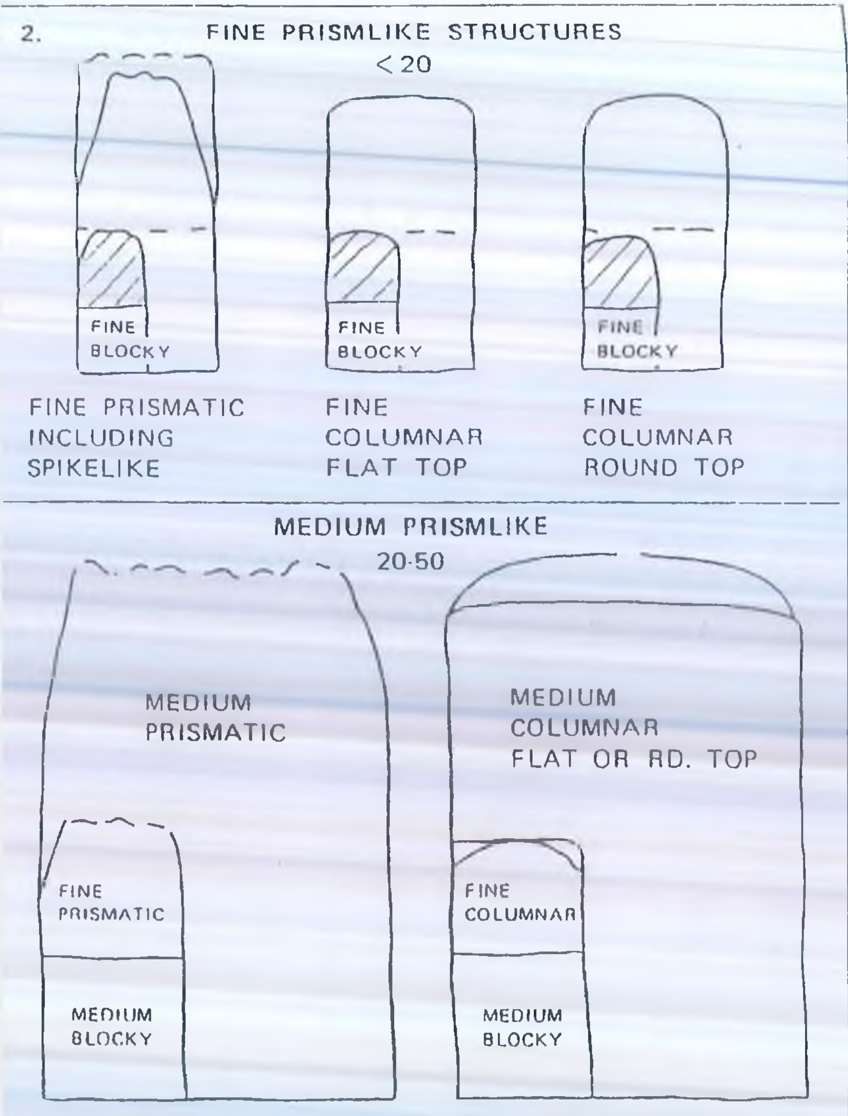


Figure .3. Diagrammatic representation of Soil Structure Type and Size

7. 6. Porosity

The spaces in the soil (pores) are where countless organisms live ranging in size from microscopic bacteria to earth worms and bettless. The size and arrangements of the spaces depends on the materials. For example, the uniform assemblage of particles in a sandy soil provides a very different spatial pattern from that of cracking clays. The percentage of total volume not occupied by solids is referred to as porosity. The range is 30 - 60%. Five sizes of soil pores are generally recognized.

Micro - pores:	small <0.075 mm diameter for storage of available water.
Very fine:	0. 075 - 1 mm
Fine:	1 - 2 mm
Medium pores:	2 - 5 mm diameter for movement of water
Macro - pores:	large>5mm diameter for aeration and infiltration.

Porosity on coarse textured soils does not vary too much, but in clay soil, it is highly variable, due to swelling and shrinkage, aggregation, dispersion, compaction and cracking.

The abundance of pores is recorded as the number per unit area of square decimeter.

None	0
Very few	1 - 20
Few	20 - 50
Common	50 - 200
Many	> 200

The pores orientation are described as: vertical, horizontal, oblique and random while, its distribution and continuity within the horizon are explained as Inped or exped and continuous or discontinuous, respectively.

7. 7. Consistence

The consistency of the soil material in each horizon has decisive bearing on several characteristics of the soil. In general sense it refers to attributes of soil material as expressed in degree of cohesion and adhesion or in resistance to deformation on rupture. It includes.

- Resistance of soil material to rupture
- Resistance to penetration
- Plasticity, toughness and stickiness of paddled soil material
- The manner in which the soil material behaves when subject to compression.

In soil survey for irrigation, consistence should be done under, moist and wet condition.

Consistence when moist: -determined by attempting to crush a mass of moist or slightly moist soil material

Loose: non coherent

Very friable: Soil material crushes under very gentle pressure, but coheres when pressed together

Friable: Soil material crushes easily under gentle to moderate pressure between thumb and forefinger and coheres when pressed together.

Firm: Soil material crushes under moderate pressure between thumb and fore finger, but resistance is distinctly noticeable.

Very firm: Soil material crushes under strong pressures, barely crushable between thumb and forefinger.

Extremely firm: soil material crushes only under very strong pressure, can not be crushed between thumb and forefinger.

Consistence when wet: indicates maximum stickiness and maximum plasticity and is the extent to which soil structure is destroyed and on the amount of water present.

Non sticky: almost no natural adhesion of soil material to fingers.

Slightly sticky: soil material adheres to one finger but other finger is clean.

Sticky: soil material adheres to both fingers and thumbs.

Very sticky: soil material strongly adheres to both thumb and finger.

Plasticity is determined by molding on hand. A soil is slightly, moderately, highly plastic and non-plastic depending on the molded wire length and pressure to deform a block of the molded material.

7. 8. Bulk Density

Bulk density is defined as the weight of oven - dry soil per unit volume and depends on the densities of the constituent soil particles (clay, organic matter ... etc) and then packing arrangement. The volume includes both solids and pores.

B.D (g/ cm^3) = Oven dry weight(g)/volume of cylinder(cm^3)

The bulk density of clay, loam and silty loam soils ranges from 1. 0 - 1. 6kg/10m^3. The bulk density of sandy soils ranges from 1. 2 - 1. 8kg/m^3. Average values of B.D are taken as 1. 65kg/m^3(see below).

Bulk density increases with the degree of compaction and tends to increase with depth in the profile because of increasing over burden and decreasing disturbance. The most usual method of bulk density measurement is to cut a cylindrical core of known volume and find the mass of the dried soil.

Soil Textural Class	B.D(g cm^3)
Clay, Clay loams and Silt loams(top soil)	1.0- 1.6
Sands and sandy loams	1.2- 1 8
Recently cultivated soils	0.9 - 1.2
Soil mineral, soils not recently cultivated	1.1 - 1.4
Soils showing root restrictions,	
Sands and loams	>1.75
Silts	1.4 - 1.6
Clays	>1.3
Compact subsoils	>2.0

Source: Birr and Koga Irrigation Project Soil Survey Manual

7. 9. Internal Soil Surface Features.

The features includes cutans, pressure faces, clay skins, slickensides and clay bridges. Soil surface features are: -

- Coats of a variety of substances unlike the adjacent soil material and covering part or all of surfaces.
- Material concentrated on surfaces by the removal of other material.
- Stress formations in which thin layers at the surface have undergone reorientation or packing by stress or shear.

All differ from the adjacent material in composition, orientation or packing and worth try to identify.

Description of surface features may include kind, nature, amount, continuity, distinctness and thickness of the feature. In addition color, texture and other characteristics that apply may be described, especially if they contrast with the characteristics of the adjacent material.

It is only, in a very few cases that, it is possible to identify the nature and composition of the soil surface coatings. It is therefore desirable to qualify the description of surface features identified in the filed as "probably", "possible" "believed " to be ... etc.

The nature may be described as argillans, organo- argillans, ferro- argillans, sesquides, salts..etc

Quantity and arrangement: patchy, broken, continues

Thickens: thin(10x magnification is needed to see), moderately thick(visible by naked eye < 1 mm thickness), thick (can be seen with out magnification > 1 mm) and very thick (easily observable on the soil peds)

Locations : vertical , horizontal ped faces and as bridges or inside pores or root channels.

7.10. Mineral Nodules and Concretions

Local concentrations of soil material constitute concretions and nodules in the soil. The term nodules carries no implication of their mode of formation and at times mode of formation may be not be known to us. The color, hardness, size, nature, shape and relative abundance of nodules and concretions are usually reported in the filed description. Quick tests can be made to determine the behavior of cementing agents. Effervescence in H_2O_2 indicates manganese oxides. Effervescence in HCL indicates presence of carbonate nodules. Silica cementation is indicated in concretions that may or may not effervescence in HCl but disintegrate after being placed in concentrated Na OH for several hours.

Nodules has to be characterized in terms of its abundance: very few(< 5 %), few(5- 15 %), frequent(25- 40 %), very frequent(40 - 80 %) and dominant(>80%) of its volume.

Size: (small < 1cmϕ), large (> 1cm ϕ), Hardness (soft, hard), shape (angular, sub angular), Color (red, black, white), nature ($CaCO_3$, iron stone, manganese, silica, gibsite ... etc.).

7.11. Compaction and Cementations

The occurrence of cementation or compaction in pans or other wise is described according to its continuity, structure, and nature of agent sand degree

Compacted material has a firm or stronger consistence when moist and a close packing of particles. Cemented materials do not slake after one hour of immersion in water.

Cementation of soil materials refers to a brittle hard consistence which is caused by some cementing agents other than clay minerals such as calcium carbonate, iron, manganese or aluminum oxides, salts, silica ..etc.

The cementation alter little when moisten and the hardness and brittlenes should persist in the wet condition. Cementation may be continues or discontinuous within a given horizon. It can be described as

Weakly cemented : brittle, hard and broken in hand
Strongly cemented: brittle and harder, can be broken with a hammer
Indurated: strongly cemented and requires a very sharp blow hammers to break

7.12. Pans and Indurations

Includes those horizons which for practical purposes can be considered to be irreversible cemented and/or indurated. Examples are Plinthite, Duripan, peterocalcic, peterogypsic..etc. Their formation may be physicochemical and at least description of their physical characteristics (depth, thickness, hardnes..etc) is important in irrigation development planning.

7.13. Moisture Condition

The moisture condition prevailing in the soil at the time of investigation should be given together with the depth of the horizon.

Classes are: dry, slightly moist, moist, wet. For example moist through out or dry to 50 cm , moist at the bottom. .etc.

Moisture condition is an indication of soil water system.

7. 14. Root Distribution.

Quantity, size and location of roots in each layer are recorded using features of the roots, length, flattening, nodulation. The relationship to special soil attributes or to structure may be analyzed. However, if there are any abnormalities in root distribution, especially related to horizontal and vertical features with in the soil profile it should be analyzed in detail.
Size: very fine (< 0.5 mm), fine (0.5-2 mm), medium(2-5mm), coarse (>5mm) diameter.

Abundance: very few (<5%), common (5-15%), Many (15-40%), Abundant (>40%)

7. 15. Animal Burrows and krotovinas

Mixing, changing and moving of soil material by animals is a major factor changing properties of soils. The features let by the work of some animals reflect mainly mixing or transport of material from one part of the soil to another or to the surface. The original material may be substantially modified physically or chemically. The range of soil micro and macro faunas are: bacteria, fungi, actnomycetes, algae, nematodes, warms, protozoas, insects, small and large mammals and non mammals, birds ..etc. The activities of soil micro fauna looks for detail investigation of soil biology.

In soil survey and land evaluation for irrigation, it is suffice to describe the activities of soil macro fauna. krotovinas are irregular tubular streaks with in one layer of material transported from another layer. They are caused by the filling of tunnels made by burrowing animals in one layer with material from out side the layer. In a soil profile they appear as rounded or elliptical volumes of various sizes. They may have a light color in dark layers or a dark color in light layers, and then other qualities of texture and structure may be unlike those of the soil around them.

The presence of the soil animal activities in the profile is recorded by the size and intense of biological activity i.e. low, medium and high biological activities depending on the mass coverage of the imprints.

7.16. Horizon Boundaries

Two measurements are considered along the Z (vertical) surface topography and along the X-Y plane.

Width of the boundary layers are : Abrupt (<2cm), Clear(2-5 cm), Gradual (5- 12), Diffuse (>12cm) between the two contrasting horizons.

Surface continuity of the horizon boundary lines are : Smooth(nearly plane), Wavy (undulating), Irregular (pockets vary more in Z axis than x-y direction.) and Broken (discontinuous with in the pedon).

7.17. Stratification

In recently developed alluvial soils there is a bedding of soil materials deposited in a few cm thickness which can not be differentiated as layers or horizon. Description of the depth, thickness, nature and formation of the stratification's are important in soil classification and land evaluation.

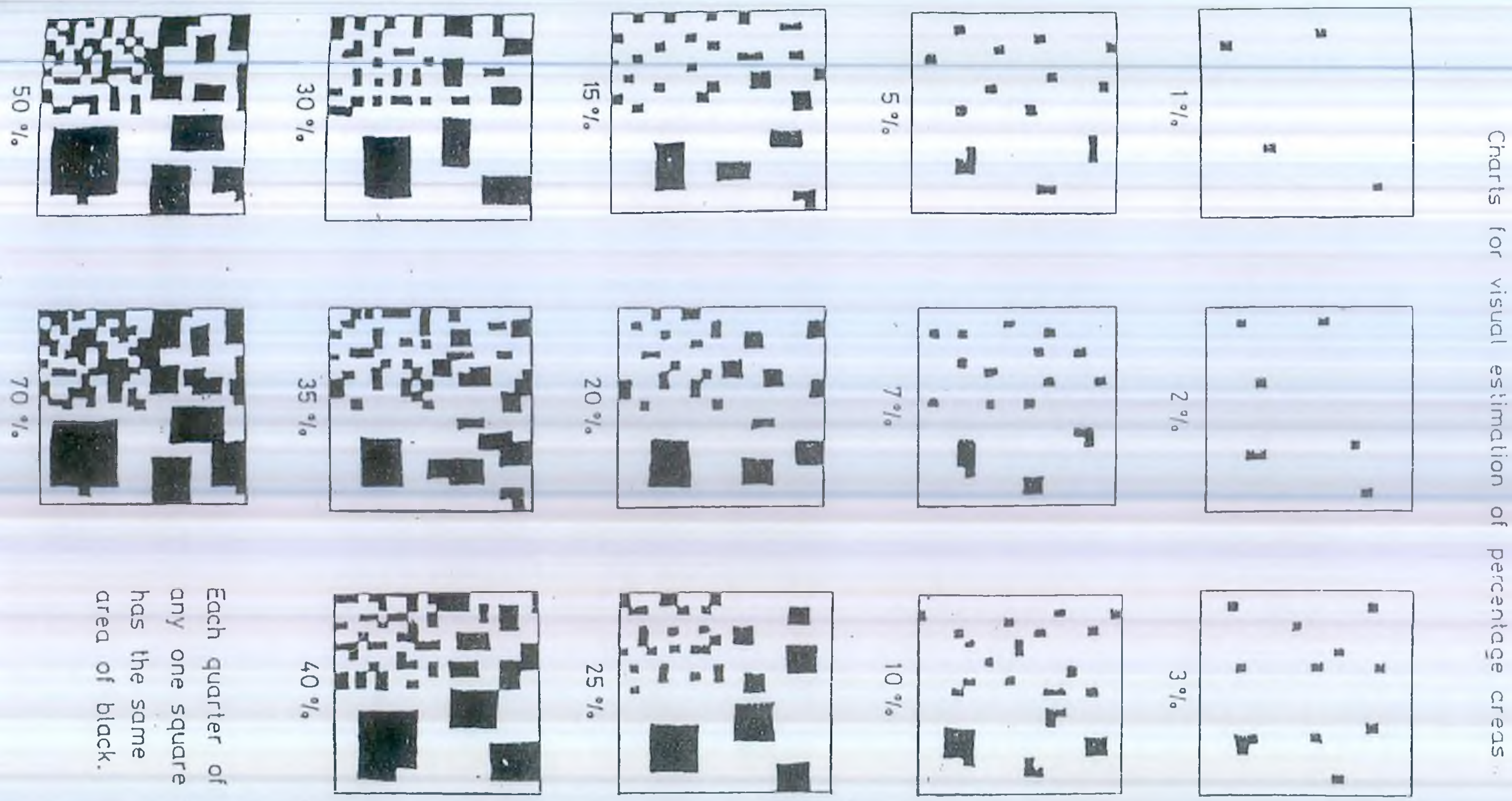
7.18. Rock fragments

Rock fragments and gravels are described according to abundance, size, shape, state of weathering and nature of the fragments. The abundance class limits correspond with the ones for surface coarse fragments and mineral nodules (as discussed in section 6) and the 40 % boundary coincides with the requirement for the skeletic phase

7.19. Soft Weathering Rock

The bed rock (R) is disintegrating in to soft weatherable materials through geopedological process. Identification of the nature, type, depth, the soil forming process in active .etc. of the soft weathering rock (SWR) is very important as it determines the soil types and characteristics to be developed.

Figure.4. Measurements of Percentage Cover of the Mass of Volumes of Soil Material



8. SOIL CHEMICAL CHARACTERISTICS

8.1. General

Soil chemical properties have a great influence on planning soil and agronomic programs best suited to the proposed irrigation projects and evaluation and monitoring of the schemes. The soil chemical characteristics of each soil types has to be analyzed and discussed based on laboratory analytical results of soil samples collected in the field.

The Rating for each of soil chemical properties have been given as mainly taken from FAO, USDA, Booker Tropical Soil Survey Manual and other materials in the reference.

8.2. Acidity and Alkalinity

Soil PH is important as it is an indicator of acidity and alkalinity in the soil. The PH of the soil determines availability and toxicity of macro and micro nutrient in the soil and the rating is shown below.

PH	Rating	Comments
< 4.0	Extremely acidic	only tea tolerates it.
4 - 5.3	Very acidic	if present Al & Mn will be toxic. Ca, Mg & Mb may be deficient. The availability of P is low in the presence of free Al & Fe, Nitrification of O.M.
5.3 - 6.0	Moderately acidic	P, Ca, Mg & Mb may be deficient, avoid fertilizers (ammonium sulfate and triple super phosphate), which may increase the acidity
6.0 - 7.0	Slightly alkaline	Fe may be deficient. Optimal availability of P
7.0 - 8.5	Moderately alkaline	Low available of P and micro nutrients, with the exception of Mb.
>8.5	Very alkaline	only few crops grow, excess of Na, deficiency of P and micro nutrients, toxicity of Boron, Nitrification of O.M., Ca may need correction.

Under high PH conditions (PH>8.0), the following phenomena can be observed:

- In the presence of calcium, phosphate tends to be converted to calcium phosphate and availability of phosphorus to plants is reduced. However, above PH 8.5, the presence of Na may increase through the formation of soluble sodium phosphate.
- Boron toxicity is a common feature of saline and sodic soils.
- Most soil PH value >8.6 indicate an exchangeable sodium percentage >15, and the possibility of soil structural defolculation which creates reclamation problems.
- High PH decreases bacterial activity and hence nitrification of organic matter.
- Availability of micro-nutrients is reduced with increasing PH except molybdenum.

8.3. Electrical Conductivity

Electrical Conductivity measurements(EC) are used as indicators of total quantities of soluble salts in soil. General interpretation of EC values in soil mapping and land evaluation is as follow.

Rating	EC mmhos	comments
Salt free	0- 2	salinity effects are mostly negligible
Slightly saline	4-8	yield of many crops restricted
Moderately saline	8-15	only tolerant crop yield satisfactory
Strongly saline	> 15	only very tolerant crops yield satisfactorily

(See FAO Irrigation and Drainage bulletin No. 24, for salinity tolerance level of crops)

8.4. Cation Exchange Capacity and Base Saturation

Cation Exchange Capacity(CEC) values and the derived base saturation percentage(BS%) are indicators of the potential fertility of a soil and possible response to fertilizer application. Rating of CEC is given below.

CEC(me/100g)	Rating	comments
>40	very high	good agricultural soil
25- 40	high	as above but minor amendment is required
15-25	medium	major amendment required
5-15	low	moderate to poor response to fertilizer
<5	very low	poor agricultural land

Base Saturation is the proportions of the CEC accounted by exchangeable bases (Ca, Mg, K and Na) and is considered an index of soil fertility in irrigation development. BSP is also used in calculating lime requirements of acid soils if amelioration is recommended.

BSP is calculated using the following formula

$$BSP = \frac{\text{Sum of Ex(Ca, Mg, K and Na)}}{CEC} \times 100$$

% BS	Rating
< 20	low
20 - 60	medium
>60	high

8.5. Exchangeable Cations

The levels of exchangeable cations in a soil indicate the existing nutrient status and can also be used to assess balances amongst cations. Many effects on soil structure and on nutrient uptake by crops, are influenced by the relative concentrations of cations as well as by their absolute levels.

Rating of exchangeable cations (meq/100g of soil) is as follow:

	Ca	Mg	K	Na
Very high	>20	>8	>1.2	>20
High	10-20	3-8	0.6-1.2	0.7-2.0
medium	5-10	1.5-3	0.3-0.6	0.3-0.7
low	22-5	0.5-1.5	0.1-0.3	0.1-0.3
very low	<2	<0.5	<0.1	<0.1

If for example the soil is said to have highest exchangeable K reserves, then a response to K fertilizer application is highly unlikely.

8.6 Organic Matter and Organic Carbon

The measurement of organic matter is conducted to evaluate availability of plant nutrients and physical condition of the soil. Organic matter content is Walkely-Black method (% of soil by weight).

Organic carbon can also be determined by the same procedures and multiplied by coefficient factor (1.72) to change to O.M. The rating in evaluation of soil and derivation of other elements are as follow:

Rating	% O.M	% Organic Carbon
Very high	>5	>20
High.	3 - 5	10 - 20
Medium	1- 3	4 - 10
Low	<1	2- 4
Very low	<2	

If the O.M of the soil is usually not exceeding 3%, it is meant that, organic and inorganic fertilizers would be needed for high yields. In the arid conditions where prevailing climate is not favorable for decomposition even though there is high vegetative cover that could be a precursor for the formation of high organic matter, organic matter is expected to be low. i.e. Even if there is a reasonable vegetation cover, the low moisture conditions prevailing in the arid region do not initiate and enhance the break down of vegetation biomass and humus formation is not significant.

8.7. Total Nitrogen

Total N is an indicator of the soil potential for the element not the measure in which it becomes available to the plants.

Nitrogen is found in the arable horizon of the soil, mostly in organic material. In soil, N is not directly available, instead solution of organic N is gradually transformed into NH4, NO2, NO3 by microbial processes. Rating for evaluation of the soil for total Nitrogen is as follow

Total N (%)	Comments
< 0.03	low
0.03 - 0.06	medium
> 0.06	high

8.8. Carbon to Nitrogen Ratio

C:N ratio is an indication of the process of transformation of organic nitrogen to available N, like ammonium nitrite and nitrate -N. It is generally considered that for most soils the ratio eventually stabilizes at about 10:1. If soil temperature and microbiological activity are high the ratio may narrow even more. Some times extreme ratio as high as 8:15 are obtained and as such there is yet no exact cutoff, for class limits.

8.9 Cationic Ratios

K: Mg Ratio

If the ratio of K: Mg is >2:1 Mg up take may be inhibited.

Ca: Mg Ratio

The interpretation of calcium to magnesium ratio is as follow:-

Ratio	Rating	Comments
>40	Extremely high	over dose of Ca or lack of Mg.
12 - 40	Very high	reduction of available P if the pH is high too.
6 - 12	High	favorable.
3.5 - 6	Moderately high	very favorable.
2.5- 3.5	Moderately low	Less favorable.
1.5- 2.5	Low	not favorable.
>1.5	Very low	severe

K: CEC Ratio

About 2% is suggested minimum level to avoid K deficiency and soil with > 25% ratio is k-rich soil.

8.10. Exchangeable Sodium Percentage

Exchangeable Sodium Percentage(ESP) indicates sodicity in the soil. Presence of sodium defloculates(disturbs) the structure of the soil profile which is important in moisture and nutrient movements. ESP is calculated by the following formula

$$ESP = \frac{\text{Exchangeable Sodium}}{\text{CEC}} \times 100$$

Soils with ESP<15 is generally non sodic requiring no amendments, where as soil with. ESP> 15 are sodic and requires amelioration method High ESP values have a more deleterious effect on strong vertisol and clays with vertic properties than on normal lattice clays, most free draining soils.

8.11. Available Phosphorus

Available Phosphorus, is the amount of P readily available for nutrient absorption by the plant roots.

(Ppm)	Rating	comments
>15	high	fertilizer response unlikely
5-15	medium	fertilizer response probable
<5	low	fertilizer response most likely

8.12. Carbonates

The amount of carbonates present, the form of its distribution in the profile and the depth to the lime rich horizons are all important in the suitability evaluation of calcareous soils in irrigated agriculture.

The presence of $CaCo_{3,}$ affects both the physical and the chemical characteristics of a soil. Continuous horizons of carbonate accumulation may not restrict water movement severely, but may prevent root penetration. Discrete particles of carbonates also affect moisture characteristics and tend to create a less fertile environment for plant roots.

$CaCo_{3,}$ can have the effect of increasing moisture diffusivity in soil, causing water movements to be faster than in non calcareous soils of similar particle size distribution. Surface crusting can be a serious problem in newly irrigated calcareous soils, especially those of low organic matter content. Crusts not only affect infiltration and soil aeration, but also impede or prevent the emergence of seedlings. Therefore, soils which have a tendency to crust will require a frequency of irrigation sufficient to prevent drying and hardening of the surface.

Nutrient deficiencies of phosphorus, iron, micronutrients are common in plants grown on calcareous soils. Soils rich in Magnesium carbonate are often fertile. A highly calcareous soil is less productive than slightly calcareous soil if all other factors are equal.

A rough idea of the quantity of $CaCo_{3,}$ can be obtained by treating a hand sample with 10% HCl and observing and listing to the degree of effervescence.
The classes of carbonates are

Rating	$CaCo_{3,}$ (meq/100gm)	$MgCo_{3}$(meq/100gm)
Low	<1	<0.3
Medium	1-4	0.3-1
High	4-10	1-5
Very high	> 10	>5

8.13. Micro nutrients

The main micronutrients are B, Cu, Fe, Mn, Mo and Zn. These elements are needed in small amounts(< 50 mg/l) for the growth of plants.

Micronutrients are not commonly determined in routine soil survey . They will be determined in very high intensity soil survey where field assessment of the crops has shown that these elements may be critical. Areas under intensive cultivation like irrigation are likely to show deficiencies of some micro nutrients like Zn, Cu, Fe. They are also toxic to the plants when their available forms are present in the soil in large amounts than can be tolerated by plants. Therefore the tolerance range of concentrations of these elements in the soil is not too great and recommendations to apply them need intensive laboratory analysis of soil and plants.

8.14 Toxic elements

Some elements if present in excessive amounts become toxic to plants and cause yield reductions. Aluminum causes toxicity problems in highly acidic soils. It is a requirement to test for Al if the PH of the soil is less than 5. Similarly Boron content > 6 ppm is toxic to most crops and 3- 6 ppm causes damage to sensitive crops.

Mo has toxicity effects at levels of 200 ppm of plant tissues. The action of Mo is PH dependent. High level of Chromium and Nickel can be toxic and even low levels of Ni may be toxic, especially if associated with high exchangeable Mg:Ca ratios.

Other soil toxic elements have to be identified through research on the specific sites.

8.15. Soluble Salts

Determination of soluble salts are important in irrigation especially in arid and semiarid areas.

The most important soluble salts are Cl, HCO3, SO4, CO3, Nitrates, Silicates(only in sodic soils with high PH), Ca, Mg, Na, K,

Note that soluble salts, although composed of similar ions are not synonymous with exchangeable ions since they are not held on soil exchange sites.

Their effect depends on the nature of clay mineralogy, abundance and management of the soil.

8.16. Gypsum

Amount of gypsum in soil is important especially in arid areas to balance sodification and defloculation. Gypsum content up to 2 % favors crop growth, that between 2 - 25 % has little or no adverse effect if in powdery form and > 25% causes substantial yield reductions due to ionic imbalance particularly K/Ca and Mg/Ca.

9. SOIL HYDRODYNAMIC CHARACTERISTICS

9.1 Infiltration

Infiltration refers to the measurement of vertical intake of water into a soil at the soil surface. For water movement through porous materials, provided the velocity is low enough, that flow is laminar and not turbulent, the rate of flow is directly proportional to the drawing force and inversely proportional to the resistance according to Darcy's law.

Infiltration is important for selection of suitable methods and design for irrigation type, calculation of deep percolation losses, irrigation efficiencies and crop water management. It also helps in interpretation of soil erosion and conservation requirements.

The water on the surface is drawn in to the pores under the influence of both a suction and gravitational head gradient. The reduction of infiltration rate with time, after the invitation of infiltration is partly controlled by factors operating at the soil surface. They include swelling of soil colloids and the crossing of small cracks which progressively seal the soil surface, the infiltration rate eventually approaches a constant value. The infiltration rate will be greater in the initial stage. The basic infiltration rate is rather, important in irrigation design. According to USDA, soil conservation service, the basic infiltration rate is the instantaneous value, when the rate of change of intake for a standard period of 1 hour is 10% or less of its value. The time at which I = I bars is found by equating the first dervate of the following equation to 0.1. I for a period of 1 hour.

DZ/dt = 0.11

Where
I = the instantaneous IR
T = Infiltration time (min)
A = Coefficient
B = dimensionless coefficient (between 0 and 1.0)

Investigation of infiltration rates for surface irrigation reveals the following :

IR(cm/hr)	Suitability for surface irrigation
<0.1	very slow, unsuitable, but suitable for rice
0.1-0.3	too slow and marginally suitable, for rice also marginally suitable
0.3-0.7	suitable, but unsuitable for rice
0.7-3.5	optimum
3.5-6.5	suitable
6.5-12.5	marginally suitable(too rapid), small basins required
12.5-25.0	suitable only under special condition, very small basin required.
>25	unsuitable(too rapid), recommended for overhead methods only.

Source: FAO, 1979

Infiltration Rates in Relation to Soil Texture

Soil Texture	Representative IR (cm/hr)	Normal IR Range (cm/hr)
Sand	5	2- 5
Sandy Loam	2	1- 8
Loam	1	1- 2
Clay loam	0.8	0.2- 1.5
Silty clay	0.2	0.03- 0.5
Clay	0.05	<0.1- 0.8

Source: FAO, 1979

9.2 Hydraulic Conductivity

Hydraulic conductivity (permeability) of the soil is the property to transmit water down ward through unit cross- section area of a soil in unit time.
4
The hydraulic conductivity of the saturated soil governs the rate of drainage. The average hydraulic conductivity of a soil profile is used to determine subsurface drainage and to evaluate the feasibility of rising perched water table conditions, which may injure crop roots.

Permeability of soils determined mainly by size and continuity of the pores. A soil having high porosity due to coarse texture has high permeability. Permeability is estimated in the field by the auger hole method and in the laboratory from undisturbed soil samples. It is the rate of water penetration through soil profile both in horizontal and vertical directions. This is important to evaluate drainablity and the possibility of perched water tables due to impermeable layers, as both can injure crop roots. The rating of hydraulic conductivity is as follow:

HC(m/day)	**Rating**
<0.2	very slow
0.2-0.5	slow
0.5-1.4	moderate
1.4-1.9	moderately rapid
1.9-3.0	rapid
>3.00	very rapid.

Table.10 Approximate Relationship between Soil Texture, Soil Structure and Hydraulic Conductivty

Texture	Structure	Hydraulic Conductivty cm/hr	m/day
Coarse sand , gravel	Single grain	> 50	>12
Medium sand	Single grain	25 - 50	6 - 12
Loamy sand, fine sand	Medium crubm, Single grain	12 - 25	3 - 6
Fine sandy loam , sandy loam	Fine crumb, coarse granular & subangular blocky	6 - 12	1.5 - 3
Light clay loam, silt, silt loam, v.fine sandy loam, loam	Medium prismatic, subangu. & angu. blocky	2 - 6	0.5 - 1.5
Clay, slity clay, sandy clay, clay loam, silty clay loam, clay loam, silt loam, silt, sandy clay loam	Fine & medium prismatic, platy, angular blocky	0.5 - 2	0.1 - 0.5
Clay loam, silty clay, clay, sandy clay loam	V.fine & prismatic, angu. Blocky, platy	0.25 - 0.5	0.1- 0.05
Clay, heavy clay	Massive, v.fine or fine columunar	<0.25	<0.05

Source: FAO, 1979

9.3 Available Water Capacity

Available water capacity (AWC) s the volume of water retained between field capacity (0-33 bar) and permanent wilting point both are measured using a pressure membrane apparatus.

However, all available moisture is not accessible to plants due to imperfect drainage, hydraulic conductivity of soil, rolling depths, root concentrations at different depths and stage of plant growth. About 50 – 70% of available moisture is considered readily available water(RAW). As a rule readily available moisture is considered 0.66% of the total available water. The formula for calculation is

$$AWC= \frac{\text{Field capacity(\% by wt) - Water content at wilting point x horizon depth x B.D}}{100}$$

Available water capacity is the potential of soils to store moisture at field capacity. Available water capacity can be correlated with soil texture as shown below.

Interpretation of the results for surface irrigation purpose is as follow.

Rating	**AWC(mm/m)**
low	<120
medium	120-180
high	>180

Table.11. Format for Calculation Of Available Water Holding Capacity and Readily Available water

SUM	Horizon cm	Depth mm	FC	PWP	B.D.	Horizon AWC	SMU AWC	Horizon RAWC	SMU RAWC
SMU1									
SMU2									
..etc									

Table: 12. Soil Texture and Available Water

Texture	Status	FC (mm/m)	PWP (mm/m)	AWC (mm/m)	Ratio of RAWC	RAWC (mm/m)	B.D. g/cm^3	pore space (%vol)
Sandy	Avg. Range	150 100- 200	70 40-100	80 60 - 100	- 0.7	55 45-70	1.65 1.55-1.75	38 36-40
Loamy sand	Avg. Range	180 130 - 230	80 50 - 110	100 70 - 130	- 0.7	70 50 - 90	1.60 1.50 - 1.70	40 38 - 42
Sandy loam	Avg. Range	210 150-170	90 60-120	120 90-150	- 0.65	80 60 - 100	1.50 1.40-1.60	43 41-45
Loam	Avg. Range	310 250-360	140 110-170	170 140-200	- 0.6	100 85-120	1.4 1.30-1.50	47 45-49
Clay loam	Avg. Range	360 310-410	170 150-200	190 160-220	- 0.55	105 90-120	1.35 1.25-1.45	49 47-51
Silty clay	Avg. Range	400 350-460	190 170-230	210 180-230	- 0.55	110 100-125	1.30 1.2- 1.4	51 49-53
Clay	Avg. Range	440 390-490	210 190-240	230 200- 250	- 0.5	115 100- 125	1.25 1.2-1.3	53 50- 55

Source: EVDSA/FAO-UNDIP, 1992 Soil survey and land classification guidelines

9.4 Soil Water Characteristic Curves

Matric potential is reduction from the attractive forces between the soil matric and the water and always has a negative sign.

In general, as water content increases, the matric potential increased (becomes a small negative number). The relation between matric potential changes and changes in soil water content, is a soil water characteristic curve. It is a complex nonlinear function and is different for each soil types and pedons. Curves relating matrix potential to volumetric water content are shown on graphs. In general, when the matrix potential is large (e.g. matrix potential near – 0.3 bars), a small change in water content causes only a very small changes in matrix potential. At small matrix potential (e.g. 10 bars), a small change in water content causes a large change in matrix potential.

The volumetric water content for each matric potential will be measured in lab. From core ring samples and calculated using the following formula.

Volumetric water content(%) = Volume of water (cm^3)x 100/ Core volume(cm^3)

The volume water is determined from the following formula

Volume of water (cm^3) = Mass of equilibrated soil (g) - Mass of oven dry core(g)

The soil characteristic curve is produced by plotting the soil water matric potentials (bars) against volumetric water content (%).

9.5. Depth to groundwater Table

Groundwater affect crop growth by depriving the roots, from oxygen interance, absorption of water and nutrients. Moreover, unless the soil is inherently saline and saline alkaline the precursor of soil salinity/ alkalinity is groundwater.

Installing pizometer, investigation of water supply wells data and deep boring during soil survey can give us an indication of the trends. Annual rise of ground water is very important in Irrigation .

The presence of deeper groundwater tables, phreatic water, can also be recorded as follow

Shallow:	2 - 3 m
Moderately deep	3 - 5 m
Deep	5 - 8
Extremely deep >8	

10. WATER QUALITY FOR IRRIGATION

10.1. Background

Irrigation planning and management is dependent on acceptable quality of irrigation water.

In soil survey and land evaluation for irrigation, water quality has to be determined as the effect of water quality is mainly dependent on the type of soil and soil characteristics including type of crops to be grown and cropping pattern.

The quality of available water may be more significant in some cases, then soil characteristics in determining the suitability of some lands for irrigation. Excellent soils may be unsuitable for irrigation, for example, if the available water would quickly render them saline or sodic. As a result evaluation of land for irrigation is made by jointly analyzing the land and soil characteristic on one hand and the quality of irrigation water on the other hand.

Moreover ground and surface water contain variable amounts and kinds of soluble salts. Therefore it is essential to make an assessment of the quality of available water before use for irrigation. This guideline has tried to establish water quality standard by adopting as relevant from FAO, Water quality for Agriculture No 29 and USDA Manual.

Water Quality Analysis is done for: PH, EC, Na, K, Ca, Mg, Cl, SAR, NO_3, NH4, SO_4, CO_3 & HCO_3, B, TDS, P, Cu, Fe, Mn, Zn, Total N, Temperature, suspended solids. The most important parameters in soil survey for irrigation are discussed here in sections below.

10.2. Conditions Affecting Measurement and Analysis of Water Quality

The quality of water for irrigation should be evaluated in relation with soil and land characteristic. Some of the important determiners of the level of water quality for irrigation are.

Watertable depth and its fluctuation :- A given quality of irrigation may be found suitable when the ground water table depth is quite deep, but when the water table depth rises to close vicinity of (< 1 meter) of the surface, the same water might become unfit for use, because it is not possible to provide any leaching allowance to the soil profile under such situations. A rise of the water table may create salinity in the soil profile thus reduces the possibility of using saline/sodic water in such soils.

Soil texture: marginally suitable water can be used successfully in light textured soils, but the same water is considered unfit in heavy textured soils, due to low permeability and restricted drainage. For example irrigation water having SAR value of 15 may be managed in coarse textured (loamy sand), but it is found unfit for fine textured (clay loam soils). Hard pans if present, further reduce the chance of using water having salinity or sodicity hazards

Soil structure:- In a structureless state observed in puddled soil or in a soil having platy structure, it is difficult to manage water having medium salinity or sodicity because of low permeability, where as in a soil having macro aggregates with large sized pores (>0.06 mm diameter) it is easy to manage marginal waters (medium salinity and sodicity).

Soil pH: the normal pH range of soil in which most irrigation waters can be used is 6.0 – 8.5. However, pH values of higher or lower magnitude than this may cause imbalance of nutrients by distabilizing or precipitating cretain nutrients. For example at pH more than 9.0, soluble sodium present, water converts soil phosphorus in to sodium phosphate, which is high soluble but available to plants.

Clay content and its nature: the higher the clay content in a soil, the lower is the upper permissible limit of saline irrigation water. The adverse effect of saline water is more on montomorllinitic than on illicit or kaolinitic clays.

Initial soil Salinity and Sodicity: initial soil salinity and sodicity decreases the upper permissible limit of salinity of irrigation water. It is because of the fact that a soil having higher initial salinity or sodicity will reach a stage sooner, where it will no more feasible to grow normal crops. So it is safer to use waters having low salinity/sodicity hazards in soils having initial salinity and sodicity problems

Soil fertility and Fertilizer use: saline water can be used in fertile soils, particularly rich in organic matter. The adverse effect of saline/sodic water can be reduced by proper dozes of fertilizer. Saline water cause imbalance of nutrients but if sufficient level of nutrients is maintained in the soil by the applications of fertilizers, the negative effect of saline water can be offset. So, it is possible to make use of marginal water by applying proper rate of fertilizers to maintain the fertility of the soil.

Crop types and agronomic practices: some crops are relatively more tolerant to salinity. Datepalm, Barely, Sugar beet, Cotton, Asparagus and spinach are tolerant to salinity up to EC of 15mmhos/cm. Wheat, Tomato, Oats, Alfalfa, Rice, Maize, Flax, Potatoes, Carrots, Onion, Cucumbers, Pomegranate, Fig and grapes are semi – tolerant, whereas red clover, peas, Beans, sugarcane orange are sensitive to salinity.

Climate: the adverse effect of saline irrigation water is more in arid and semi arid area than humid regions. Normally there are no changes of salt balance in the soil profile in areas where rainfall is more than 700 mm during the main season.

Areas with higher PET rates are likely to be salinized faster then areas with lower PET when irrigated with low to moderately acceptable quality of water.

10.3. Sodium Absorption Ratio and Electrical Conductivity of Water

The proportion and concentration of different ions present in water determines its quality. An important criterion used in estimating water quality is Sodium Absorption Ratio (SAR), which is calculated by the following formula.

$$SAR = \frac{Na+}{\sqrt{\frac{Ca^{2+} Mg^{2+}}{2}}}$$

where NC^{+}, Ca^{2+} and Mg^{2+} are ionic concentrations in meq/l of solution.

The rating of SAR for irrigation is as follow

SAR(meq/l)	Rating
< 10	Suitable for most crops
10 – 18	Suitable coarse textured soil
18 – 26	may be used with special amendments like gypsum
> 26	generally unfit for irrigation

The irrigation water salinity is also measured by EC. The following ratings of irrigation water salinity are used to classify the irrigation water.

EC (ms/cm)	Ratings
< 250	Suitable for all situations, No risk of soil Salnization
250 – 750	suitable for semi-salt tolerant crops with leaching
750 – 2250	May be used with adequate drainage and for salt tolerant crops
> 2250	Not suitable for ordinary condition may be used in coarse textured soils, having adequate drainage with considerable leaching for extremely salt tolerant crops

10.4. Other Water Quality Measurement

The quality of irrigation water have to be also tested for other cations and anions if found to be necessary. These are:

Cations: like Ca, Mg, Na, K, and Total Dissolved Solids (TDS) are important parameters.

Anions: such as Bicarbonate (HCO_3)), Chloride, Carbonate and others. For sprinkler irrigation system, water with more than 3meg/l Cl causes leaf burn due to direct contact. In case of Bicarbonate, the range of irrigation water is none for < 1.5 me/l, light to moderate for 1.5 - 8.5 me/l and sever for > 8.5 me/l.

Residual Sodium Carbonate: Salinity and Sodicity can also be indicated by RSC calculated by the formula.

$$RSC = (CO^{2}_{3} - HCO^{-}_{3}) - (Ca^{2+} + Mg^{2+})$$

If RSC < 1.25 water probably safe for irrigation, and 1.25 < RSC < 1.25 water marginally suitable for irrigation. However RSC > 2.5 water is unsuitable for irrigation.

Table 13. Format for Water Quality Analysis

Water Samp. No.	Date & Site	EC	PH	Alk.	Ca	Mg	Na	SAR	CO_3	HCO_3	Other elements/ compounds as necessary	TDS mg/l
01												
02												
etc.												
Class												

11 SOIL CLASSIFICATION AND CORRELATION

11. 1. The purpose of soil classification

Any object has a variability with in natural population. The classification of population to classes is to try and impose an ordered structure from our experience in dealing with them. Soil classification is more difficult and disputable than that of other natural populations, because a soil lack the hereditary characteristics by which individuals with in one generation to the next be traced. The soil population presents a continuum of variation so that arbitrary judgment are inevitable in the creation of classes.

For practical and effective soil and land resource planning there must be a well designed soil classification which is capable of accommodating all soil types to be found in nature. Class definitions and a key to differentiate categories must all be clear and exclusive. Those soil characteristics that are easy to measure and observe are preferred in classification.

The classification system must be well structured, such that the similarities and differences between soils can easily be understood. The aim is to find a simple way to permit more accurate communication about soils, both among and between soil scientists and non soil scientists. Classification is also promotes a better understanding of the relationships that exist among soils and between soils and environment. This led to a different soil classification system being constructed based on climatic, morphological and genetic principles.

11. 2. Kinds of classification

Specific or single purpose classification: this kinds of classification is made with a specific aim in mind and is based on, one of a very few selected soil properties.

For example, soil texture, classification for irrigation or soil salinity classification using exchangeable sodium percentage (ESP) or EC..etc.

General purpose classification : this kind of classification is intended for many uses, and therefore, the classes should be defined on as many properties as possible, provided that the properties chosen are relevant to the utilization of the soil. The classification will be useful, if not, may be academically elegant but of less practical value. It will be useful to choose certain diagnostic properties. For example, the color of the "A" horizon may be correlated with organic matter content, and mottling of the subsoil is indicative of a low hydraulic conductivity.

There are several soil classification system in the world. Most of the developed countries have their own locally specific soil classification system. However the FAO-UNESCO/ISRIC and USDA soil taxonomy are widely used in the world.

11 3. FAO/ UNESCO ISRIC International Soil Classification System.

11.3.1. General back ground and Purpose of Classification

The 7th international soil science society, made in USA in 1960, recommended the preparation of international soil classification system as a legend to soil map of the world. Accordingly FAO-UNESCO have been given a man date, and established an international soil classification system. Since then, FAO in collaboration with other international and bilateral organization has revised the classification. The latest is the 1998 world reference base for soil resources.

FAO/ UNESCO soil classification system is aimed to be a scientific basis for the transfer of experience between countries and areas with similar environments.

11.3.2. Basis of Classification

Diagnostic horizons: are a set of properties, which are used for identifying soil units. They are defined properties produced by soil forming processes. These are: *Albic horizon, Andic horizon, Anthraquic horizon Anthro pedogenic horizon, Argic horizon, Calcic, Cambic, Chernic, Cryic, Duric, Ferralic, Ferric, Folic, Fragic, Fluvic, Gypsic, Histic, Hydragric, Hortic, Irriagric, Melanic, Mollic, Natric, Nitic, Ochric, Pertocalcic, petroduricc, Petrogypsic, Petroplinthic, plaggic, plinthic, Salic, Spodic, Sulfuric, Takyric, Terric, Umbric, Vertic, Vitric, Yermic.*

Diagnostic properties: Abrupt textural change, Albeluvic tonguing, Alic Properties, Aridic Properties, Continuous hard rock, Ferralic properties, Geric properties, Gleyic properties, Permafrost, Secondary Carbonates, Stagnic Properties, Strongly Humic properties.

Diagnostic materials: Anthropogeomorphic soil materials, Calcaric Soil materials, Gypsiric soil martial, Organic Soil material, Sufidic Soil matial, Tephric Soil materials.

(For details refer to FAO – ISRIC – ISSS, 1998 World Reference Base for Soil Resources)

Table. 14 FAO-ISRIC/ISSS 1998 Soil units and Subunits of the world Reference Bases for Soil Resources

HISTOSOLS	CRYOSOLS	ANTHROSOLS	LEPTOSOLS	VERTISOLS
Cryic	Histic	Hydragric	Lithic	Thionic
Glacic	Lithic	Irragric	Gleyic	Salic
Salic	Leptic	Terric	Rendzic	Natric
Gelic	Turbic	Plaggic	Umbric	Gypsic
Thionic	Salic	Hortic	Yermitc	Duric
Folic	Natric	Gleyic	Aricic	Calcic
Fibric	Gleyic	Stagnic	Vertic	Alic
Sapric	Andic	Spodic	Gelic	Gypsiric
Ombric	Mollic	Ferralic	Hyperskeletic	Pellic
Rheic	Gypsic	Luvic	Mollic	Grumic
Alcalic	Calcic	Arenic	Humic	Mazic
Toxic	Umbric	Regic	Gypsiric	Chromic
Dystric	Yermic		Calcaric	Mesotrophic
Eutric	Aridic		Dystric	Hyposodic
	Glacic		Eutric	Eutric
	Thionic		Haplic	Haplic
	Oxyaquic			
	Stagnic			
	Haplic			
FLUVISOLS	**SOLONCHAKS**	**GLEYSOLS**	**ANDOSOLS**	**PODZOLS**
Histic	Histic	Histic	Vitric	Gelic
Thionic	Vertic	Thionic	Eutrisilic	Gleyic
Salic	Gleyic	Anthraquic	Silic	Stagnic
Gleyic	Sodic	Endosalic	Gleyic	Densic
Mollic	Mollic	Andic	Melanic	Carbic
Umbric	Gypsic	Vitric	Fulvic	Rustic
Arenic	Duric	Plinthic	Hydric	Histic
Takyric	Calcic	Sodic	Pachic	Umbric
Yermic	Petrosalic	Mollic	Histic	Entic
Aridic	Takyric	Gypsic	Mollic	Placic
Gelic	Yermic	Calcic	Duric	Skeletic
Stagnic	Aridic	Umbric	Umbric	Fragic
Humic	Gelic	Arenic	Luvic	Lamellic
Gypsiric	Stagnic	Takyric	Placic	Anthric
Calcaric	Hypersalic	Gelic	Leptic	Haplic
Sodic	Ochric	Humic	Acroxic	
Tephric	Aceric	Alcalic	Vetic	
Skeletic	Chloridic	Alumic	Calcaric	
Dystric	Sulphatic	Toxic	Arenic	
Eutric	Carbonatic	Abruptic	Sodic	
Haplic	Haplic	Calcaric	Skeletic	
		Tephric	Thaptic	
		Dystric	Dystric	
		Eutric	Eutric	
		Haplic	Haplic	
PLINTHOSOLS	**FERRALSOLS**	**SOLONETZ**	**PLANOSOLS**	**CHERNOZEMS**
Petric	Plinthic	Vertic	Histic	Chernic
Alic	Gleyic	Gleyic	Vertic	Vertic
Acric	Andic	Salic	Thionic	Gleyic
Umbric	Acric	Mollic	Endosalic	Luvic
Albic	Lixic	Gypsic	Plinthic	Glossic
Stagnic	Arenic	Duric	Gleyic	Calcic
Endoeutric	Gibbsic	Calcic	Sodic	Siltic
Geric	Geric	Magnesic	Mollic	Vermic
Humic	Humic	Takyric	Gypsic	Haplic
Endoduric	Histic	Yermic	Calcic	
Vetic	Mollic	Ardic	Alic	
Alumic	Umbric	Stagnic	Luvic	
Abruptic	Endostagnic	Albic	Umbric	
Pachic	Vetic	Humic	Arenic	
Glossic	Posic	Haplic	Gelic	
Ferric	Alumic		Albic	
Haplic	Ferric		Geric	
	Hyperdystric		Petroferric	
	Hypereutric		Alcalic	
	Rhodic		Alumic	
	Xanthic		Ferric	
	Haplic		Calcaric	
			Rhodic	
			Chromic	
			Dystric	
			Eutric	
			Haplic	

KASTANOZEMS	PHAEOZEMS	GYPSISOLS	DURISOLS	CALCISOLS
Vertic	Leptic	Petric	Petric	Petric
Gypsic	Vertic	Leptic	Leptic	Leptic
Calcic	Gleyic	Vertic	Vertic	Vertic
Luvic	Andic	Endosalic	Gypsic	Endosalic
Hyposodic	Vitric	Sodic	Calcic	Gleyic
Siltic	Sodic	Duric	Luvic	Sodic
Chromic	Luvic	Calcic	Arenic	Luvic
Haplic	Stagnic	Takyric	Yermic	Yermic
	Greyic	Yermic	Aridic	Aridic
	Pachic	Aridic	Chromic	Skeletic
	Abruptic	Arzic	Hyperochric	Hyperochric
	Glossic	Skeletic	Haplic	Hypercalcic
	Tephric	Hyperochric		Hypocalcic
	Calcaric	Hypergypsic		Haplic
	Skeletic	Hypogyspic		
	Siltic	Haplic		
	Vermic			
	Chromic			
	Haplic			
ALBELUVISOLS	ALISOLS	NITISOLS	ACRISOLS	LUVISOLS
Histic	Vertic	Andic	Leptic	Leptic
Gelic	Plinthic	Molltic	Plinthic	Vertic
Gleyic	Gleyic	Alic	Gleyic	Gleyic
Alic	Andic	Umbric	Andic	Andic
Umbric	Nitic	Humic	Vitric	Vitric
Arenic	Umbric	Vetic	Umbric	Calcic
Fragic	Arenic	Alumic	Arenic	Arenic
Stagnic	Stagnic	Rhodic	Stagnic	Stagnic
Alumic	Albic	Ferralic	Geric	Albic
Endoeutric	Humic	Dystric	Albic	Hyposodic
Abruptic	Abruptic	Eutric	Humic	Profondic
Ferric	Profondic	Haplic	Vetic	Lamellic
Siltic	Lamellic		Abruptic	Ferric
Haplic	Ferric		Profondic	Rhodic
	Hyperdystric		Lamellic	Chromic
	Skeletic		Ferric	Cutanic
	Rhodic		Alumic	Hyperochric
	Chromic		Hyperdystric	Dystric
	Haplic		Skeletic	Haplic
			Rhodic	
			Chromic	
			Hyperochric	
			Haplic	
LIXISOLS	UMBRISOLS	CAMBISOLS	ARENOSOLS	REGOSOLS
Leptic	Gelic	Gelic	Gelic	Gelic
Plinthic	Leptic	Leptic	Plinthic	Leptic
Gleyic	Gelyic	Vertic	Gleyic	Gleyic
Andic	Arenic	Fluvic	Hypoluvic	Thaptoandic
Vitric	Stagnic	Enosalic	Yermic	Thaptovitric
Calcic	Albic	Plinthic	Aridic	Arenic
Arenic	Humic	Gelistagnic	Ferralic	Takyric
Stagnic	Ferralic	Stagnic	Albic	Yermic
Geric	Skeletic	Gleyic	Gypsiric	Aridic
Albic	Anthric	Andic	Calcaric	***Gelistagnic***
Humic	Haplic	Vitric	Lamellic	***Stagnic***
Vetic		Mollic	Rubic	Antrhropic
Abruptic		Takyric	Fragic	Aric
Profondic		Yermic	Hyposalic	Garbic
Lamellic		Aridic	Tephric	Reductic
Ferric		Sodic	Hypoduric	Spolic
Rhodic		Ferralic	Protic	Urbic
Chromic		Gypsiric	Dystric	Humic
Hyperochric		Calcaric	Eutric	Vermic
Haplic		Skeletic	Haplic	Hyposalic
		Rhodic		Hyposodic
		Chromic		Gypsiric
		Hyperochric		Calcaric
		Dystric		Tephric
		Eutric		Skeletic
		Haplic		Hyperochric
				Dystric
				Eutric
				Haplic

1.4. Identification Characteristics of FAO 1998 Soil Units

For describing and defining the reference soil groups of the World Reference Base for Soil Resources, use is made of soil characteristics, properties and horizons that are combined to define soils and their relationships.

Soil Characteristics are single parameters, which are observable, or measurable in the filed or laboratory, or can be analysed using microscope techniques. They include such characteristics as colour, texture and structure of the soil features of biological activity, arrangement of voids and pedogenic concentrations (mottles, cutans, nodules, etc) as well as analytical determinations (soil reaction, particle-size distribution, cation exchange capacity, exchangeable cations, amount and nature of soluble salts, etc.).

Soil properties are combinations ("assemblages") of soil characteristics which are known to occur in soils and which are considered to be indicative of present or past soil-forming processes (e.g vertic properties, which are a combination of heavy texture, smectitic mineralogy, slickensides, hard consistence when dry, sticky when wet, shrinking when dry and swelling when wet).

Soil horizons are three-dimensional pedological bodies, which are more or less parallel to the earth's surface. Each horizon contains one or more property, occurring over a certain depth, which characterizes it. The thickness varies from a few centimetres to several metres; most commonly it is about a few decimetres. The upper and lower limits ("boundaries") are gradual, clear or abrupt. Laterally, the extension of a soil horizon is never infinite and it disappears or grads into another horizon.

Soils are defined by the vertical combination of horizons, occurring within a defined depth, and the lateral organization ("sequence") of the soil horizons, or by the lack of them, at a scale reflecting the relief or a land unit.

<u>Key to the Reference Soil groups Of The World Reference Base for Soil Resources</u>

Soils having a histic or folic horizon,

1. either a) 10cm or more thick from the soil surface to a lithic or paralitic contact; or
   b) 40 cm or more thick and starting within 30cm from the soil surface; and
2. Lacking an andic or vitric horizon starting within 30cm from the soil surface.

Histosols (HS)

Other soils having
One or more cryic horizons within 100cm from the soil surface.

Cryosols (CR)

Others soils having ether
1. a hortic, irragric, plagic or terric horizon 50cm or more thick; or
2. an anthraquic horizon and an underlying hydragric horizon with a combined thickness of 50cm or more.

Anthrosols (AT)

Other soils which are either

1. Imitated in depth by continuous hard rock within 25cm from the soil surface; or
2. Overlying material with a calcium carbonate equivalent of more than 40 percent within 25 cm from the soil surface; or
3. Containing less than 10 percent (by weight) fine earth to a depth of 75cm or more from the soil surface: and
4. Having no diagnostic horizons other than a mollic, ochric, umbric, yermic or vertic horizon.

Leptosols (LP)

Other soils having

1. a vertic horizon within 100 cm from the soil surface; and
2. after the upper 20cm have been mixed, 30 percent or more clay in Illuvial horizons to a depth of 100 cm or more, or to a contrasting layer (lithic or paralithic contact, pertrocalcic, petroduric or pertrogypsic horizons, sedimentary discontinuity, etc) between 50 and 100 cm and
3. Cracks[2] which open and close periodically

Vertisols (VR)

Other soils having

1. *fluvic* soil material starting within 25cm from the soil surface and continuing to a depth of at least 50cm from the soil surface; and
2. no diagnostic horizons other than a *histic, mollic, ochric, takyric, umbric yermic, salic or sulfuric* horizon.

Fluvisols (FL)

Other soils having

1. a *salic* horizon starting within 50 cm from the soil surface; and
2. no diagnostic horizons other than a *histic, mollic, ochric, takyric, yermic, calcic, cambic, duric, gyupsic* or vertic horizon.

Solonchaks (SC)

Other soils having

1. gleyic properties within 50cm form the soil surface; and
2. no diagnostic horizons other than antraquic, *histic, mollic, ochric, takyric, yermic, calcic, cambic, duric, gypsic plinthic, salic, sulfuric or vitric* horizon within 100cm from the soil surface.

Gleysols (GL)

Other soils having

1. either a vitric or an andic horizon starting within 25cm from the soil surface; and
2. having no diagnostic horizons (unless buried deeper than 50cm) other than a histic, fulvic, melanic, mollic, umbric, ochric, duric or cambic horizon.

[2] A crack is a separation between gross polyhedrons. If the surface is strongly self-mulching, i.e a mass of granules ("grumic"), or if the soil cultivated while cracks are open, the cracks may be filled mainly by granular materials from the soils surface but they are open in the sense that the polyhedrons are separated. A crack is regarded as open if it controls the infiltration and percolation of water in dry, clayey soil (Soil survey Staff, 1994). If the soils is irrigated the upper 50 cm has a coefficient of linear extensibility (COLE) of 0.06 or more throughout.

Andosols (AN)

Others soils having
a spodic horizon starting within 200cm from the soil surface, underlying an albic, histic, umbric or ochric horizon, or an anthropedogenic horizon less than 50cm thick.

Podozols (PZ)

Others soils having either
1. a petroplinthic horizon starting within 50cm from the soil surface; or
2. a plinthic horizon starting within 50cm from the soil surface; or
3. a plinthic horizon starting within 100cm from the soil surface when underlying either an albic horizon or a horizon with stagnic properties.

Plinthosols (PT)

Other soils
1. having a ferralic horizon at some depth between 25 and 200cm from the soil surface; and
2. lacking a nitic horizon within 100 cm from the soil surface; and
3. lacking a layer which fulfils the requirements of an argic horizon and which has in the upper 30cm, 10 percent or more water dispersible clay (unless the soil material has geric properties or more than 1.4 percent organic carbon.

Ferralsols (FR)

Others soils having
a nitric horizon with 100cm from the soil surface.

Solonetz (SN)

Others soils having
1. an eluvial horizon, the lower boundary of which is marked within 100cm form the soil surface, by an abrupt textural change associated with stagnic properties above that boundary; and
2. no albeluvic tonguing.

Planosols (PL)

Others soils having
1. a mollic horizon with a moist chrome of 2 or less if the texture is finer than sandy loam, or less than 3.5 if the texture is sandy loam or coarser, both to a depth of at least 20cm, or having these chromes directly below any plough layer; and
2. Concentrations of secondary carbonates starting within 50cm of the lower limit of the Ah horizon but within 200 cm from the soil surface; and
3. no petrocalcic horizon between 25 and 100 cm from the soil surface; and
4. no secondary gypsum; and
5. no uncoated silt and sand grains on structural ped surfaces.

Chernozems (CH)

Other soils having
1. a mollic horizon with a moist chroma of more than 2 to depth of at least 20cm, or having this chroma directly below any plough layer; and
2. concentration of secondary carbonates within 100 cm from the soil surface; and
3. no diagnostic horizons other than an argic, calcic, cambic, gypsic or vertic horizon.

Kastanozems (KS)

Others soils having
1. a mollic horizon; and
2. a base saturation (by 1M NH_4Oac) of 50 percent or more and a calcium carbonate-free soil matrix at least to a depth of 100 cm from the soil surface, or to contrasting layer (lithic or paralithic contact, petrocallcic horizon) between 25 and 100cm; and
3. no diagnostic horizons other than an albic, argic, cambic or vertic horizon, or a petroclacic horizon[3] in the substratum.

Phaeozems (PH)

Others soils having
1. either a gypsic or petrogypsic horizon within 100cm from the soil surface, or 15 percent (by volume) or more gypsum, which has accumulated under hydromorphic conditions, averaged over a depth of 100cm; and
2. no diagnostic horizons other than an ochric or cambic horizon, an argic horizon permeated with gypsum or calcium carbonate, a vertic horizon, or a calcic or petrocalcic horizon underlying the gypsic horizon.

Gypsisols (GY)

Others soils having a duric or petroduric horizon within 100 cm from the soil surface.

Durisols (DU)

Other soils having
1. a calcic or petrocalcic horizon within 100cm of the surface; and
2. no diagnostic horizons other than an ochric or cambic horizon, an argic horizon which is calcareous, a vertic horizon, or a gypsic horizon underlying a petrocalcic horizon.

Calcisols (CL)

Others soils havingan argic horizon with in 100 cm from the soil surface with an irregular upper boundary resulting from albeluvic tonguing into the argic horizon.

Albeluvisols (AB)

Other soils having
1. an argic horizon, which has a cation exchange capacity (by 1 M NH_4OA_C) of 24 $cmmol_c\ kg^{-1}$ clay or more, either starting within 100cm from the soil surface, or within 200cm fram the soil surface if the argic horizon is overlain by loamy sand or coarser textures throughout; and
2. alic properties in the major part between 25 and 100 cm from the soil surface; and
3. no. diagnostic horizons other than an ochric, umbric, albic, andic, ferric, nitic, plinthic or vertic horizon.

[3] A petrocalcic horizon may be present locally (e.g tile "Tosca" in Argentian). Such petrocalcic horizons are considered to be polygenetic and may best be handled for classification purposes at phase level (e.g Luvic Phaezem, tosca phase).

Alisols (AL)

Other soils having
1. a nitic horizon starting within 100cm from the soil surface; and
2. gradual to diffuse horizon boundaries between the surface and the underlying horizons; and
3. no ferric,plinithic or vertic horizon within 100 cm from the soil surface.

Nitisols (NT)

Other soils having
1. an argic horizon, which has a cation exhange capacity (by 1M NH_4OA_C) of less than 24 $cmol_cKG^{-1}$ clay in some part either starting within 100cm from the soil surface, or within 200cm form the soil surface if the argic horizon is overlain by loamy sand or coarse textures throughout, and
2. a base saturation (by 1M NH_4OA_c) of less than 50 percent in the major part between 25 and 100cm

Acrisols (AC)

Other soils having
an argic horizon with a cation exchange capacity (by 1M NH_4Oac) equal to or morethan 24 cmolc KG^{-1} clay throughout.

Luvisols (LV)

Other soils having an argic horizon

Lixisols (LX)

Others soils having
1. an umbric horizon; and
2. no diagnostic horizons other than an anthropedogenic horizon less than 50cm thick, or an albic or cambic horizon.

Umbrisols (UM)

Others soils having either
1. A cambic horizon: or
2. a molic horizon overlying a subsoil which has a base saturation (by 1M NH_4Oac) of less than 50 percent in some part within 100cm form the soil surface: or
3. one of the following diagnostic horizons within the specified depth
   a. an andic, vertic or vitric horizon starting between 25 and 100cm
   b. a plinthic petroplnthic or salic horizon starting between 50 and 100cm, in the absence of loamy sand or coarser textures above these horizons.

Cambisols (CM)

Other soils having
1. a texture which is loamy sand or coarser either to a depth of at least 100cm from the soil surface, or to a plinithic, peteroplinthic or salic horizon between 50 and 100 cm from the soil surface; and
2. less than 35 percent (by volume) of rock fragments or other coarse fragments within 100 cm from the soil surface; and
3. no diagnostic horizons other than an ochric, yermic or albic horizon, or a plinthic, pertroplinthic or salic horizon below 50cm from the soil surface, or an argic or spodic horizon below 200cm depth.

Arenosols (AR)

Other soils
Regosols (RG)

11. 5. Soil Taxonomy/USDA Soil Classification System.

The United Stated Department of Agriculture(USDA), soil classification known widely as Soil Taxonomy (soil survey staff, 1975 and revised 1994) depends primarily on the properties of the profile rather than on genesis. The properties selected are mainly of those " A" and "B" horizons and often includes those of the "C" horizons. The properties of the "A" horizon are given more emphasis and are used for separating the soils of the highest level of category in the system. The properties of the "B" horizon are taken for separation at the next lower level. The properties of the "C" horizon and other characteristics of the soil are used at the lowest level in the system. Soil horizons that have a set of quantitatively defined properties which are used for identifying soil units are called as in pervious system "diagnostic horizons". The soil forming processes are not used as criteria, but only their effects expressed quantitatively in terms of morphological properties that have identification value.

Diagnostic Surface Horizons(Epipedon): Epipedon is not the same as an "A" horizon, it may include part or all of the elluvial "B" horizon. There are 7 diagnostic surface horizons that have formed at the soil surface. These are *Anthropic, Histic, Melanic, Mellic, Ochric, Umbric epipedons.*

Diagnostic Subsurface Horizons. They are formed below the surface of the soil, and some are regarded as "B" horizons while others are generally regarded as parts of the A horizon. These are *Agric, Albic, Argillic, Calcic, Cambic, Duripan, Fragipan, Glossic, Gypsic, Kandic, Natric, Oxic, Petrocalcic, Petrogypsic, Placic, Salic, Sombric, Spodic and Sulfuric horizons*,

Diagnostic Soil Characteristics : are features helps in distinguishing the soil behavior. They are : Abrupt textural change, Albic material, Andic soil properties, Aquic conditions, Anthraquic conditions, Coefficient of linear extensibility (COLE), Durinodes, Identifiable secondary carbonates, Interfingering of albic materials, Linear extensibility (LE), Lithic contact, Plinthite, Sequum and bisequum, Slicken sides, Soil moisture regimes, Soil temperature regimes, Sulfidic materials, Weatherable minerals.

(for detail information refer to USDA soil survey manual 1994/1996)

11.6. Categories and Identification Characteristics of the USDA Soil Taxonomy.

i.	Higher categories are Organic soils and Mineral soils	
ii.	Order :	11
iii.	Suborder:	47
iv.	Great Groups :	225
v.	Family :	4500
vi.	Series:	10500

Soil orders are differentiated by the presence or absence of diagnostic horizons or features that are marks in the soil or the differences in the degree and kind of the dominant sets of soil forming processes (see Table.8.)

Table .15 Soil Orders in Soil Taxonomy and Major Characteristics.

S. N.	Soil orders	Formative element.	Major characteristics
1	Entisols	-	Little profile development, ochric epipedon common.
2	Inceptisols	L.Inceptum beginning	Embryonic soils with few diagnostic features, ochric or umbric epipedon cambic horizon.
3	Mollisols	L. Mollis, soft	Mollic epipedon, high base saturation, dark soils, some with argillic or natric horizons.
4	Alfisols	-	Argillic or natric horizon, high to medium base saturation.
5	Ultisols	L. Ultimus: fast	Argillic horizon, low base saturation.
6	Oxisols	Fr. Oxide	Oxic horizon, non argillc horizon, highly weathered.
7	Vertisols	L. Verto: turn	High swelling clays, deep cracks when dry.
8	Aridisols	L. Aridus: dry	Dry soil, ochric epipedon, sometimes argillic or natric horizon.
9	Spodosols	Greek spodos: wood ash.	Spodic horizon commonly with Fe, Al and humus accumulation.
10	Histosols	Greek. Histos, tissue	Peat or bog: > 30% organic matter.
11	Andisols	Modified from Ando	From volcanic ejecta, dominated by allophone or AL - hums complexes.

11. 7. Correlation of Different soil Classification Systems.

The strategy of achieving the intended target in soil survey is soil classification and correlation. Soil correlation is establishing a common denominator between different soil classification systems, and to combine the major characteristics of the different classification systems. Lack of a generally accepted systems of international soil classification system is a major obstacle in soil survey and also agro- technology transfer due to differences in approaches to classification. A good classification system is one which maximizes homogeneity with in groups and minimizes heterogeneity between groups. Soil is a continuum in space and time. It is not a discrete object. Hence it is impossible to avoid classification bias.

FAO soil map of the world was based on collection of information's regarding soil types and characteristics from all over the world. Soil taxonomy is prepared to serve USA and economically allied countries. USAID projects may necessarily have to be done using Soil taxonomy.

There are many similarities between soil taxonomy and the FAO - UNESCO legend. Many of the diagnostic horizons carry similar definitions.

There is no one to one correspondence between the FAO classes and the categories of soil taxonomy. A characteristics used to define a class in FAO legend may be a sub group defining criteria in soil taxonomy. A property, such as the duripan, which defines some great groups in soil taxonomy is only used as a phase in the FAO legend.

There are also some minor differences in definitions which prevents a direct correlation. For examples, cambisols in the FAO legend exclude aridic moisture regime. In soil taxonomy, soil with aridic soil moisture regime and with a cambic horizon belongs to the suborder of cambids. Despite, the above and other problems soil correlation is done cautiously by deeply investigating the soil properties and diagnostic features of both systems.

In any soil survey, soil classification using FAO-UNESCO/ISRIC 1998 should first be established and then correlated to USDA 1994/1996 system as shown on Table 16 below. One can correlate any known soil classification system using the same procedures. The major advantage of soil correlation is to transfer the rich international scientific and practical information's on soil physical , chemical properties and limitations and above all their management practices.

Table .16. Format for Soil Classification and Correlation

Soil type	SMU	FAO-UNESCO /I SRIC, 1998	Major Characteristics	Representative Profile	USDA 1994/ 1966	Major Characteristics	Comments Remarks
A	SMU1						
B	SMU2						
C	SMU3						
D	SMU4						
E	SMU5						
..etc	..etc						

12. LAND EVALUATION FOR IRRIGATION

12. 1. General Background.

The principal objective of land evaluation is to select the optimum land use for each defined land unit and soil mapping unit, taking in to account both physical and socio - economic considerations and the conservation of environmental resources for future use. It is the optimization and the conservation of the requirement of land use with the resources offered by the land, both their positive and negative characteristics.

In discussion of land evaluation reference is frequently made to land capability evaluation of USDA and land suitability evaluation of FAO.

The 1976, FAO framework for land suitability evaluation lays out, both the principle and the concepts on which local, national or regional evaluation systems can be constructed. The principles and procedures set out can be applied from major to specific land development planning and management. Moreover the framework has allowed the subsequent preparation of evaluation guidelines for each major and specific land use types such as Irrigation and Drainage (FAO, 1985), Rainfed Agriculture (FAO, 1982), Forestry (FAO, 1984) and Extensive Grazing (FAO, 1991).

Moreover each farmer or estate managers has his own conventional land evaluation system for his farm/farm unit, where by he decides the type of crops to be grown and management system to apply, based on the land characteristics and land use requirements as investigated by him using long years of traditional experience.

12. 2. FAO Land Evaluation System

12.2.1 The FAO Framework

The FAO framework for land evaluation is based on six principles.

I. Land suitability is assessed and classified with respect to specified kinds of land use. e.g. rainfed agriculture, irrigated farming, (for broad groups) and specific crops say cotton, maize, sugarcane farming (for detailed studies)

II. Evaluation requires a comparison of the out puts (benefits) obtained and the inputs needed on different types of land.

III. Multidisciplinary approach is required. Key disciplines are soil survey and land evaluation **(has to have leading role)**, agro-climatology, (climatic suitability), soil erosion and conservation(constraints), agronomy(crop requirement, land use planning(land use requirements), farming systems, sociology and economics. Too often land evaluation is seen as a by product of soil survey, rather than soil survey being one input in to land evaluation.

IV. Evaluation is made in terms relevant to the physical, economic, Institutional, and social context of the area concerned. Thus, similar land may have different suitability for similar uses in different socio-economic contexts.

V. Suitability refers to use on a sustained basis. This is a critical aspect as most of the so called Virgin and most of the cultivated land areas, in Ethiopia are degraded.

VI. Evaluation involves comparison of more than one kind of land use, for example irrigation vis a vis dryland agriculture or mechanized vis a vis small holder agriculture. .etc.

There are two suitability orders and five classes of suitability for each LUT. These are Suitable, S not suitable, N and S1(class 1), S2(class 2), S3(class 3) where as N1 refers to currently unsuitable and N2 is permanently unsuitable(Table 17 shows the structure of the land suitability classification).

There are two categories of land evaluation system

Current Suitability: refers to the suitability for a defined use of land in its present conditions, with out major improvements. A current suitability evaluation may refer to the present use of the land, either with existing or improved management practices or to a different use.

Potential Suitability: refers to the suitability for a defined use of land units with in their condition at some future date, after specified major improvements have been completed as and where necessary. It is necessary to identify the economic factors included in the estimated cost of their improvements. Land improvements are major or minor activities which causes beneficial changes in the qualities of land itself.

In irrigation development planning, current suitability is evaluated.

Table.17. The Structure of the Land Suitability Classification

Category	Name	Definition
Order S	Suitable	Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk or damage to land resources
Class S1	Highly suitable	Land having no significant limitations to sustained application of a given use or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2	Moderately suitable	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.
Class S3	Marginally suitable	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits or increase required inputs that this expenditure will be only marginally justified.
Order N	Not suitable	Land which has qualities that appear to preclude sustained use of the kind under consideration
Class N1	Currently unsuitable	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2	Permanently unsuitable	Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Source : Modified from FAO, 1976

In principle the boundaries between suitability classes are subject to revision as new technologies develop and political and social changes occur, and as such land suitability should be viewed as a dynamic process. For each suitability class there are a number of sub-classes that reflect the type of limitations that restrict the suitability of that land mapping unit for the specific LUT, or improvement measures required (for example K= workability, w= wetness, n= nutrient availability. Note that S1. has no specific limitations.

Different land use systems have different requirements. After considering the agronomic, land development, management, conservation, environmental and socio - economic factors, the relevant land qualities are determined for each land use type. Suitability evaluation involves relating land mapping units (LMU) of the land use type, to specified types of land use requirements.

12.2.2 . Land Use Types and Land Use Requirements

a. **Land Utilization Type:** is a specific subdivision of a major kind of land use serving as the subject of land evaluation and defined as precisely as possible in terms of produce and management.

Major kind of land use is a major sub-division of rural land use, such as rainfed agriculture or irrigated agriculture. Major kind of land use are usually considered in land evaluation studies of a qualitative or reconnaissance nature 1: 250,000 scale and above. Land utilization type (LUT) is a kind of specific land use described or defined in a degree of detail greater than that of major kind of land use (e.g. 1: 50,000 scale and above).

b. **Land Use Requirements:** Having described the land utilization types, the next step is to define the requirement of land for successful operation. It is the conditions of land necessary or desirable for successful and sustained practice of a given land utilization such as agronomic, management, land development, conservation requirements or limitations. In other words land use requirement refers to the set of land qualities that determine the production and management condition of a kind of land use.

For each land utilization type it is necessary to establish.

- The conditions which are best for its operation.
- The range of conditions which are less optimal but still acceptable
- Conditions which are unsatisfactory and limiting

C. Land Characteristics and Land Qualities: Land characteristics are measurable properties of the physical and soico - economic and environmental conditions directly related to land use. Land characteristics are made available through soil and land use survey, socio - economic and farming system survey, environmental assessment. Some of the land characteristics and qualities are. climate, topography, soil physical and chemical properties, soil fertility, salinity and alkalinity ... etc. Critical class limiting factors have to be established for each land qualities(see Table.18) .

Land qualities are an attribute of land or their expressions as a diagnostic criterion, which limits the potential of land for a specified kind of use. It is derived from measured land characteristics.

Factor ratings refer to the degree of effect of one land quality on the land use type or specifically crop, as assessed from class determining factors and their critical class limits.

The following land qualities measured and estimated by means of their respective land characteristics can be selected for evaluation.

Land quality	Land characteristics
Moisture availability & status	Length of growing period (LGP)
Topography/land form	Slope
Drainage	Soil drainage class, structure of soil
Rooting conditions	Effective soil depth, Texture
Nutrient retention capacity	CEC/meq/100g soil
Nutrient availability	Soil nutrient status, PH
Soil workability	Soil structure & consistence
Erodibility	Vegetation/land use - land cover, Slope
Water availability	quality and quantity
Socio - economic	level of the beneficiaries and infrastructures
Management system	low, medium and high input level

D. Land Evaluation Limiting Factor

The Limiting factors have been amalgamated in to land qualities that affect the land and these have been given a suffix to denote the main limiting factor or factors that affect the soil mapping unit. Limiting factors governing land suitability evaluation for irrigation are given in Table 18. These describe the units as a suffix with symbols given as follow:

t - topography, steep slope, dissection

d - poor drainage, excessive drainage

r - restricted rootability, limited depth to bedrock, indurated horizon

n - low nutrient retention, low nutrient availability

w - difficult workability for seed bed preparation

e - erosion

s - soil toxicity, saline and sodic soils

Other specific soil and land limiting factors have to be identified during the course of specific site soil survey and land evaluation.

Table . 18. Typical exapmle of Land use requirement and land quality Criteria and critical class limits for surface irrigation

Limiting Factor	Class 1 (S1)	Class 2 (S2)	Class 3 (S3)	Class 4 (N1)	Class 5(N2)
Slope %	1-2	0.5- 3	3-5	5-8	>8
Drainage	Well	Moderately well	Imperfect	Excessive, poor	v.poor
Depth (cm)	>200	120-200	60-120	30-60	<30
Texture	Silty loam - clay loam	Sandy loam - clay	Loamy sand - clay	Sand, clay	Sand, gravel
Stoniness %	<0.1	1-3	3-15	15-50	>50
Salinity (ms/cm)	<4	4-8	8-12	12-16	>16
CEC (meq/100g)	>20	5-20	<5	<5	
O.M	3-5	1-3	<1	<1	
C/N	10-12	6-10	<6	<6	
PH	7-8.5	7-8.5	7-8.5	<9,>4.5	>9, <4.5
Structure	well blocky & granular/crumb	well prismatic and weak SAB	weak prisimatic weak platy	weak Platy, Massive	Massive
Consistence	Slightly st. Sl. pl	Sticky, plastic	Very st., very pl.	Very st., V.Pl	
Vegetation	No clearing req.	Scattered trees	Frequent	Forest (Dense)	
Erosion	None	Medium/ slight	Severe	Very severe	
ESp	<10	10-15	15-20	>20	>20
Others specific to the site					

E. Land and Soil Characteristics of the Soil Mapping Units

The land and soil characteristics of each soil mapping units have to be established from soil, land use survey and to some extent from agricultural and socioeconmic survey. It is the basic data of land evaluation for irrigation(see Table 19).

Table. 19. **Format for description of Land and Soil Characteristics of The SMU**

Land & soil charct.	SMU1	SMU2	SMU3	SMU4	SMU..etc
Slope %					
Drainage					
Depth (cm)					
Texture					
Stoniness %					
Salinity (ms/cm)					
CEC (meq/100g)					
O.M					
C/N					
PH					
Structure					
Consistence					
Carbonate					
ESP					
Erosion					
Others Specific to the site					

F. Matching and Irrigation Suitability evaluation

Matching is a procedures where by the land characteristics and qualities and limiting factors of the soil mapping units matched against the land use requirement to derive a suitability rating for each soil mapping unit. Initially matching proceeds for each land quality for each land unit. These individual ratings are then combined in to an overall suitability for the land unit/soil mapping unit.

To arrive at the final land suitability classification for implementation, possible remedial measures have been considered pertaining to each land from which such measures are considered to be practicable and feasible.

The land suitability result has to be mapped with same scale of soil map.

Table. 20 Format for Matching and Irrigation Suitability Evaluation

Soil Mapping Unit	Potential Suitability	Suitability under Proposed Irrigation	Area (ha)	Remarks
SMU1				
SMU2				
SMU3				
SMU4				
SMU5				
SMU..etc				
Gross Irrigable area				
Net Irrigable area				

Legend: Suitable(S) not suitable(N) and S1(class 1), S2(class 2), S3(class 3) where as N1 refers to currently unsuitable and N2 is permanently unsuitable

G. Steps in land evaluation

Planning: the scale, intensity , work activities and logistics of a multidiscplinary field work has to be designed. The land evaluation expert has to plan and prepare program and check list for datas to be collected.

Field survey: survey on land use types, farming system, agroclimatology, and above all soil survey and classification. This leads to the maps on which the evaluation is based showing land/soil units and for each the relevant land qualities and characteristics have to be measured and estimated.
Evaluation: Matching i.e. a comparison between land use requirement and land properties which may lead to modification of the land use types.

Results: presentation of the provisionally irrigation suitability maps with legends, description and recommendation on input and management .

Determination of irrigable land: Finally on the basis of information from all other disciplines and additional field survey (if necessary) and data collection the final suitability evaluation i.e. an area which can be irrigated under an economically and financially viable alternatives including analysis of financial and economic benefits of each selected options and prepare full fledged reports for investment and management.

H. Crop Suitably Evaluation

Crop suitability evaluation shall be made both for existing and recommended crops. In evaluation of land and soil for selected crops, crop requirements, productivity data, socioeconomic data, Input data(such as fertilizer, seeds, chemicals, machinery.. etc), irrigation water supply and management ..etc. has to be obtained from Irrigation agronomists and socioeconomist.

A crop requirement is an optimum land characteristics and qualities required to achieve average and high yield plus a potential for improvement in the future as more experience and management capacity is gained. Matching of land use requirement of a given soil unit with a crop requirement give a crop suitability unit. Crop suitability map with the same scale of soil and land suitability map has to be prepared. The crop suitability map enable planners and managers including farmers to consider all viable alternative cropping pattern. (see Table 21).

(Refer to FAO Soil bulletins No. 42 and 55 for detail datas on crop requirements)

Table.21. A Typical Example of Crop Requirements for selected crops under irrigation in Eastern Oromia

Crop requirements	Sorghum	Maize	Haricot beans	Cow pea	Ground nuts	Onions	Sweet Potato	Pepper	Cauliflower	Grass (Alfalfa)	Mango	Guava
Slope %	1- 4	1- 4	1- 6	2-4	2-4	2-4	2-4	2-4	2 - 8	1- 8	2-5	2-8
Drainage	well-mod well	well-mod well	well	well	well	well	well	well	well	Moderate	well	well
Rooting Depth (cm)	>100	> 100	60- 100	>60	75	50	>50	> 60	>50	> 70	120-200	100-150
Texture	C - SCL	C- SCL	SL - C	L	SL - L	L, SL	SL, CL	L	CL	SL, CL	SCL, CL	Scl, CL
Stoniness %	none - common	none-common	none - few	None	none	none	none	none- few	none -few	few	None-few	none-common
Salinity (mmhos/cm	0 - 12	0 - 8	0 - 4	<4	<4	< 2	< 4	<4	<4	<4	< 4	<4
CEC (meq/100g)	>16	>16	>12	>12	>12	>25	>25	>25	>25	>20	> 40	>40
O.M	0.86	0.86 - 2.58										
PH	5.5- 8.5	5.8 - 8.5	5.5. - 6.0	5.5-6.5	6.0-7.5	6.7- 7.8	5.2 - 8.2	5.5 - 5.6	6.0- 7.0	6.0- 8.0	5.5 - 7.8	5.5.- 7.8
Structure	SAB, platy	SAB platy	SAB, AB	SAB, AB	AB, Gr	AB- Gr	AB	AB, Gr	AB,Gr	SAB Platy	SAB,Platy	SAB, platy
Consistence	SST, SPL	Sst SPL	Nst NPL	NST, NPL	NST,NPL	NST, NPL	NST, NPL	NST, NPL	NST, NPL	SST, SPL	NST,NPL	NST,NPL
Carbonate	0 - 10	0 - 10	< 4	<4	<4	<2	<2	< 2	<4	< 4	<4	<4
Erosion	slight	slight	slight	slight	slight	slight	Slight	Slight	Slight	slight	slight	slight
ESp	0 - 35	0 - 25	< 20	< 20	< 10	< 15	<15	< 15	<10	<15	<10	<10
Crop requirements	Sorghum	Maize	Haricot beans	Cow pea	Ground nuts	Onions	Sweet Potato	Pepper	Cauliflower	Grass (Alfalfa)	Mango	Guava

Temp(avg.)	18 - 25	21 - 30	20 - 22.5	22.5 -30.5	22 - 28.0	18 - 25	20 - 25	21- 25	20 - 25	18- 26	22- 26	20- 26
Socioeconomic*												
Agr. Input*												
Productivity*												
Infrastructures*												
Post harvest storage*												
Environmental Sustainability*												
...etc												

* To be established for each specific site and crops based on management level

Table .22. Typical Format of Crop Suitability Evaluation for Soil Mapping Units

Crops	SM U1	SMU 2	SMU 3	SMU 4	SMU ..etc	Suitable area for each siutablity unit (S1, S2, S3, N1&N2	Total Suitable area (say for Sorghum)	Total unsuitable area (say for Sorghum)	Remarks
Sorghum									
Maize									
Haricot bean									
Cow pea									
Ground nut									
Onions									
Sweet Potato									
Pepper									
Cauliflower									
Forage grass									
Mango									
..etc									
Total									

12.3 Alternative Land Evaluation

Alternative land evaluation should be made for irrigated pasture, dry land agriculture and other land use types for optimal utilization of the land resources, as land has to always be used for its best use. The steps are more or less similar with irrigation suitability evaluation as discussed above. Typical examples of the criteria's are given below in Table 23 and 24.

Table.23. Typical example of Land use requirement and land quality Criteria and critical class limits for Irrigated Pasture

Land qualities	Class 1 (S1)	Class 2 (S2)	Class 3 (S3)	Class 4 (N1)	Class 5(N2)
Slope %	0 – 1	1-2	2-5	5-10	>10
Effective soil depth (cm)	>150	100-150	60-100	30-60	<30
Texture	loam, Silty loam silty clay clay loam, sandy clay loam.	silty clay loam, Sandy loam - clay	Loamy sand - clay	Sand, clay	Sand, gravel
Stoniness and rock out crops %	<10	10-20	20-30	30-40	>40
Salinity (ms/cm)	<4	4-8	8-12	12-16	>16
O.M	3-5	1-3	<1	<1	
Infiltration(cm/hr)	0.5-3.5	3.5-6.5	6.5-12.5	12.5-25 or 0.2-0.5	>25 or< 0.2
PH	7-8.5	7-8.5	6 - 7	<9,>4.5	>9, <4.5
water holding cpacity(mm/soil depth)	>2000	150-200	100 - 150	50-100	<50
Vegetation	No clearing req.	Scattered trees	moderately densest	Forest (Dense)	
Erosion	None	Medium/slight)	Severe	Very severe	

Table.24. Typical Example of Land use requirement and land quality Criteria and critical class limits for Dry land Agriculture

Land quality	Class 1 (S1)	Class 2 (S2)	Class 3 (S3)	Class4 (N1)	Class 5(N2)
Slope %	1-8	8-16	16-25	25-35	>35
Moisture availability (MAR)in mm	>1000 mm	800 –1000	600-800	400-600	<400
LGP(days)	>180	120-180	90-120	60- 90	<60
Soil depth	>150	100 - 150	50 - 100	25- 50	<25
Soil Texture	Silty loam – clay loam	Sandy loam - clay	Loamy sand - clay	Sand, clay	Sand, gravel
Stoniness %/rock out crop	<1	1-10	10-20	20-50	>50
Nutrient status by CEC of top soil (meq/100g)	>20	5-20	<5	<5	
Vegetation cover	No clearing req.	Scattered trees	moderately dense vegetation	Forest (Dense)	
Erosion	None	Medium/slight	Severe	Very severe	

12.4. USDA Land Capability Classification.

The USDA Land Capability Classification is based on the potential of the land with assumed high management practices and permanent limitations such as slope, drainage, climate, erosion and soil root zone. For the most part it emphasis the negative features(limitations) of land and there is no socio - economic input to the system. Indeed it responds very well to the problem of the soil erosion and water conservation of the USA for which it was originally developed, and as such their application for irrigation is less useful. Even if one wants to do so it has to be used only for exploratory and reconnaissance level study, to identify the potential and major limitations

The land is grouped in to 8 classes of which I - IV can be used for cultivation. They are in increasing order of limitation and progressively reducing the choice of farming system and types of crops, or else require more expensive amelioration methods.

Classes V - VII can not be used for agriculture, but only for improved pasture, rough grazing, forestry recreation and wild life in decreasing order of choice.

Class VIII is not suitable for any type of development except for watershed management.

The application of land Capability Evaluation for study of medium and small scale irrigation is limited other than identifying the potential at the exploratory and reconnaissance stage.

12.5. USBR Irrigation Suitability System.

The system is based on the economics of land development in which land is ranked according to its payment capacity under irrigation. Therefore this classification has taken account of direct development costs, running costs and the likely returns. Six arable land classes are defined, of which the first four are arable and potentially irrigable, the fifth is identified as a provisional class for lands that are not arable under existing conditions, but which have potential value sufficient to warrant segregation for special study. Class 6 is non arable. Ideally farm budgets are used for evaluating the costs and benefits based on economic effects of a numbers of physical land deficiencies acting singly or together, such as soil characteristics, topography and drainage (see Table 25).

The USBR system is not widely used for medium and small scale irrigation studies in Ethiopia. However one may encouraged to use under the USAID bilateral financed irrigation projects.

Table.25. USBR Irrigation Suitability Evaluation.

Suitability Class	Suitability Status	Descriptions
Class 1	Arable	Land that is highly suitable for irrigated farming on a sustainable and high yield bases, high payment capacity.
Class 2	Arable	Land of moderate suitability for irrigated agriculture, suited to a narrower range of crops, more expensive to develop or less productive than class 1 land.
Class 3	Arable	Land of marginal suitability to irrigated farming, such land usually has a serious single deficiency appropriate management and can provide adequate payment capacity.
Class 4	Special use land	Land suited only to special crops like fruit, rice ... etc.
Class 5	Non Arable	Land assessed as unsuited to arable farming on the basis of particular problems e.g. excessive salinity, occurrence of flooding. Further investigation is required to reclassify the land
Class 6	Non Arable	Unsuitable land for irrigation development as a result of, for example steep slope rough topography, inadequate drainage.

12.6. Authomatic Land Evaluation System

Automated Land Evaluation System (ALES): Rosster and Van wambeke, 1989; is widely used In USA and other developed countries. The model as such can be developed by a particular model builder land evaluator to satisfy local needs, to utilize locally available information and knowledge. There is neither a fixed list of land use requirements by which land uses are evaluated nor a fixed list of land characteristics from which land qualities are inferred. Such a checklist is determined by evaluator himself to suite local conditions depending in the availability of data and objectives.

In Ethiopia, Automatic Land Evaluation system was only been used in Tekeze Integrated River Basin Master Plan. It has not yet been widely used by the soil survey and Land evaluation experts in the country. Before recommendation for land evaluation under irrigation, the Ministry of water Resources and Ministry of agriculture with the collaboration of national Regional State have to popularize through workshops and case studies.

12.7. Land management Unit and Farm Management Plan

Land Management Unit(LMU) amalgamates a few or many Soil Mapping Units which for intended use and management are converging to similar practices.

For example, if mapped Soil Mapping Units, A,C, D,F have more or less similar depth, drainage and similar requirement of irrigation, fertilizer and other major farm inputs then we can say that they are in one land/soil management unit. Land management unit/soil management unit is better if established after several years of actual field operation experience especially if the irrigation development is under farmers practice.

For any system of farming there is a minimum operational area, the smallest area to which it is both technically practicable and economically feasible which inturn depends on the specific crops to be grown for the given type of farming enterprise or agro industry. A soil surveyor and land evaluator should be aware of the minimum feasible farm management unit. For example, a sugar factory needs a certain minimum supply of cane to achieve maximum efficiency and optimum financial and economic return. It is said to be that, sugar factory is feasible, when the cane area is more than 4 000 ha.

An oil extracting plant or a ginnery requires an optimum input from the yield of oil crops and cotton respectively, to run profitably.

The other criteria for establishing farm management plan is operational capacity hence in farm management plan investigation of the existing system and problems and constraints encountered is very essential. For example in Awash valley 3 state farm enterprises of each about 20 000- 30 000 ha was established. Most of the farms have about 1 000 - 5 000 ha farm area. Again there is a farm unit of about 500 ha(in some state farms a farm unit is about 1000 ha). A block or irrigation field unit is about 50 ha.

The experienced in Ethiopia for commercial farms delineation and organization is follow .

Field unit---> Farm block--->Farm unit(optional)---> Farm--->Farm enterprise(optional).

In soil survey and land evaluation for irrigation , a soil mapping unit is recommended to be a minimum management unit. But factors other than soil dictate the size and shape of practical filed management area. For example, for large scale mechanized irrigated farming a field unit of minimum 10 - 20 ha and for small scale irrigation 2 - 5 ha is necessary. For grain crops the manageable area is more extensive than for industrial crops like cotton or sugar cane. For horticultural enterprises the size is considerably smaller. Again perennial trees like fruits and orchards need intensive management in small field units. In practice the experience and data on actual minimum size for farm unit area, farm management area and is absent.

Soil surveyor and land evaluation experts has to decide in consultation with socio - economist and irrigation engineers, the feasible farm area, farm unit, secondary, tertiary and field irrigation blocks.

13. SOIL AND WATER CONSERVATION MEASURES

13.1. General

Soil erosion constitutes an important social and economic problem and is an essential factor in assessing the sustainablity of an ecosystem. Moreover, it reduces the availability of the basic plant nutrients required for crops, trees and other plants and decreases the diversity and abundance of soil organisms.

Sediments washed away to reservoirs, dry and running streams degrade the quality of the water delivered for municipal and industrial use and provide an important transporting medium for a wide range of chemical pollutants that are readily adsorbed on the surface of the sediments.

Erosion control is therefore essential for proper land and water management including sediment transport to the reservoirs.

The major cause of erosion in ctchment is water in form of rain splash and runoff.

Hence proper land use and agricultural practices integrated with soil conservation measures can control soil erosion and sedimentation in irrigation development.

Methodologies for assessment and estimation of erosion should be done by soil and water conservation engineer and/or watershed management expert with in the team .

In this guideline, the impact of soil erosion and conservation measures have been briefly discussed for adoption according to local socioeconomic and farming system, climate, land use, nature of the drainage basin.. etc.

13.2. Impacts of Soil erosion on the Reservoirs

Soil erosion has the following main effects on irrigation infrastructures such as canals, conduits ,culverts, drop and division structures, reservoir operation and management

Siltation: Runoff and flood waters transport eroded soil from the catchments as suspended solids. The bed load and suspended solids settle in the reservoir, thereby reducing its operational volume. In extreme cases, the reduction of the operational volume may lead to abandonment of the reservoir.

Deterioration of water quality: the suspended solids have a number of deleterious effects on the quality of reservoir water and consequently on water turbidty and reservoir maintenance costs owing to the following.

- higher maintenance costs
- the sediments may have a deleterious effect on the interrelationship between the macro-fauna, micro-fauna and micro- flora. This may cause blooming of undesirable species of algae, reduction of the fish carrying capacity, higher filtration and disinfecting costs and offensive smell, color and taste of the water.

- Some of the clay minerals in the suspended solids are characterized by very high adsorption capacity of chemical compounds, ammonium and phosphates, which may induce water eutrification. Certain other adsorbed chemicals such as herbicide and pesticide residues are toxic to human beings, and to flora and fauna. Hence, although the suspended elements may not contribute considerably to reservoir siltation, they may be chemically hazardous.

Harmful effects on management of water use: the concentration of suspended solids in the water may also affect water use e.g. the time that must elapse between flood flows and commencement of pumping(to avoid pumping of silt), pumping rates, required additional filtration system capacity., etc.

Moreover soil erosion has several harmful effects on the catchment areas such as reducing soil depth and soil fertility, silting up canals of drainage ditches and culverts, destruction of road embankment, etc.

The following measures are recommended for prevent on rehabilitation and mitigation.

13.3. Biological Soil Conservation Measures

Crop rotation: Where erosion rates are low, crop rotation may be done every other year, but in very erodible areas, they may be permissible only once in five or seven years. The best crops for rotation are legumes and grasses.

Cover crops and green manuring: Cover crops are grown as a conservation measure either during the off-season or as ground protection under trees. The plants in most cases grown on the surplus moisture after the food or cash crop is harvested. Such crops are ploughed in , to form a green manure. However there is a constraint as farmers with little land have a high priority for using every bit of green matters grown in the field instead of ploughing it. Cover crops are grown under tree crops to protect the soil from the impact of water drops falling from the canopy.

Inter Cropping: is growing of more than two crops in the same field at a time. In southern and western Ethiopia perennial trees like enset, banana, citrus, Mango, avocado. .etc are intercropped with annual crops like sorghum, maize, legumes and vegetables.

Strip cropping: With strip cropping, row crops and protection effective crops are grown in alternating strips aligned on the contour or perpendicular to the wind. Erosion is largely limited to the row crop strips and soil removed from these is trapped with in and behind the next strip down slope or down wind which is generally planted with a legumes or grass crop.

Multiple cropping: The aim of multiple cropping is to increase the production from the land whilst providing protection of the soil from erosion and increase organic matter and water infiltration. The method involves growing two or more crops a year on the same piece of land. In multiple cropping some of the crops grown will cover the soil quickly, while other crops will cover slowly.

Hedgerows: on areas with slopes less than 15 % , hedge rows of leguminous trees and shrubs would be planted to make field boundaries ,while at the same time serving as fodder for animals . Such trees have high soil conservation value.

Relay cropping: has much in common with inter cropping but the distribution in time between the crops is different In Shewa, Harrarghe, Welo and southern Ethiopia this system exists, combining example sorghum and chick peas. Sorghum is planted in March, chick pea in September and October. This sorghum is harvested in December, the chickpea in January, keeping the soil in most time covered.

High density planting: by increasing planting population per unit area of land it is tried to obtain the same effect for a mono culture that multiple cropping achieves with two or more crops.

Agro- Forestry: Trees help preserve the fertility of the soil through the return of organic matter and fixation of nitrogen. Trees improve the soil structure and helps maintain high infiltration rates and greater water holding capacity. As a result less run off is generated and erosion is better controlled.

Trees can be used to supplement existing erosion control measures by being added to contour grass strips or on terraces or on crop lands.

The most important tree species are *Leuccaena leucocephala*, which is a quick growing fodder tree but also provides timber for fuel and pulp wood , *Acacia albida* which is well adapted to sandy soils and produce good fodder, *Acacia nilotica* and *Sesbania grandflora*. However alternative trees which might generate more income could include fruit trees and Orchards.

13. 4. Soil Conservation By Soil Management

The aim of soil management is to maintain the fertility and structure of the soil. Highly fertile soils result in high crop yields, good plant cover resulting in conditions which minimize the erosive effects of rain drops, runoff and wind. The central theme in here is soil fertility must be seen as a key to soil and water conservation.

Additions of Organic Matters: To increase the resistance of an erodible soil by building up organic matter is a lengthy process. The O.M context must be raised above 2% to bring any effect on SWC. On soils with less than 1% organic content, a large supply of organic material is required. Additions of organic matter is quite appropriate and profitable in proposed agricultural development, as use of inorganic chemicals will be discouraged due to pollution of the water supply reservoir.

Conservation tillage: Conventional tillage is ploughing with local ploughs, disc or mould board plough, one or more disc harrowing, and then planting instead of pulverizing several times.

Zero tillage: Soil undisturbed prior to planting which takes place in a narrow 2.5 - 7.5cm wide seed bed. Crop residue covers of 50 - 100% retained on surface. Weed control is by herbicides.

Strip tillage:- Soil disturbed only along the strips. Intervening areas of soil untilled. Weed control is by herbicides and cultivation.

Mulch tillage: Soil surface disturbed by tillage prior to planting using chisels, field cultivators, discs or sweeps, at least 30% residue cover left on surface as a protective mulch. Weed control is by herbicides and cultivation.

Minimum Tillage:- Any other tillage practice which retains at least 30 % residue cover. In minimum tilled plots soil loss is lowered to 1.6t/ha compared with 4.1 t/ha from conventional tillage.]

13.5. Physical Soil Conservation System

Contour Ridges: on steep, rocky hills and mountainous terrain ridges are constructed to protect heavy runoff and mass slides of the materials . The ridges may be formed from rocks, boulders and old tree logs.

Contour Bunds: are earth banks 1.5 - 2m wide thrown across the slope to act as a barrier to runoff, to form a water storage area on their up slope side and to break up a slope into segments shorter in length then is required to generate over land flow. It can be formed from soil (soil bund) or stones (stone bund).

Soil Bund: this mostly practiced in deep soil and in recently vegetation removed area. A construction height of 75cm that can slumps to 50cm with a width of 1m is suitable. To restrict side way water movement a tied ridge at interval of 6-10m can be made. Soil bund can be stabilized with couch, star and rhodes grass types and cut and feed live stock.

Terraces: are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable out let at a non erosive velocity and shorten slope length. They differ from contour ridges being larger and designed to more stringent structure.

Water ways: are channels designed to receive runoff from cutoff ditches, road drains and terraces and to carryout that runoff down a slope to a point where it can be safely discharged into a valley bottom or a stream. The constraint is, the shortage of land and the difficulty of finding an acceptable alignment. Even natural water ways are often used for cropping or have already developed in to gullies.

Check dams : are a gully pullging structures using rocks/stones, compacted soil or selected material, earth bank, wood racks, gabon's and also planting trees and grass to stabilize the system. Each material has different sediment trapping and flood protecting capacity. Check dams can be easily applied in all gullies of less than 2m depth and 5m width. Vertical intervals between check dams are equal to the height of check dams.

Flood protection dikes: these are an embankments along the rivers, streams and water collection points to protect the overtopping and erosion of the soil. It can be used on any water ways to protect damage of crop, grazing land and any property.

Embankment or road cut slope: construction of feeder roads and main roads in command area exposes the embankment and cut slopes to mass slides and run off erosion. Hence rapid establishment of grass or legume cover is essential to minimize erosion and enhance slope stability. Planting natural turf over the slope is a standard practice . The turf should be up rooted with about 100 mm thickness of soil to serve as a seed bed . Once the soil has been stabilized ornamental trees and shrubs, may be planted or the land can be left to be colonized by native vegetation on road sides.

13.6. Area Closure System of Soil Conservation

Area closure is a best means of conservation of highly eroded areas by allowing regeneration or rehabilitation of vegetation, soil, organisms microclimate and avoid human and animals including livestock. It is a protection system and saving mechanism of land against any external influences including erosion. In enclosed areas any suitable soil conservation measures discussed above can be applied to reduce erosion. About 500 m in the periphery of reservoir is recommended to be fenced or gazzeted and kept as much as possible, protected . No livestock is allowed to graze in the closed area and no human interference permitted through out the year. Natural grasses are entertained to flourish and improved forage species could be integrated. Moreover Leguminous grasses and trees can form a good combination of conservation and utilization values. Alternatively perennial fruit trees like citrus, Avocado, Apples. etc which requires inquiries minimum soil disturbance can be planted.

Cut and carry can be allowed after the tree and/or grass cover of over 80% is obtained or if undesirable herb and shrubs required to be removed. It provides fodder for livestock as well as fire wood and small fuel and construction wood from area closure. It is advisable to cut the grass once during the rainy season for immediate feeding of the livestock and immediately after rainy season before the grass is completely dry. Forage should be cut at about 10 cm above the ground before or at the flowering stage, but only if sufficient soil coverage is assured. Forage can be conserved as hay or silage for dry season feeding. Cut and carry allows permanent vegetation cover and maximum soil protection. Livestock trampling and extreme grazing down to the roots is avoided with resultant higher productivity, while water is retained during storms and runoff is reduced. Natural vegetation grows with better competition between plants because there is no more selective eating by livestock. However, animal droppings are reduced with negative effects on soil fertility but positive effects on the reservoir water quality.

13.7. Water Harvesting for Soil Conservation

Run off from the land is one of the most erosive forms of water leaving the land with rills and gullies. This runoff can be held on the soil surface and encourage to infiltrate.

Moreover water harvesting involves optimal and immediate utilization of rain water, flood water, streams or river water, where all of them are a causes of erosion and sedimentation.

Hence, proper water harvesting techniques are not only efficient means of soil and water conservation but also improve significantly local food security, income levels, crop yields and standard of living of people in the area.

13.8. Integrated Watershed Management Approach

Development of irrigation and other land and water resources should be planned and designed under the auspices of watershed management plan, for the sake of sustainablity.

The management of watershed has been almost exclusively on biophysical aspects such as slope, soil texture and vegetation cover, without proper regard for socioeconomic aspects. Although important gaps do exist in our knowledge of biophysical process and methods of controlling degradation problems, the failure for most part is attributed to lack of integration. Hence , the watershed approach can be integrated with or be part of programs in development of land and water resources, agricultural development, rural and community development programs, infrastructure and soil and water conservation it self .

The methods and system of integrated watershed management, is by itself a subject of worth treating independently(See ESRDF Small scale irrigation Project study and design manual Watershed Management Annex).

14. SOIL AND LAND MANAGEMENT

14.1. Basis of soil management

The principal objective of any soil and crop management program is sustained profitable production. The strength and longevity of any agrarian society depend on the ability to sustain and /or increase the productive capacity of its agriculture. Sustainable agriculture in Irrigation should encompass land and soil management, attaining proper crop-water balance and management, watershed management and environmental conservation, combating salinity and sodicity problems. .etc.

14.2. Drainage and Reclamation

The effective utilization of soils with imperfect and poor natural drainage requires the removal of excess soil moisture. This is done by encouraging of percolation through soil horizons. Soil permeability and depth to a drainage barrier stratum such as impermeable clay layer, indurated or cemented hardpans, shale, rock and affects soil drainability.

Drainage problems also occurs due to rising water table. In irrigation critical depth of ground water determines salt accumulation.

Critical depth	Salt content
2 - 2.5cm	10 - 15g/lt
1 - 0.5 cm	1 - 2g/lt

Thus a water table with in 1 - 2m of the soil surface can lead to excessive accumulation of salts at the surface. The water table for crops other than paddy rice should not be closer to surface than 90 - 120cm for over 24 hr(see Table 26).

Two general types of drainage systems can be used i.e. open (ditch) and closed (subsurface). A widely acceptable design criterion for draining wet impermeable soils is to lower the water table to 0.5m below the surface, 24hr, after the end of rainfall.

If the hydraulic conductivity is too low, the drains would need to be placed at uneconomical close spacing. The practical solution is to use wider spacing with secondary treatments such as moling and sub-soiling to improve the flow to the drains.

Table 26. Typical Crop Yield loss (%age) due to Rising Watertable

Depth of WT (cm)	Vegetables	Cotton	Banana	Maize, Sesame &Citrus	Sorghum
150	4	20	15	10	0
125	7	25	55	15	5
100	15	30	5	25	30
75	35	45	100	40	65
50	80	75	100	90	95
25	100	100	100	100	100

Source, FAO 1979

14. 3. Management of Saline, Saline- Sodic and Sodic Soils

The criteria for identification of Saline, Saline-sodic and Sodic soil is as follow

Classification	EC(mmohs)	Soil PH	ESP	Physical condition
Saline	>4	< 8.5	<15	Normal
Sodic	<4	>8.5	>15	Defloculated
Saline-Sodic	>4	<8.5	>15	Normal

Saline soil is characterized by a saturation extract with an electrical conductivity of >4 mmohs /cm and pH generally <8. The saturation extract in this case is dominated by salts of calcium and magnesium rather than sodium.

Sodic soils are formed by the influence of a high proportion of the soil exchange complex by sodium ions. Land which is alkaline is generally but not invariably, saline on account of the poor internal drainage. A saline soil becomes a saline sodic soil when the ESP exceeds 15%.

The development of saline and sodic soils under irrigation can be controlled by adequate drainage, good irrigation management and soil management practices. Salinity or sodic conditions encountered during soil survey should be considered as correctable when evaluating land for irrigation development. However in difficult conditions the costs for reclamation may exceed the anticipated benefits, so that reclamation cost must be estimated

Reclamation Procedures

Reclamation of Saline soils

I. Leaching of a saline -sodic soil may reduce the salt content such that the EC value of the soils falls below 4 mmhos /cm. Reclamation of saline, saline-sodic and sodic soils requires leaching with water of a low enough SAR to initiate Ca^2 exchange for Na^+, but sufficiently high total salt concentration to preserve the soils permeability.

To prevent accumulation of salts during irrigation, sufficient water must be applied to maintain salinity of the soil at acceptable level. The leaching requirement for surface irrigation can be calculated by the following equation.

$$LR = \frac{Ecw}{5\,Ece - Ecw}$$

Where LR = the minimum theoretical net leaching requirement (as a fraction of the applied water needed to control salts in the root zone).
Ecw = electrical conductivity of the applied water
Ece = Ece corresponding to 90% yield potential for crop under consideration.

Values of LR < 10% are considered low, where as >20% are considered high.
The timing of leaching does not appear to be critical provided crop tolerances are not exceeded by the built up of salinity for extended or critical periods of time.
The leaching can be done at each irrigation, each few irrigation, once each years, or after long intervals depending on the critical limits and crop factor.

II. Efficient distribution of water to prevent excessive deep percolation

III. Construction of a good Surface drainage system to remove runoff water from each field

IV. Growing of salt tolerant crops

There are moderately and highly salt tolerant crops (refer to FAO, 1979, 1984 , Booker Tropical soil Manual and USDA Salinity hand book). Continuous growing of highly salt tolerant crops will deplete the salinity level to a moderate level.

Reclamation of Saline- Sodic and Sodic soils

Any procedures, whether chemical, physical or biological which provides soluble calcium to replace sodium in the exchange complex will assist the reclamation process.

Physical aids to reclamation are:

- Deep ploughing, especially on stratified soils with permeable and impermeable layers or on soils with gypsum.
- Subsoiling, especially to break an indurated B horizon
- Profile inversion where the upper subsoil has undesirable properties.
- Sanding, involving the spreading and mixing of sand into the upper horizons of the textures soils, but not effective on heavy soils
- Both living and dead organic matter affect biological amelioration principally by improving soil structure, permeability and by releasing carbon dioxide.
- Chemical amendments are very often necessary to neutralize free sodium and to supply a cation that will replace sodium in the exchange complex. Gypsum is by far the most commonly used amendments. The amount of gypsum or other amendments required is related to the

quantity of sodium to be removed. Several tons of gypsum/ha is usually required. The soil must be kept moist to hasten the reaction and the gypsum should be thourghly mixed in to the surface by cultivation, not simply ploughed under. The treatment must be supplemented both by a through leaching of the soil with irrigation water to leach out some of the sodium salt.

14.4. Management of Acid and Toxic Soils

The source of soil acids includes O.M, clay minerals, Fe, and Al oxides, exchangeable Al^3.
Al toxicity is the most important growth limiting factors in many acid soils, particularly when pH is < 5. Liming of acid and toxic soils will improve and sustain productivity.

As a general rule, liming is required in soils with PH < 5.5 to improve nutrient availability and reduce Al toxicity. The aim of liming is to increase the PH values sufficient to prevent Al and micronutrient toxicity. Liming would usually increase PH to values above 5.5, the value sufficient to prevent Al and micronutrient toxicity. When manganese toxicity is suspected, PH should be raised to 6.0.

The materials commonly used for liming soils are Ca and Mg oxides, Hydro oxides, Carbonates and Silicates. The accompanying anions must lower H^+ activity nad hence Al^{3+} in the soil solution. Marls (unconsolidated deposits of $CaCo_3$) can also be used. The fresh material is stock piled and allowed to dry before being applied to the land.

The lime requirement can be determined using different methods. The direct method of estimating lime requirement is by making use of data on cation Exchange Capacity and Base Saturation Percentage, with the help of a monogram

14.5. Management of Vertisols.

Vertisols are extensively distributed in Ethiopia. It has higher natural fertility, high water holding capacity and responds well to several crop requirements. However their drainage and workability impose critical limit to agricultural production and management especially under irrigation. There are two broad management practices.

i. **Selection of proper crops**: best adapted to the inherent characteristics of vertisols with minimum yield reduction.

Tree crops: considering the problems of the soil, trees are not suited to vertisols. Due to their fine texture, weak soil structure especially at depth, shrink properties and very poor internal drainage inhibits the deep rooted trees.

Graminaceous crops: such as cereals, sugar cane and pasture grasses are best suited for these soils. In their life cycle, the crops are usually at their maturation phase when extensive soil cracking occurs.

Vegetable crops: most of them have low success history.

Natural pasture: - the wide spread use of vertisols is for pasture. The grasses which are usually aquatic or semi - aquatic grow vigorously in wet season and set seed in the beginning of the dry season for the next wet season. Very little is yet known about adaptability and persistence of legume pasture on these soils.

ii. **Use traditional and modern technologies** developed for improved management of vertisols. These includes

- Shaping of land to promote disposal of excess water by introduction of broad beds and furrows or ridges and furrows or cumberbeds.
- Using minimum tillage or non till system for seed bed preparation.
- Usage of herbicides.
- Land preparation and sowing of crops (dry sowing) before the on set of rainy season.

The broad bed and furrow land management system is selected because at present it is widely accepted land management means world wide for vertisols and probably the most profitable. Provision of adequate external drainage during the wetter part of the year is also a very important aspect for successful production.

14.6. Management of Gypsiferous soils

In management of gypsiferous soil, it is required to know, the morphology, chemical and physical characteristics of gypsiferous soils which, depend to a great extent on the origins of the gypsic soil profile.

When this layer is located 30 cm or more below the surface, the top layer of the soil often has morphological and phyisico-chemical characteristics similar to those of non gypsiferous soils encountered in the same pedogentic condition. Example: chernozem and phyozem.

The characteristics and management of gypsiferous soils are also determined by the fact that gypsum is easily redistributed with in the soil profile by alternating rainfall and evaporation . As a gypsic layer is situated close to or at the soil surface, even dew formation can also play an important role in the migration of gypsum.

The varying origin of gypsiferous soil and the easy redistribution of gypsum in the soil may result in a great variance in the morphology of the soil profile and there by require different management practices. A gypsic layer can have either a powdery or a sandy appearance depending on the size of the gypsum crystals. In a soil layer gypsum may appear as very fine gypsum crystals, lumps consisting of sand and soil particles cemented by gypsum, gypsum rosettes or hard horizontal or vertical crusts. The genesis of these crusts is not clear. Powdery gypsic layer are characterized by a low bulk density and soft consistence. The low bulk density is due to a relatively low specific weight of about 2.3gm/cm^3. Lumps and crusts, however are hard and can have a low porosity.

With gypsum over 25 % the cemented and indurated layers form a mechanical impediment to root growth and have adverse properties on water retention and transmission.

Some crops grow on gypsiferous soil under strict management of fertilizer and water at the expense of sacrificing more than 50% yield loss. There is a hazard of subsidence which is critical not only on root growth but also on hydraulic structures. The engineering problems on gypsiferous soils further complicated by the corrosive effects on structures and materials by sulfate released from gypsum.

The Most important agricultural management of gypsisols is growing of gypsum adapting crops. This practice is successful in USA and needs adaptive research before application under Ethiopian Conditions.

14.7. Wetland Utilization and Management

Wetlands typically occur in low lying areas that receive fresh water at the edges of lakes, ponds, streams, rivers, spring, salt water from hot springs. Because wetlands depend on water sources, their extent and boundaries can change and their characteristics is also varies depending on vegetation, soil type, water supply and water chemistry.

Wetland areas, are seasonally or permanently waterlogged for a few months per year and the whole year, respectively . They may appeared as, forest, grassland, open wood land , bush land, shrub land or bare soil.

The potential of reclamation for irrigation have to be investigated. For example the suitability of the major swamps like Gedabssa swamp in Awash basin, for cotton and sugarcane has been evaluated and is known to be low and the area cannot be recommended for the irrigated production of these crops. It is also very unlikely to reclaim for other domestic crops. However, two other potential land uses can be recommended for these areas, improved pasture and rice. The soil requirement for pasture and rice are not as strict as for sugarcane, cotton and other common crops. Clay soils and restricted drainage do not pose very serious problems, although preference would again be given to more medium textured soil. In the soil requirement of rice, low infiltration rates and hydraulic conductivity are advantageous and as the surface soil puddles the soil structure is not a problem. The area may be suitable for rice production, but the major problem will still be the possibility of high groundwater tables. The cultivation of rice will require excellent water management to prevent the soil surface from drying out and good drainage control to prevent secondary salinization. Indeed rice is the only effective means of using saline/alkaline clay soils in the area. The possibility of reclaiming for rice should be investigated in detail.

In irrigation study special attention should be given for the wet lands in the command area and the catchement both for utilization and conservation of the ecosystem.

14. 8. Soil Testing and Fertilizer Application

Soils vary in their capabilities for supplying plant nutrients according to their parent materials and the process by which they were formed. There are at least fourteen essential elements, including micro and macro nutrients that plants obtain from the soil. Two of the macro nutrients, calcium and magnesium are applied as lime in regions deficient in these elements. Although usually applied as soil amendments lime does exert a profound nutritive effect.

Sulfur has to be applied as commercial fertilizer, especially in areas where little sulfur is returned to the soil from the atmosphere.

Three other macro elements Nitrogen, phosphorus and Potassium are commonly applied in commercial fertilizers and are often referred to as the fertilizer element. The soils in Ethiopia are said to be rich in Potassium leading to a tradition of applying only Nitrogen and Phosphorus. Nitrogen is applied as Urea and Phosphorus as Di ammonium Phosphate (DAP). Of the seventeen elements known to be essential for plant growth, eight are required in such small quantities that they are called micro nutrients and trace elements. These are iron, manganese, zinc, copper, boron, molybdenum, cobalt and chlorine.

Fertilizer application and management involves many intricate details regarding soil, crops, fertilizers and external atmosphere. Because of the great variability from place to place in each of these factors, it is difficult to arrive on recommendation for fertilizer use.

Currently the farmers are traditionally apply 100 kg/ha of each Urea and DAP. The response to this conventional rate of application is not exactly recorded.

Recommendations and application of fertilizer should be based on the physical and chemical properties of each soil unit or soil mapping unit. The requirement and rate of fertilizer has to be tested for each soil units. National Fertilizer Industry Agency(NFIA) in collaboration with Regional Agricultural Bureaus have established several zonal laboratories for this purpose. Hence it is strongly advised not to recommend and/ or apply fertilizer prior to testing for each variable soil types.

On the other hand, in recent years, world communities have expressed their interest for food stuffs and industrial raw materials grown on soils to which only natural organic materials have been added. The source of these organic materials are farmyard manure, crop residues, composite ... etc. There are also commercial organic fertilizers such as bone meal, dried blood, oil seed meals, fish tankage and other food processing wastes. The readily available nutrients in these materials are only a fraction of those in commercial inorganic fertilizes. Once again recommendation and application rate is a challenge to the soil scientist. Application rate should be dependent on the smallest soil unit and have to be based on research works and adaptation tests.

In the absence of any information's on fertilizer recommendation a soil surveyor should make fertility test to establish fertilizer application rate as follow

- Separate uniform fields should be selected after considering slope, drainage, soil type and crop growth,
- Select 5 - 6 spots at random in zigzag fashion in a field
- Clean the surface to remove any debris if present
- Collect a uniform soil sample from 0 - 25 cm depth with Auger or V shape hoe/shovel
- Make a composite sample from 5 - 6 spots . In a standing crop sample should be collected between the row of plants . Avoid taking samples from a fertilized band, old fence or places where manure was piled earlier.
- Label the sample as per the standard
- Send to certified soil testing laboratories for determination of soil macro and micro nutrients.
- Analyze the result and correlate with soil mapping unit description data
- Recommend types of fertilizers and rate of application for each soil units or farm blocks.

15. Land Resource Development Scenario

After identifying the land resource potentials, opportunities and Constraints in irrigation development, different scenarios and options have to be forwarded to the planners and decision makers for further consideration.

Land resource development scenarios have to be recommended from alternative land suitability evaluation results based on the objective/target and interest of the client. For example, improvement of existing rainfed, Irrigated crops, Irrigated pasture, ..etc

APPENDICES

Appendix .I. References and Assessment of pervious works

A systematic review of existing international and local methodologies of soil survey for irrigation has been made briefly, to formulate and establish methodologies of the procedural guidelines. The following pervious local and international guidelines, maps, data and information's have been investigated .

- ESRDF : 1997, Small Scale Irrigation Projects Guidelines by Continental Consultants and CES of India. Volume IV Soil and Irrigation Agronomy
- EVDSA-FAO/UNDIP: 1992, Soil Survey Guideline for prefeasiblity and feasibility study of medium scale irrigation projects
- EVDSA:1993, Guide line for the preparation of irrigation and Multipurpose projects
- Working Group report: 1980, Guide lines for the preparation of detailed projects of irrigation and multipurpose projects, Government of India, Ministry of Irrigation
- Birr and Koga Irrigation Project: 1993, Soil Survey Manual
- Soil Survey Staff :1993, Soil Survey Manual USDA-SCS , Washington
- Key to Soil Taxonomy: 1994 : USDA – SCS.
- Avery, B.W. 1986: Soil Survey Methodology
- Soil Survey and Land Research center, Silso, U.K.
- Bueol, S.W. etal.1989. Soil Genesis and Classification
  Iowa State University press, USA.
- Butler, B.E. 1980: Soil Classification for Soil Survey
  Oxford University Press, UK
- Davidson, D.A. 1992, Soil and Land use Planning, U.K.
- Dent.D.and Young, A. 1981: Soil Survey and Land Evaluation
- FAO, 1976: A Frame Work for Land Evaluation
  FAO Soil bulletin No. 32
- FAO, 1979: Soil Investigation for Irrigation
  FAO Soil bulletin No. 42
- FAO: 1985 : Guide Lines : Land Evaluation for Irrigation
  FAO Soil bulletin No. 55
- FAO: 1987 : Soil and Water Conservation in Semiarid areas
  FAO Soil bulletin No. 57
- FAO-ISRIC/ISSS: 1998 World Reference Base for Soil Resources No.84
- London.J.R. 1996: Booker Tropical Soil Manual

- Webster.R. and Oliver, M.A. 1990, Statistical Methods in Soil and Land Resources, Oxford university press
- Western, N: 1979. Soil Survey and quality Control, U.K.
- Wilding. L.P, N.E. and Hall, G.F.1983 : Pedogensis and Soil Taxonomy, USDA Volume I and II
- Moulder.D.R 1987: Remote Sensing in Soil Science.
- W.Siderius 1986: Land Evaluation for Land use Planning and Conservation in Sloping areas. ILRI publication No 40
- Buringh. P. 1979: Introduction to the Study of Soil in Tropical and Subtropical Regions
- Van. Wambeke.1992: Soils of the Tropics, Properties and appraisals.
- Gerrard.J. 1992. Soil Geomorphology, An Integration of Pedology and Geomorphology, Chapman publications
- Mcrae S.G and Burnham.C.P.1981 Land Evaluation
- Richards etal 1985: Geomorphology and Soils
- Barkland.P.w 1984. Soils and Geomorphology
- Morgan 1995: Soil Erosion and Conservation
- Canadian Soil Survey Committee 1978: The System of Soil Classification for Canada

Besides Semi detailed and Detailed Irrigation Project Studies conducted for Water Resources Authority, Ethiopian Valleys Development Studies Authority, Ministry of Water Resources and Ministry of Agriculture (for small scale) in the last two decades have been reviewed.

Appendix II. Soil and Land Suitability Report Contents

Summary

a) Location and area of study, with map.
b) Reasons for selection of study area and summarized purpose of study
c) General description of the area
d) Broad description of soils, classification and mapping units
e) Tabulated soil areas and percentages
f) Broad description of land suitability and management
g) Tabulated land suitability areas and percentages.

The summary should be well written and readable, and should include cross-references to relevant chapters, particularly those on recommendations; the degree of technical depth will depend on the reader aimed at.

Chapter 1. Introduction

a) Outline of TOR; brief mention of modifications of TOR.
b) Aims of survey (in so far as not covered by TOR).
c) Selection of area(s) of study, where appropriate.
d) Special features of survey (e.g. where TOR changed and why).
e) Outline of report structure .
(For annex: detailed TOR - and names of participants).

Chapter 2. The Environment

a) Location: Latitude and longitude, relation to national or regional geography and administrative areas, main and local towns, altitude, major landforms and relative relief.
b) Communications:- Roads (and surfaces), tracks (motorable or not), seasonal closures, railways, air and river transport.
c) Human settlement and present economic activities population numbers, density, distribution; occupations; health and endemic diseases. Industry, agriculture and forestry; main crops, marketing and processing (more details of land use can go into main report).
d) Infrastructure: Local, regional and national government administrative institutions; agricultural stations; dispensaries and hospitals, schools and colleges, power and water supplies.
e) Climate : Rainfall quantity, intensity and distribution; wind speeds and directions, maximum, minimum and mean temperatures, bright sunshine hours, solar radiation, evaportanspiration, moisture surpluses/deficits, frost/storm action, seasonal trends, incidence of a typical but crop-damaging weather, statistical analysis where appropriate, references to standard local works (if any).
f) Water resources: River flows and GWT levels (seasonal variation); water storage; water quality; regional drainage; flood risks, duration and depths.
g) Geology and geomorphology: Major terrain types, basic geology and geomorphology; specific landforms and their relationship with soils. References to standard local works, if any. Map, if appropriate, with text.
h) Natural vegetation and present land use - Overall pattern, especially as related to landscape features; major tree and shrub species and uses. Present land use - major crop

and weed species, type(s) of cultivation, crop rotations, land management, livestock, problems (e.g. erosion), agricultural research. References and, if appropriate, map.

Diagrams: of general location; agro-climatic data; major geological/geomorphological units (locations and cross-sections); vegetation/ecology.

Chapter 3. Soil Survey Methods

a) Level of survey(s) made, grid spacing. Site intensity; how/why varied; area(s) covered at given intensity.
b) Numbers of auger and of pit sites and observation density.
c) Numbers of GWT observations
d) Depths of all observations; method of description (keep brief and cross reference to FAO guidelines)
e) Processing of data (keep brief and cross-reference to annex on details of calculations)
f) Details of AP cover used - Date(s), scale(s) and area(s) covered, quality, limitations.
g) Map compilation - Scale, base map(s), how boundaries drawn (keep brief and cross-reference to chapter on map units), number of maps produced and subject(s).
h) Special measurements - Numbers of sites, replicates and brief method descriptions regarding, e.g. infiltration rate, hydraulic conductivity, bulk density etc.; also laboratory work (numbers of sites, samples, replicates, tests made and methods used). Cross-reference to annex on detailed methods of investigation, and to chapter and annex containing results.

Diagram: Site locations on main maps

(For Annexes: details of data processing; details of methods of investigation - field and laboratory).

Chapter 4. Soils and Soil Classification

a) Previous studies and classifications, including level of study, proportions of field-work and API, observations made (depths of profiles, properties recorded).
b) General description of soils (origin, morphology, chemical, physical) and classification adopted.
c) Summarized profile descriptions of soil units (in small type further details in annex).
d) Correlation's with any previous classification(s) - Tabulate grouping; soil names, soil symbols; local, FAO and/or USDA units.
e) Tabulated physical and chemical data, including means and/or medians, SD/SE, ranges.

Diagrams: Water release curves; infiltration rates; detailed soil/ vegetation/ geomorphic/ topographic relationships.

Chapter 5 Soil Units and Soil-mapping units

a) Accuracy of soil boundaries; minimum mapped area
b) Discussion of phases, variants, complexes.
c) Description of individual units (grouped by landscape unit or soil grouping, as appropriate) with tabulations of most important data; include data on slopes, microtopography, erodibility, drainage, potential crop yields etc.
d) Table of areas and percentages; both of mapping units and individual soils.
e) Purity of units; major impurities.

Diagrams: of mapping unit occurrence related to landscape; soil associations; general locations of major soil-mapping units. Main soil maps as discussed in section - below

Check following points on soil classification:

a) System should be based on soil morphology or observed/measured properties, not merely inferred genesis.
b) Definitions of all mapping/classification units should be included, if possible with chemical and physical data. Check that agriculturally significant properties for intended use(s) can be identified.
c) Specific properties (e.g. salinity, stoniness) should be adequately described/quantified.
d) Areas and locations of soil types should be identified, and purity of units should be quantified.

(For Annexes:

a) Detailed soil profile descriptions, with physical and chemical data.
b) Sample data sheets - Soil morphology and soil physical tests; auger and pit sheets
c) Statistical treatment of results
d) Investigations of special sites, e.g. pilot farm areas)

Chapter 6. Water quality for irrigation

6.1. Background

6.2. Conditions Affecting Measurement and Analysis of Water Quality

- Water table depth and its fluctuation .
- Soil texture
- Soil structure
- Soil pH
- Clay content and its nature
- Initial soil Salinity and Sodicity
- Soil fertility and Fertilizer use
- Crop types and agronomic practices
- Climate

6.3 Evaluation Of water quality for irrigation

Chapter 7 Land suitability

a) Objectives of classification and context - Data and assumptions in physical, social and economic terms. Present and proposed land usage with respect to land suitability. Previous classifications in or near the study area.
b) Management and improvements envisaged before, at and after the time during which the land suitability classification is expected to be applicable; agricultural methods; engineering installations.
c) Basis of classification - Modified USBR, FAO principles; based on repayment capacity or downgrading according to limitations (or however done); level of technology/management assumed; crop ranges.
d) Tabulated land class descriptions (see examples): general;
e) specific, with quantified limits for subclasses (see below).
f) Criteria chosen for differentiating classes and subclasses.
g) Description of subclasses, with reference back.
h) Deficiencies/restrictions; effects on yields. Tabulation of symbols.
i) Tabulated subclass areas, percentages, estimated crop yields.
j) Details of subclasses including impurities (if long, this section could be put in small print).
k) social, financial and economic evaluation - assessment and comparison of alternatives. Normally handled by the team economist and/or financial analyst.
l) Source data - Maps, previous reports, local information, either as annex or accompanying documentation.

Check following points on land suitability evaluation

a) Range of properties and values of class limits used as the basis for the classification should be relevant to the planned development, and not necessarily just standard systems.
b) Definitions of units should be unambiguous and related to the proposed land use(s).
c) Specific problems should adequately quantified and based on sufficient measurements.
d) Areas and locations of classes and subclasses should be given.
e) There should be adequate interpretation of survey results for practical users; e.g. management practices for the land units should be specified where appropriate.

Diagram: Simplified land class occurrence (and/or on summary map). Main land suitability maps as Section 9.5 below.

Chapter 8 Soil and land management

a) Must be well written and explicit; full cross-references to soil and land suitability chapters.
b) soil fertility - Aims (eg increase Ca, increase all nutrients); recommended applications and types of fertilizer (also those not recommended); specific nutrient problems; field trials; micronutrients; release of nutrients (leaching, split applications).
c) Crop varieties - Normally cross-reference to other sections
d) Pests and diseases - Especially soil-related ones, for example nematodes (cross-reference to other sections).
e) Erosion - Shelter belts; cover crops and mulching; contour cultivation; prevention of capping.
f) Land preparation - Grading, leveling (especially with respect to problem soils, e.g. shallow profiles, infertile subsoil's); pan prevention, weed control; tillage methods. Cross-reference to section 2h.
g) Drainage - Infield: type recommended, in general terms. Regional GWT movement; water quality (e.g. after leaching). Cross-reference to engineering sections
   ii. Irrigation - Discuss choice of method and/or cross-reference to other sections

(For Annex: specifications of designs and design criteria, levelling/grading measurements, details of salinity/sodicity preventative precautions, details of conservation measures etc.).

Chapter 8. Summary of technical findings, and specific recommendations

a) In list form; very brief.
b) Including need for further work
c) cross-referenced to relevant sections.

Supporting figures, photographs and maps - major land units/vegetation cover. Main soil types. Major problems (e.g. erosion).

Soil and land suitability maps

General choice of map subjects and scales Soil and land suitability maps are often used without reference to the accompanying report(s). Choice of map subjects and presentation should therefore aim at being as self-explanatory as possible, and should cover all the major aspects relating to the proposed development.

a) Map subjects - These will normally include:
   i) Soils:
   ii) land suitability (separate map set for each use envisaged);
   iii) specific soil parameters relevant to development, e.g. salinity, depth (separate set for each development);
   iv) summary map of whole area (usually land suitability).

(i) to (iii) normally at same scale; (iv) smaller scale to allow presentation on one sheets. In surveys of single farms or other small areas, or where soil and land unit boundary configurations are simple, one map sheet may suffice for all the topics.

b) Map scales - These are conventionally chosen so that the field-sampling intensity corresponds to between 1.0 and 0.25 site cm^2 on the final map (FAO, 1979a, b 89). For many consultancy uses, however, this gives a map that is too small to be useful, and in practice choice of scale depends on:
   - i) scale of available base maps;
   - ii) allowing sufficient space for site numbers to be drawn in;
   - iii) scale that will be of most value to other users (design engineers; agronomists designing cropping patterns; field engineers);
   - iv) production of maps that are small enough to use comfortably in the field.

This usually means for most feasibility studies (medium-intensity surveys) that maps are produced at A1 size (approximately 60 x 85 cm) as a maximum, and at a scale between 1:5000 and 1:20 000 (1:10 000 most common). The summary maps, often intended for wall display, may be produced up to about A0 size (approximately 85 x 120cm).

General map presentation All maps (soil, land suitability, parameter or theme, summary) should usually include the following features:

a) title (including client, project, map number and subject, country);
b) date:
c) map or sheet code and number;
d) scale (linear scale, and numerically);
e) north-point (magnetic/true) and latitude and longitude reference points (or grid system and references);
f) index diagram to adjoining sheets;
g) compilation source(s) (e.g. aerial photographs, topographic maps-authors, reference numbers, scales and dates);
h) company and associates' names, addresses and logos; where other companies have provided technical inputs such as aerial photography/base maps or cartography they also require mention;
i) specific subject legend
j) conventional symbol legend to explain all general symbols (roads, rivers etc.);
k) indication of map reliability/intensity of survey;
l) cross-reference to accompanying report;
m) copyright attribution.

The maps should be a self-contained and as easy to interpret as possible.

1. Soil map legends

   a) Keep as simple as possible.
   b) General soil
   c) Additional data, such as slopes; suitability for different crops; climatic data (or cross-references).
   d) FAO symbol/name
   e) Composition of complexes (percent of each soil type), and 'reliability' of map (depth and intensity of observations; purity of units).
   f) Possibly (where easily portrayed) diagrammatic cross-sections showing soil-topography-vegetation associations (or in report).
   g) Perhaps field investigation sites.

2. Land suitability map legends

   a) Separate map for each land use envisaged
   b) Keep as simple as possible, especially symbols .
   c) Major limitations and/or use restrictions indicated.
   d) Crop yields indicated, if possible, class by class.
   e) Management inputs specified.
   f) Field investigation site locations and numbers and indication of whether pit or auger; chemical and physical sampling sites (using symbols).

Field classification **Final Classification**

Appendix III. Proformas for Soil Profile Description

Profile No:
Date:
GPS Co-ordinates; N:
Physiog. Position :
Micro relief:
Elevation:
Parent material:
External drainage
GWTD(cm):
Human disturbance:
Crops grown:

Location
Author:
East:
Land form:
Slope %:
Surface crust/cracks:
Surface stones/rock out crops:
Erosion:
Flooding:
Land use:
Type of Fertilizer:

Description

Depth (cm)	H1	H2	H3	H4	H5	H6
Moisture status						
Color: Dry Moist						
Texture						
Mottles Ab/s/ct/col						
Structure Dev/s/type						
Const. dry moist wet						
Porosity ab/s/dis/type						
Cutans						
Cementation						
Fauna						
Roots						
Miner. nodules ab/t/si/const/sh						
Gravels/ stones ty/si/sh/arng						
Permeability						
Carbonates						
Boundary						
Horz.sampled Disturbed Undisturbed						
Comments/sketch/Diagram						

Appendix IV Proforma for Soil Auger Observation

Auger No:
Date:
GPS Co-ordinates; N:
Phsyiog.Postion :
Micro relief:
Elevation:
Parent material:
External drainage
GWTD(cm):
Human disturbance:
Crops grown:

Location
Author:
East:
Land form:
Slope %:
Surface crust/cracks
Surface stones:
Erosion:
Flooding:
Land use:
Type of Fertilizer:

Observations

Depth					
Moisture					
Color: dry moist					
Texture					
Mottles ab/s/ct/col/					
Consistency					
Hard pan					
Nodules					
gravels/stones					
Carbonates					
General Comments					
Diagram and/ or comments between sites					

Field classification

Final Classification

Appendix .V. Laboratory Analysis of Soil and Water Quality

1. Background

There are over 40 Soil, water and plant testing laboratories in Ethiopia owned by different institutions such as higher learning institutions, ministry of agriculture, research organization and other institutions. Some of them are unable to perform efficiently, due to lack of chemicals, laboratory equipment, spares, maintenance problems and lack of trained personnel. Moreover most laboratories do not carry out analysis for external sample, other then their own.

In selecting laboratories care should be taken to identify their area of specialization and whether the laboratory and their methodologies are certified. It is save to request a submission of a license and certificate from Ethiopian quality and Standard Authority.

Most of the laboratories have their own adopted standard procedures. Recently National Fertilizer Industry Agency and National Soil Research center Laboratories have prepared laboratory testing procedures and distributed to all the laboratories in the country inorder to standardize the methodologies. However the following brief procedures have been presented to facilitate the soil surveyor what possible methods are available, other wise each laboratory is equipped with acceptable standards and suffice to quote only the name of the methods to them during request for service . The detail shall be left for the laboratory itself.

2. Summary of laboratory testing procedures.

Particle size distribution : sample is pretreated with hydrogen peroxide to remove organic matter. Prior to this, if pH > 6.8 carbonates are removed with a mildly acid butter (pH 5) of sodium acetate/ acetic acid. Clay and silt are separated from sand by wet sieving (50Nm) and determined by the pipette method. Sand is fractionated by dry sieving.

Bulk density: - dry weight of a 100ml undisturbed core sample taken at field - moist conditions (33k Pa water).

PH :- measured by a pH meter in the suspension of a 1: 2.5 soil : liquid mixture of water or 1M Kcl.

EC:- is measured with a conductivity meter in the saturation extract.

Organic carbon: - the walkley - black procedure is followed. It applies wet combustion of the organic matter with a potassium dichromate/sulfuric acid mixture and titration of residual dichromate with ferrous sulfate.

Exchangeable bases: - are measured by percolation of the sample with ammonium acetate at pH 7. The Ca, Mg, k and Na are determined in percolate.

Cation exchange capacity: - after percolation with ammonium acetate at pH 7, the sample is washed free of excess salt and percolated with potassium chloride. Ammonium is determined in the percolate. Alternatively after percolation with ammonium acetate at pH 7, the sample is percolated

4. **Format for analysis of Soil Laboratory Results(Chemical Analytical Data).**

Lab. No	Field No	Depth cm	pH H_2o 1:2.5	Exch. acidity	EC ms/cm	Avl.P ppm	CaCO3 %	AVl.K	Micro nutrients (if found important
Mean									
Sd									
C.V.									
Lab.No.	Field No	Na	K	Ca	Mg	Sum	CEC	BSP	ESP
	Meq/100 gm soil						Meq/100g	%	
Mean									
Sd									
C.V.									
Lab.No	Field No	O.C	O.M.	N	C:N	Mg:K	Ca:Mg	K:Mg	K:CEC
Mean									
Sd									
C.V.									

Laboratory Results(Physical Analytical Data).

Silt %	Clay %	Texture	Moisture content %	Porosity (%vol.)	Particle Density gm/cm^3	Bulk Density gm/cm^3	F.C.	P.W.P	AWC mm	RAW (66%)

Appendix. VI. Field Testing Procedures.

1. Infiltration test.

- Prepare steel cylinder sets, 40 cm high. The two cylinders are of deferent diameters, usually the inner one about 20 - 30cm and the outer one about 45 - 60cm in diameter. The other equipment's are one steel plate (15cm x 15cm), sledge hammer or heavy weight with handle, drums or water trailers and buckets for water, three floats with scale, auger and shovel, A knife or sward for cutting vegetation.

    - Select a representative site near representative soil pit. Remove all the vegetation on the soil surface by clipping. Record information on the soil surface which might affect the rate of water intake (like surface litter, cracks, ploughings ...etc.). It is preferable to pre-wet the sampling area (saturate the soil) about- 2 days depending on the type of soil, before the testing data.

    - Select 3 test sites in a triangle format, about 10m apart, for three replicate measurements.

    - Drive the infiltrometer rings in to the pre-wetted soil to approximately 15 cm depth placing the driving plate over the cylinder with heavy timber on top of the cylinder with heavy timber on top of the driving plate. Make sure that vertical penetration of the rings is uniform by continuously checking and rotating the piece of the hard wood after every few blows.

- Fill both rings to a depth of about 15 - 20 cm and record the time and height of water in the inner ring using the floating scale in the still well. If no floating scale is available, levels can be measured from the water surface to the top of the cylinder at each measurement. Repeat the measurement, first every minutes and as the rate of infiltration reduces every 5, later 10, 15, 30 minute intervals until the rate of infiltration becomes steady for at least 2 readings (basal infiltration). Also record water levels immediately before and after each refill. Make sure that the water level in the inner and outer ring stays at the same level. Repeat the same procedure for each replicate.

- Record readings on a standard form and calculate the rate. The curves of infiltration versus time should be plotted on paper to obtain cumulative and basal infiltration.

Proforma for measurement of Infiltration Rate

Project
GPS (N & E)
Date:
Measured by:
Source of water

Site No:
Location:
Replicate No:
Site Characteristics:
Prewetting

Local Time (hr:mins)	Time intervals (mins)	Depth to water in ring (cm)	Intake (cm)	cumulative intake (cm/hr)	Infiltration Rate (cm/hr) Instantaneous	Infiltration Rate(cm/hr) Mean

2. Hydraulic Conductivity.

Several methods for field determinations of soil hydraulic conductivity exists. Measurements of HC can be made using Gulph permeameter, auger hole and inverse auger hole methods as follow

Gulph permeameter

- Using a screw-type or bucket auger, excavate a hole or well to the desired depth.
- Assemble and install the Guelph permeameter as per the instruction given on product manual.
- Close the water out let valve at the top (push down) and file the barrel with water (with no air space, and preferably use local water which is planned to be used for irrigation).
- Lift the air tube slowly to establish and maintain the desired depth of water in the well (the air tube height marker gives desired depth of ponding in the well, H) adjust the height if the permeability is too slow or too fast.
- Select the barrel (x or y) by turning the Knob (if the flow is slow, select small barrel).
- Measure the rate of fall of water level in the reservoir, using the reservoir graduated scale and a stop watch until three constant readings are obtained (R).
- Calculate the reading data using the following formula.

$Kfs = CAR/ [(2x3.14 \times H^2+3.14 \times c \times a^2 + (2 \times 3.14 \times {}^4/_5)]$

Kfs = Field saturated hydraulic conductivity in cm/sec.

A = Cross - section of reservoir (x = 35. 39 and y = 2.16cm^2).

R = Steady state of fall of water level in reservoir(cm/sec).

c = Dimensionless shape factor.

H = Steady depth of water in the well, air tube height marker level in reservoir (cm/sec).

a = Radius of the well in cm.

s = Soil texture/structure parameter in cm.

0 .01/cm for compact clay soils.
0 .04/cm for unstructured soils.
0 .012/cm for structured soils (for most soils).
0 .36/cm for coarse sands.

Inverse auger hole method

The inverse auger method is an auger hole test above the water table. It consists of augering a hole to a given depth, filling it with water and measuring the rate of fall of the water level.

Due to the swelling properties of soil, the test has to be done under saturated condition by perwetting the site or conducting the test immediately after an infiltration measurement.

The data can be calculated using the formula

$$K = \frac{1.15r[\log(h(t_1)+ r/2) - \log(h(t_n)+r/2]}{t_n - t_1}$$

The inverse auger hole - constant level methods is done in circumstances desirable to maintain the level of the water in the hole during an inverse auger hole test so that the water remains, say, with in a particular soil horizon. The hydraulic conductivity is then calculated from readings of the volume of water necessary to maintain the constant level in the hole.

Auger hole method

The auger hole method is based on a hole bored in to the soil to a certain depth below the water table. When equilibrium is reached with the surrounding ground water, a volume of water is removed from the hole and the surrounding ground water allowed to seep into replace it. The rate at which the water rises in the hole is measured and then converted by a suitable formula to the hydraulic conductivity (K) for the soil .The use of this method is limited to areas where a high GWT occurs and where a boring of known shape can be maintained through out the test. Hence in certain sandy soils it is necessary to use a perforated tube as support from the sides. This method is unsuitable to use in very stony or coarse soils because of the difficulty of augering a uniform hole in such materials. Calculation should be done using Ernst formula (see Booker Tropical Manual)

Proforma for measurement of Hydraulic Conductivity

Project
GPS
Date:
Replicate No:
Radius of hole,r(cm)
Source of water
Site Characteristics:

Site No:
Location:
Measured by
Methods: Inverse auger hole
Depth of hole, D(cm)
Depth of GWT
Pre wetting

i	t_i sec	$h'(t_i)$ cm	$h(t_i)$ cm	$(ht_{i+r/2})$ cm	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
.etc					

Diagrams/comments:

3. Piezometers.

To investigate drainage problems, piezometers should be rammed in to the ground, from which the water depth is read. By running several of these piezometers in to the grounds close to each other, but down to different levels, it is easy to establish the hydrostatic pressures at different elevations. The piezometers can then be used to detect the direction of groundwater movement. Piezometer monitoring should be regularly conducted and analyzed.

4. Observation Wells.

Open and closed wells could be dry to check conductivity.

Auger holes can serve as temporary observation wells for determining the free ground water levels. For permanent observation they should be partially filled with gravel and the top part caused by concrete or steel pipe section.

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER RESOURCES

GUIDELINE, MANUALS & STANDARD DESIGN OF SMALL & MEDIUM SCALE IRRIGATION PROJECTS

PART I-C
DESIGN GUIDELINE ON HYDRAULIC STRUCTURE GATES

JUNE, 2002

CONCERT ENGINEERING AND CONSULTING ENTERPRISE P.L.C. (CECE)

ENGINEERS WATER RESOURCES & AGRICULTURAL DEVELOPMENT PLANNERS

P.O.BOX 6064 TEL. 627660 FAX 627690
ADDIS ABABA E-mail coneng@telecom.net.et
ETHIOPIA

IN ASSOCIATION WITH

CONTINENTAL CONSULTANTS

Tel. 62 55 78 Fax 251 1 62 55 79
P.O.Box 22640
E-mail: cc@telecom.net.et
Addis Ababa, Ethiopia

PART I.A:	IRRIGATION SYSTEM
PART I.B:	IRRIGATION STRUCTURES
PART I.C:	HYDRAULIC STRUCTURES GATES
PART I.D:	DRAINAGE DESIGN
PART I.E:	DAM DESIGN
PART I.F.1 PART I.F.2 PART I.F.3	INLET/OUTLET SPILLWAY RETAINING WALLS
PART I.G	DIVERSION STRUCTURES
PART I.H	GEOTECHNIQUE
PART II.A	SURVEYING & MAP PRODUCTION
PART II.B	PUMPING FACILITES
PART II.C	WATER MANAGEMENT
PART III.A	TECHNICAL SPECIFICATIONS

TABLE OF CONTENT

LIST OF TABLES

FORWARD

This production was initiated and prepared under the auspicious of the Ministry of Water Resources of the Federal Democratic Republic of Ethiopia. Its purpose is to give counsel to the practicing professionals in the small and medium scale irrigation development and affiliated water resources engineering planning, study, surveys, explorations, design, field and laboratory tests, constructional materials investigation and geotechnical designs and

treatments. It can also be used as a baseline for further future update and revision.

This guideline represents an advice of good practice and therefore takes the form of recommendations. Compliance with it does not confer immunity from relevant statutory and legal requirements.

The document is prepared by Concert Engineering and Consulting Enterprise (CECE) in association with Continental Consultants (CC). It covers the following components relevant to the design of small and medium scale irrigation projects:-

Guidelines

- Irrigation System Design (Part I-A)
- Irrigation Structure (Part I-B)
- Hydraulic structures Gates (Part I-C)
- Drainage System Design (Part I-D)
- Dam Design (Part I-E)
- Dam Apartment Structures (I-F)
- Diversion Structures (Part I-G)
- Geo-techniques (Part I-H)

Manuals

- Surveying and Map Production (Part II-A)
- Pumping Facilities (Part II-B)

Standards

- Irrigation Water Management (Part III-A)
- Technical Specifications (Part III-B)

1.0 INTRODUCTION

1.1 Objective

The objective of this sub-component is to lay the basis for structural design of the most commonly used gates viz. flat/slide & radial gates for small & medium scale irrigation projects.

1.2 Scope

This sub-component is intended to demonstrate the design consideration & principles of gate design. However, it should be noted that the guideline couldn't be used for fabricating or manufacturing of the said gates, as it doesn't contain all the necessary details.

1.3 Definition of Terms

The following definitions are used for the purpose of this guideline:-

a) **Small head gate:** Category one. a gate which is subjected to a head of water above 4 meters but not exceeding 15.0 meters from the sill. Category two, a gate subjected to less than 4-meter head.

b) **Medium head gate:** a gate, which is subjected to head 15m up to 45m. The small or medium head gates can further be classified as follows.
   i. **Service/regulation gate:** to be used for regulating & routine operation.
   ii. **Emergency closure gate:** to close opening of flowing water in case of emergency.
   iii. **Maintenance gate:** used for maintenance activities at a down stream location.
   iv. **Complete shutoff gate:** required to shut off opening during construction.

2.0 DESIGN REQUIREMENT

The gates recommended in this guideline should meet the following requirements.

- Should be reasonably watertight. Leakage if any unless other wise specified shall not exceed 5 to 15 liters per minute per meter length of periphery of the sealing surface.
- Shall be rigid, smooth, straight & without offset at joints.
- Bottom shape of the gate shall be suitably designed to minimize down pull & to provide a converging fluid way.
- Slot shall be as narrow as possible in conformity with structural safety of the gate leaf.
- The gate as a whole shall be capable of being raised or lowered by the hoisting mechanism provided.

3.0 FLAT/SLIDE GATES

3.1 Flat /Slide Gates for Diversion Weirs & Irrigation Structures

3.1.1 General

This considers gates subjected to few meters upto 4.0 meters head of water from seal level. For this purpose the gate consists gate leaf & embedded parts (sliding frame & seals), hoisting device. The slide gates are generally operated by screw spindles or winch type mechanical hoists. These are mostly sluice gates & low head bottom outlet gets, etc.

3.1.2 Gate Leaf Thickness

The gate leaf or the operating member is a rigid structure consisting of skin plate, sufficiently strong to withstand forces (static & hydrodynamic) acting on the plate.

The required thickness is governed by the following formula & the detailed calculation procedure is shown in Appendix A.

$$\sigma = \frac{K}{100} \times \frac{P \times a \times b}{S^2} \left(N / Cm^2 \right)$$

Where,

σ - Bending stress in flat plate (N/cm^2)
K - non-dimensional factor (as shown in Appendix A)
a,b - bay width & height (cm)
S - skin plate thickness
P - Water pressure in N/cm(relative to the plate center).

To take care of corrosion, the actual thickness of skin plate to be provided shall be at least 1.5mm more than the theoretical thickness computed based on the stress given under column 'dry condition" of the Appendix B. Alternatively the design stresses specified in the column "wet condition" in Appendix B shall apply, in which case corrosion allowance shall not be necessary. The thickness of the skin plate shall be not less than 6mm, inclusive of the corrosion allowance. Wherever required, the skin plate shall be stiffened by providing horizontal & vertical stiffness.

The maximum deflection for the gate shall not exceed 1/800 of the span. (Center-to-center of the seat).

3.1.3 Loading

The gate shall be designed for hydrostatic and hydrodynamic forces. In addition to water load, the designer may at his discretion add 1 to 2m of water head to the static head to account for the sub-atmospheric pressure down stream of gates located in conduits /sluices.

The loading analysis & determination of leaf thickness are outlined in illustration No. 1, below.

3.1.4 Embedded Parts

The embedded parts which provide sealing surface, and grooves for the gate leaf are embedded in concrete or masonry & securely an chored. The grooves will have sufficient space to allow the movement of gates while at the same time shouted not allow excessive leakage.

Where the frame serves as a groove, the clearances should be as follows:

a) Longitudinal (along the flow) clearance between the leaf & frame is 3 to 5mm.
b) Transfers (perpendicular to the flow) clearance between the leaf and frame is 5 to 8mm.

ILLUSTRATION NO. 1
METHODS OF COMPUTATION OF BENDING STRESSES IN FLAT PLATES

STRESSES OF FLAT PLATES IN PANELS

Bending stresses in flat plates may be computed from the following formula:

$$\sigma = \frac{k}{100} \cdot \frac{pa^2}{S^2} N/cm^2$$

σ = bending stress in flat plate in N/cm^2,
k = non-dimensional factor,
p = water pressure in N/cm^2 (relative to the plate center),
a,b=bay width in cm as in figures. 1 to 6 of Appendix A.
S = plate thickness in cm

The values of *k* for the points and support conditions shown in figure 1 to 6 are given in tables 1, 2 and 3 of Appendix A.

Problem

The diversion weir of Hara project is expected to handle a head of about 4.5m during the flood season. The weir is designed to have a simple flat slide gate of 1x1m size. Determine the appropriate thickness.

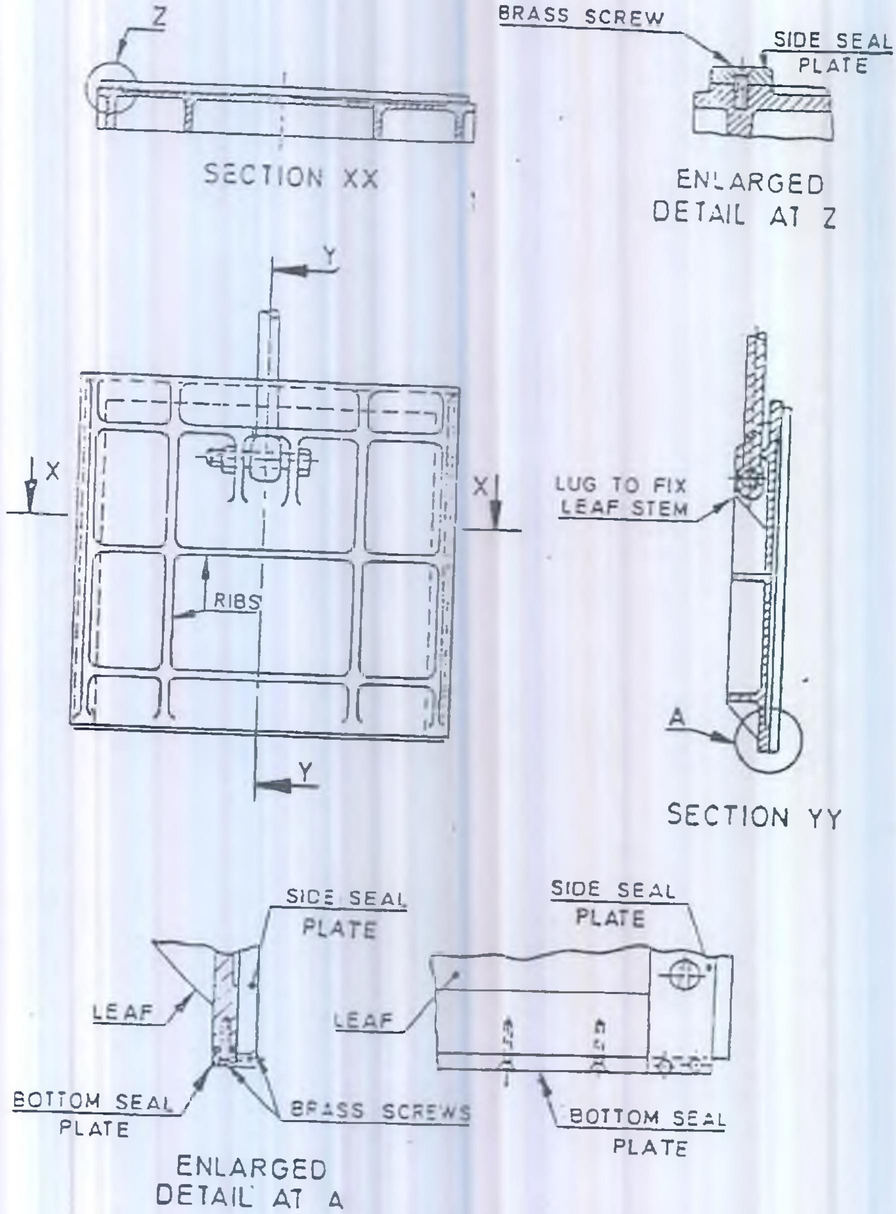
Given

i) Structural steel, with tension & bending, wet condition, accessible,
   σ_{all} = 0.45 x 470 ---------------- (Appendix B)
   = 212 N/mm2
   = 2.12 $N/cm^2 x 10^4$

ii) Head of 4.5m water exerts pressure at the bottom of the gate the hydrostatic pressure it will be
   $P_t = 10kN/m^3 x 4.5m$
   $= 45kN/m^2$
   at the center of the gate the hydrostatic pressure will be:

$$P = \frac{4 \times 45}{4.5} = 30kN/m^2$$

$$= 3N/cm^2$$



Project GUIDELINE, MANUALS & STANDARDS PREPARATION	Subject Part I.C	Status
Client MINISTRY OF WATER RESOURCES	Title TYPICAL DIAGRAM SHOWING LOW HEAD SLIDE GATE LEAF	
Engineer CONCERT ENGINERING CONSULTING CONTINENTAL CONSULTANTS	Fig 3.1a	Date

iii) Plate thickness in cm from Appendix A will be

$$\sigma = \frac{k}{100} \times \frac{Pa^2}{S^2}$$

$$S = \sqrt{\frac{k}{100} \times \frac{Pa^2}{\sigma}}$$, k value for b/a = 1/1 = 1 & figure end condition, 1, K = 28.7

$$= \sqrt{\frac{28.7}{100} \times \frac{3 \times (100)^2}{2.12 \times 10^4}} = 0.64 cm, \text{ which is } 6.4 mm$$

3.2 Flat/Slide Gates for Small Head (Category 1-head of 4 up to 15m)

3.2.1 General

The flat gate consists of gate leaf, stiffness, guides, embedded parts and seal as shown in Fig. 3.1. The embedded parts shall serve to transmit water load on the gate leaf to the supporting structure (concrete), to guide the gate leaf during operation & to provide sealing surface. These gates are generally operated by screw/winch type mechanical hoists.

3.2.2 Gate Leaf Thickness

The gate leaf or the operating member is a rigid structure consisting of skin plate suitably ribbed or reinforced.Upstream skin plate avoids accumulation of debris inside the gate leaf. The gate leaf may be cast iron, cast steel or structural steel in welded construction. The skin plate and stiffness shall be designed together in a composite manner. To take care of corrosion the actual skin plate to be provided shall be at least 1.5mm more than the theoretical thickness computed based on the stream given under ''Dry condition in appendix B. Alternatively the design stress specified in the column 'wet condition' in Appendix B shall apply for which case corrosion allowance shall not be necessary. The minimum thickness of skin plate shall not be less than 8 mm inclusive of corrosion allowance. The maximum deflection of the gate under normal leaf shall be limited to 1/800 of the span. (center-to-center the seat).

3.2.3 Structural Analysis

The skin plate shall be designed for the following two conditions.

- In bending across the stiffness or horizontal girders or as panels and
- In bending, co-acting with stiffners and/or horizontal girders (Appendix C).
- In all cases (a or b) earth quake forces have to be considered in accordance with EBCS (Ethiopian Building Code Standard or other relevant standards.)

The width of skin plate co-acting with beam or stiffness in bending condition shall be determined as outlined in Appendix C. Alternatively the co-acting width of the skin plate in non-panel fabrication may be restricted to the least of the following values:-

a) 40 *t + B,

Where, t = thickness

B= width of stiffner flange in contact with skin plate

b) 0.11 x span

c) Center to center distance of stiffner

The combined stress on the skin plate shall be calculated using the following formula in order to ensure the allowable limit as per Appendix B.

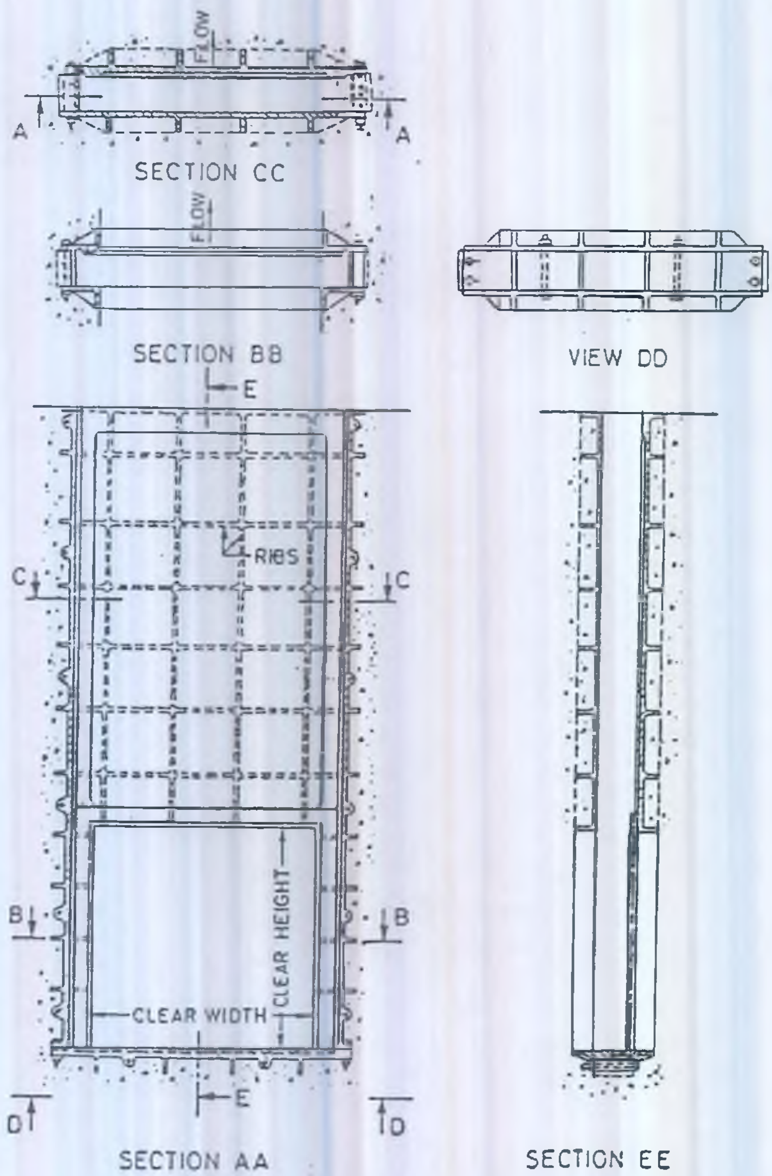
$$\sigma_v = \sqrt{\sigma x^2 + \sigma y^2 - \sigma x \sigma y + 3\tau xy^2}$$

Where, σ_v = Combined stress

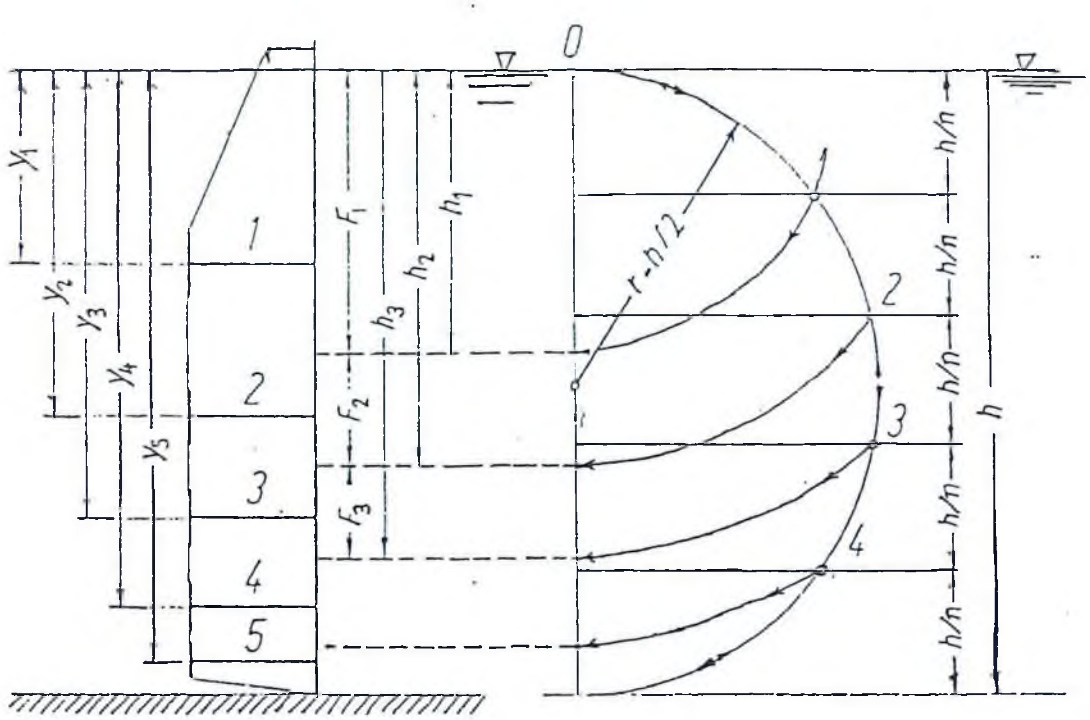
σ_x = Sum of stress along x-axis

σ_y = Sum of stress along y-axis

τ_{xy} = Sum of shear stress in x-y plane



Project GUIDELINE, MANUALS & STANDARDS PREPARATION	Subject Part I.C	Status
Client MINISTRY OF WATER RESOURCES	Title TYPICAL DIAGRAM SHOWING EMBEDDED FRAME OF LOW HEAD SLIDE GATE	
Engineer CONCERT ENGINERING CONSULTING CONTINENTAL CONSULTANTS	Fig. 3.1b	Date



GIRDER SPACING

Project: GUIDELINE, MANUALS & STANDARDS PREPARATION	Subject: Part Ic		Status
Client: MINISTRY OF WATER RESOURCES	Title: GIRDER SPACING		
Engineer: CONCERT ENGINEERING CONSULTING CONTINENTAL CONSULTANTS	Fig. 3.1c		Date

3.2.4 Horizontal & Vertical Stiffeners /Girders

The horizontal & vertical stiffness shall be designed as simply supported or continuous beams depending upon the framing adopted. Spacing between main horizontal girders shall be such that all girder carry almost equal loads.

The span of the horizontal girders shall be taken between centers of end vertical girders. The end vertical girder shall be designed as continuous beam having concentrated loads from horizontal girders and uniform reaction from bearing plate. The following exercise is shown for illustrative purpose.

Theoretically, the problems of girder spacing can be solved by the following formula (See fig 3.1.C).

$$h_k = H.\sqrt{\frac{K+u}{n+u}} \quad ,u=\frac{h(H-h)^2}{H^2-(H-h)^2}$$

h_k= distance to centroid of divisions between girders
H = total height of water
n = total number of division
k = order to girders spacing form top.

$$Y_k = \frac{2H}{\sqrt[3]{n+u}}\left[(k+u)^{1.5}-(k-r+u)^{1.5}\right]$$

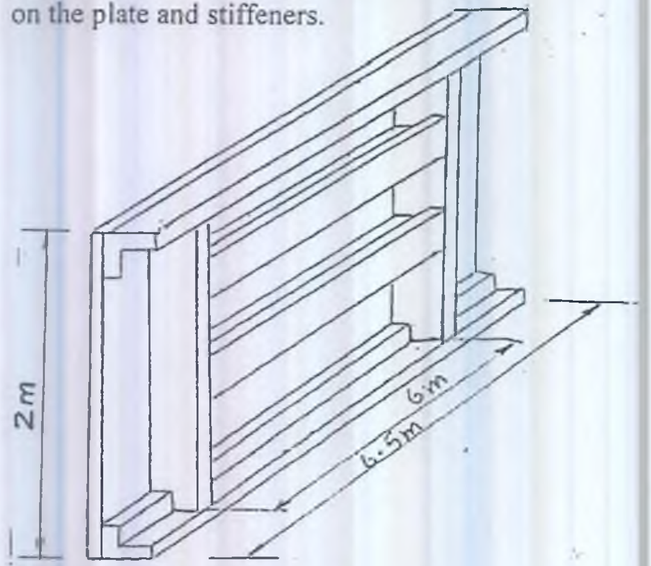
Y_k = distance to center of girder
H= total height of water
n = total number of division
K = order of girder spacing form top

There are various considerations pertaining to the requirements of general rigidity of the frame work, and to the possibility of damage due to accidental causes, which may occasionally impose departures from the described ideal spacing.

Illustration No. 2 Calculation of Girder spacing and Co-acting width

a)Girder spacing considering loading condition

The flat gate at the anglele Bolhamo irrigation project desilting basin has the following geometry and dimension. determine the stress on the plate and stiffeners.



i) **General Loading**

- Hydrostatic pressure

p_1= 10*2.95 = 29.5KN/m2
p2= 10*4.95= 49.5KN/m2

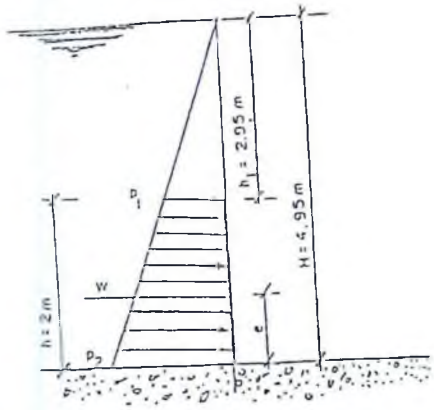
- Hydrostatic Load (W)
  W=γ*B*h (H-h/2)
  W=10*6.5*2(4.95- 2/2)=513.5KN
- Application point (e)

$$e = \frac{H-h_1}{3}\left[\frac{H-2h_1}{H+h}\right]$$

$$e = \frac{4.95-2.95}{3}\left[\frac{4.95+2(2.95)}{4.95+2.95}\right] = 0.92\ m$$

- Number of horizontal beams (n) (for preliminary calculations)

$$n=\frac{100h}{t}\sqrt{\frac{Hm}{2*\sigma_{per}}}=\frac{100*2}{12}\sqrt{\frac{3.95}{2*240}}=1.51=2$$



) Depth of horizontal strips(h_k)

$$h_k = H\sqrt{\frac{k+\beta}{n+\beta}};\beta = \frac{h(H-h)^2}{H^2-(H-h)^2}$$

$$\beta = \frac{2(4.95-2)^2}{(4.95)^2-(4.95-2)^2} = 1.1$$

$$h_k = 4.95\sqrt{\frac{k+1.1}{2+1.1}} = 2.811\sqrt{k+1.1}$$

$$h_1 = 2.811\sqrt{1+1.1} = 4.074m$$

$$h_2 = 2.811\sqrt{2+1.1} = 4.949m 4.95m$$

ii) Position of horizontal beams (Y_k)

$$y_k = \frac{2H}{3\sqrt{n+\beta}}\left[(k+\beta)^{3/2} - (k-1\beta)^{3/2}\right]$$

$$y_1 = \frac{2*4.95}{3\sqrt{2+1.1}}\left[(1+1.1)^{1.5} - (1-1+1.1)^{1.5}\right]$$

$$= 3.541m$$

$$y_2 = \frac{2*4.95}{3\sqrt{2+1.1}}\left[(2+1.1)^{1.5} = (2-1+1.1)^{1.5}\right]$$

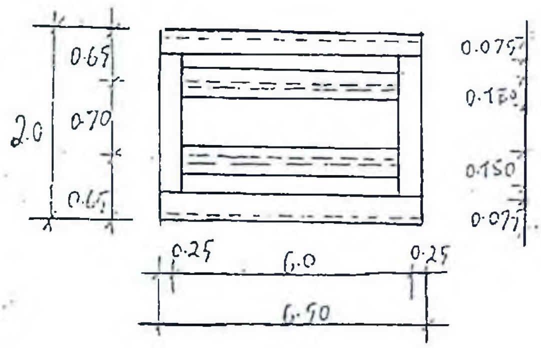
$$= 4.526m$$

Add two "L" shape horizontal beams; one for hoisting and the other one for sealing purpose.

b) Girder spacing with uniform spacing of girders and calculation of acting width

The flat gate at the Angelele Bolhamo irrigation project desilting basin has the following geometry & dimension. Determine the stress on the plate & stiffeners. Assuming the following:-

- Plate thickness 12mm
- Web height = 180mm
- Lower flange width 100mm
- Web thickness = 10mm



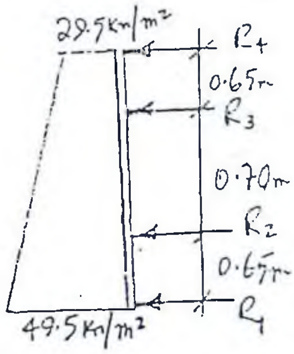
i) General Loading

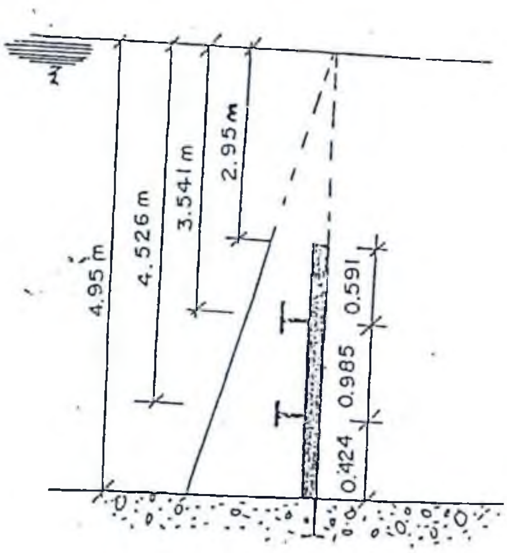
- Hydrostatic load

Total static head = 4.95m

Load at top of gate P_1 = 10x2.95
= 29.5kN/m^2

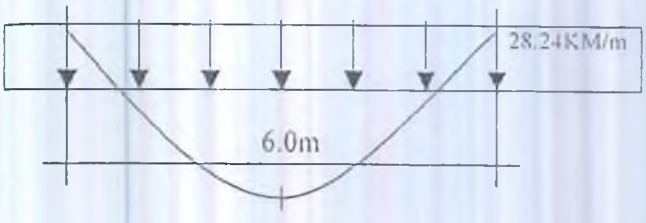
Load at bottom gate P_2 = 10x4.95
= 49.5kN/m^2





Assuring equal span continuous beams & uniformly distributed loads.
R1=R4=0.4 * W
W=UDL *L, UDL =Uniformly distributed load
UDL = $\frac{495+29.5}{2}$=39.5Kn/m^2
L = Single span =0.65m
W = 39.5*0.65 =25.67 kn/m
R1 = R4= 0.4*25.67=10.27 kn/m
R2 = R3=1.10*w
= 1.10*25.67=28.24kn/m

Select 28.24 kn/m as design loading



$$M = \frac{W1^2}{8},$$

$$M_{1max} = \frac{28.24(6)^2}{8} = 127.08\ KN - m.$$

$$M_{2max} = \frac{10.27(6)^2}{8} = 46.22KN - m.$$

ii) Calculation of co-acting width of skin plate with stiffness
b = V x B, b = effective flange width
V = reduction factor
B = half span of plate

a) Short direction	b) Long Direction
L_2 = 2.0m	L_1 = 6.00m
2B = 650cm	2B = 650cm
$B = \frac{650}{2} = 325cm$	$B = \frac{650}{2} = 325cm$
$L_2/B = \frac{200}{325} = 0.615$	$L_1/B = \frac{600}{325} = 1.85$
V_2 = 0.13 ----(from Appendix c)	V_1= 0.36
b_2 = 0.13 x 325=42.3cm	b_1 = 0.36 x 325
= 423 mm	= 117 cm
	= 1170mm

The next step is to calculate the stress at support & field locations. Thus considering moment of field (long direction), which is 127.08KN-m, the following check on the allowable stress can be carried out. Similar exercise could be done for support at long direction while for short direction, support & field stress could also be calculated but in the final analysis they would not yield higher values than long direction.

iii) Check on the structural strength of the stiffner at long direction

An in-house computer programme "sec.dim" is used to calculate the section modules of the composite section. The input for the programme is:

a) Short direction	b) Long direction
- b = 423mm	-b = 1170 mm
- Top flange width = 423mm	1170 mm
- thickness = 12mm	12mm
- Bottom flange width = 180mm	180mm
thickness = 12 mm	12 mm
E_s/E_c = 1	

The result output for long direction field location is presented below.

TUCTURAL SECTION PROPERTIES COMPOSITE BEAM
==

ITLE OF DATA:illustration

CONCRETE DIMENSIONS:

FFECTIVE FLANGE WIDTH= 0
CONCRETE DEPTH (SLAB) = 0
(TOTAL) = 0

TEEL BEAM DIMENSIONS:

OP FLANGE
WIDTH = 1170
THICKNESS= 12
BOTTOM FLANGE
WIDTH= 180
THICKNESS= 13
WEB
THICKNESS= 8

RATIO OF Es/Ec = 1

RESULTS OF THE COMPUTER CALCULATION:

WEB HEIGHT	CENTRE OF GRAVITY	MOMENT OF INERTIA	SECTION MOD 0 CONCRETE 0	SECTION MOD STEEL
180	165.9647	8.462451E+07	2167894	509894.8
190	173.9514	9.424581E+07	2295957	541793.9
200	181.9116	1.044456E+08	2423982	574155.8
210	189.8455	1.15232E+08	2551951	606977.8
220	197.7536	1.266133E+08	2679850	640258
230	205.6361	1.385975E+08	2807669	673993.8
240	213.4935	1.511925E+08	2935402	708183.2
250	221.3259	1.644063E+08	3063047	742824.5

Checking stress

$$\sigma = \frac{M}{Z}, \sigma_{all} = 240\ \text{N/mm}^2$$

$$\therefore 240 \geq \frac{127.08 N-mm \times 10^6}{Z}$$

$$Z \geq \frac{127.08 \times 10^6}{240}$$

$Z \geq 529{,}500\ \text{mm}^3$. since the actual value is 574.155mm^3. (see table.computer output).Therefore the selected section is ok.

3.2.5 Embedded Parts

The embedded parts shall be rigid & adequately anchored in the concrete/masonary. The section of embedded parts shall be so chosen that bearing pressure on concrete/masonry shall not exceed the permissible values.

3.2.6 Water Seals

The types of water seals that are generally employed are wood, rubber & metal. The wood seals are used in such a manner that the compression is parallel to the grains. Rubber seals shall be fixed to the gate leaf by means of seal clamps & bolts /stainless steel screws. Typical rubber seals are shown in Appendix E. The metal seal plates shall be either brass or bronze & shall be fixed to the gate leaf by counter sunk screws made of stainless steel or of the same material.

3.2.7 Bearing Plates /Seal Seats

For the purpose of bearing or seal plates the materials that can be used could be: cast iron, structural steel, brass, bronze or stainless steel. The material for seal plates (Appendix E) shall be somewhat softer than material for bearing plate so that wearing is on seal plates and not on bearing plates.

When fixing bearing plates, the holes in the bearing plates shall be suitably counter board and when assembled, the heads of screws/bolts shall remain one millimeter below the surface of the bearing plate. In other instances bearing plates of structural steel may be welded to embedded parts.

The edges of seal seat should be rounded /chamfered in order to prevent damage to rubber seal during gate operation.

3.2.8 Guides

Suitable guides (Appendix E) shall also be provided on the embedded parts to limit it's lateral and longitudinal movements within

tolerance of 3mm in every 3m height with overall tolerance of 5mm.

3.2.9 Tolerances, Clearances & Coefficient of Friction

The tolerance for embedded parts and in components of gate shall be as given in Appendix F. Values of coefficient of friction recommended for the design of gates are given in Appendix G.

3.3 Flat/Slide Gates for Medium Head

3.3.1 General

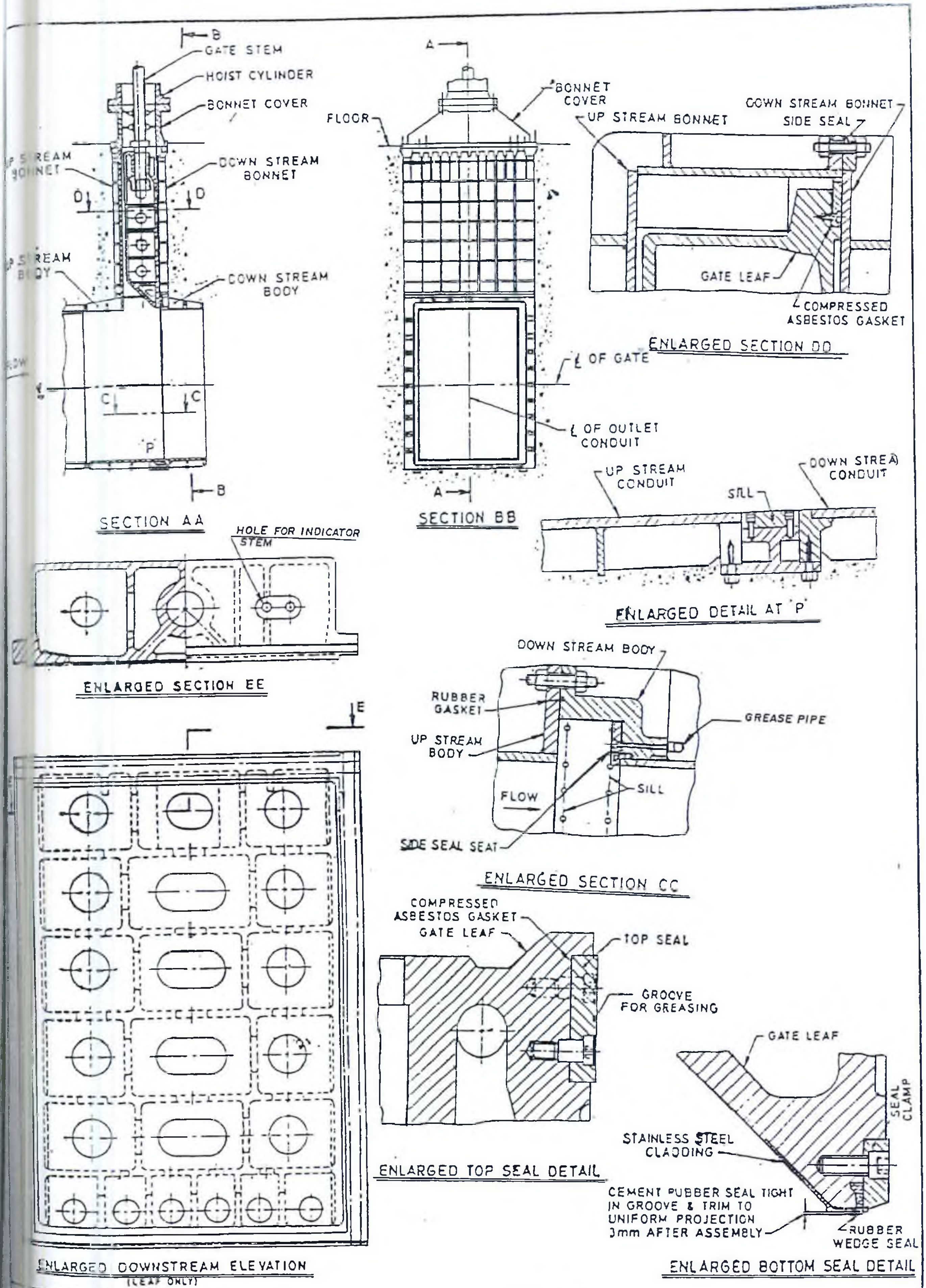
The typical installation of a slide gate for medium head is shown in figure 3.2. It consists of gate leaf which moves in a frame. The frame consists of body which houses the gate in the closed position & bonnet which houses the gate in open position. The body & bonnet are embedded in concrete. The bonnet is covered by a bonnet cover with a staffing box through which the stem rod passes. The hoisting mechanism may be supported directly over the bonnet cover or over a separate set of girders at higher level.

3.3.2 Gate Leaf Thickness

With respect to gate leaf thickness, the requirements are those indicated for small head under section 3.2.2. The maximum deflection for the gate shall not exceed 1/2000 of span.

3.3.3 Frame

The frame consists of sill girder with bottom seal seat, body, bonnet & bonnet cover. Bottom seal seat shall be flush with bottom of the opening & shall be fixed on the sill girder either by screwing or by welding to provide bottom sealing surface for the gate. The body which houses the gate leaf in closed position may be in sub-assemblies with joints. The body should be properly ribbed to give a charge with the surrounding concrete. Guides are also fixed to the body for guiding the gate. The bonnet houses the gate leaf in open position. It has flanges on the bottom for bolting it to the body and on the top for the bonnet cover. Guiders are fixed to the bonnets in continuity of the guides fixed on the body for guiding the gates. The bonnet cover is provided to seal the gate slot & provide a support for the hoist.



ject: GUIDELINE, MANUALS & STANDARDS PREPARATION	Subject: Part I.C	Status:
nt: MINISTRY OF WATER RESOURCES	Title: DETAILS OF SLIDE GATE	
ineer: CONCERT ENGINERING CONSULTING CONTINENTAL CONSULTANTS	Fig. 3.2	Date:

3.3.4 Materials

The materials to be used for different components shall be as presented in table 3.1.

Table 3.1 Materials for the Components of Medium and High head Slide Gates.

Ser. No.	Component part	Recommended Material
1	Gate leaf, sill girder, bodies, bonnet and	Forged steel
	Bonnet cover	Structural steel
		Cast steel
2	Seal seats, bearing plates & bottom seal seat	Bronze
		Corrosion resistance steel
3	Guide bars	Bronze
4	Guides	Brass
		Corrosion resistance steel
5	Clamps	Corrosion resistance steel
6	Fixing screws/bolts	Mild steel Stainless steel
7	Gland stuffing box	
	a) Body & stuffing collar	Structural steel
	b) Bushing and bushing collar	Cast steel Bronze
	c) Seals	Rubber Chevron

3.3.5 Loading & Stress

Gates should be designed for hydrostatic forces as outlined under section 3.1.3.
The permissible value of stresses in the structural parts shall be as specified in Appendix B. The permissible values of stresses in welded connection shall be the same as permitted for the parent material. The permissible stresses given in Appendix B shall be increased by 25% in case of earthquake conditions subject to an upper limit of 85% of yield point stress. In case of nuts & bolts, increase in stresses shall not be more than 25% of permissible stress.

3.3.6 Slide/flat gate design procedure

The generalized simplistic procedure for designing flat /slide gates is as follows

Step 1:

Determine opening geometry and dimension of the gate and select the plate thickness.

Skin plates which are subject to bending stress from water pressure shall be computed in accordance with the theory of elasticity.

$\sigma = \pm \frac{K}{100} P \frac{a^2}{s^2}$ (for more information see illustration $N^0 1$)

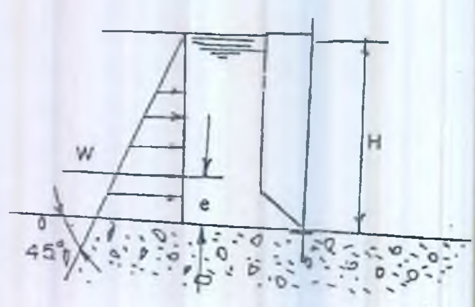
Step 2.

Calculate the maximum hydrostatic load (W) and its application point (e) for surface and submerged conditions.

- Surface gates

$$w = \frac{1}{2}\gamma * B * H^2, B \text{ is gate span}$$

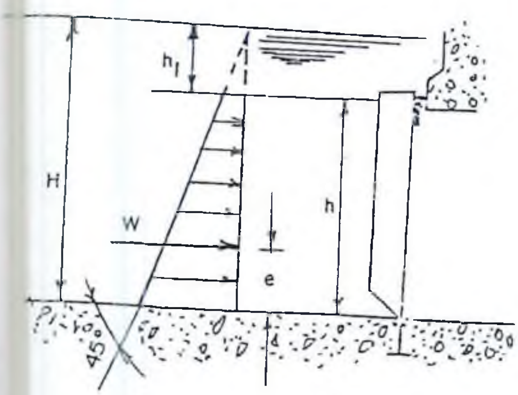
$$e = \frac{1}{3}H$$



- Submerged gates

$$w = \gamma * B * h\left(H - \frac{h}{2}\right)$$

$$e = \frac{H - h_1}{3}\left(\frac{H + 2h_1}{H + h_1}\right)$$



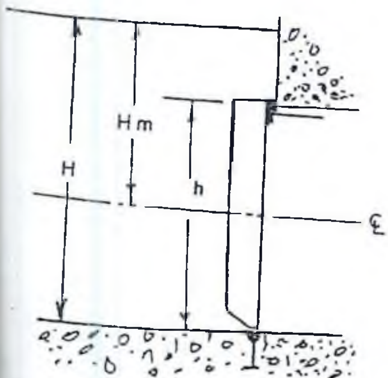
Step 3.

Calculate the number of horizontal beams (for preliminary calculations)

$$n = \frac{100h}{t}\sqrt{\frac{Hm}{2 * \sigma_{perm}}}$$

Where;

σ_{perm}: Permissible bending stress in Mpa
h,Hm : See figure
t : Plate thickness in mm



Step 4.

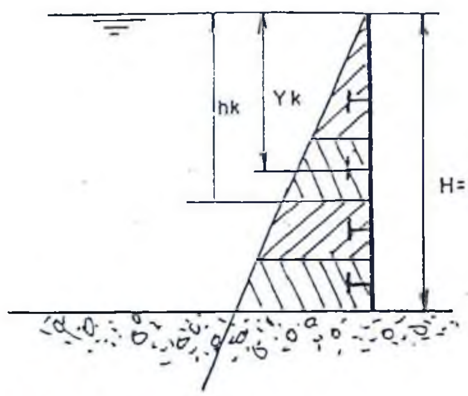
Calculate the depth of horizontal strips (hk)

In order to establish the water pressure loading on the gate it is necessary to draw a pressure distribution diagram. This diagram is normally subdivided in series of horizontal strips representing the selected number of horizontal beams.

- Surface gates

$$h_k = h\sqrt{\frac{k}{n}}$$

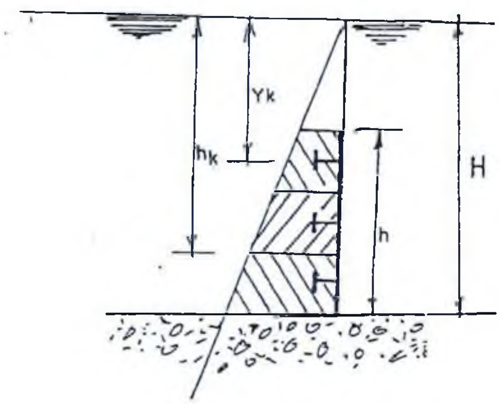
n: number of horizontal beams
k: 1,2,3,...,n



- Submerged gates

$$h_k = H\sqrt{\frac{k + \beta}{n + \beta}}$$

$$\beta = \frac{h\left(H - h^2\right)}{H^2\left(H - h\right)^2}$$



Calculate the position of horizontal beams(Y_k)

- Surface gates

$$Y_k = \frac{2h}{3\sqrt{n}}\left[K^{\frac{3}{2}} - (k-1)^{\frac{3}{2}}\right]$$

- Submerged gates

$$Y_k = \frac{2H}{3\sqrt{n+\beta}}\left[(k+\beta)^{\frac{3}{2}} - (k-1+\beta)^{\frac{3}{2}}\right]$$

$$\beta = \frac{h(H-h)^2}{H^2-(H-h)^2}$$

Spacing between the beams normally is proportionally reduced towards the bottom of the gate to absorb the progressively increasing pressure.

Step 5.

Determine the reaction of loads and the maximum bending moments.

Determine the appropriate beam dimensions.
By experience and practical considerations, beam height (b), flange thickness(t_f) and web thickness(t_w) are assumed

- Web thickness(t_w)

$$t_w = \frac{W}{2h * \tau_{perm}}$$

Where:

t_w = minimum web thickness ,mm
h = web height, mm
τ_{perm}= permissible stress(shear)
w =hydrostatic load acting on beam in Newton

- Beam height(b)

for preliminary calculations use the following table.

water column above sill	beam height
up to 15m	b=(1/12 to 1/9)*L
from 15 to 30 m	b=(1/9 to 1/7)*L
more than 30 m	b=(1/7 to 1/5)*L
* L : Span of the horizontal beam	

- Flange thickness(t_f)

$$t_f \geq t_w$$

- Flange width(b_f)

$$b_f = \frac{1}{5}b(\text{for preliminary calculations})$$

Step 6:

Calculate the effective flange width (see Appendix C, Fig. 1 and 2)

Step 7:

Check the stability (Buckling) of horizontal beams.

According to DIN 4114, item 15.3 web stability will be checked when the relation between the web height(hw) and web thickness (t_w) is equal or greater than 45.

$$\frac{h_w}{t_w} \geq 45$$

Calculation sequence

a) Calculate the reference stress of Euler,

$$\sigma_E = \frac{\Pi^2 E * t_w^2}{12(1-\mu)b^2}$$

Where;

t_w = web thickness, mm

b = beam height, mm

E = Mod. of elasticity, N/mm^2

E = Mod. of elasticity, N/mm^2

μ = Poisson coefficient

For E= 206000N/mm^2 and $\mu = 0.3$

$$\sigma_E = 1.862 X 10^5 \left(\frac{t_n}{b}\right)^2$$

b) Calculate the ideal stress of buckling.

$$\sigma_{fi} = K_1 * \sigma_E \,(For\ compression)$$

$$\tau_{fi} = K_2 * \sigma_E \,(For\ shear)$$

Where:

K_1 and K_2 = buckling coeff.(Appendix H)

c) Calculate the ideal compression stress.

$$\sigma_{fic} \frac{\sqrt{\sigma_1^2 + 3\tau^2}}{\frac{1+\Psi}{4} * \frac{\sigma_1}{\sigma_{fi}} + \sqrt{\left(\frac{3-\Psi}{4} * \frac{\sigma_1}{\sigma_{fi}}\right)^2 + \left(\frac{\tau}{\tau_{fi}}\right)^2}} \le \sigma_{perm}$$

Where:

σ_1 = Maximum compression stress

σ_2 = Maximum tension

ψ= coefficient $= \frac{\sigma_2}{\sigma_1}$

When $\sigma_{fic} > \sigma_{Permissible}$, σ_{fic} will be replaced by σ_{cr}(critical (real) compression stress). See Appendix J.

d) Calculate buckling safety coefficient, and check when $\sigma_{fic} > \sigma_{per}$

$$V_f = \frac{\sigma_{cr}}{\sqrt{\sigma_1^2 + 3\tau^2}} \le (1.25 to 1.35)_{Minimum}$$

Step 8

Check adequacy of skin plate thickness between beam webs(DIN 19704) by calculation of stresses.

$$\sigma_{max} = \frac{M_{max}}{Z} \le \sigma_{perm}$$

$$\tau_{max} = \frac{P_{max}}{A} = \tau_{perm}$$

4.0 RADIAL GATES

4.1 General

Radial gates are so named because they are made to the shape of a portion of a cylinder & rotate about a horizontal axis as shown in fig. 4.1a & 4.1b.

Normally the water is against the convex side but in few installations, the water load has been applied to the concave side. The water load on the skin plate is carried by horizontal beams, which are supported by end beams. The end beams are supported by radial arms, emanating from the pin bearings located at the axis of the cylinder. In some cases, the weight of the gate and arms is partly counter balanced to reduce the size of the hoist required. The arms transmit the water load to the trunnion a charge girder. Suitable seals are provided along the curved ends of the gate and along the bottom (Appendix E). Guide rollers may be provided to limit the sway of the gate during raising or lowering. The requirements outlined in chapter 2 for gates will in general be applicable in the structural design of radial gates.

The radial gates are suitable for both small & medium head gates, the major selection criteria being cost.

A standard radial gate installation consists of the following:

- leaf including skin plate, horizontal beams & vertical side beams
- two arms
- four or six guide rollers (optional for small heads)
- two pin bearings consisting of pin, bracket & anchor bolts
- rubber seals, sides, bottom & corner with damp bars
- wall plates, one each side, with anchor bolts
- gate sill, with anchor bolts
- hoisting mechanism

The materials to be used for parts of radial gates are presented in Table 4.1.

Table 4.1 Materials for the Radial Gates

Ser. No.	Component part	Recommended Material
1	Gate plate, stiffeners, horizontal girders, arms, bracings, tie members, anchorage girder, yoke girder, embedded girder, rest girder, load carrying anchors	Structural steel
2	Guide rollers	Cast steel Structural steel
		Forged steel
		Wrought steel Cast iron
3	Trunnion, hub and bracket	Cast steel Structural steel
4	Pin	Structural steel*
		Cast steel* Forged steel*
		Corrosion resisting steel
5	Bushing	Bronze
6	Seal seat, sill beam	Stainless steel plate or stainless steel clad plate
7	Seal base and seal seat base	Structural steel

4.2 Proportions of Gates

In designating the size of a radial gate, the width, b is given first followed by the height h. The height of the gate is the vertical projection of the distance from the sill to the top of the gate.

4.3 Location of Trunnions

The trunnions of gate shall be so located that under conditions of maximum discharge over spillway, these should preferably remain at least 1.5m clear of the water profile. With gates having the trunnions on the upstream side, the trunnions have to remain submerged in water, but suitable precautions should be taken to prevent corrosion of the trunnion parts under such conditions.

The trunnions shall be so located that the resultant hydraulic thrust through the gate in the closed position for reservoir full condition lies as close to the horizontal as possible. This will reduce the upward or downward force that will other wise be imposed on the anchorage.

In case of conduits and tunnels the trunnion shall be located near the water profile under free flow condition. However in case of pressure conduits, these shall be designed for submerged condition.

4.4 Radius of the Gate

The radius of the gate, that is the distance from the centers of trunnion pins to the inside face of the skin plate shall, as far as possible, be from h to 1.25h, consistent with the requirements of the trunnion location outlined in 4.2, where h is the height of the gate.

4.5 Skin Plate & Stiffeners (horizontal beams), Side Beams

The skin plate & stiffeners shall be designed together in a composite manner. The requirement & design procedures outlined under section 3.2.2 will be applicable. The stiffeners may, if necessary, be of a built-up section or be of standard rolled section, that is, tees, angles, channels, etc.

The horizontal beams (stiffeners) are designed as continuous over two supports with uniformly distributed load. The formula for bending moment calculation $M = \frac{wl(1-4k)}{8}$ in which w is the total water load over the section of the skin plate supported by the beam, L is width of gate & k is that proportional part of L, which extends from the center line of the side beam to one side of gate.

The side beams are built up from plate & welded, one side of the beam being curved to fit the skin plate. For the purpose of design, the side beams are considered to be straight and of length equal to the area of the skin plate. The load on each beam equals one-half the water load on the gate, increasing from top to bottom. For illustrative exercise refer to Appendix D.

4.6 Horizontal Girders

The number of girders used shall be a minimum to simplify fabrication & erection and to facilitate maintenance. The girders may be so spaced that the bending movement in the vertical stiffness at the horizontal girders as a continuous beam, are about equal. The girders shall be designed taking into consideration the fixity at arms support. Where inclined arms are used, the girders should also be designed for the compressive stress induced. The girders shall be checked for shear at the points where they are supported by the arms. The shear stress shall not exceed the value specified in Appendix B.

The standardization of girder design, is a major consideration in assessing the cost of the work, particularly when and order for a large number of gates is contemplated and the same rolled section is used for all of them. Detailsion girder spacing procedures is as shown in section 3.2.4

4.7 Arms

Each gate arm is composed of two main members fastened to the side beams of the gate skin plate with bolts or welded. Each member is designed as a column with an L/r ratio equal to or less than 120, where r is the least radius of gyration. The two members converge and are connected to a hub. Each hub is bushed with a bronze bushing and lubricated from pressure grease fitting.

In some instances horizontal girders shall be used to connect pairs of arms in order to render sturdiness of the gate.

4.8 Trunnion Pins

The trunnion pins are designed for bearing or bending, whichever requires the larger size. Shearing stress in the pin are very small. The bending, bearing & shear stress in the trunnion pin shall not exceed 0.2UTS, 1.0 UTS & 0.66 UTS of bending stress respectively, where UTS stands for ultimate tensile strength.

4.9 Trunnion Bush/Bearing

This shall normally be slide type bushing but anti- friction bearing may be used for gates in conduits and tunnels or for very large sized gates at the crest. The slide type bushing shall be force fit in the trunnion hub & a running fit on the trunnion pin. If roller type bearing is provided, the outside diameter of the bearing is provided, the outside diameter of the bearing shall be force fit in the trunnion hub and the inside diameter of the bearing shall be force fit on the trunnion pin. The thickness of bushing can be determined by the following formula;

Minimum thickness of bushing in mm = 0.08*d+3,
Where d is the pin diameter in mm.

4.10 Trunnion Bracket

The bracket shall be rigidly fixed to the anchorage support girder by bolt. It shall transfer the total load from the trunnion to the anchorage. Ribs & stiffeners shall be provided on the trunnion bracket, particularly on the siders of the bracket arms to ensure sufficient structural rigidity.

4.11 Load Carrying Anchors

These shall be designed to withstand the total water load on the gate and transfer it to the piers and abutments or to the civil structure within the tunnel or the conduit.

The load may be transferred to the civil structure either in bonds as a bond stress between the anchors & the concrete (fig. 4.1a) or in bearing as a bearing stress between the concrete and the embedded girder at the upstream end of the anchors, which in this case are insulated from the concrete (fig 4.1b) where the load is transferred by bond stress, rods are generally used as load carrying anchors. For insulated load carrying anchors, any convenient shape may be used:

For determining the force to be borne by load-carrying anchors, the procedure outlined below shall be adopted: Maximum horizontal & vertical force on the trunnion pin shall be determined under the following two conditions:-

- Gate resting on sill & head on the gate varying from zero to maximum.
- Water load constant at the maximum level for which the gate has to be designed and the gate position varying from fully closed to fully open. The worst combination of horizontal & vertical forces shall then be chosen.
- If anchors used are inclined to the horizontal by an angle θ, the horizontal force so determined shall be multiplied by sec θ.

4.12. Trunnion Girder or Yoke Girder

The trunnion girder or yoke girder may not be embedded in concrete. It shall support the trunnion bracket & be held in place by the load carrying anchors. This girder shall be designed so as to be safe in bending, shear & torsion if any caused by the forces calculated as per section 4.11.

4.13 Thrust Block & Trunnion Tie

The thrust block or trunnion tie is required only if inclined arms are used with gate. Alternatively, the lateral thrust can be directly transferred to the concrete pier through bearing from a plate embedded in concrete. The thrust block is used when the horizontal force from the trunnion is directly transferred to a yoke girder immediately behind the trunnion (fig 4.1b).

The thrust block is fixed to the anchorage girder and is designed to withstand the bending and shear force caused by the side thrust on the trunnion due to inclined arms.

4.14 Water Seals

The seals shall be fixed so as to bear tightly on the seal seats and prevent leakage in the fully closed position of the gate. These molded rubber seals are bolted to the upstream side of the skin plate along both sides and the bottom. The side seals are installed in contact with the wall plates (refer to Appendix E for details).

4.15 Guide Roller & Anchor bolts

Guide rollers shall be provided on the sides of the gate to limit the lateral motion or side sway of the gate to not more than 6mm in either directions. The rollers shall be adjustable & removable. They shall travel on wall plates but the portion of the wall plates on which they travel may be made of structural steel than stainless steel. Each gate roller shall be designed for 5 to 10 percent of the total dead weight of the gate. Anchor bolts should preferably be of not less than 16mm diameter. The anchor bolts shall invariably be used with washers.

4.16 Forces to be Considered in Design

Earthquake, wave effect & overtopping effects shall be considered in the analysis of forces. The earth quake forces wave effect & occasional overtopping may not be considered to act simultaneously while computing the increased stress in the gate. The approximate water load on the gate is calculated from the formula $W = W = \frac{1}{2}\alpha b h^2$, $\frac{1}{2} * 10 * bh^2$, $5bh^2 (kN/m^2)$, the resultant of the horizontal & vertical components of the water load is assumed to act a point located one third of the head above the gate sill & on a line through the pin bearings.

4.17 Tolerances

The tolerances for embedded parts & components of gates are given in Appendix F.

4.18 Radial Gate Design Procedures

The generalized and simplistic procedure for designing radial gates is follows

Step 1:

Define the geometry of the gate and dimension the gate including spacing of horizontal beams. Calculate the skin plate thickness (see section 3.2.2.)

Step 2:

Determine the total design load on gate for surface and submerged conditions.

a) Hydrostatic load

- Horizontal component (W_h)

$$W_h = \gamma * B * h\left(H - \frac{h}{2}\right)$$

- Vertical component (W_v)

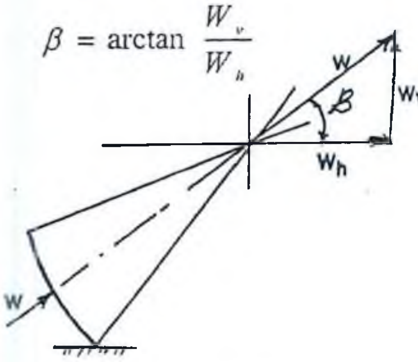
$$W_v = \gamma * B * R\left[\begin{array}{l} Dn(\cos\alpha_s - \cos\alpha_i) + \frac{R}{2}(\alpha_i - \alpha_s) \\ + \frac{R}{2}(\sin\alpha_s * \cos\alpha_s - \sin\alpha_i * \cos\alpha_i) \end{array}\right]$$

Where: γ = Sp.weight of water,KN/mm^3
B = gate span,mm
R = gate radius, mm
α_s = arcsin D_s/R
α_i = arcsin D_i/R
D_s ,D_i,D_m,h,H, : see Fig. A

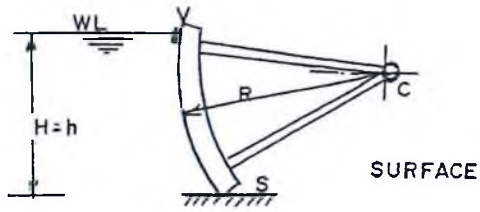
- Resultant load (W)

$$W = \sqrt{W_h^2 + W_v^2}$$

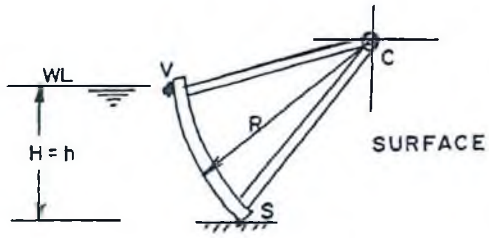
$$\beta = \arctan\frac{W_v}{W_h}$$



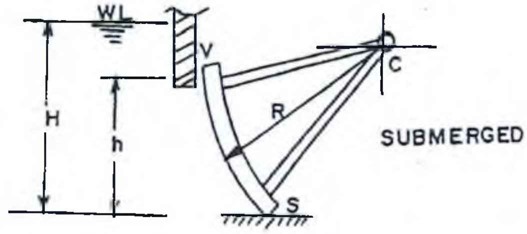
$$D_m = EL(W.L) - EL(C) > 0 \quad (+)$$
$$D_s = EL(C) - EL(V) < 0 \quad (-)$$
$$D_i = EL(C) - EL(S) > 0 \quad (+)$$



$$D_m = EL(W.L) - EL(C) < 0 \quad (-)$$
$$D_s = EL(C) - EL(V) > 0 \quad (+)$$
$$D_i = EL(C) - EL(S) > 0 \quad (+)$$



$$D_m = EL(W.L) - EL(C) > 0 \quad (+)$$
$$D_s = EL(C) - EL(V) > 0 \quad (+)$$
$$D_i = EL(C) - EL(S) > 0 \quad (+)$$

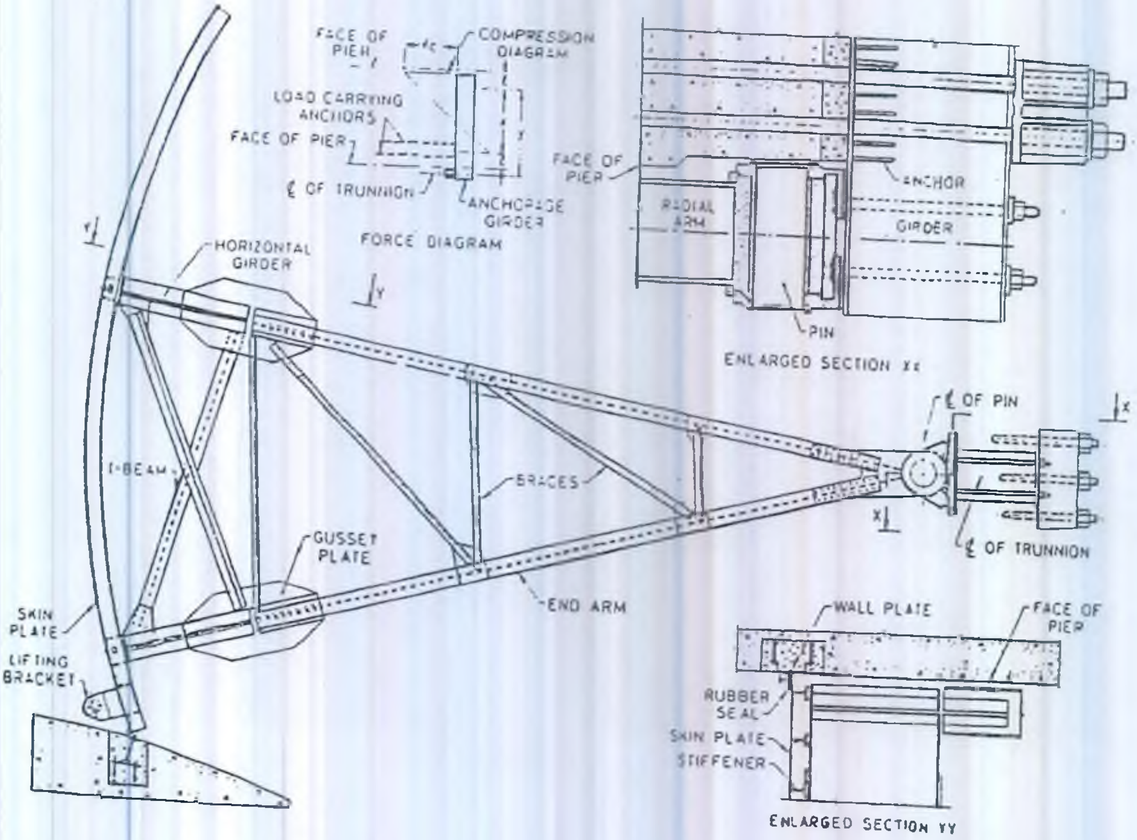


WL=WATER LEVEL
Fig-A EL=ELEVATION

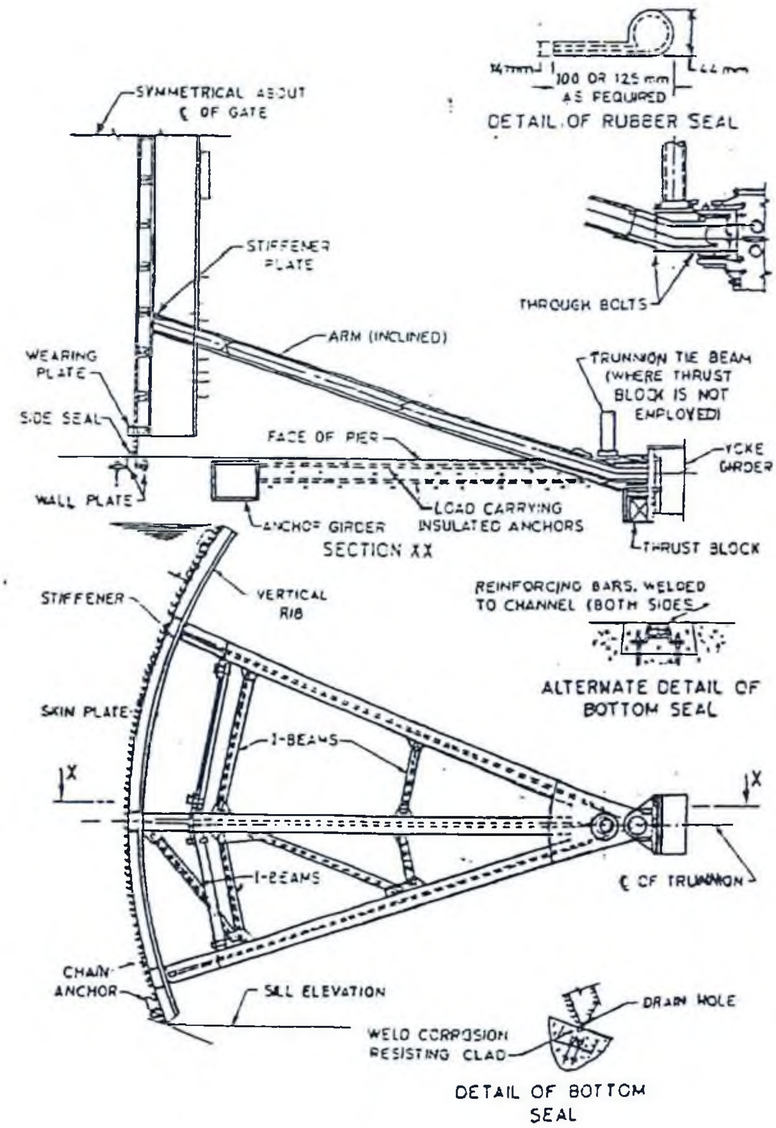
b) Hydrodynamic load

- Load due to discharge conditions of the gate. Approx. equal to 0.5 times the Hydrostatic water road.
- Load due to earthquake (where applicable)

$$P = \frac{7}{8} * h * \gamma * \alpha$$



Project GUIDELINE, MANUALS & STANDARDS PREPARATION		Subject Part I.C.	Status
Client MINISTRY OF WATER RESOURCES		Title RADIAL GATE WITH PARALLEL ARM	
Engineer CONCERT ENGINERING CONSULTING CONTINENTAL CONSULTANTS		Fig. 4.1a	Date



Project GUIDELINE, MANUALS & STANDARDS PREPARATION	Subject Part I.C	Status
Client MINISTRY OF WATER RESOURCES	Title RADIAL GATE WITH INCLINED ARM	
Engineer CONCERT ENGINERING CONSULTING CONTINENTAL CONSULTANTS	Fig. 4.1b	Date

Where:

P: hydrostatic pressure, KN/m^2
h: water depth, m
α: acceleration coeff. (α=0.2)
γ: Unit weight of water, KN/m^3

c) The total design load will be:
Design Load=Hydrostatic Load+Σ Hydrodynamic Load

Step 3:
Design skin plate
- Calculate loads and member forces on the skin plate.
- Check stress

$$\sigma_{max} = \frac{M_{max}}{Z} \leq \sigma_{perm}$$

$$\tau_{max} = \frac{P_{max}}{A} = \leq \tau_{perm.}$$

Step 4:

Design Horizontal and vertical beams.
- Calculate loads and member forces
- Calculate the effective flange width (b)
  b=V*B (see appendix C and D)
- Check adequacy of skin plate thickness between beam webs(DIN19704) by calculation of stresses.

$$\sigma_{max} = \frac{M_{max}}{Z} \leq \sigma_{perm}$$

$$\tau_{max} = \frac{P_{max}}{A} = \leq \tau_{perm.}$$

$$\tau = \frac{V * Q}{I * b} \leq \tau_{perm.}$$

Step 5:

Design Arms
- Calculate the position of arms. (See appendix K)
- Calculate the axial load on each beam.

Parallel arms

- Axial load on each arm (upper)

$$R_u^* = \frac{w}{2} * \frac{\sin \alpha_l}{\sin(\alpha_u + \alpha_l)}$$

- Axial load on each arm (lower)

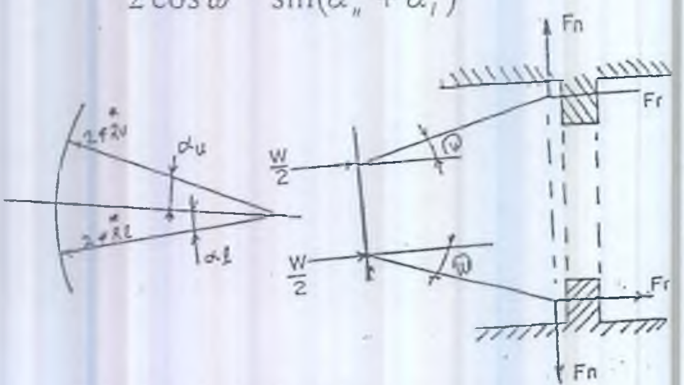
$$R_l^* = \frac{W}{2} * \frac{\sin \alpha_u}{\sin(\alpha_u + \alpha_l)}$$

Inclined arms
- Upper arm

$$R_u = \frac{W}{2\cos\varpi} * \frac{\sin \alpha_l}{\sin(\alpha_u + \alpha_l)}$$

- Lower arm

$$R_l = \frac{W}{2\cos\varpi} * \frac{\sin \alpha_u}{\sin(\alpha_u + \alpha_l)}$$



- Calculate the loads on bearings

$$F_n = \frac{1}{2} W * \tan\varpi$$

$$F_r = \frac{1}{2} W$$

- Check stability (Buckling)
General procedure for buckling.
- Assume an allowable stress
- Based on computed area requirement, select a section.

- Based on KL/r for the section selected, compute allowable stress.
- Compute $\sigma = \dfrac{P}{A}$ and compare with allowable stress
- If $\dfrac{P}{A}$ is less than allowable or not more than 2 to 3% greater, generally the design would be considered acceptable, otherwise repeat all steps.

$$F_a = \frac{F_y}{F_s}\left[1 - \frac{(KL/r)^2}{2C_c^2}\right]$$

$$C_c = \sqrt{\frac{2\Pi^2 * E}{F_y}},\quad F_s = \frac{5}{3} + \frac{3}{8}\left[\frac{KL/r}{C_c}\right] - \frac{1}{8}\left[\frac{KL/r}{C_c}\right]^3$$

Where:
F_a=allowable stress.
F_s=factor of safety
K = Effective -length factor
L = Length of column b/n supports
r = radius of gyration
F_y = yield point of steel
E = Mod. of elasticity

Step 6:

After finalizing the stress calculation in both the skin plate and the beams, the equivalent stress in the skin plate is calculated according Von Mises(DIN 19704 and DIN 19705)

$$\sigma_e \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\tau_{xy}^2} \le \sigma_{perm}$$

Where:
σ_x=sum of stress along x-axis
σ_y=sum of stress along y-axis
τ_{xy}=sum of shear stress in x-y plane.
σ_c=combined stress.

5.0 HOISTING DEVICE

5.1 General

Power operated gate hoists are usually used for operating slide & radial gates. These hoists are used for capacities more than 2500kg (fig 4.1b).

Manually operated gate hoists are usually used for capacities less than 2500kg. For even lighter weights thread & spindle arrangement may suffice.

These lifting frames are used with gates, stop logs & bulk head & are designed to operate below the water surface, utilizing the guides or slots provided for the equipment being handled. Whenever possible sliding gates should be lifted from a single point.

Chain & sprocket hoists are used for raise & lower gates, which regulate the discharge of water over spillway & are operated only at infrequent intervals.

The exact method for determining the water load requires that the horizontal & vertical components be calculated as illustrated in Appendix D.

5.2 Classification of Hoists

5.2.1 General

Hoists could be classified based on:-
a) drive (manually, electrically, float, hydraulic)
b) Operating mechanism (mechanical, screw, chain & sprocket)
c) mounting (portable, stationary, moving)

5.2.2 Gates and Hoist Commonly Used & Their Locations

Table 5.1 presents the recommended location, type of gate & type of hoist to be used with remarks on utilization.

Table 5.1 Gates and Hoists Commonly Used and Their Locations

Ser. No.	Location	Types of Gate	Type of Hoist	Remarks
i.	Crest	a) Fixed wheel vertical/ radial	Rope drum/hydraulic hoist	These gates are used in the spillway for discharge of flood. Vertical gates/radial gates should be chosen from the consideration of factors like head, superstructure height and available width of pier etc. However, the limiting height of vertical lift gate should be 8m.
		b) Automatic gates	Float operated/ counterweight operated hoist. (Automatically operates when water level reaches the required level).	
		c) Stop log gates which are fixed wheel- vertical gates or slide type in number of elements	Gantry crane/ Monorail crane with automatically operated lifting beam.	These gates facilitate the maintenance of main crest gates.
ii.	River sluice	Service/Emergency gate fixed wheel type or radial gates or jet flow gate	Screw hoist or rope drum hoist or hydraulic hoist.	Sluice gates are used to control the flow of water to the river on downstream side. For small heads, fixed wheel type gate operated with rope drum/ screw hoists are provided. However, provision of screw hoist is limited to 15 tonnes capacity. High seal gates/jet flow gates are to be operated by hydraulic hoist.
iii.	Construction sluice, diversion tunnel, etc.	Fixed wheel vertical lift gates	Rope drum hoist/ chain pulley blocks/ winches/movable cranes	These gates are meant for making construction sluice/diversion tunnel dry, which has to be plugged after construction
iv.	Canal system			
	a) Head regulators b) Regulators c) Cross regulators d) Automatic gates	Fixed wheel vertical lift/radial gates Ditto Ditto Hinged type gates	Screw/rope drum/ hydraulic hoist Ditto Ditto Float, counter weight operated	Gates are used for regulating water from reservoir to main canal. Capacity of screw hoist should be limited to 15t. These gates are used for the maintenance of constant upstream/downstream water levels.

REFERENCE

1. WRDA & ELACO (1986) Angelele Bohamo Irrigation Project Detailed Design Calculation.
2. ESRDF (1996), Component IV, Guidelines on SSIP head works & irrigation system design.
3. USBR (1956), Design standard No. 7, Gates Valves and Steel Conduits.
4. C.D Smith (1985), Hydraulic Structures.
5. Indian standard 5620 (1984). Recommendations for Structural Design of Low Head Slide Gates.
6. Indian standard 4623 (1984). Recommendations for Design of Radial Gates.

APPENDICES

APPENDIX - A

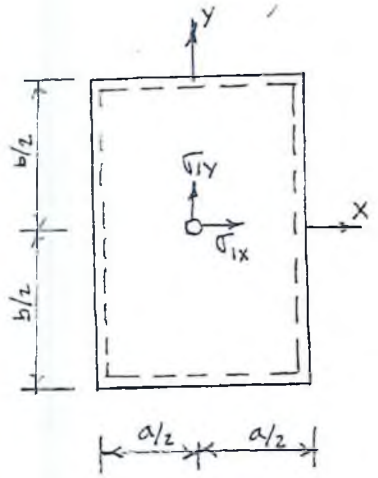


Fig 1, All edges simply supported

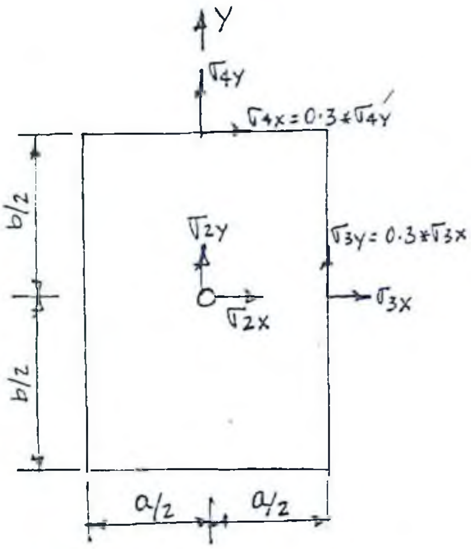


Fig 2, All edges ridgly fixed

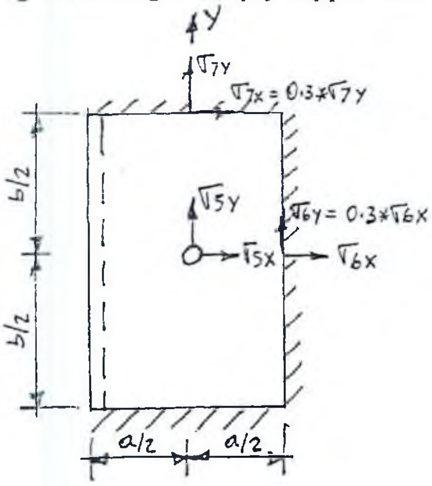


Fig 3, Two short and one long edge fixed & one long edge simply supported

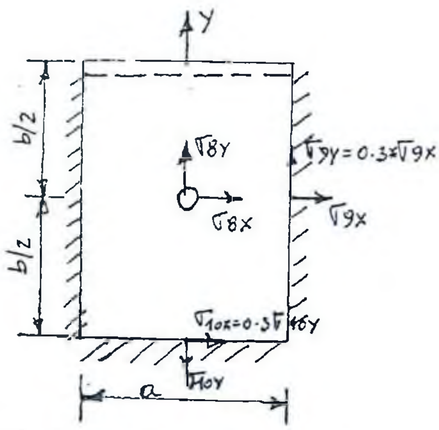


Fig 4, Two long edge and one short edges fixed & one short edge simply supported

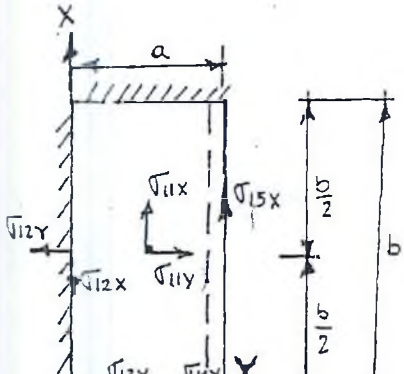


Fig5, Three edges fixed & one longer edge free

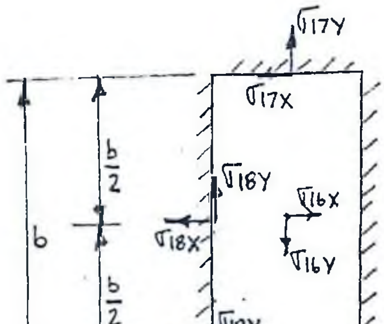


Fig 6, Three edges fixed & one (shorter) edge free

APPENDIX-A

Table 1 values of *k* for points and support conditions shown in fig. 1 to 4

b/a	$\pm\sigma_1x$	$\pm\sigma_1y$	$\pm\sigma_2x$	$\pm\sigma_2y$	$\pm\sigma_4y$	$\pm\sigma_3x$	$\pm\sigma_5x$	$\pm\sigma_5y$	$\pm\sigma_7y$	$\pm\sigma_6x$	$\pm\sigma_8x$	$\pm\sigma_8y$	$\pm\sigma_{10}y$	$\pm\sigma_9x$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
α	75	22.5	25	7.5	34.2	50	37.5	11.3	47.2	75	25	7.5	34.2	50
3	71.3	24.4	25	7.5	34.3	50	37.4	12.0	47.1	74.0	25	7.6	34.2	50
2.5	67.7	25.8	25	8.0	34.3	50	36.6	13.3	47.0	73.2	25	8.0	34.2	50
2	61.0	27.8	24.7	9.5	34.3	49.9	33.8	15.5	47.0	68.3	25	9.0	34.2	50
1.75	55.8	28.9	23.9	10.8	34.3	48.4	30.8	16.5	46.5	63.2	24.6	10.1	34.1	48.9
1.5	48.7	29.9	22.1	12.2	34.3	45.5	27.1	18.1	45.5	56.5	23.2	11.4	34.1	47.3
1.25	39.6	30.1	18.8	13.5	33.9	40.3	21.4	18.4	42.5	47.2	20.8	12.9	34.1	44.8
1	28.7	28.7	13.7	13.7	30.9	30.9	14.2	16.6	36.0	32.8	16.6	14.2	32.8	36.0

TABLE 2 VALUES OF *k* FOR POINTS AND SUPPORT CONDITIONS GIVEN IN FIG. 5

b/a	$\pm\sigma_{11}x$	$\pm\sigma_{11}y$	$\pm\sigma_{12}x$	$\pm\sigma_{12}y$	$\pm\sigma_{13}x$	$\pm\sigma_{13}y$	$\pm\sigma_{14}x$	$\pm\sigma_{14}y$	$\pm\sigma_{15}x$	$\pm\sigma_{15}y$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
∞	22·00	75·00	90·00	200·00	91·00	28·00	205·00	62·00	2·00	0
1·0	17·67	12·29	9·45	31·5	37·64	11·29	44·55	13·4	27·96	0
1·25	22·5	13·0	15·5	51·5	48·0	14·8	53·0	16·2	37·0	0
1·50	23·5	14·2	20·5	72·5	59·5	18·2	82·0	22·7	48·0	0
1·75	23·0	14·0	25·8	87·0	67·5	20·8	112·0	34·8	61·0	0
2·0	19·49	6·72	33·98	113·28	72·96	21·89	134·4	40·32	69·88	0
2·5	18·37	2·88	42·05	140·16	51·84	15·55	124·8	37·44	52·42	0
3·0	19·78	7·68	44·93	149·76	65·28	19·59	109·44	32·84	52·41	0

TABLE 3 VALUES OF *k* FOR POINTS AND SUPPORT CONDITIONS GIVEN IN FIG. 6

b/a	$\pm\sigma_{16}x$	$\pm\sigma_{16}y$	$\pm\sigma_{17}x$	$\pm\sigma_{17}y$	$\pm\sigma_{18}x$	$\pm\sigma_{18}y$	$\pm\sigma_{19}x$	$\pm\sigma_{19}y$	$\pm\sigma_{20}x$	$\pm\sigma_{20}y$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
∞	29·00	9·00	9·00	30·00	50·00	15·00	51·00	16·00	29·00	0
1·0	17·67	12·29	9·45	31·5	37·64	11·29	44·55	13·4	27·96	0
1·25	20·8	11·70	8·96	29·07	28·0	8·4	34·5	10·35	28·53	0
1·50	25·51	11·12	8·48	28·28	21·04	6·31	25·53	7·66	29·11	0
1·75	26·48	10·56	8·49	28·3	32·0	9·6	36·5	10·95	28·97	0
2·0	27·46	10·0	8·5	28·36	45·52	13·66	50·09	15·27	28·81	0
2·5	28·07	9·13	8·51	28·38	46·66	14·0	50·8	15·24	28·78	0
3·0	28·18	8·68	8·51	28·38	46·94	14·08	50·81	15·24	28·77	0

APPENDIX B
PERMISSIBLE MONOAXIAL STRESSES FOR STRUCTURAL COMPONENTS OF HYDRAULIC GATES

Ser No.	Material & Types of Stress	Wet Condition		Dry Condition	
i)	Structural Steel				
a)	Direct compression and compression in bending	0.45 YP	0.40 YP	0.55 YP	0.45 YP
b)	Direct tension and tension in bending	0.45 YP	0.40 YP	0.55 YP	0.45 YP
c)	Shear stress	0.35 YP	0.30 YP	0.40 YP	0.35 YP
d)	Combined stress	0.35 UTS	0.50 YP	0.75 YP	0.60 YP
e)	Bearing stress	0.035UTS	0.25 UTS	0.40 UTS	0.35 UTS
ii)	Bronze or Brass				
	Bearing stress	0.035 UTS	0.030 UTS	0.04 UTS	0.035 UTS

Note 1 - YP stands for minimum guaranteed yield point stress, UTS stands for ultimate tensile strength. For materials which have no definite yield point, the yield point may be taken at 0.2 percent proof stress.

Note 2 - The term 'wet condition' applies to skin plates and those components of gate which may have a sustained contact with water, for example, horizontal girder and other components located on upstream side of skin plate. The term 'dry condition' applies to al components which generally do not have a sustained contact with water, for example, girders, stiffeners, etc, on downstream side of skin plate, even though there may be likelihood of their wetting due to occasional spray of water. Stoplogs are stored above water level and are only occasionally used. Hence stresses given under dry and accessible conditions should be applied to them.

Note 3 - The term 'accessible' applies to gates which are kept in easily accessible locations and can, therefore, be frequently inspected and maintained, for example, gates and stoplogs which are stored above water level and are lowered only during operations. The term 'inaccessible' applies to gates which are kept below water level and/or are not easily available for frequent inspection and maintenance, for example, gats kept below water level or in the bonnet space even while in the raised position or gates which on account of their frequent use are generally in water.

Note 4 - In gate leaves made of cast iron, the maximum permissible tensile strength should be limited to 10 percent of ultimate tensile strength.

APPENDIX C

METHOD OF CALCULATION OF CO-ACTING WIDTH OF SKIN PLATE WITH BEAM OR STIFFENERS

METHOD

Co-acting width of skin plate is given by 2 VB.

where

V = reduction factor (non-dimensional) depends on the ratio of the support length to the span of the plate and on the action of the moments, and is ascertainable from Fig. 1 and 2 and

B = half the span of the plate between two girders (*see* Fig. 1) or overhang length of a bracket plate.

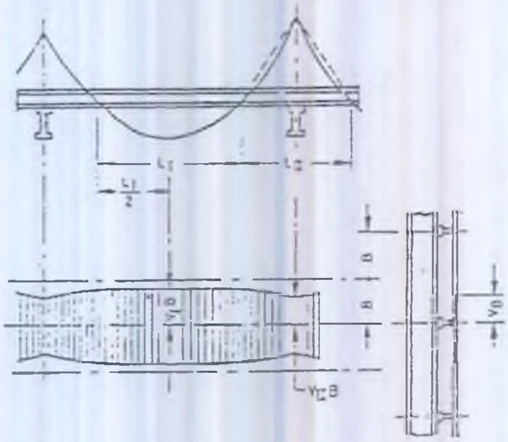


FIG. 1 FIGURE SHOWING VARIATION OF CO-ACTING WIDTH FROM SUPPORT TO SUPPORT

The ideal support length (L_I or L_{II}, *see* Fig. 1) corresponding to the length of the moment zone of equal sign shall in the case of continuous girders be basic as support length L.

In the case of single bay girders, the ideal support length corresponds to the actual.

V_I = reduction factor correponding to the parabolic moment zone (*see* Fig. 1 and 2), and

V_{II} = reduction factor corresponding to the moment zone composed of two concave parabolic stresses and approximately the triangular shaped moment zone (shown with dashes in Fig. 1 and 2).

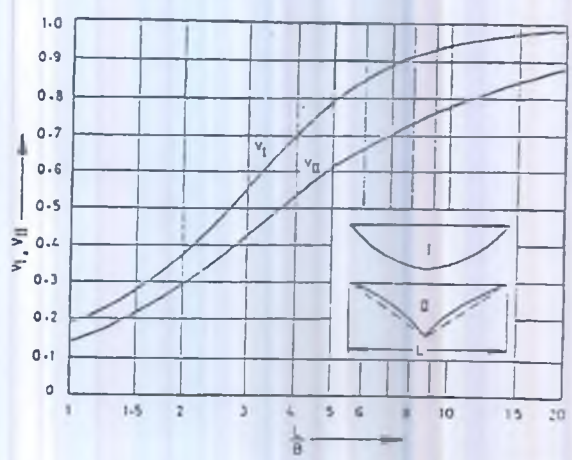


FIG. 2 CURVES SHOWING RELATIONSHIP BETWEEN $\frac{L}{B}$ AND REDUCTION FACTORS V_I AND V_{II}

Appendix – D

Illustration on the Calculation of Radial Gate Design

Design Statement.

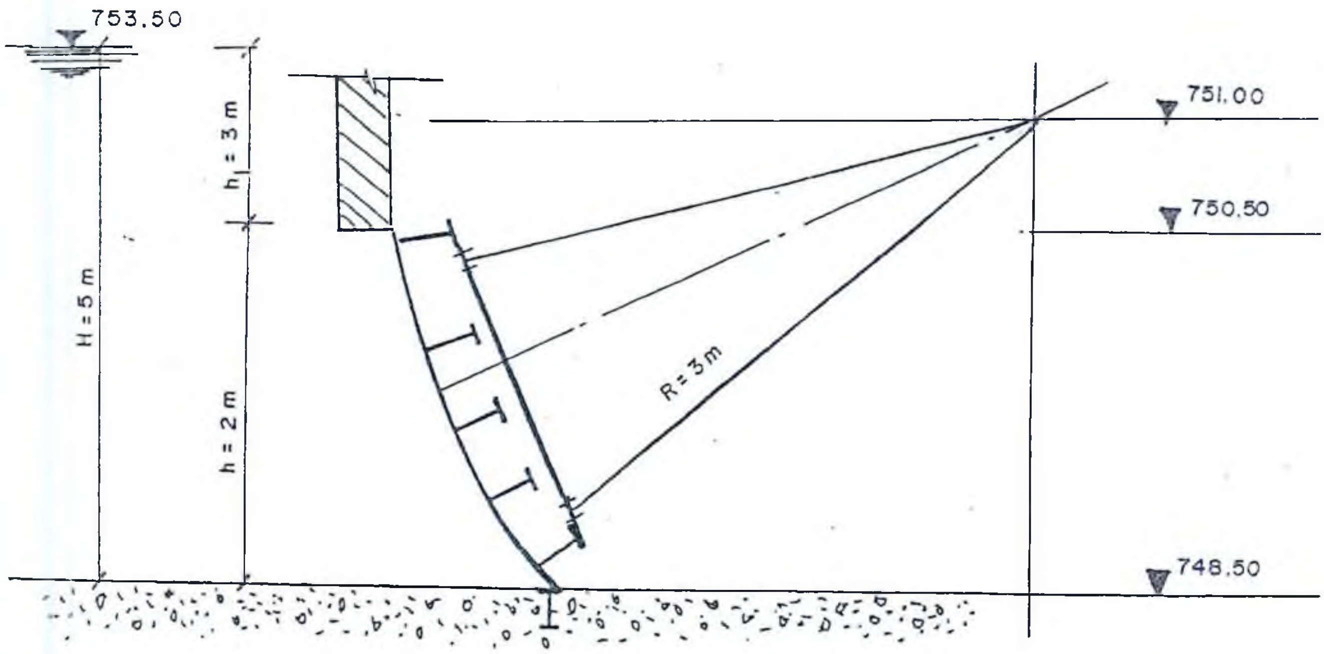
The gate of the Angelele Bolhamo Irrigation Project has the following geometry and dimensions

i) Design the radial gate and check the stress (flexure and shear) on the skin plate

ii) Design the horizontal and vertical beam and the arm.

Design condition

- Section dimension of Gate
  - Height = 2m
  - Span (B) = 4m
- Gate plate thickness (t) = 12mm
- Gate radius (R) = 3m
- Sp. Weight of water (γ) = $10KN/m^3$
- Main Material of gate = steel grade 42 ASTM A 572
- Permissible stress of main material = $\sigma_{Per.}$ = 210N/mm2, τ_{per} = 140 N/mm^2
- Number of horizontal beams = 5
- Number of Vertical beams = 2



I. Loads

Hydrostatic Pressure

$$P_1 = \gamma * h_1 = 10*3 = 30KN/m^2$$
$$P_2 = 10*5 = 50KN/m^2$$

Hydrodynamic pressure

- During discharge (assume 0.5 times the hydrostatic pressure)
  $P_1 = 0.5*30KN/m^2 = 15KN/m^2$
  $P_2 = 0.5*50KN/m^2 = 25KN/m^2$
- Earthquake
  $P_1 = 7/8 * h_t*\gamma*\alpha$; take $\alpha = 0.2$
  $P_1 = 7/8 * 3*10*0.2 = 5.25\ KN/m^2$
  $P_2 = 7/8 * 5*10*0.2 = 8.75\ KN/m^2$

Then the total design pressure will be:

$P_1 = 30 + 15 + 5.25 = 50.25\ KN/m^2$
$P_2 = 50 + 25 + 8.75 = 83.75\ KN/m^2$

Hydrostatic water load

- Horizontal component

$$W_h = \gamma * B * h\left(H - \frac{h}{2}\right) = 10*4*2\left(5 - \frac{2}{2}\right) = 320KN$$

- Vertical component

$$W_v = \gamma * B * R\left[D_m(\cos\alpha_s - \cos\alpha_t) + \frac{R}{2}(\alpha_t - \alpha_s) + \frac{R}{2}(\sin\alpha_s * \cos\alpha_s - \sin\alpha_t * \cos\alpha_t)\right]$$

According to Fig. A

D_m = EL 753.5 – EL 751 = 2.5m
D_s = EL 751 – EL 750.50 = 0.5m
D_t =EL 751 – EL 751 = 2.5m

$$\alpha_s = arc\sin\frac{D_s}{R} = arc\sin\frac{0.5}{3} = 9.5941^0 = 0.1674\,rad$$

$$\alpha_t = arc\sin\frac{D_t}{R} = arc\sin\frac{2.5}{3} = 56.4427^0 = 0.9851\,rad$$

$\cos \alpha_s = \cos 0.1674 = 0.9860$
$\cos \alpha_t = \cos 0.9851 = 0.5528$
$\sin \alpha_s = 0.1666$
$\sin \alpha_t = 0.8333$

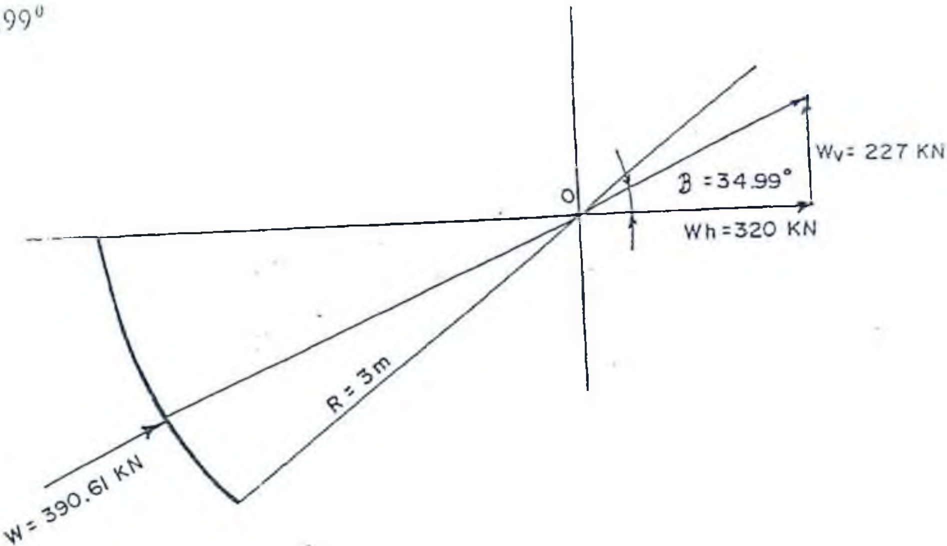
$$W_v = 10*4*3\left[2.5(0.986-0.5528)+\frac{3}{2}(0.8333-0.666)+\frac{3}{2}(0.1666*0.9860-0.8333*0.5528)\right] = 223.797KN$$

$W_v = 224KN$

Resultant water load (w)

$$W = \sqrt{W_h^2 + W_v^2} = \sqrt{(320)^2 + (224)^2} = 390.61KN$$

$$\beta = arc\tan\frac{W_v}{W_h} = arc\tan\frac{224}{320} = 34.99^0$$



Hydrodynamic water load

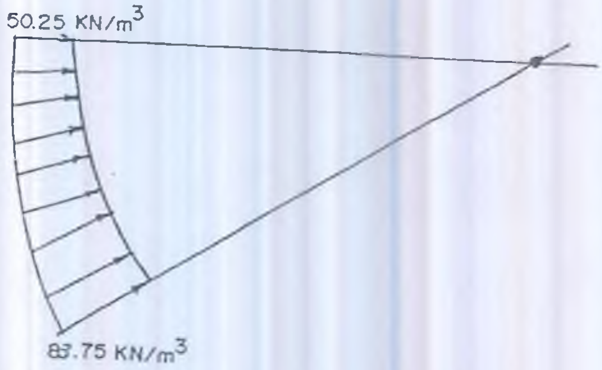
- Loads induced by flow during discharge (take 0.5 times the hydrostatic load)

  = 0.5*390.61 = 195.305KN

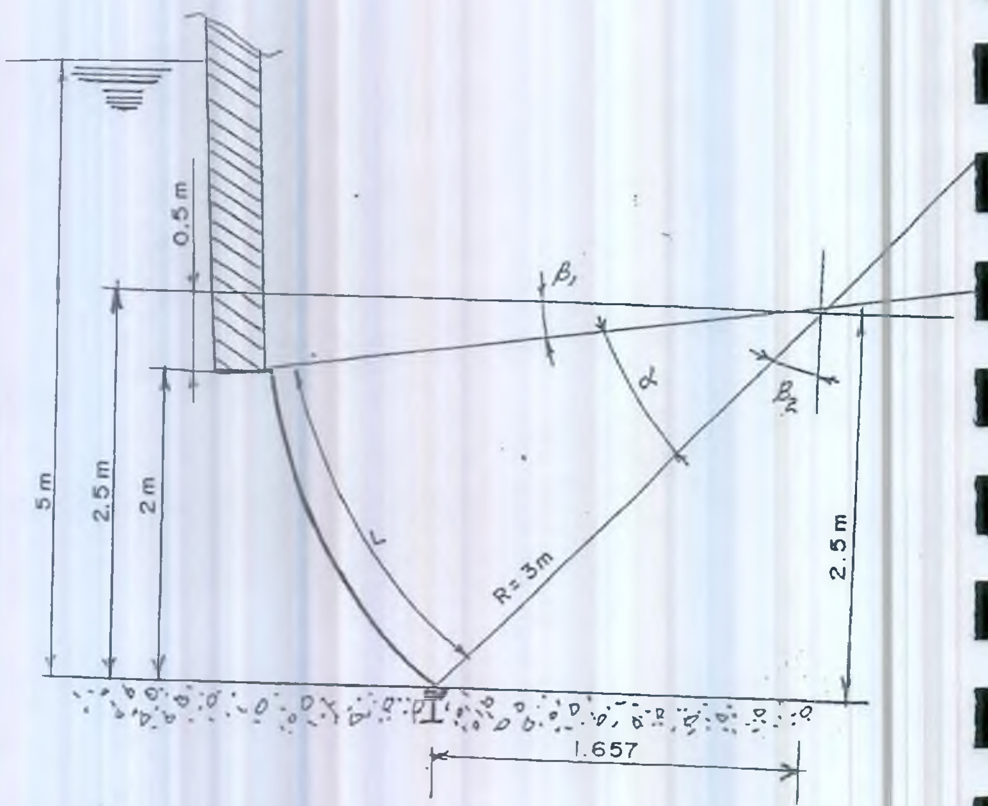
- Earthquake

  $P = 7/8*H*\gamma*\alpha$, $\alpha = 0.2$
  $P = 7/8*5*10*0.2 = 8.75KN/m^2$
  Load (p) = Pressure * gate area
  $$P = 8.75\frac{KN}{m^2}*(4m*2m) = 70KN$$

Then, the design load will be:
W = 390.61 + 195.305 + 70KN = 655.915KN
W = 656KN



II. Geometry



$$L = \frac{2\pi * R * \alpha}{360}$$

$$Sin\beta_1 = \frac{0.5}{3} = 0.1667 \Rightarrow \beta_1 = 9.594^0$$

$$Cos\beta_2 = \frac{2.5}{3} = 0.833 \Rightarrow \beta_2 = 33.557^0$$

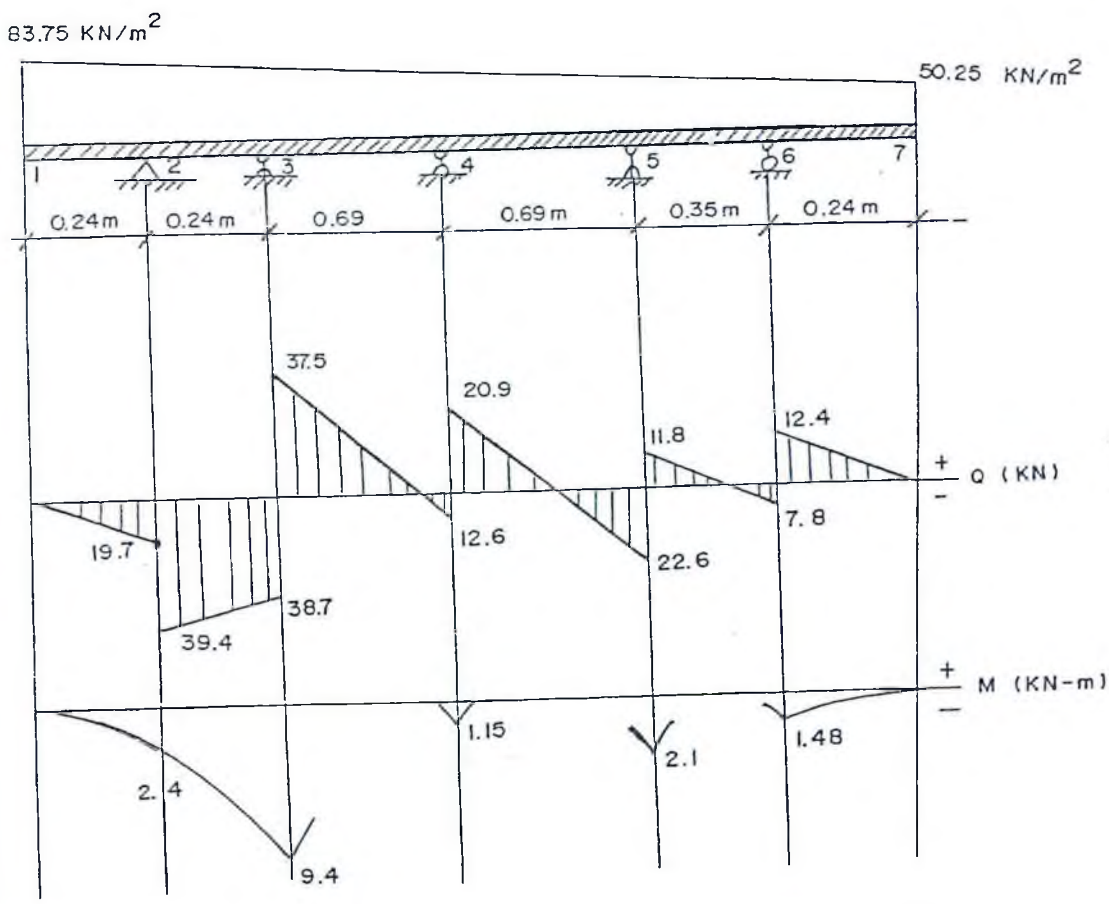
$$\alpha = 90^0 - (9.594^0 + 33.557^0) = 46.849^0$$

$$L = \frac{2\pi * 3 * 46.849}{360} = 2.450m$$

II. Summary of Calculations

Hydrostatic	390.61 KN
Hydrodynamic - During discharge - Earthquake	 195.305 KN 70.00 KN
Total design load (W)	656 KN

III. Structural Forces



The Structural analysis is carried out using a computer software "RAWEBME" and the results are tabulated below.

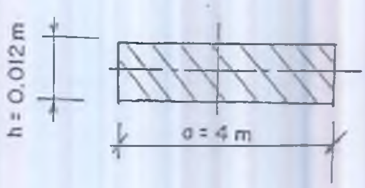
No.	Node	Shear (KN)	Moment (KN-m)
1	1	0	0
2	2	-19.716/-19.716	2.381
3	3	37.542/-38.664	9.402
4	4	-12.517/20.855	1.149
5	5	11.787/-22.615	2.134
6	6	-7.760/12.444	1.478
7	7	0	0

IV Checking stress on the skin plate.

Flexure, $\sigma_{max} = \frac{M_{max}}{z} \leq \sigma_{per}$

Where M_{max} = Maximum moment = 9.4 KN.m (see computer output)

Z = Section mod. (for rectangular section)



$$Z = \frac{bh^2}{6} = \frac{4(0.012)^2}{6}$$

$$Z = 9.6 * 10^{-5} m^3$$

$$\sigma_{max} = \frac{9.4}{9.6x10^{-5}} = 97916.7 Kn/m^2$$

$$= 97.92 N/mm^2 < 210 N/mm^2 \therefore ok$$

Shear, $\tau_{max} = \frac{P_{max}}{A} < \tau_{per}$

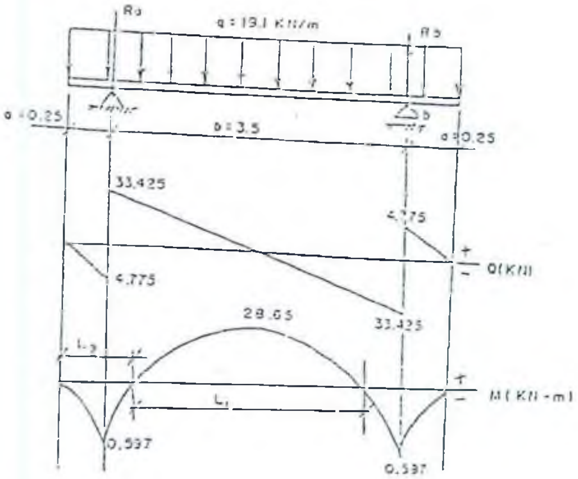
A: Area = 0.012*4=0.048m^2

$$\tau_{max} = \frac{38.7}{0.048} = 806.25 Kn/m^2$$

$$= 0.8063 N/mm^2 < 140 N/mm^2 \therefore ok$$

V. Horizontal beams

a) Load and member forces.



$$q = \frac{P_{max}}{4} = \frac{76.2065KN}{4m}$$

$$q = 19.05\frac{KN}{m}$$

$R_a = R_b = q\,[b/2+a] = 19.1\,[3.5/2 + 0.25] = 38.2KN$

- Bending moment
  - Support, $M_s = -1/2\ a^2 * q = -1/2\ (0.25)^2 * 19.1 = -0.597$ KN-m
  - Field, $M_f = M_s + 1/8\ b^2 * q = -0.597 + 1/8\ (3.5)^2 * 19.1 = 28.65$KN-m

- Shear Force
  - @the left side = a*q = 0.25*19.1 = 4.775 KN
  - @ the right side = 1/2b*q = ½ (3.5)*19.1 = 33.425 KN

b) Long direction of flange width and stresses.

- Effective flange width (b = V*B)

At Support
$L_2 = 0.26$
(L_1 and L_2, from moment diagram)
2B = 0.40m, B = 0.2m

At field
$L_1 = 3.48$

$L_2/B = 0.26/0.2 = 1.3$
$V_2 = 0.21$

$L_1/B = 3.48/0.2 = 17.4$
$V_1 = 0.98$

(V_1 and V_2, from Appendix C)

$b_2 = V_2 * B$
$= (0.21*0.2)_2$

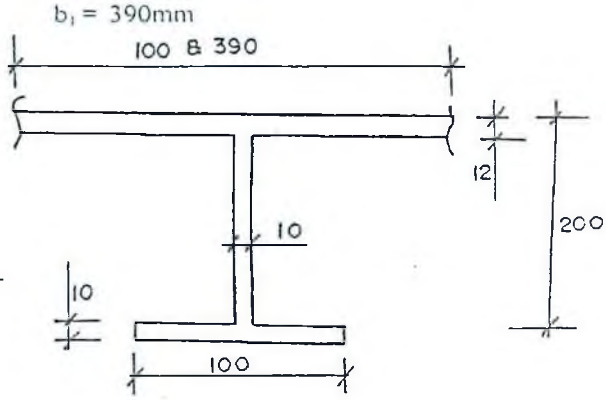
$b_2 = 0.084$m = 84mm, say

$b_2 = 100$mm

$b_1 = V_1 * B$
$= (0.98*0.2)_2 = 0.392$m

$b_1 = 392$m . say

$b_1 = 390$mm



- Stresses

$\sigma = M/Z \le \sigma_{per}$. $\tau = P/A \le \tau_{per}$

The structural section properties for the composite section is analyzed using a computer program "SEC.DIM" as shown below.

STUCTURAL SECTION PROPERTIES COMPOSITE BEAM

TITLE OF DATA:

CONCRETE DIMENSIONS:

EFFECTIVE FLANGE WIDTH= 0
CONCRETE DEPTH (SLAB) = 0
(TOTAL) = 0

STEEL BEAM DIMENSIONS:

TOP FLANGE
WIDTH = 100
THICKNESS= 12
BOTTOM FLANGE
WIDTH= 100
THICKNESS= 10
WEB
THICKNESS= 10

RATIO OF Es/Ec = 1

RESULTS OF THE COMPUTER CALCULATION:

WEB HEIGHT	CENTRE OF GRAVITY	MOMENT OF INERTIA	SECTION MOD O CONCRETE O	SECTION MOD STEEL
200	115.2857	3.108026E+07	291247.4	269593.3

STUCTURAL SECTION PROPERTIES COMPOSITE BEAM

TITLE OF DATA:

CONCRETE DIMENSIONS:

EFFECTIVE FLANGE WIDTH= 0
CONCRETE DEPTH (SLAB) = 0
(TOTAL) = 0

STEEL BEAM DIMENSIONS:

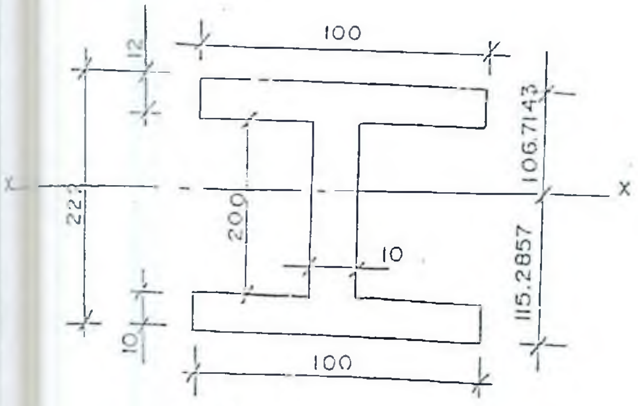
TOP FLANGE
WIDTH = 390
THICKNESS= 12
BOTTOM FLANGE
WIDTH= 100
THICKNESS= 10
WEB
THICKNESS= 10

RATIO OF Es/Ec = 1

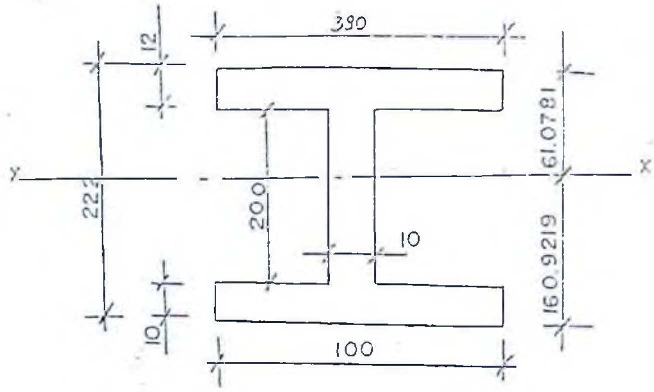
RESULTS OF THE COMPUTER CALCULATION:

WEB HEIGHT	CENTRE OF GRAVITY	MOMENT OF INERTIA	SECTION MOD O CONCRETE O	SECTION MOD STEEL
200	160.9219	5.042612E+07	823600.3	313357.8
210	167.6324	5.579736E+07	869884	334018.8
220	174.2995	6.190374E+07	914369	355154.5
230	180.9248	6.816542E+07	959060.6	376761
240	187.5099	7.478548E+07	1003963	398034.8
250	194.0562	8.176992E+07	1049089	421372.3
260	200.5652	8.912519E+07	1094436	444370.2
270	207.0382	9.685766E+07	1140014	467825.1
280	213.4764	1.049736E+08	1185827	491734.1
290	219.8811	1.134793E+08	1231879	516094
300	226.2535	1.223809E+08	1278176	540901.9

Support



Field



$$Z_{skin} = \frac{I}{Y_{skin}}$$

$$Z_{skin} = \frac{5.042612x10^7}{61.0781} = 8.26x10^5\,mm^3$$

$$= \frac{3.108026x10^7}{106.7143} = 2.9x10^5\,mm^3$$

$$Z_{flange} = \frac{3.108026x10^7}{115.2857} = 2.7x10^5\,mm^3$$

$$Z_{flange} = \frac{5.042612x10^7}{160.9219} = 3.13x10^5\,mm^3$$

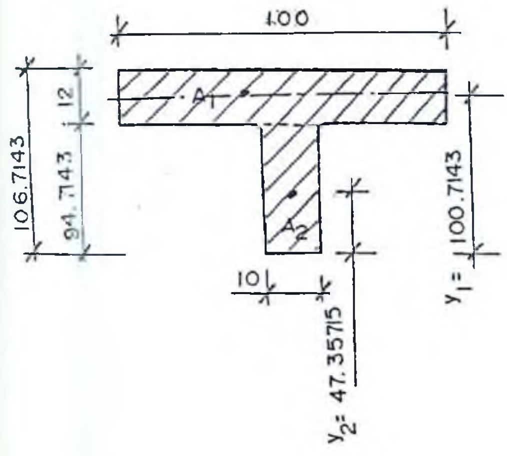
$$\sigma_{skin} = +\frac{0.597x10^6}{2.9x10^5\,mm^3} = 2.06N/mm^2$$

$$\sigma_{skin} = -\frac{28.65x10^6\,N-mm}{8.26x10^5\,mm^3} = -34.7\frac{N}{mm^2}$$

$$\sigma_{flange} = -\frac{0.597x10^6}{2.7x10^5\,mm^3} = -2.21N/mm^2$$

$$\sigma_{flange} = +\frac{28.65x10^6\,N-mm}{3.13x10^5\,mm^3} = 91.5\frac{N}{mm^2}$$

All values of σ are less than 210 N/mm^2 $\therefore$ ok



$$Q = A_1\,Y_1 + A_2\,Y_2$$

$$Q = (100*12*100.7143) + (10*94.7143*47.35715)$$

$$Q = 165711.2mm^3$$

$$\tau = \frac{V*Q}{I*b} \le \tau_{permissible}$$

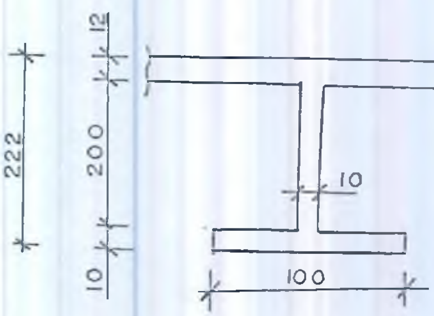
$$= \frac{38.2x10^3\,N*165711.2mm^3}{3.108026x10^7\,mm^4*12mm}$$

$$= 16.97N/mm^2 < 140N/mm^2 \;\therefore ok$$

Summary of the results

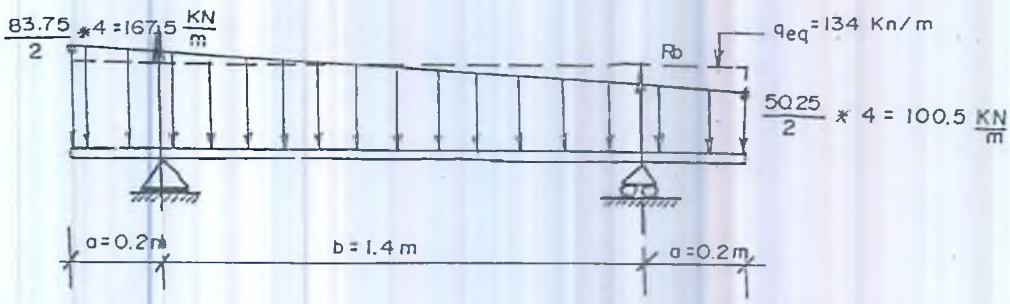
	σ_{skin} (N/mm^2)	σ_{flange} (N/mm^2)	τ (N/mm^2)
Field	-34.7	91.5	-----
Support	2.06	-2.21	16.97

Section adopted



VI. Vertical beams

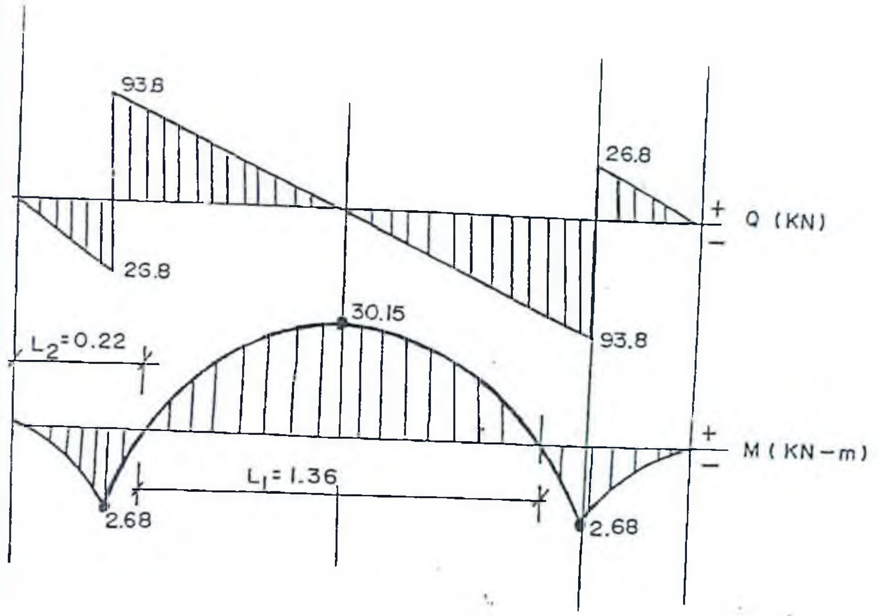
a) Loads and member forces.



$$q_{eq} = \frac{167.5 + 100.5}{2} = 134 KN/m$$

$$R_a = R_b = q_{eq}\left[\frac{b}{2}+a\right] = 134\left[\frac{1.4}{2}+0.2\right] = 120.6KN$$

- Bending moment
  - Support . $M_s = -1/2\ a^2 * q = -1/2 * (0.2)^2 * 134 = -2.68KN\text{-}M$
  - Field . $M_f = M_s + 1/8\ b^2 * q = -2.68 + 1/8\ (1.4)^2 * 134 = 30.15KN\text{-}M$
- Shear fore
  - @ the left side , $a*q = 0.2 * 134 = 26.8$ KN
  - @ the right side , $½ * b * q = 93.8$ KN



STUCTURAL SECTION PROPERTIES COMPOSITE BEAM

TITLE OF DATA:

CONCRETE DIMENSIONS:

EFFECTIVE FLANGE WIDTH= 0
CONCRETE DEPTH (SLAB) = 0
(TOTAL) = 0

STEEL BEAM DIMENSIONS:

TOP FLANGE
WIDTH = 250
THICKNESS= 12
BOTTOM FLANGE
WIDTH= 150
THICKNESS= 10
WEB
THICKNESS= 10

RATIO OF Es/Ec = 1

RESULTS OF THE COMPUTER CALCULATION:

WEB HEIGHT	CENTRE OF GRAVITY	MOMENT OF INERTIA	SECTION MOD O CONCRETE O	SECTION MOD STEEL
250	163.2857	8.430176E+07	773443.3	516283.7
260	168.9437	9.157274E+07	809974.5	542031.3
270	174.3833	9.919275E+07	844792.8	568168.5
280	180.2055	1.071676E+08	879900.2	594693.6
290	185.8108	1.155008E+08	915298.7	621604.3
300	191.4	1.241993E+08	950990.1	648899.2
310	196.9737	1.332677E+08	986975.9	676576.3
320	202.5325	1.427113E+08	1023258	704634.1
330	208.0769	1.525352E+08	1059838	733071
340	213.6076	1.627445E+08	1096717	761885.5
350	219.125	1.733446E+08	1133897	791076.1

STUCTURAL SECTION PROPERTIES COMPOSITE BEAM

TITLE OF DATA:

CONCRETE DIMENSIONS:

EFFECTIVE FLANGE WIDTH= 0
CONCRETE DEPTH (SLAB) = 0
(TOTAL) = 0

STEEL BEAM DIMENSIONS:

TOP FLANGE
WIDTH = 300
THICKNESS= 12
BOTTOM FLANGE
WIDTH= 150
THICKNESS= 10
WEB
THICKNESS= 10

RATIO OF Es/Ec = 1

RESULTS OF THE COMPUTER CALCULATION:

WEB HEIGHT	CENTRE OF GRAVITY	MOMENT OF INERTIA	SECTION MOD CONCRETE	SECTION MOD STEEL
250	171.3947	9.015924E+07	895970.4	525916.7
260	177.2857	[illegible]	935123.1	552332.9
270	183.1538	[illegible]	974542.6	579159.1
280	189	1.146002E+08	1014232	606392.8
290	194.825	[illegible]	1054194	634031.7
300	200.6296	1.320316E+08	1094432	662073.7
310	206.4146	[illegible]	1134947	690516.6
320	212.1807	[illegible]	1175742	719358.5
330	217.9286	[illegible]	1216820	748597.3
340	223.6588	[illegible]	1258182	778231.5
350	229.3721	[illegible]	1299830	808259.1

b) Short direction flange width

- Effective flange width (b = V*B)

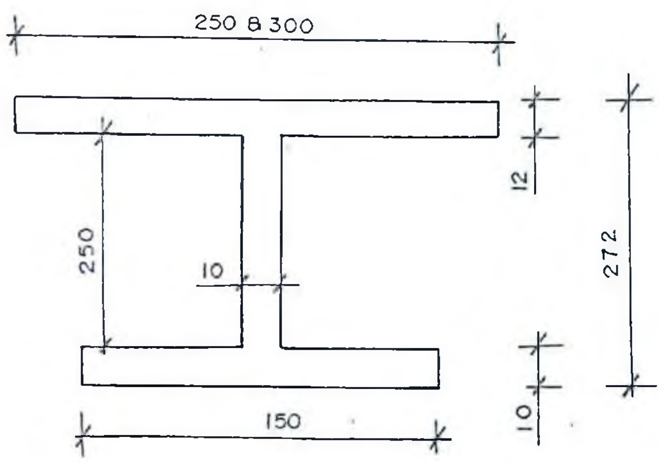
$$2B = 1.4 \Rightarrow B = 0.7$$

$$\frac{L_2}{B} = \frac{0.22}{0.7} = 0.31 \Rightarrow V = 0.42$$

$$b_2 = (V * B) = 0.42 * 0.7 = 294mm,\ say\ 300m$$

$$\frac{L_1}{B} = \frac{1.36}{0.7} = 1.94 \Rightarrow V = 0.34$$

$$b_1 = (V * B) = 0.34 * 0.7 = 0.238m,\ say\ 250mm$$



- Check stress
- Support

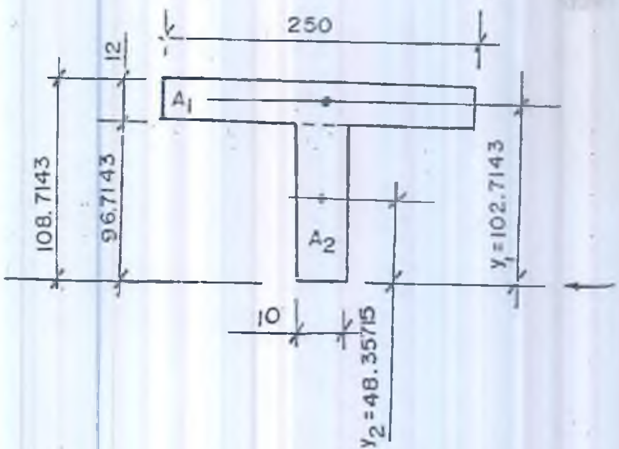
$$\sigma_{skin} = +\frac{2.68 \quad x10^6 N - mm}{7.75x10^5 mm^3} = 3.46 N/mm^2 \subset 240 N/mm^2$$

$$\sigma_{flange} = -\frac{2.68 \quad x10^6 N - mm}{5.16x10^5 mm^3} = -5.19 N/mm^2 \subset 240 N/mm^2$$

- Field

$$\sigma_{skin} = -\frac{30.15 \quad x10^6 N - mm}{8.9597x10^5 mm^3} = -33.65 N/mm^2 \subset 240 N/mm^2$$

$$\sigma_{flange} = \frac{30.15 \quad x10^6 N - mm}{5.2592x10^5 mm^3} = 57.33 N/mm^2 \subset 240 N/mm^2$$



$$Q = A_1 * Y_1 + A_2 * Y_2$$
$$Q = (250*12*102.7) + (10*96.7*48.4)$$
$$Q = 3.55x10^5 mm^3$$

$$\tau = \frac{V*Q}{I*b} \subseteq \tau_{per.}$$

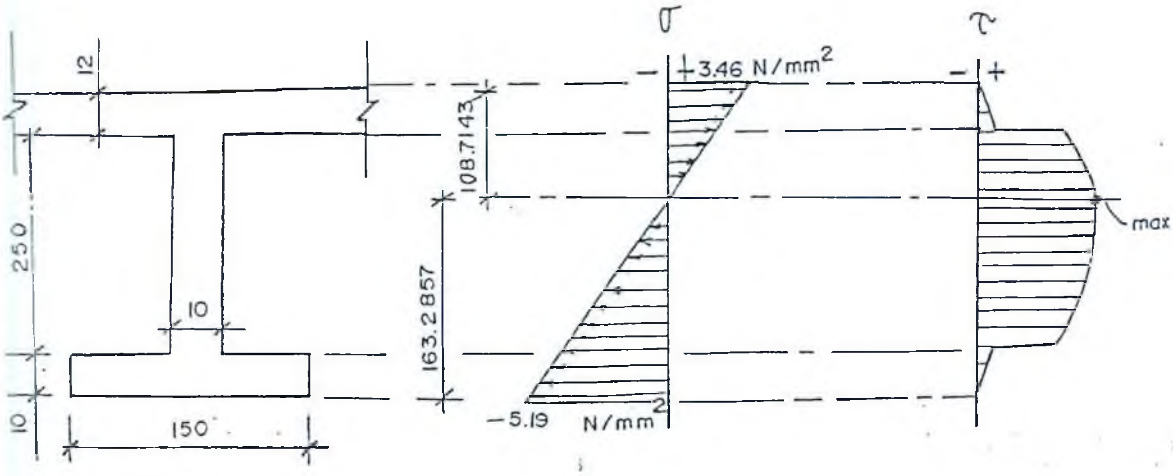
$$\tau = \frac{120.6\ x10^3 * 3.55x10^5}{8.43x10^7 * 12}$$

$= 42.32 N/mm^2 < 140 N/mm^2 \quad \therefore ok$

Summary of Results

	σ_{Skin} (N/mm²)	σ_{flange} (N/mm²)	τ (N/mm²)
Field	- 33.65	57.33	-
Support	3.46	-5.19	42.32

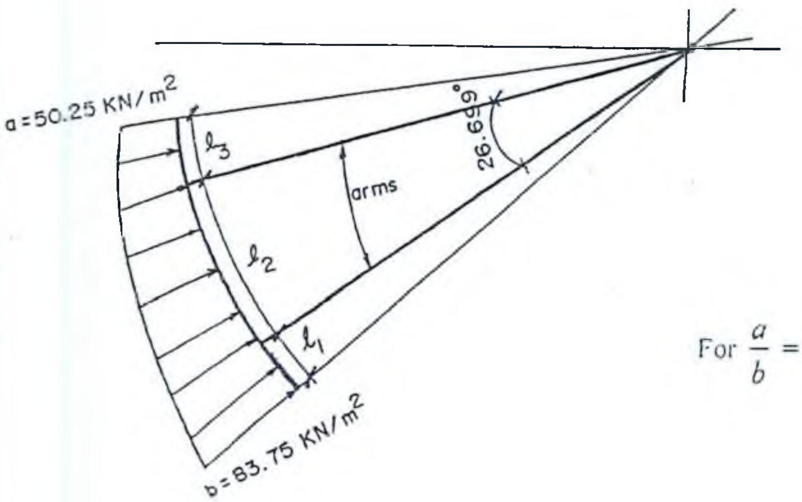
Section adopted



VII. Design of the arm

a) Loads and member forces

- Position of arms (see radial gates design procedure)



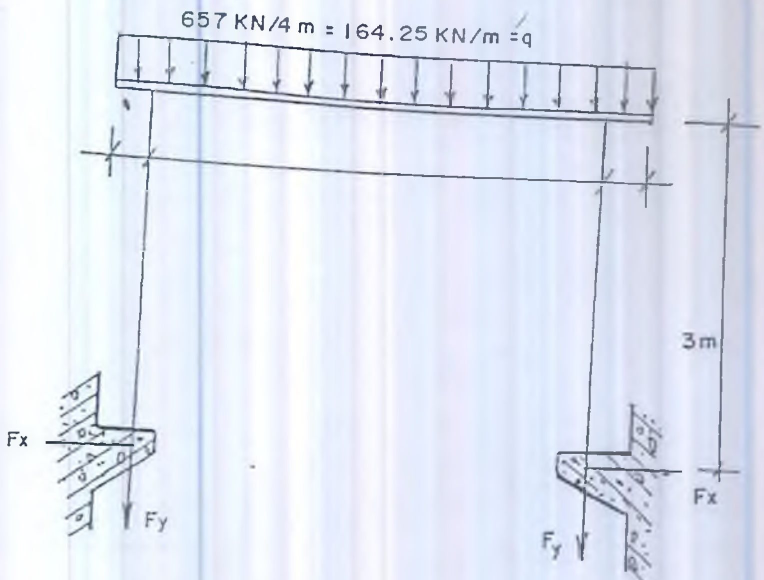
$$\frac{a}{b} = \frac{50.25}{83.75} = 0.6$$

For $\frac{a}{b} = 0.6$, α=0.1918, β=0.57, γ=0.2382 } Appendix K

$L_1 = \alpha * L = 0.1918 * 2.450 = 0.47$m

$L_2 = \beta * L = 0.57 * 2.450 = 1.396$m

$L_3 = \delta * L = 0.2382 * 2.450 = 0.584$m



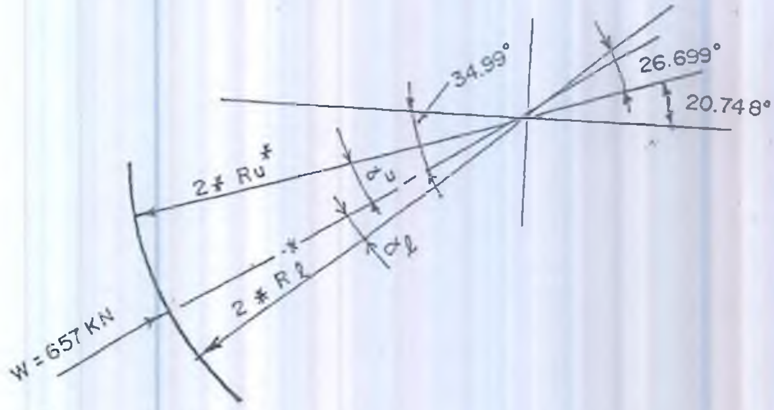
$$F_x = \frac{1}{2} W * \tan \varpi$$

W=657KN, ϖ= o°

$F_x = 0$

$$F_Y = \frac{1}{2} W = \frac{1}{2} * 657 = 328.5 KN$$

- Axial load on arms



$\alpha_u = 34.99^0 - 20.748^0$
$\alpha_u = 14.242^0$
$\alpha_l = 26.699^0 - 14.242^0$
$\alpha_l = 12.457^0$

- Upper arm

$$R_u^* = \frac{W}{2} * \frac{\sin \alpha_l}{\sin(\alpha_l + \alpha_u)} = \frac{657}{2}\left[\frac{\sin 12.457^0}{\sin(12.457^0 + 14.242^0)}\right] = 157.71 KN$$

- Lower arm

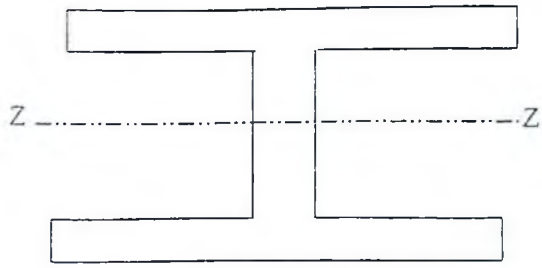
$$R_l^* = \frac{W}{2} * \frac{\sin \alpha_u}{\sin(\alpha_l + \alpha_u)} = \frac{657}{2}\left[\frac{\sin 14.242^0}{\sin(12.457^0 + 14.242^0)}\right] = 179.87 KN$$

$$\sigma = \frac{P}{A} \subseteq \sigma_{per.}$$

$$\sigma = \frac{179.87 KN}{3880 mm^2} = 0.0464 \frac{KN}{mm^2}$$

$= 46.36\ N/mm^2 < 210\ N/mm^2$ $\therefore$ ok

Bucking on Z axis



$$F_a = \frac{F_y}{F_s}\left[1 - \frac{(KL/r_z)^2}{2C_c^2}\right]$$

$$C_c = \sqrt{\frac{2\pi^2 * E}{F_y}}$$

Where: F_a = allowable stress on gross area under service, or working, load.

F_s = factor of safety

K = factor that depends on the end conditions.
or effective – length factor
K = 0.5 for a column with both ends fixed
L = Length of column b/n supports = 3m
r_z = radius of gyration of column section
r = 6.57m
F_y = yeald point of the steel
For steel grade st – 37 F_y = 235.4 N/mm^2
E = 2.15x10^5 N/mm^2

$$C_c = \sqrt{\frac{2 * \pi^2 * 2.15x10^5 N/mm^2}{235.4 N/mm^2}} = 134.27$$

$$KL/r_z = \frac{0.5 * 3}{6.57} = 0.23$$

$$F_s = \frac{5}{3} + \frac{3}{8}\frac{KL/r_z}{C_c} - \frac{1}{8}\left(\frac{KL/r_z}{C_c}\right)^3$$

$$F_s = \frac{5}{3} + \frac{3}{8}\left(\frac{0.23}{134.27}\right) - \frac{1}{8}\left(\frac{0.23}{134.27}\right)^3$$

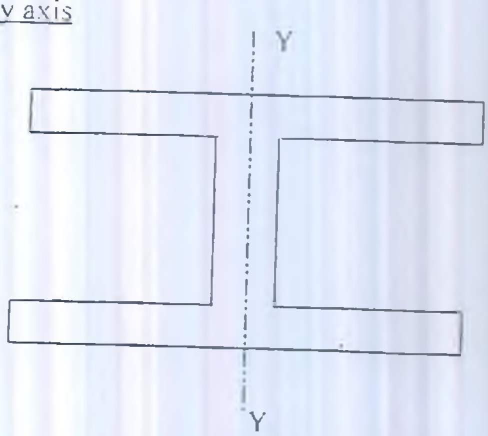
$F_s = 1.67$

$$F_a = \frac{235.4N/mm^2}{1.67}\left[1 - \frac{(0.23)^2}{2(134.27)^2}\right]$$

$F_a = 140.96/mm^2$

140.96 N/mm^2 > 46.36 N/mm^2

<u>Bucking on y axis</u>



K = 0.5
L = 3m
γ_y = 3.98m
E = 2.15 x 10^5 N/mm^2
F_y = 235.4 N/mm^2
C_c = 134.27

$$KL/r_y = \frac{0.5*3}{3.98}$$

= 0.38

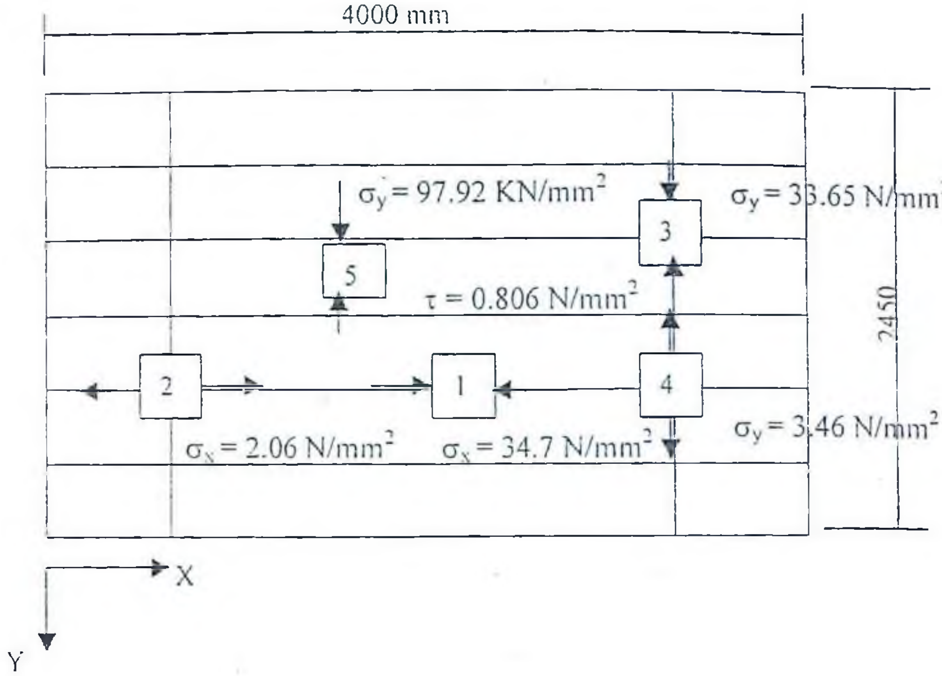
$$F_s = \frac{5}{3} + \frac{3}{8}\left(\frac{KL/ry}{C_c}\right) - \frac{1}{8}\left(\frac{Kl/ry}{C_c}\right)^3$$

$$= \frac{5}{3} + \frac{3}{8}\left(\frac{0.38}{134.27}\right) - \frac{1}{8}\left(\frac{0.38}{134.27}\right)^3 = 1.67$$

$$F_a = \frac{235.4}{1.67}\left[\frac{(0.38)^2}{2(134.27)^2}\right] = 140.96N/mm^2$$

140.96 N/mm^2 > 46.36 N/mm^2

Equivalent stress in the skin plate



Section	σ_x [N/mm²]	σ_y [N/mm²]	τ [N/mm²]
1 and 5	34.7	97.92	0.806
2 and 3	2.06	33.65	-
2 and 4	2.06	3.46	-

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\tau_{xy}^2} \leq \sigma_{per}$$

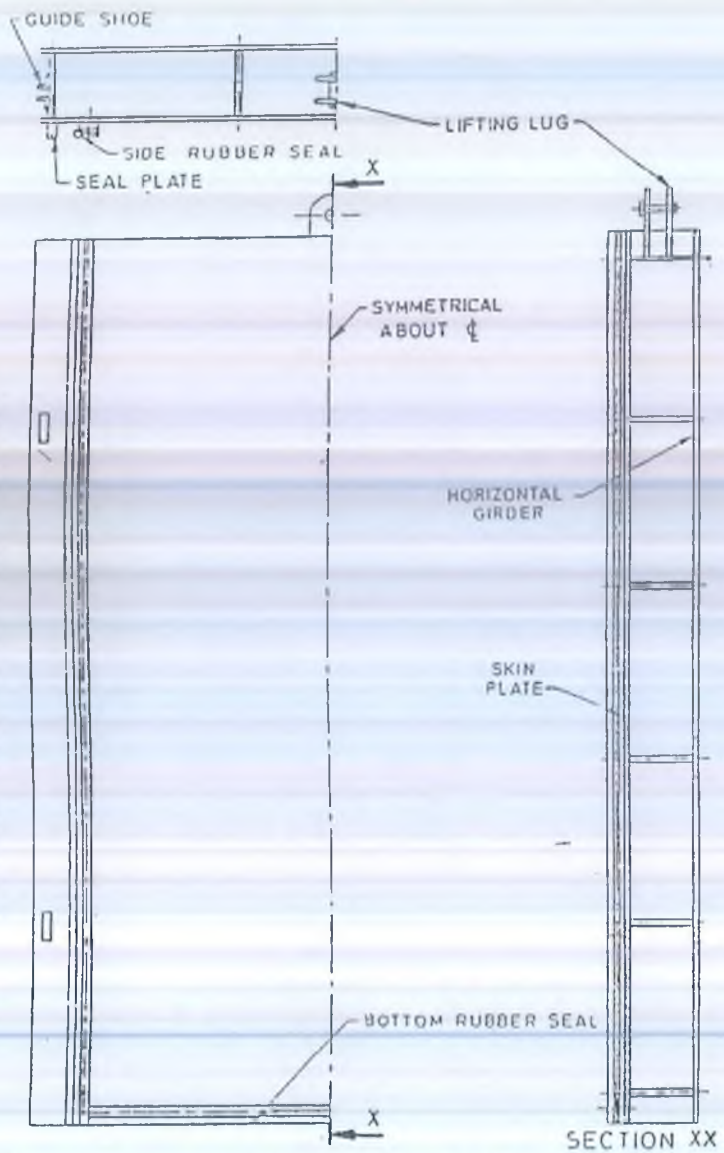
Section 1 and 5

$$\sigma_e = \sqrt{(34.7)^2 + (97.92)^2 + 34.7 * 97.92 + 3(0.806)^2}$$

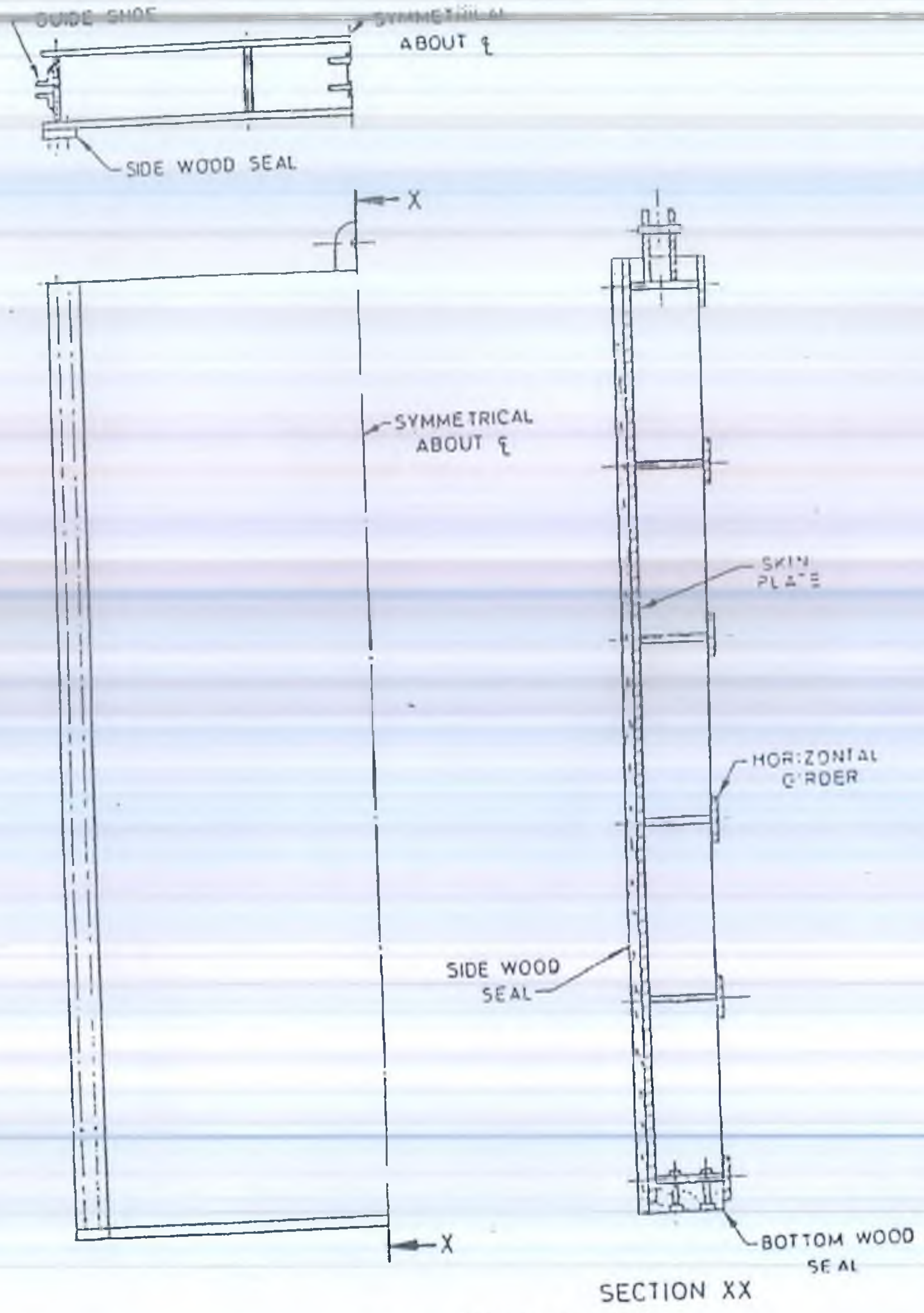
$= 119.13$ N/mm² < 240 N/mm² $\therefore$ OK

APENDIX-E

TYPICAL WATE SEAL ARRENGMENT

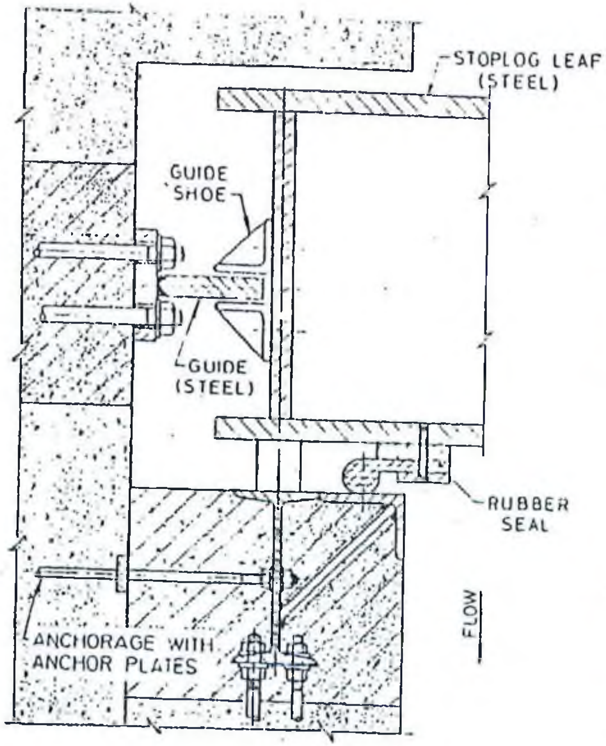


Stoplog (With Rubber Seal)

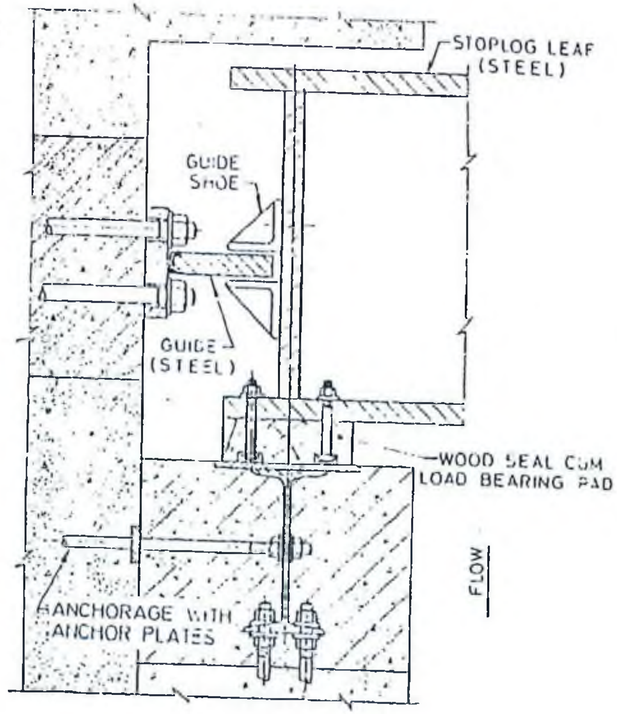


Stoplog (With Wood Seal)

APPENDIX - E
(Contd.)



Details of Rubber Seal



6D Details of Wood Seal

APPENDIX F

a) TOLERANCE FOR EMBEDDED PARTS AND COMPONENTS OF SLIDE GATES

Components	Tolerances (mm)
a.1 EMBEDDED PARTS	
i) Side Seal Seal:	
a) Alignment in plane parallel to flow	± 0.50
b) Distance between center line of opening and seal seat	± 1.50
ii) Top Seal Seal:	
a) Alignment parallel to flow	± 3.00
b) Height above sill	± 1.50
iii) Side Guide Track:	
a) Alignment in plane normal to flow	± 1.50
b) Distance between center line of opening and guide track	± 1.00
c) Alignment in plane parallel to flow	± 1.00
iv Critical Dimensions:	
a) Centre-to-centre distance between side seal seat	± 3.00
b) Face-to-face distance between side guide tracks	± 2.00
a.2 GATE	
i) Side and Top Seal Seat:	
a) Alignment parallel to flow	± 0.50
b) Coplanerness	± 0.50
ii) Side Guide:	
a) Alignment parallel to flow	± 1.50
iii) Critical Dimensions:	
a) Center to center distance between side seal plates	± 1.50
b) Face-to-face distance between side guides	± 1.50

a) TOLERANCE FOR EMBEDDED PARTS AND COMPONENTS OF RADIAL GAGES

Components	Tolerances
b.1) EMBEDDED PARTS	
a) Distance between centre line of opening and face of wall plate at sill end	+ 0.00 - 2.00
b) Distance between centre line of opening and face of wall plate at top end	+ 2.00 - 0.00
c) Straightness of face of wall plates and sill plates	Offset at joints to be ground smooth
d) Normally of face of wall plate to gate sill and center line of trunnion bearings	± 0.01° - 0.00°
e) Alignment of sill plate in horizontal plane	± 0.25
b.2) COMPONENTS OF GATE	
1) Guide Roiler/Guide Shoe:	
Distance between center line of gate and face of guide roller/guide shoe	+ 0.0 - 2.00mm
or	
2) Side Seal	
Distance between center line of gate and face of side seal	± 1.0mm
3) Trunnion Bearings:	
a) Colinearity of center lines of both the trunnion bearings	± 0.25
b) Horizontality of center lines of both the trunnion bearings	± 0.25
c) Parallel distance of center lines of both the trunnion bearings from upstream bottom edge of skin plate	± 3.00
d) Tolerances in diameters of pin, hub and bracket of trunnion assembly	To suit diameters & required fits

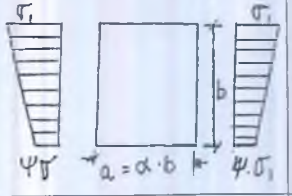
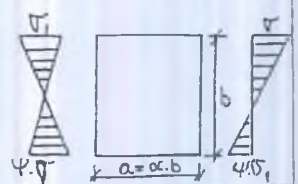
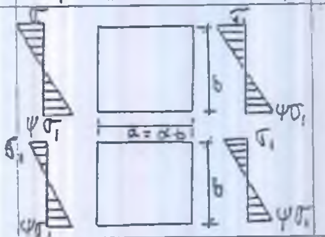
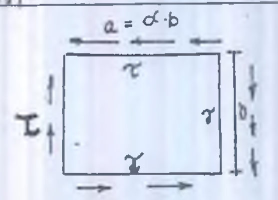
APPENDIX G

RECOMMENDED VALUES OF COEFFICIENTS OF FRICTION TO BE USED IN THE DESIGN OF SLIDE GATES

Ser No	Material	Coefficient of Friction	
		Starting	Moving
i.	Rubber seal on steal	1.5	1.20
ii.	Brass on bronze	0.40	0.25
iii.	Brass of branz on steel	0.5	0.30
iv.	Steel on steel	0.6	0.40
v.	Stainless steel on steel	0.50	0.30
vi.	Wood on steel	1.00	0.70
vii.	Gun metal on gun metal	0.40	0.25
viii	Fluorocarbon on stainless steel	0.20	0.15

Appendix H

Buckling Coefficients K_1, K_2 (DIN 4114)

	1		2	3	4
1	Load		Buckling Stress	Region	Buckling Coeff.
2	Compression stress $0 \leq \Psi \leq 1$		$\sigma_{ki} = K_1 . \sigma_E$	$\alpha \geq 1$	$K_1 = \frac{8.4}{\psi + 1.1}$
				$\alpha < 1$	$K_1 = \left(\alpha + \frac{1}{\alpha}\right)^2 \frac{2.1}{\psi + 1.1}$
3	Compression and tension $-1 < \Psi < 0$		$\sigma_{ki} = K_1 . \sigma_E$	$\alpha < 1$	*
4	Compression and tension with a limit value of $\Psi = 1$ tension $\Psi < -1$		$\sigma_{ki} = K_1 . \sigma_E$	$\alpha \geq \frac{2}{3}$	$K_1 = 23.9$
				$\alpha < \frac{2}{3}$	**
5	Shear Stress uniform distributed		$\tau_{ki} = K_2 . \sigma_E$	$\alpha \geq 1$	$K_2 = 5.34 + \frac{4}{\alpha^2}$
				$\alpha < 1$	$K_2 = 4 + \frac{5.34}{\alpha^2}$

$* K_1 = (1+\Psi) K' - \Psi K'' + 10 \Psi (1+\Psi)$

K' = buckling coeff. for $\Psi = 0$ (line2)

K'' = buckling coeff. for $\Psi = -1$ (line 4)

$** K1 = 15.87 + \frac{1.87}{\alpha^2} + 8.6 \alpha^2$

Appendix I.

Approximate weight of gates.

No	Gate type	Approximate weight
1	Radial (Surface)	$G = 0.698\ (B^2*h*H)^{0.675}$
2	Radial (Submerged)	$G = 3.688\ (B^2*h*H)^{0.521}$
3	Slide gate with $B^2*h*H>2m^4$	$G = 0.706\ (B^2*h*H)^{0.7}$
4	Slide gate with $B^2*h*H<2m^4$	$G = 0.888\ (B^2*h*H)^{0.659}$
5	Stop logs	$G = 0.503\ (B^2*h*H)^{0.716}$
6	Flap gate	$G = 2.389\ B(h*H)^{0.643}$
7	-	-

G = Weight of the gate, KN

B = Gate span, m

h = Gate height, m

H = Head of water over sill, m

Appendix J

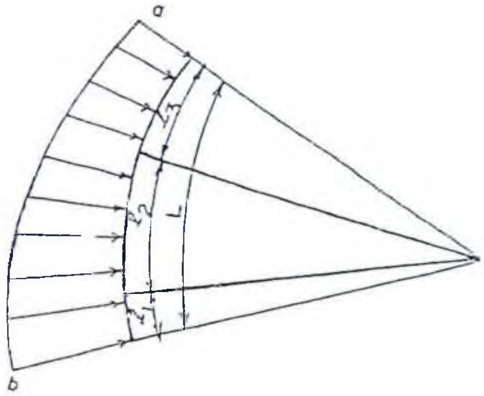
Compression stress (Reduced)

σ_{fic} [N/mm^2]	σ_{cr} [N/mm^2]	
	Steel st-37 {f_y = 235.4 N/mm2}	Steel st-52 {f_y = 353.2 N/mm^2}
188.4	188.4	188.4
196.2	194.5	196.2
206.0	199.7	206.0
215.8	203.8	215.8
225.6	206.9	225.6
235.4	209.5	235.4
245.3	211.7	245.3
255.1	213.7	225.1
226.9	215.2	226.9
274.7	216.7	274.7
284.5	217.9	284.4
294.3	219.1	291.7
313.9	220.9	301.9
333.5	222.4	308.9
353.2	223.7	314.2
372.8	224.7	318.6
392.4	225.6	322.2
412.0	226.4	325.0
431.6	227.1	327.5
451.3	227.7	329.5
470.9	228.2	331.4
490.5	228.7	333.0
539.6	229.6	336.1
588.6	230.2	338.4
637.7	230.8	340.3
686.7	231.3	341.8
784.8	232.1	343.9
981.0	232.9	346.5
1962.0	234.4	350.6
∞	235.4	353.2

Appendix K

Position of arms

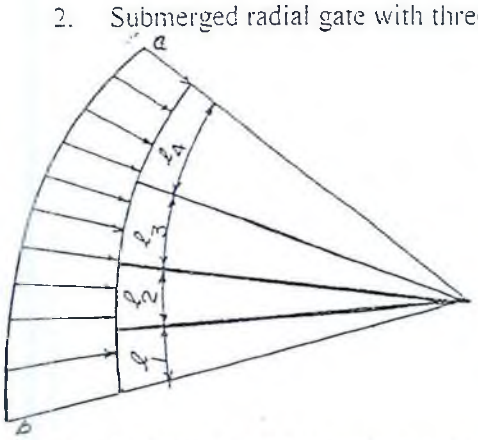
1. Submerged radial gate with two arms.



a/b	α	β	Υ
0.1	0.1536	0.5114	0.3350
0.2	0.1634	0.5348	0.3018
0.3	0.1718	0.5496	0.2786
0.4	0.1790	0.5596	0.2614
0.5	0.1858	0.5656	0.2486
0.6	0.1918	0.5700	0.2382
0.7	0.1974	0.5728	0.2298
0.8	0.2028	0.5740	0.2232
0.9	0.2078	0.5748	0.2174

$l_1 = \alpha * L$
$l_2 = \beta * L$
$l_3 = \Upsilon * L$

2. Submerged radial gate with three arms.



a/b	α	β	Υ	δ
0.1	0.1046	0.3029	0.3462	0.2468
0.2	0.1111	0.3105	0.3567	0.2157
0.3	0.1167	0.3262	0.3613	0.1958
0.4	0.1216	0.3338	0.3628	0.1818
0.5	0.1262	0.3394	0.3627	0.1717
0.6	0.130	0.34	0.3619	0.1639
0.7	0.1343	0.3475	0.3605	0.1577
0.8	0.1381	0.3505	0.3587	0.1527
0.9	0.1416	0.3531	0.3568	0.1485

$l_1 = \alpha * L$
$l_2 = \beta * L$
$l_3 = \Upsilon * L$
$\delta * L = l_4$

3. Surface radial gate with two arms

$l_1 = 0.1414 * L$

$l_2 = 0.4737 * L$

$l_3 = 0.3852 * L$

4. Surface radial gate with three arms.

$l_1 = 0.0964 * L$

$l_2 = 0.2824 * L$

$l_3 = 0.3233 * L$

$l_4 = 0.2999 * L$