THIRD EDITION

THE OIL & GAS ENGINEERING GUIDE

Hervé Baron

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Guide

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Preface

Oil & Gas project teams are very international and diverse, therefore practices spread quickly. The industry has developed advanced execution methods in all areas.

So, it is rather surprising to find that so many projects fail, in the sense that they are subject to large delays and cost overruns. It is also frustrating to find that many projects fail for the same reasons.

The existing Engineering and Project Management courses are often theoretical and provide few practical resources to implement on the job.

This observation prompted IFP Training to develop a wide range of project management training courses. The author is in charge of the Engineering management course.

Hervé consolidated his experiences while working on many projects and with engineering majors. He derived, and describes in this book, the effective and proven methods to conduct Engineering activities.

I am convinced that this material will prove a significant help to improve project execution.

J.-L. Karnik, CEO, IFP Training

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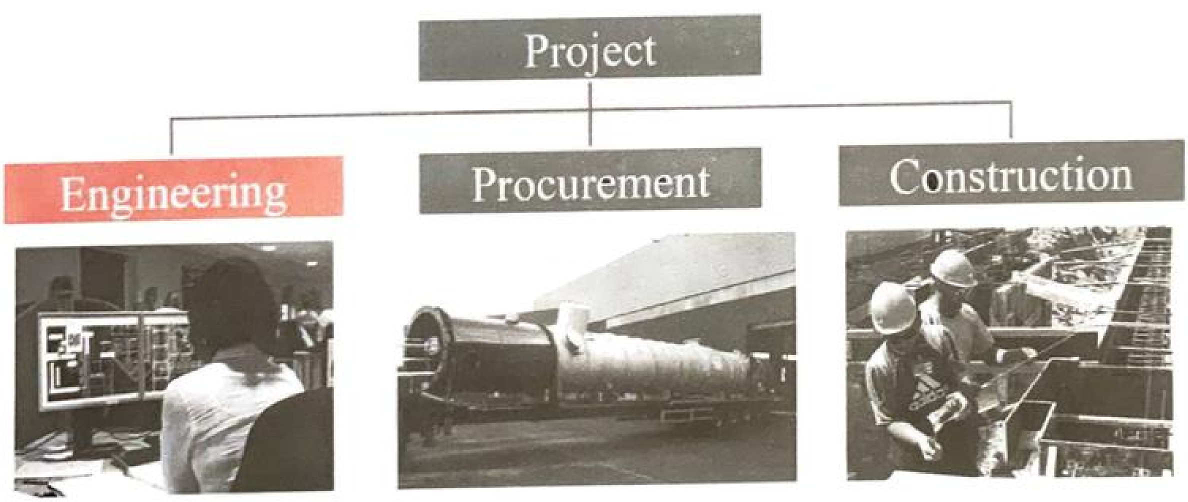
Usual Engineering Abbreviations

3D	3 Dimensions
BOM	Bill Of Materials
BOQ	Bill Of Quantities
CWI	Civil Works Installation drawing
DCS	Distributed Control System
EPC	Engineering, Procurement and Construction
ESD	Emergency Shut Down
FEED	Front End Engineering Design
F&G	Fire and Gas
GAD	General Arrangement Drawing
HAZID	HAZard and IDentification
HAZOP	HAZard and OPerability study
HMB	Heat and Material/Mass Balance
HSE	Health, Safety and Environment
HVAC	Heating, Ventilation and Air Conditioning
ICSS	Integrated Control and Safety System
IFC	Issue For Construction
IFD	Issue For Design
IFR	Issue For Review
LLI	Long Lead Item
LSTK	Lump Sum Turn-Key
MTO	Material Take-Off
NDE	Non Destructive Examination
PCS	Process Control System
PFD	Process Flow Diagram
P&ID	Piping & Instrumentation Diagram
PWHT	Post Weld Heat Treatment
QRA	Quantitative Risk Analysis
SIL	Safety Integrity Level
UCS	Unit Control System
UCP	Unit Control Panel
TBT	Technical Bid Tabulation

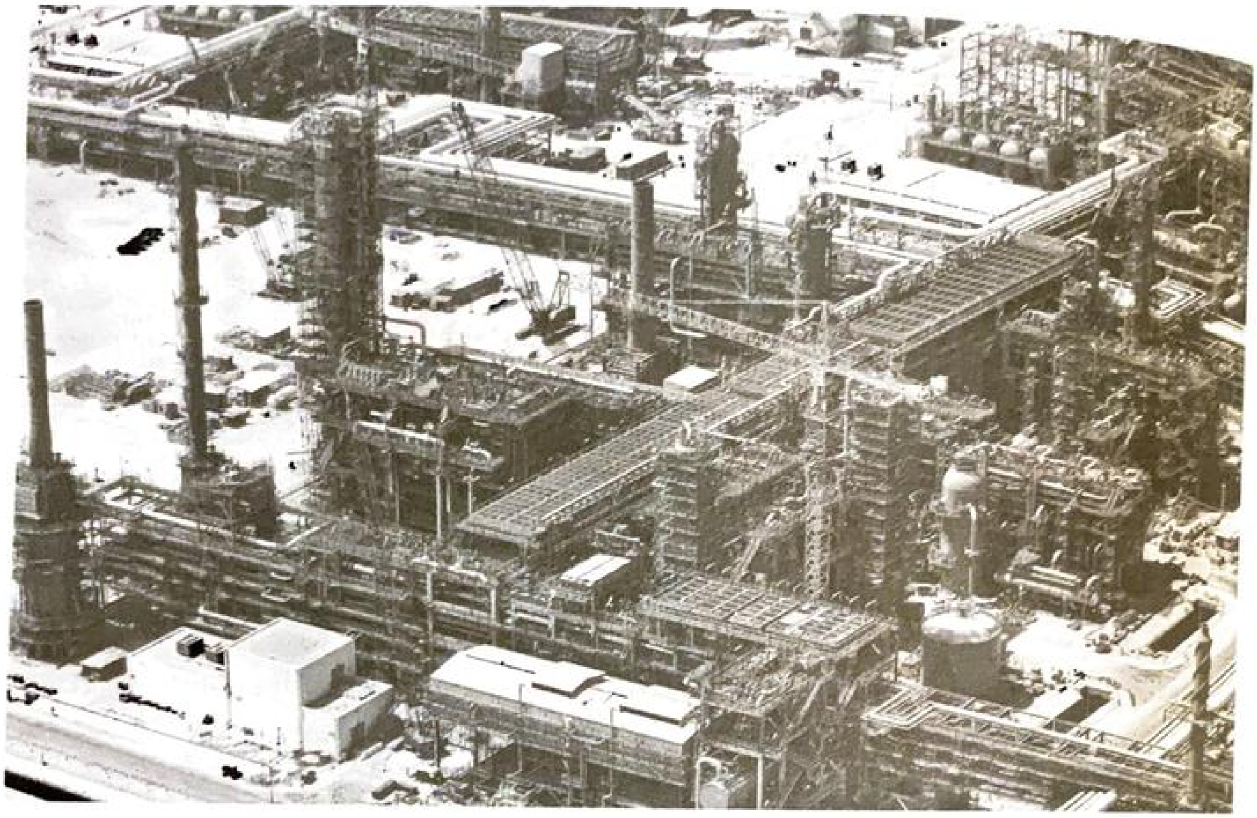
Introduction

The execution of a Project for an industrial facility consists of three main activities: Engineering, Procurement and Construction, which are followed by Commissioning and Start-up.



Engineering designs the facilities, produces the list, specifications and data sheets of all equipment and materials, and issues all drawings required to erect the Plant. Procurement purchases all equipment and materials based on the lists and specifications prepared by Engineering.

Construction erects all equipment and materials purchased by Procurement as per the drawings and in accordance with the specifications produced by Engineering.



Engineering design is the first, and most critical part, of the execution of a project. It is indeed Engineering that writes the music that will then be played by all project functions: Procurement procures nothing else that what Engineering specified and Construction erects as per engineering drawings.

Engineering is the task of translating a set of functional requirements into a full set of drawings and specifications depicting every detail of an industrial facility. It involves several disciplines: Process, Safety, Mechanical, Piping, Civil, Electrical, Instrumentation etc. and a large number of tasks, from high level conceptual ones to the production of very numerous and detailed installation drawings.

Cost pressures in the past decade have resulted in the transfer a many tasks from high cost countries to low cost satellite offices. This does not make it easy for today's engineers to get the full picture. Providing such overall picture is one of the objectives of this work.

The first Chapters describe the work of the different engineering disciplines, showing a sample of each document commonly produced. The work of engineering disciplines is highly interwoven. Chapter 14 explains the overall work process.

The following Chapters describe effective methods to organize and control Engineering activities to ensure they match the project needs, particularly its schedule.

What is described in this book is applicable to both On-Shore and Off-Shore facilities. The specificities of Off-Shore Engineering are covered in Chapter 13.

This work is dedicated to my colleagues, who generously shared the knowledge collected here.

I wish to specifically acknowledge the contribution of Michel Angot and to thank SAIPEM, TECHNIP and LABBE Stainless Steel Vessel Manufacturer (www.labbe-france.fr) for their authorization to show their documents.

I will be glad to receive the reader's feedback and can be contacted at herve.baron@gmail.com

Chapter 1

Project Engineering

An Oil & Gas facility project is usually developed in 4 steps.

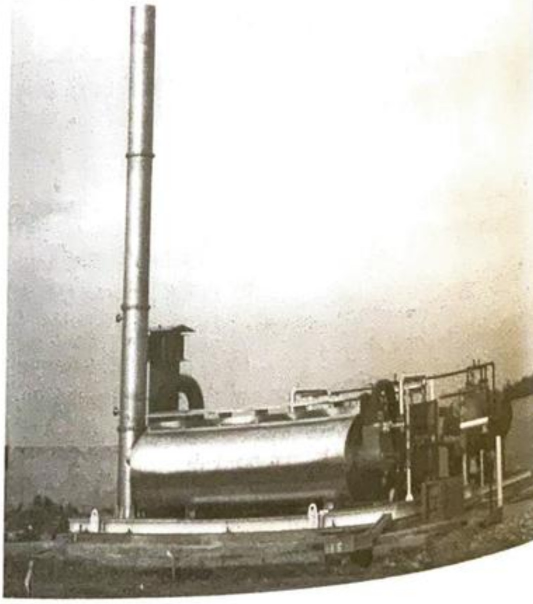
- The business planning phase,
- The conceptual design, also called Basic Engineering phase,
- The Front End Engineering Design (FEED) stage,
- The facility Detail Engineering and Construction,

	Decision to proceed (or not)	Decision to proceed (or not)
Business Planning Phase « APPRAISE » (FEL-1)	BASIC Engineering/Conceptual « SELECT » (FEL-2)	FEED « DEFINE » (FEL-3)
Objective: Define the business opportunity	Objective: Confirm feasibility, select technology, estimate CAPEX and OPEX, identify risks	Objective: Refine cost estimate, prepare all documents for EPC
Content: Technical assessment, milestone schedule, estimated cost range	Content: Evaluate alternates, confirm feasibility, develop process design	Content: Develop Plant design & layout, P&IDs, Equipment specifications, issue inquiries, define the design basis, the applicable codes & specifications
Deliverables: Functional requirements, economic evaluation	Deliverables: Process design (PFD+HMB), Main Equipment List, Utilities consumption, ±30-40% CAPEX estimate	Deliverables: ±15-20% CAPEX estimate, technical basis for the EPC, Project schedule
By: Plant Owner	By: Engineering Company + Process Licensors (if any)	By: Engineering Company

The BASIC Engineering, sometimes called the SELECT phase, aims at selecting the best Process scheme to minimize CAPEX and OPEX. The deliverables at this stage are mainly the Process Equipment List, which serves to estimate the Plant CAPEX with ± 30-40% accuracy, and the utility consumption, which serves to calculate the Plant OPEX. The CAPEX and OPEX, along with cost of the feedstock and the sales price of products allow to calculate the Net Present Value (NPV) of the Project. Should the NPV look promising, decision will be taken to go to the next stage of the Project, the FEED stage. During the FEED, sometimes called DEFINE stage, the Plant design is developed up to a point that enables to estimate the CAPEX with an accuracy of ± 15-20% required to take the investment decision, i.e., to go to the EPC, sometimes called EXECUTE, stage.

The objective of the FEED is also to produce a comprehensive set of documents that precisely define all technical requirements (scope of work, drawings, and specifications) for the Plant detail design and construction, which can thus be contracted under a Lump Sum contract.

Detail Design entails the specification of all Plant Equipment, and the preparation of all Construction drawings and specifications.



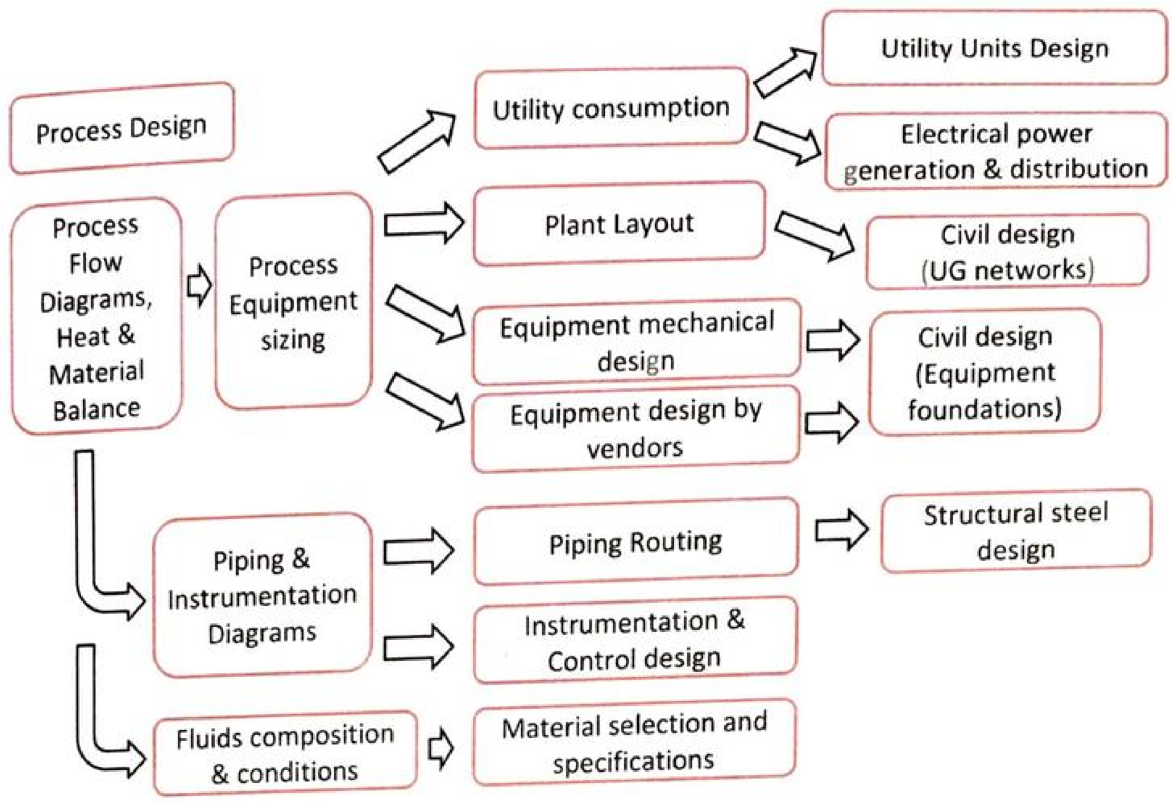
The main difference between FEED and Detail Design is that no Equipment is purchased at FEED stage.

During Detail Design, on the contrary, Equipment are purchased from vendors.

This allows equipment data, such as dimensions, electric power consumption, etc. to be received from Vendors and Equipment to be integrated into the Plant design.

At FEED stage, the Plant design is based on estimates of equipment dimensions, power consumptions, etc.

The overall design of a facility can be summarized as depicted hereinafter.



Process design comes first. It establishes the process scheme, performs simulations enabling to define the size/duty of process equipment.

Equipment mechanical design follows, which yields equipment dimensions, from which the Plant Layout can be done, and weight/loads, based on which equipment foundations are designed.

Process design progresses further and defines all lines and instruments required for Plant operation. These serve as scope of work for Piping and Instrumentation disciplines.

Piping routing determines the required pipe-racks, access platforms for operator access to valves, etc.

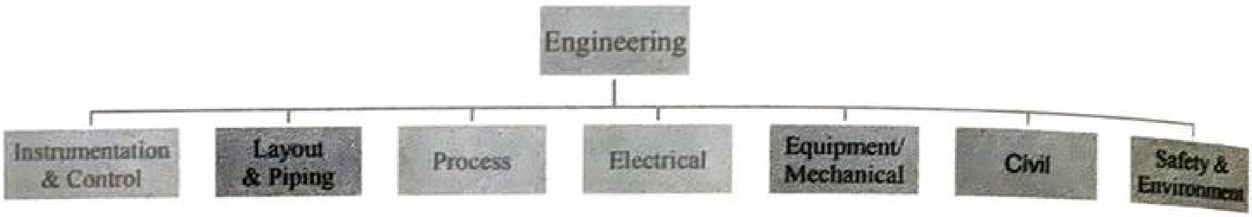
Electrical power generation is sized from equipment consumption. Electrical power distribution is designed on the basis of the Plant layout and location of the main consumers.

The same applies to other utilities required by the Plant equipment, such as cooling or heating fluids, fuel gas, etc.

The material of construction of each line and equipment is selected on the basis of the operating conditions and the fluid handled.

Engineering is not, however, a linear process. It is an iterative process. The Plant layout, for instance, might require to be revised upon the results of subsequent design activities including equipment design by vendors, piping routing and calculation, routing of underground networks (sewage, cables, fire water).

Engineering work is split among disciplines. The usual split among disciplines is shown below:



The split in disciplines corresponds to a split of the Plant equipment/materials by type, e.g., mechanical equipment, pipes, electrical equipment, instruments, systems, etc. Each discipline is assigned certain categories of equipment/materials that it is responsible to specify and quantify to allow their purchase.

Each engineering discipline is headed by a Lead Discipline Engineer (LDE). The LDE establishes the design bases and criteria, plans and oversees the activity of the discipline and interfaces with other disciplines and with the Client. Engineers are in charge of the designs and calculations. They provide design results to Designers & Draftsmen who prepare the drawings.

The disciplines are coordinated by the Engineering Manager. The work of the engineering disciplines, which is described in Chapters 3 through 13 of this book, is highly interdependent. Chapter 14 explains the overall work process and the interfaces.

The role of the engineering manager is to co-ordinate the engineering disciplines, making sure, through regular meetings with all disciplines, that information awaited by one discipline from another is identified and promptly provided. The engineering manager may be assisted by Project Engineers who are assigned transversal tasks involving several disciplines.

Thousands of Engineering documents and drawings are issued on a Project. They are nevertheless only of a few types.

For instance, although Piping issues many drawings to cover the whole Plant area, all are of the same type: "Piping General Arrangement Drawing".

A sample of all commonly issued Engineering drawings and documents is shown in this book.

Engineering documents and drawings are called deliverables, as they constitute what Engineering delivers.

A document codification system is used, allowing quick identification of the project number, unit number, issuing discipline, document or material type, serial number and revision.

Serial number

Revision index

Document number			Document title	Document revision
A	1	48104	Service building instrument. rooms cables routing	B
A	2	48102	Trouble shooting diagrams	D
A	3	48134	F&G system architecture drawing	E
A	4	50100	Instrument index	B
A	7	50003	Spec for instrument installation works and service	C
A	8	50960	Instrument Data sheets for temperature switches	B
A	9	50110	Requisition for pressure relief valves	B
M	1	62059	General plot plan	B
M	2	62020	Piping details standard	C
M	2	62070	Piping general arrangement Area 1	D
M	4	60100	Special items list	D
M	5	62250	Piping isometrics booklet	C
M	6	60000	Pipes and fittings thickness calculation	A
M	6	62351	Calculation note CN1 - piping stress analysis	A
M	7	60001	General piping specification	C
M	8	60103	Data sheets for station piping material	B
M	9	60200	Requisition for pipes	F

Discipline code	
A	Instrumentation & Control
C	Civil engineering
E	Electrical
G	Project general documents
J	Mechanical
K	Safety
M	Piping & Layout
P	Processes
S	Steel Structures
V	Vessels – Heat exchangers
W	Materials – Welding

Document type	
1	Installation drawings
2	Detail drawings
3	Diagrams
4	Lists – Bill of Quantities
5	Isometrics
6	Calculation notes
7	Specifications
8	Data sheets
9	Requisitions

The Master Document Register shows at any time the list and current revision of all documents.

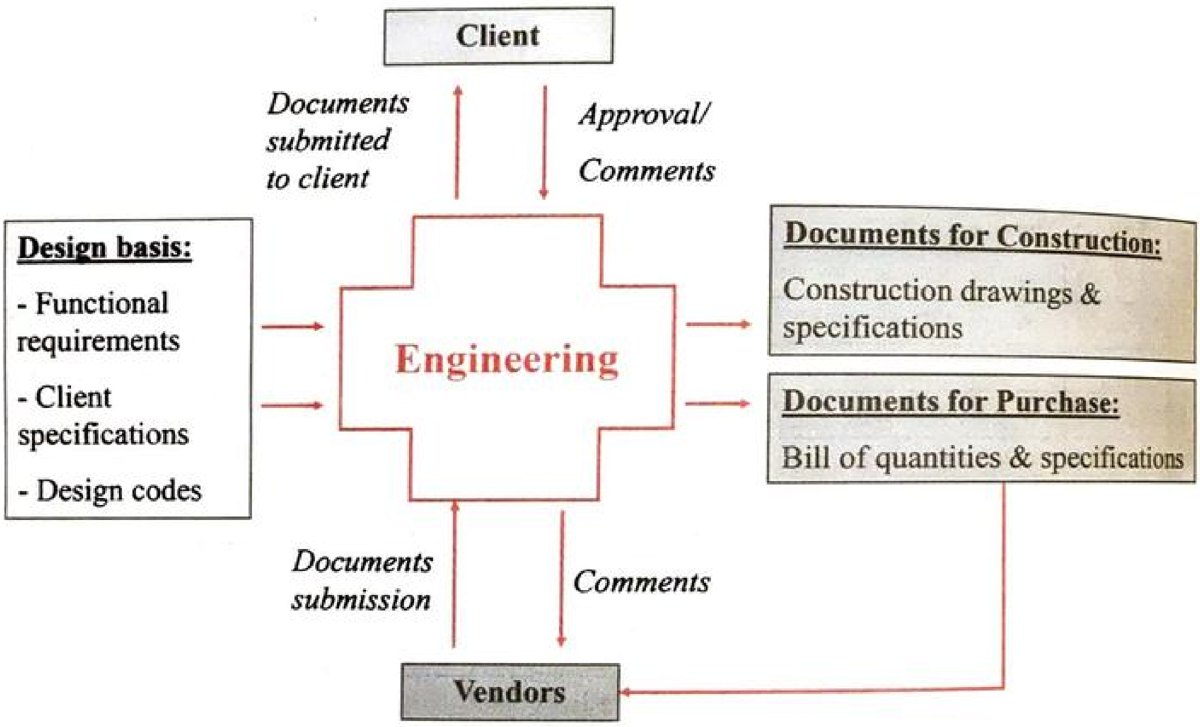
The Engineering process is iterative. Documents undergo revisions as design progresses. A document is typically issued for the Client review (IFR), for design (IFD) and finally for construction (IFC).

The typical time schedule of Engineering is shown in Chapter 14.

Engineering documents include diagrams, which show a concept, drawings, which show the physical reality, have a scale and an orientation to the North, key plans, which show the sub-division of the Plant territory in individual drawings, data sheets, calculation notes and specifications.

Specifications include **Design Specifications**, containing the design bases and criteria, **Supply Specifications**, containing technical requirements for equipment and materials and **Site Works Specifications**, prescribing requirements for construction.

The parties involved in Engineering include the Plant Owner, i.e., the Engineer's "Client", who reviews the design, as well as suppliers.



Supplies include equipment and materials. Equipment means Mechanical Equipment, such as a pressure vessel, heat exchanger, etc. Materials, also called bulk, mean non-itemized commodities such as pipes, manual valves, cables, etc.

The Engineer usually carries out Engineering and Procurement in-house and sub-contracts Construction activities to local contractors.

An Independent Design Verification body (third party) is required by law in some countries to review some parts of the design, and may also be imposed by the Client.

Chapter 2

The design basis

The design of a new process facility starts by the definition, as per Client requirements, of its function. In short, what is the process to be performed: liquefaction of natural gas, separation and stabilisation of crude oil, etc., the required capacity, the feed stock composition, products specifications and Plant performance (thermal efficiency, etc.).

The typical duty of an oil production facility would be:

"The facilities will be designed to handle production rates of 1391 m3/hr (210 kbpd) (annual average) of oil production and a peak of 13.6 Msm3/d (480 Mscfd) of gas production.

The full wellstream production from the subsea wells will be separated into oil, water, and gas phases in a three-stage flash separation process with inter-stage cooling designed to produce a stabilized crude product of 0.897 bara (13 psia) (true vapor pressure). Water will be removed in the flash separation/stabilization process in order to reach of 0.5 vol.% BS&W oil specification. The produced gas will be compressed, dehydrated and be injected into the reservoir to maintain pressure as well as conserve the gas."

The functional requirements are guaranteed by the Engineer who provides a Performance Guarantee. The Engineer also provides a Mechanical Warranty for a limited period (typically 2 years) against faulty design, materials and workmanship.

The liability of the Engineer, even under the most inclusive forms of contract (LSTK), does not extend beyond these performance guarantee and mechanical warranty.

The Owner has additional needs, including that the facilities lasts its intended life, typically 25 years, operates continuously with minimum downtime, is easy to operate and maintain, etc.

The way for the Owner to ensure that these requirements are taken into account is to specify industry codes and standards, as well as its own specifications.

The industry standard for pumps, for instance, prescribes design, material selection and inspections during fabrication to limit wear and need for maintenance, ensuring uninterrupted operation over a long time.

Even though specifying compliance to international codes and standards should ensure long lasting service, all Oil & Gas companies impose additional requirements gathered in their own specifications.

The design basis, which includes the functional requirements and defines the technical referential, shall be agreed with the Client before the start of the design work. To this end, the information shown below shall be gathered, by the Engineering Manager, in a document, called the (Basic) Engineering Design Data, which shall be submitted and approved by the Client. Once approved, this document shall become the reference document used by all parties (Engineering disciplines, Vendors) in order to ensure consistency of design data.

- Brief description of the projected facilities, scope of work, facility systems and infrastructures
- Unit of measures
- Applicable codes and standards, with revision
- Legal requirements, e.g., code/certification applicable to pressure vessels,
- Environment requirements: maximum level of pollutants (CO, NOx) in the exhaust of turbines, fired heaters, etc.
- Applicable Client specifications and standards
- Feedstock conditions, composition, variation over Plant life
- Plant capacity, design case and turndown
- Products specifications

- Battery limits & battery limits conditions
- Design life of facility
- Design basis and criteria in each discipline (may be in separate documentsfor each discipline)
- Outline of operating and control philosophy
- Equipment sparing philosophy
- Energy efficiency, performance guarantees, maximum noise level
- Site climatic conditions: temperature, humidity, rain, wind, seismic
- Available utilities and their characteristics: Fuel gas, electric power, steam, etc.
- Relief system, type of drains and rain water treatment to be provided
- For a revamping: shutdown and tie-in strategy

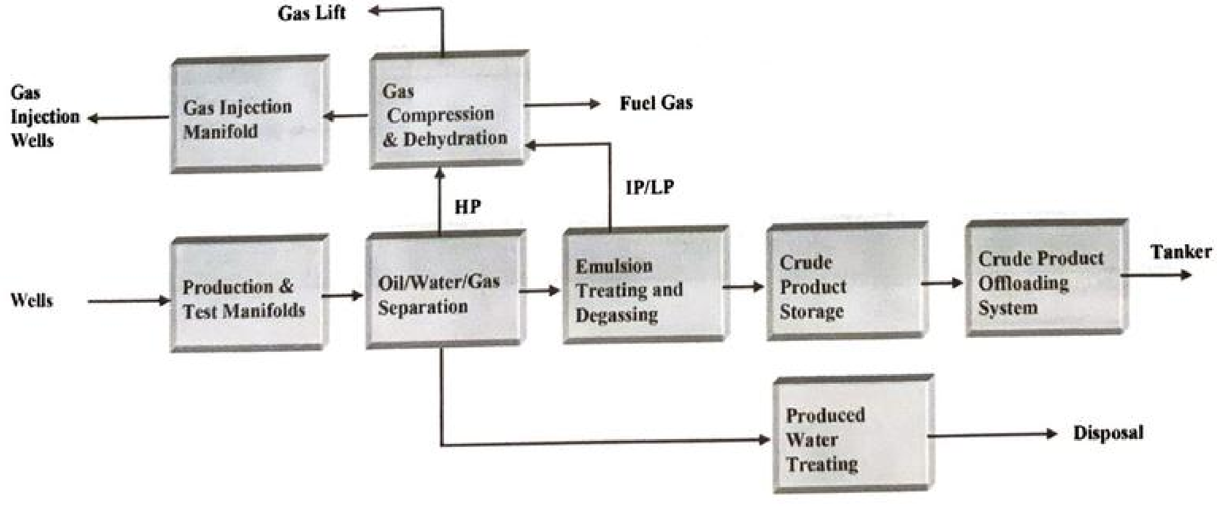
Chapter 3

Process Engineering

The first task of the Process engineer designing Oil & Gas facilities is to define the process scheme to transform the feedstock into the required products.

Processes applied in Oil & Gas facilities are always the same, as the products (crude oil, sales gas, LPG, gasoline, etc.) and their specifications are the same.

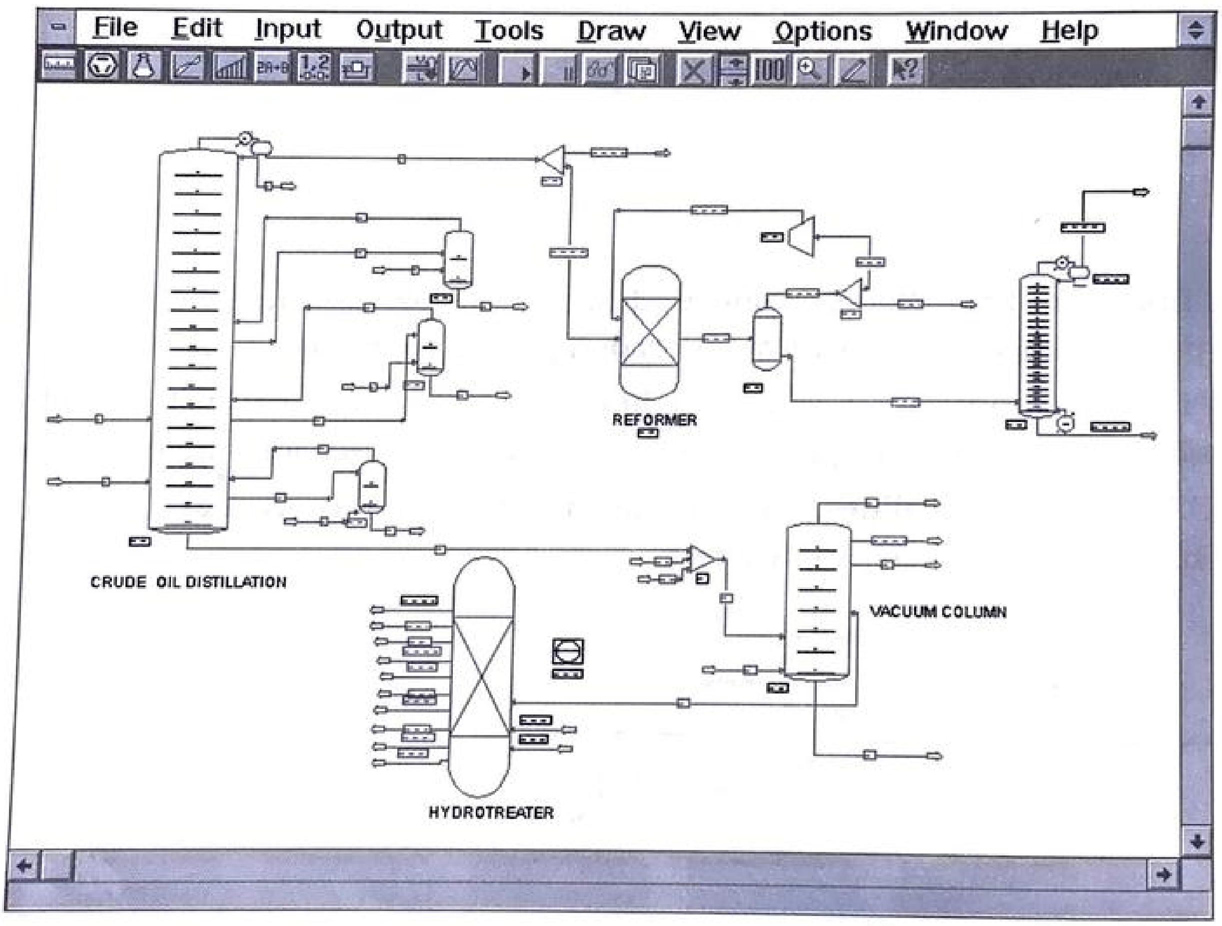
Oil production facilities, for instance have an overall process as depicted on the Block Flow Diagram shown here:



The Process engineer adapts the above standard process to the particularity of the feedstock, which will vary from one facility to the other as the reservoir fluids are always different.

The feedstock will also vary over the facility's life. As a reservoir depletes, for instance, its pressure decreases, more gas and water and less oil are present in the wells effluent. The range of feedstock that the facility will be designed to treat is the basis for the process design.

The Process engineer models the tentative process scheme in a thermodynamic simulation software. The later uses thermodynamic models to simulate fluid behaviors under the different process operations: phase separation, compression, heat exchange, expansion, etc.

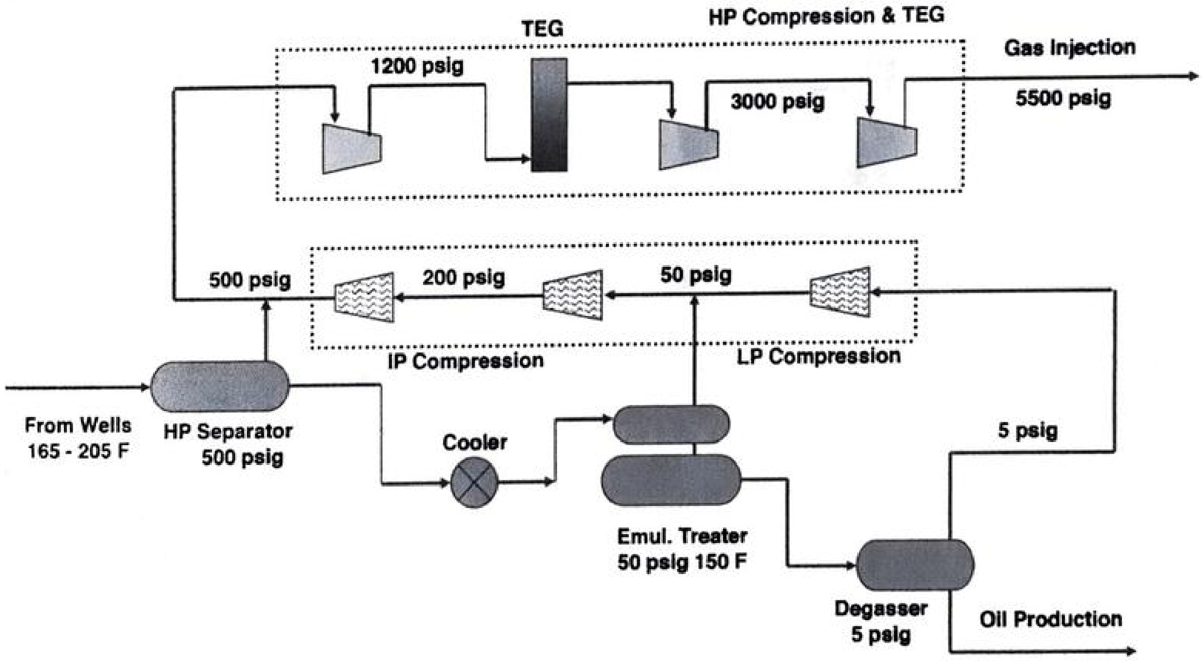


The calculations done by the software would be very difficult to do manually, as petroleum fluids contain a large variety of components. The software incorporates the thermodynamic properties of all these components.

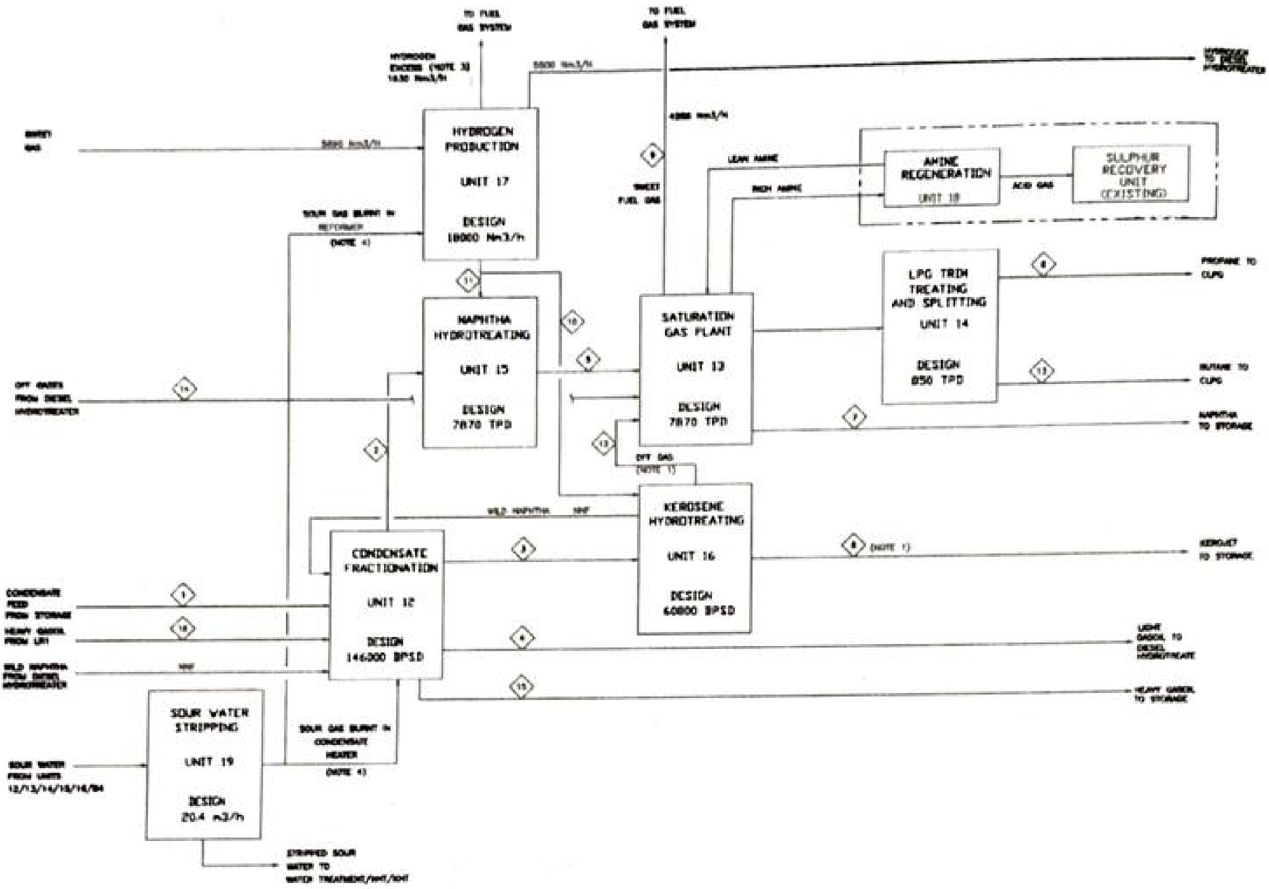
The software also calculates the duty of the equipment, which is the difference between the enthalpy of the equipment inlet and outlet streams.

```
CONDENSER DUTIES (GJ/h)
        Wasteheat Exchanger (WHE1) . . . . . . .        -94.714
                  Condenser (CD1) . . . . . . .         -20.921
                  Condenser (CD2) . . . . . . .         -12.664
                  Condenser (CD3) . . . . . . .          -5.671
                  Condenser (CD4) . . . . . . .          -4.220
        Wasteheat Exchanger (WHE2) . . . . . . .        -46.997
```

Different variations of the basic process scheme are tested to find the economical optimum. In an oil production facility, for instance, the number of oil/gas separation stages and their respective pressure are optimized to meet the required oil degassing specification while minimizing the number of equipment and matching the available compressor sizes.



A facility is made of a set of interconnected process units as shown on the Block Flow Diagram.



Most technologies employed in Oil & Gas processing are called "open art", which means that they do not use proprietary intellectual property. A few process units, in particular in Refining, use licensed technologies which belong to Process Licensors. Examples are units using proprietary catalysts or chemicals, as well as units using publicly available catalysts/chemicals but whose thermodynamic and kinetic performance were mapped by research work and tests. The process design of such units is purchased from the Process Licensor as well as a license to use the technology.

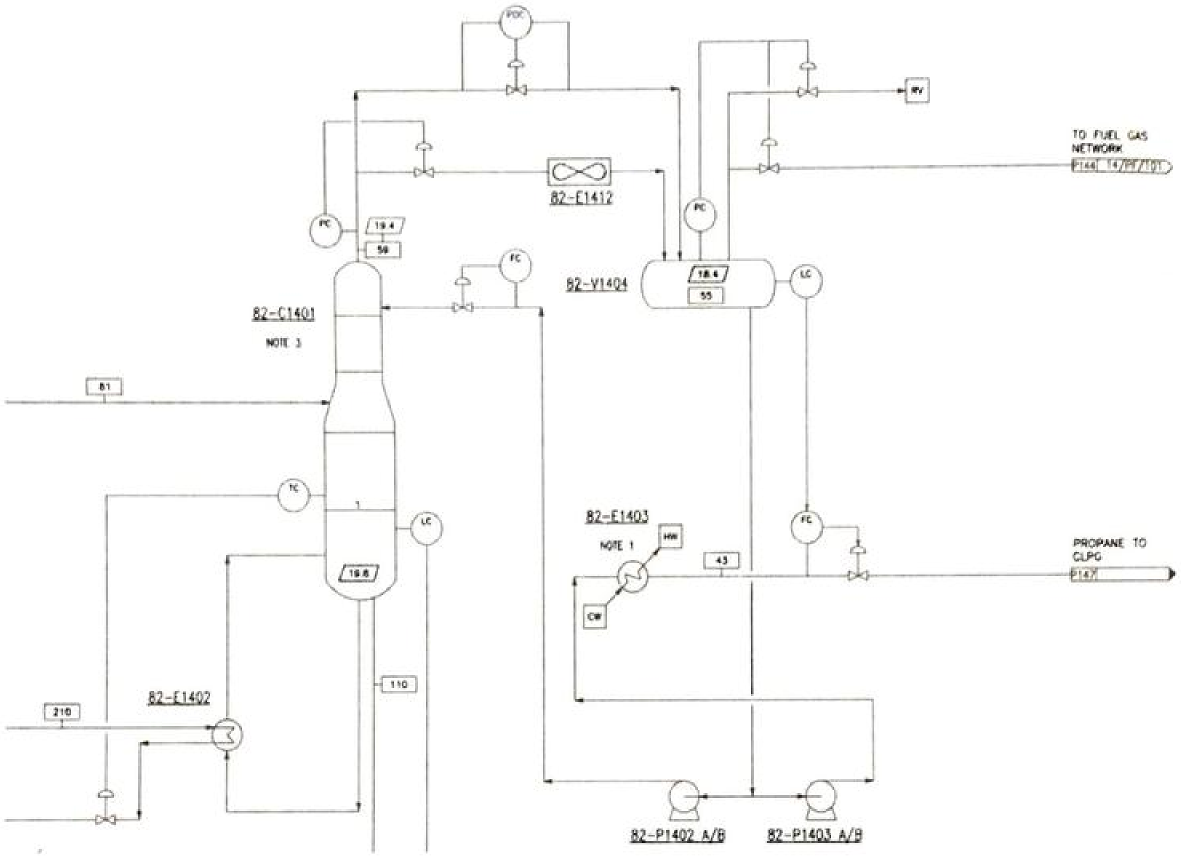
The choice of the technology is done at BASIC Engineering stage. An inquiry is issued to Process licensors with the unit duty specification. Each Process Licensor makes a proposal including the description of the technology and its performances, the cost of the license and of the process design work, the list and cost of proprietary equipment, if any, as well as information enabling the owner to estimate the CAPEX and OPEX of the unit: the sized Process equipment list and the utility/catalyst consumption list.

The selected Process Licensor then performs the process design of the unit and issues the documents described in this Chapter as part of what is called the Process Design Package (PDP). The Process Engineer of the Engineering contractor customizes to the Project and further develops these documents.

For each unit a Process Design Data document is issued. It specifies the unit maximum and minimum (turndown) capacity, the range of operating cases, the feedstock composition and conditions, the product specifications and battery limit conditions.

This allows the process design work to be organized, i.e., split between process engineers, by unit. The documents described in this chapter: PFDs and HMB, process description, P&IDs, C&E diagrams, equipment list, lines list, utility balance, are issued for each process and utility unit.

The selected process scheme is shown on the Process Flow Diagrams (PFDs). These diagrams show the process equipment, e.g., separators, heat exchangers, pumps, etc., the main process lines and the process controls.



The Process description walks the reader through the PFDs and explains how the process operates and is controlled.

Propane is withdrawn on top of the column under pressure control and is routed to Condenser 82-E1412.

Liquid Propane in then sent to the Ovhd Drum 82-V1404. Non condensable vapors are exiting the drum at the top and are routed to the fuel gas network under pressure control. It is also possible to release these non-condensable vapors to the flare in case the pressure in the drum keeps increasing. The drum operates at pressure of 18.4 barg and the pressure is ensured by differential pressure control between the drum and the Column Overhead.

Propane is refluxed on the top tray of Column 82-C1401 under flow control by pumps 82-P1402 A/B.

Remaining product is sent to CLPG, by pumps 82-P1403 A/B, under flow control (cascaded by level control), through the Propane Trim Cooler 82-E1403 that further cools down the Propane to 43°C.

Process streams are numbered on the PFDs. Their flow, conditions and composition are obtained from the process simulator and tabulated, for the various operating cases, in the **Heat & Mass Balance (HMB)**.

HEAT AND MATERIAL BALANCE DESIGN CASE - SUMMER				
Stream Number		12	13	14
Stream Phase		Vapor	Liquid	Liquid
Total Molar Comp. Rates	KG-MOL/HR			
WATER		0,1	0,1	0,1
HYDROGEN SULFIDE		0,0	0,0	0,0
METHANE		0,0	0,0	0,0
ETHANE		11,0	11,0	9,1
N2		0,0	0,0	0,0
PROPANE		1040,9	1040,9	869,1
I-BUTANE		26,4	26,4	22,0
N-BUTANE		6,2	6,2	5,2
NEOPENTANE		0,0	0,0	0,0
I-PENTANE		0,0	0,0	0,0
N-PENTANE		0,0	0,0	0,0
CARBON DIOXYDE		0,0	0,0	0,0
Total stream rate	KG-MOL/HR	1 084,5	1 084,5	905,6
	KG/HR	48 121	48 121	40 182
Temperature	C	59	55	55
Pressure	BARG	19,4	18,4	18,4
Total Enthalpy	M*KCAL/HR	4,94	1,78	1,48
Total Molecular Weight		44,4	44,4	44,4
Liquid Mole Fraction		0,00	1,00	1,00

The Heat and Mass Balance shows the characteristics of the inlet and outlet streams for each piece of equipment (compressor, heat exchanger, separator, etc.). This is the basis for the specification of the equipment.

Process discipline only designs, i.e., sizes, some type of equipment. Other equipment are simply specified by Process, i.e., their duty only is defined while the sizing is left to Equipment suppliers.

Equipment performing a process function, such as phase separation (separators), distillation (columns), reaction (reactors) are **designed** by process. Equipment performing a mechanical function (pumps, compressors) or thermal function (heat exchangers, heaters, boilers) are **specified** only.

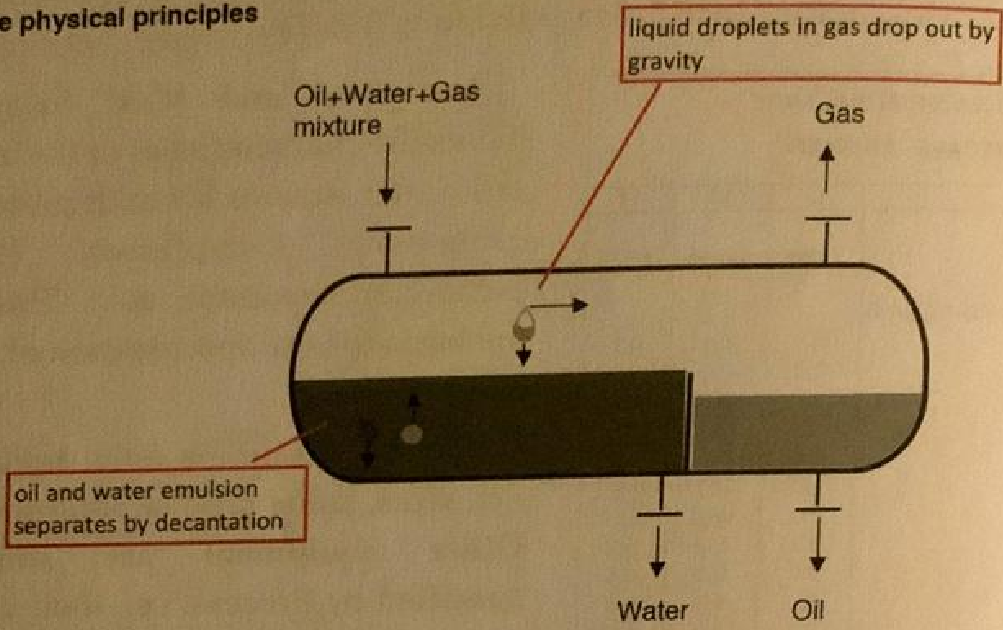
The example that follows shows how a typical process equipment, a production separator, is sized.

The function of a production separator is to separate the oil, water and gas present in the effluent coming from the wells. It separates oil from water, on the one hand, and gas from liquids, on the other hand, by gravity.

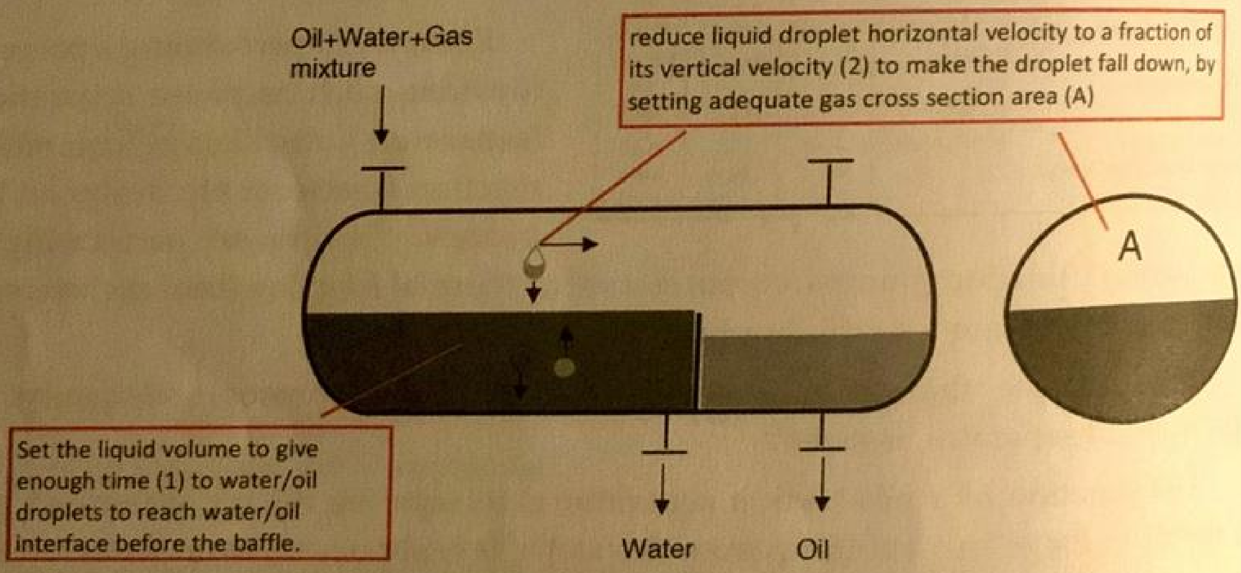
The vessel is sized to reduce the velocity of the liquid droplets present in the gas phase so that they fall to the liquid phase at the bottom of the vessel, and to provide sufficient time for the liquids (oil and water) to separate by decantation.

Sizing of a production separator

The physical principles



Application of principles



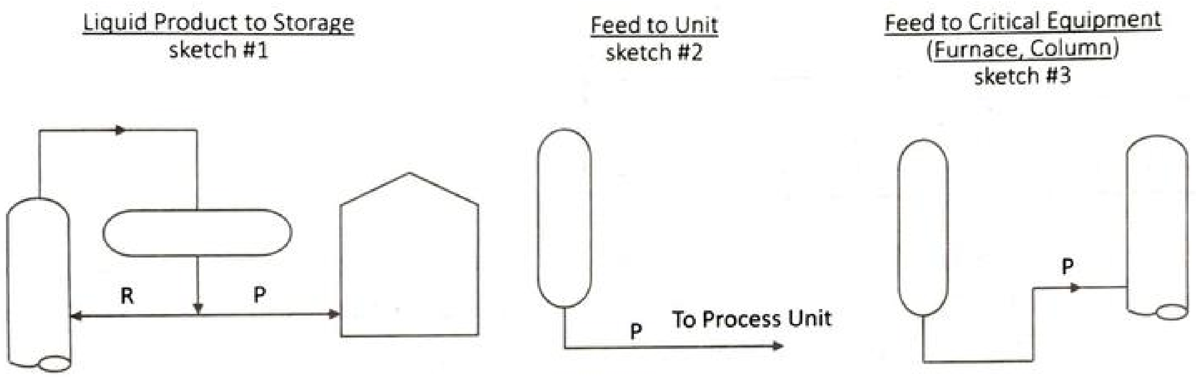
(1) oil/water setttling velocity is given by Stokes law. It depends on the difference of density between oil and water and viscosity.
(2) vertical velocity is given by Newton law. It depends on the difference of densities between liquid ans gas.

Such sizing of process equipment is done following the **Process Design Criteria**.

The **Process Design Criteria** defines the following :

Equipment and lines design pressure and temperature: the design pressure is usually set 5-10% above the maximum operating pressure. The design temperature is usually set 15-20°C above the maximum operating temperature.

Equipment sizing rules: Phase separators are sized, as shown in the above example, to achieve a given gas velocity and liquid residence time. Accumulator vessels, e.g., reflux drum, are sized to hold typically a few minutes of the outlet flow. The diameter of distillation/absorption columns is determined by the liquid/gas flow rates and their height the number of trays, itself depending on the required purity to be achieved. Reactors are sized to ensure sufficient contact time with the catalyst.



HOLD UP VOLUMES FOR PROCESS DRUMS

SERVICE	SKETCH	HOLD UP VOLUME (HL – LL), whichever is larger
REFLUX DRUM		
Liquid product to storage	1	5R or 2P
LIQUID SURGE DRUM		
Feed to Unit	2	10P
Feed to critical equipment (furnace, column)	3	5P

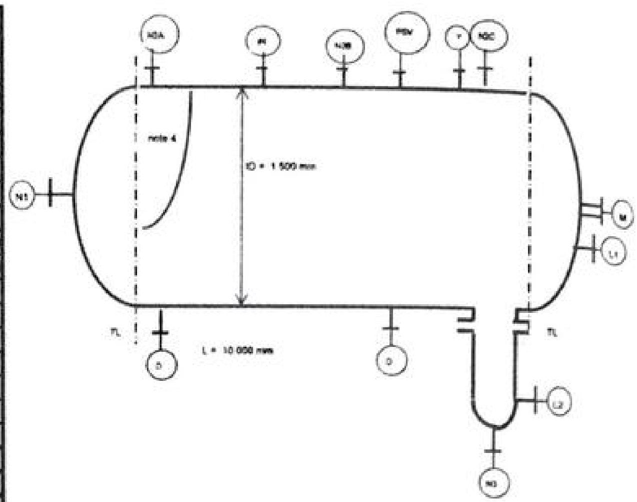
Line sizing rules: the diameter of lines is determined to comply with the allowable pressure drop as well as to limit erosion, vibration and noise. Criteria are different for liquids and gas and for different service, e.g., liquid at bubble point at pump suction, and for continuous or intermittent operation. The criteria are usually expressed as maximum velocity.

Equipment overdesign: Equipment are usually overdesigned by 10% compared to the most stringent operating, called design, case.

The resulting dimensions of the vessel are shown on a squeleton drawing part of the Equipment Process Data Sheet.

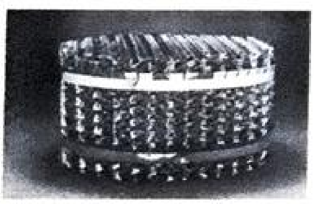
SERVICE	Slug Catcher	VESSEL	
OPERATING CONDITIONS			
FLUID		Natural Gas	
OPER. PRESSURE		9.7	MPa(a)
OPER. TEMPERATURE		30	°C
LIQ. DENSITY		1000	kg/m³
EROSION, CORROSIVE DUE TO		H2S : max 5mg/Sm3	
FLAMMABLE - EXPLOSIVE		Flammable	
CONSTRUCTION DATA			
DESIGN PRESSURE		10.11	MPa(a)
DESIGN VACUUM PRESSURE			MPa(a)
DESIGN TEMPERATURE		-20/50	°C
CAPACITY		18	m³
MATERIAL		CS	
CORROSION ALLOWANCE		3	mm
STRESS RELIEVE	YES ☐	NO ☐	
LINING, INSULATION, INTERNALS			
REFERENCE CODE		ASME VIII div1	

NOZZLES			
MARK	Nb	SIZE	SERVICE
PSV	1	3"	Relief Valve
N1	1	48"	Inlet
N2A/B/C	3	24"	Gas Outlets
N3	1	4"	Liquid Outlet
L1 / L2	2	3"	Standpipe
M	1	24"	Manhole



The process data sheet indicates the full range of operating conditions, the design conditions, including the lowest temperature expected in service, called Minimum Design Metal Temperature (MDMT), the fluid properties, any special service (cyclic/sour/toxic), the material of construction (generic type) of the Equipment, defined jointly with the Materials specialist (see chapter 8) and corrosion allowance, the specification of the vessel internals: demister, distributor, baffle, the type of capacity control required if applicable, etc.

For columns, a dedicated data sheet is issued to specify the trays or packing.



PROCESS DATA SHEET COLUMN TRAYS			Max.	Min.
Tray type			VALVE	VALVE
Number of trays			18 (2- 19)	18 (2- 19)
Trays item			2	19
Inside diameter (A)		mm	1400 (2)	1400 (2)
Tray spacing		mm	500	500
P Max. / Tray		mbar	(3)	(3)
Max. flooding		%	80	80
Number of passes			1	1
Product quality			Amine	Amine
Foaming factor			0.85	0.85
VAPOR TO TRAY	Temperature	°C	130.3	116.8
	Pressure	bar g.	1.5	1.32
	Density at T	kg/m³	1.38	1.67
	Flowrate	kg/h	6200	4726
	Flow under conditions	m³/h	4486	2833
	Molecular weight		18.1	22.8
LIQUID FROM TRAY	Temperature	°C	130.3	116.8
	Viscosity	Cp	0.44	0.53
	Surface tension	dynes/cm	46.3	47.7
	Density at T	kg/m³	957.6	979
	Total flowrate	kg/h	60537	59440
	Total flow at T	m³/h	63.2	60.7
Tray material			SS 316 L (4)	SS 316 L (4)
Corrosion allowance		mm	0	0
Valve material			SS 316 L	SS 316 L

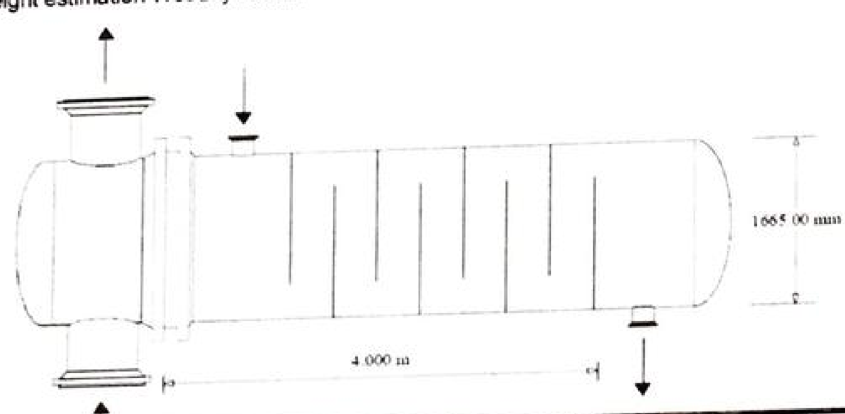
NOTES: (*) Trays shall operate satisfactorily when loads range between 50% and 110% of design load
(2) Diameter to be confirmed by supplier
(3) Total pressure drop accross column shall not exceed 200 mbar @ maximum capacity

For the most common type of heat exchangers, the shell & tubes heat exchangers, Process defines the Equipment further: bundle type (removable/non removable), tubes type (straight tubes/U-tubes), requirement for floating head and type of heads. The choice is made on the basis of the conditions and fouling factors of the 2 fluids and requires cost awareness of the different options.

Process usually performs the thermal design of shell & tubes heat exchangers, which results in the definition of the Equipment dimensions, number and diameter of shells, number and length of tubes, etc. A computer software is used for this purpose, which calculates the heat transfer based on the heat exchange surface area, geometry, fluid velocities and properties. The results are recorded on the Thermal Data Sheet.

Shell Construction Information

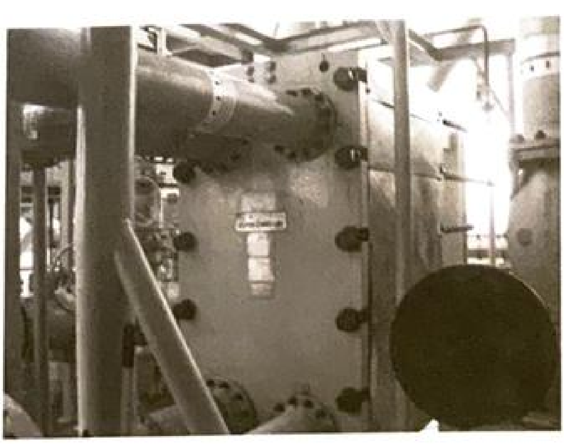
TEMA shell type	BEU	Shell ID	(mm)	1665.00
Shells Series	1 Parallel 4	Total area	(m2)	2747.19
Passes Shell	1 Tube 2	Eff. area	(m2/shell)	641.005
Shell orientation angle (deg)	0.00			
Impingement present	Rectangular plate	Imp. length/width (mm)		295 / 572
Pairs seal strips	2	Passlane seal rods (mm)	0.000	No. 0
Shell expansion joint	No	Full support at U-Bend		No
Weight estimation Wet/Dry/Bundle	45140.8 /	28756.6 /	15909.2 (kg/shell)	



Tube Information

Tube type		Plain	Tubecount per shell		1894
Length to tangent	(m)	4.000	Pct tubes removed (both)		2.16
Effective length	(m)	4.241	Outside diameter	(mm)	25.400
Total tubesheet	(mm)	303.000	Wall thickness	(mm)	2.110
Area ratio	(out/in)	1.1992	Pitch (mm) 31.7500	Ratio	1.2500
Tube metal		304 Stainless steel (18 Cr, 8 Ni)	Tube pattern (deg)		90

For equipment that are *specified* rather than *designed* by Process, i.e., plate & frame heat exchangers, air-cooled heat exchangers, rotating equipment, fired heaters, the Process Data Sheet simply indicates the conditions of the inlet and

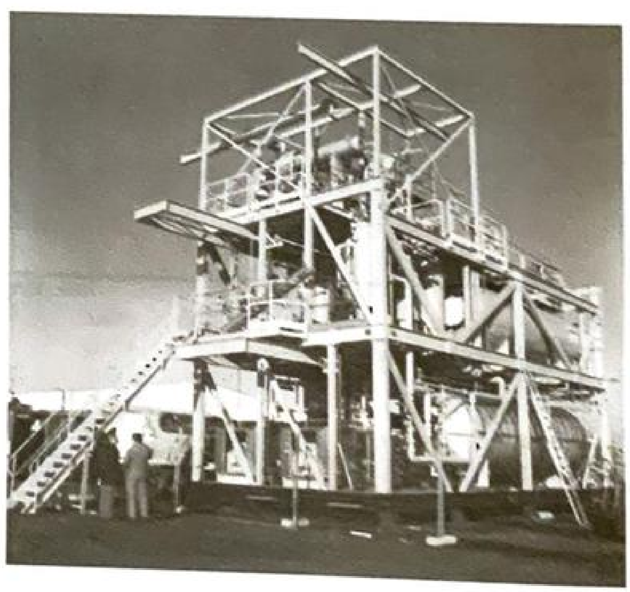


outlet streams, which define the duty, and the required equipment overdesign, typically 10%.

The sizing of the equipment is left to the Equipment vendor.

ITEM	82-E1403		SHELL SIDE: PROPANE			
SERVICE	PROPANE TRIM COOLER		TUBES SIDE : COOLING WATER			
OPERATING CASE	Design case : Summer					
HEAT EXCHANGED	0.08	MW	SHELL SIDE		TUBES SIDE	
PROCESS DATA	TOTAL FLOWRATE	kg/h	7939 (1)		13931 (1)	
			INLET	OUTLET	INLET	OUTLET
	LIQUID HC	kg/h	7939	7939		
	H2O	kg/h			13780	13780
	OPERATING TEMPERATURE	°C	55,3	43	35	40
	OPERATING PRESSURE	bar g.	31,7	31,2		
	DESIGN TEMPERATURE	°C	80 / -42		80	
	DESIGN PRESSURE	bar g.	37,5		28,9	
	ALLOWABLE PRESSURE DROP	bar	0,5		0,7	
	FOULING FACTOR	h°Cm²/kcal	0,0003		0,0004	
	FLEXIBILITY		50%		50%	
CHARACTERISTICS LIQUID			INLET	OUTLET	INLET	OUTLET
	SPECIFIC GRAVITY 60/60				Water properties	
	SPECIFIC GRAVITY at T		0,446	0,468		
	VISCOSITY	cP	0,07	0,08		
	SPECIFIC HEAT	kcal/kg°C	0,712	0,668		
	THERMAL CONDUCTIVITY	kcal/h m² °C/m	0,0855	0,0947		
	ENTHALPY	kcal/kg	36,6	28,1		
	POUR POINT	°C				
NOTES:	10% overdesign to be considered on duty and flow.					

Parts of the Plant are purchased as functional units, called packaged units or packages. This is the case of units which require a specific know-how. Their process design is done by vendors. The Engineer specifies their functional equirements in the **Duty Specification** which indicates the inlet stream characteristics, product specification, required unit capacity, battery limit conditions and the performances to be guaranteed.



The **Process Equipment List** shows the list of process equipment and their main characteristics.

IDENTIFICATION		DESIGN CONDITIONS										
				OVERALL DIMENSIONS								
TAG	SERVICE	POWER/DUTY kW	POSITION	DIAMETER (ID) / WIDTH mm	LENGTH mm	HEIGHT mm	Design flow m3/h	Head (m)	inlet temperature °C	Design pressure barg	Design Temperature °C	MATERIAL
	VESSELS											
82-C1401	LPG Splitter		V	1600		8900				21.3	125 / -4	CS+1.5
	ROTATING EQUIPMENT											
82-P1401 A/B	LPG Splitter Feed Pumps	75					74	312			80	CS
82-P1403 A/B	Propane Export Pumps	22					20	308			80/ 42	LTCS
	EXCHANGERS											
82-E1402	LPG Splitter Reboiler	4,6								shell 21.7 / tube 25	shell 125/-4 / tube 230	shell CS+1.5 tube CS+3
	HEATERS											
82-E1401	Regeneration Gas Heater	0.35							49	33	335	CS+3
	PACKAGES											
82-Y1401	LPG Dryer Package						66.8					

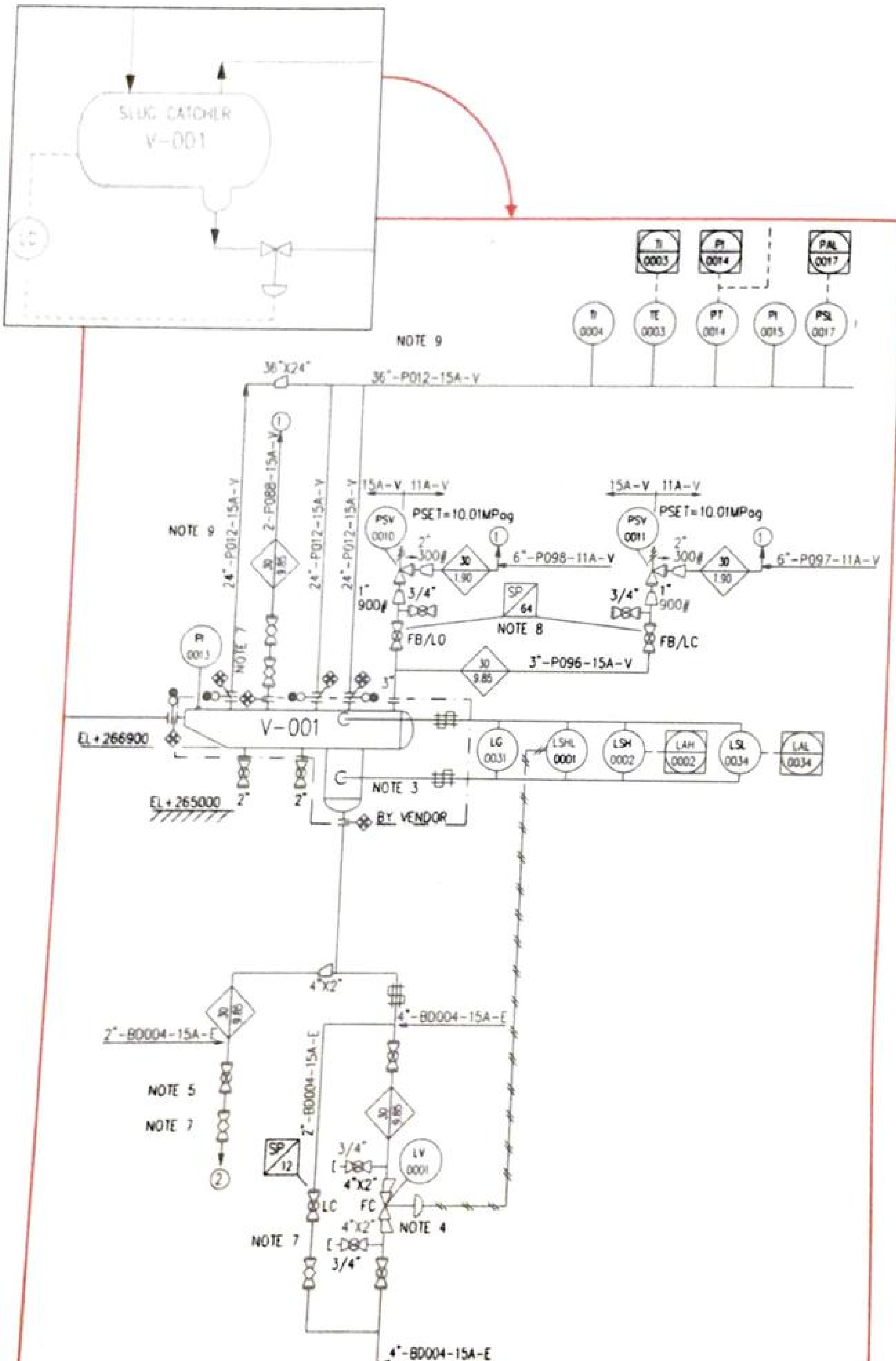
The cost of the equipment can be estimated on the basis of the above list and recent similar equipment purchases. The overall facility CAPEX can then be estimated by applying a factor, accounting for the cost piping, instrumentation, civil, etc., typically around 5, to the main equipment cost.

Process determines the utility consumption of each equipment, such as that of cooling/heating fluid, fuel gas, etc. and tabulates it in the **Utility Consumption List**.

ITEM N°	SERVICE	ELECTR. POWER CONSUMPT. kWh/h	BOILER FEED WATER, STEAM, CONDENSATES				COOLING WATER DESIGN FLOW m3/h	FUEL GAS kg/h	NITROGEN Nm3/h	INSTRUMENT AIR Nm3/h
			STEAM t/h	BOILER FEED WATER t/h	CONDENSATES t/h	LOSSES t/h				
82-Y1401	LPG Dryer Package	-360						-1790		
82-E1403	Propane Trim Cooler						-14			
82-E1412	LPG Splitter Condenser	-180								
82-P1401 A/B	LPG Splitter Feed Pumps	-58								
82-P1402 A/B	LPG Splitter Reflux Pumps	-20								
82-E1406	Cold flare gas heater		-0,30							
	Unit 14 Instrument Control									-60
	UNIT TOTAL	-618	-0,3				-14	-1790		-60
NOTES:	+ FOR PRODUCED QUANTITIES	- FOR CONSUMED QUANTITIES								

The Utility consumption list provides the design basis for the Utility units. It also serves to estimate the facility operating cost (OPEX).

The process diagrams (PFDs) are developed into Piping & Instrumentation Diagrams (P&IDs).

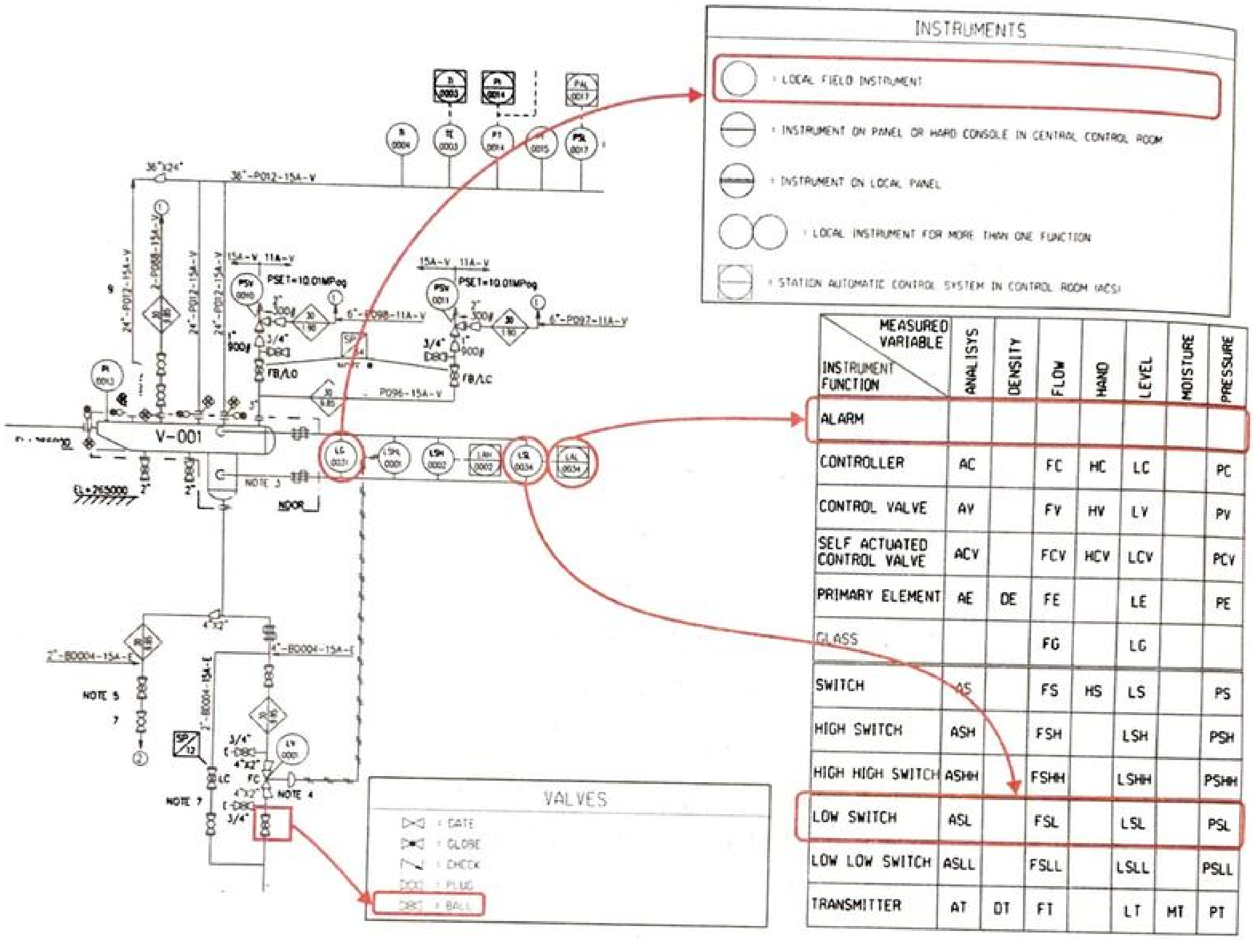


P&IDs show in details the equipment, piping, valves (manual/motorized/ control safety), instrumentation, process controls, process alarms, process and emergency shutdown devices required during normal operation, as well as for start-up, maintenance, operation of the Plant a low throughput, etc.

The P&IDs take into account numerous requirements for Operation, Safety, Maintenance, etc. including:

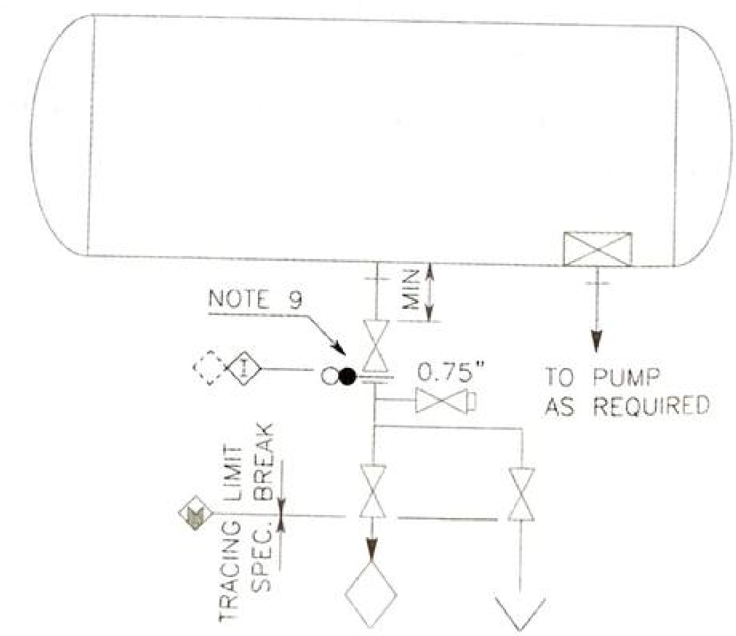
- Process monitoring: temperature, pressure and flow instruments, including indication whether the measured value shall be available locally only or displayed in control room,
- Process controls, which are shown on the P&IDs by means of a dotted line between the controlled process parameter (flow, pressure, temperature) and the controlling valve,
- Process automations,
- Redundancy of equipment and instruments,
- Process emergency shutdown: sensors and shutdown valves,
- Plant emergency isolation and depressurization: to limit the extent of a leak, the Plant is split in sections that can be isolated, by emergency shutdown valves, and depressurized,
- Isolation philosophy to allow dismantling for maintenance: Isolation and bypas valves are provided for isolation of equipment and instrument for maintenance. Vents, drains and inerting lines are provided to depressurize, drain and inert the equipment.
- Drainage philosophy: recovery and segregation of drains,
- Pressure relief system (equipment pressure safety relief valves, vent and flare lines),
- Start-up and shutdown lines for pressurization, warm-up, etc.
- Equipment and line heat insulation/tracing,

The **Legend and Symbols P&ID** shows the meaning of the graphical elements and symbols used on the P&IDs. For instrumentation, a depiction standard (ISA) is used, providing a means of communicating instrumentation, automation and control requirements that all parties can readily understand.



MEASURED VARIABLE / INSTRUMENT FUNCTION	ANALISYS	DENSITY	FLOW	HAND	LEVEL	MOISTURE	PRESSURE
ALARM							
CONTROLLER	AC		FC	HC	LC		PC
CONTROL VALVE	AV		FV	HV	LV		PV
SELF ACTUATED CONTROL VALVE	ACV		FCV	HCV	LCV		PCV
PRIMARY ELEMENT	AE	DE	FE		LE		PE
GLASS			FG		LG		
SWITCH	AS		FS	HS	LS		PS
HIGH SWITCH	ASH		FSH		LSH		PSH
HIGH HIGH SWITCH	ASHH		FSHH		LSHH		PSHH
LOW SWITCH	ASL		FSL		LSL		PSL
LOW LOW SWITCH	ASLL		FSLL		LSLL		PSLL
TRANSMITTER	AT	DT	FT		LT	MT	PT

Numerous arrangements are repeated several times on P&IDs: Equipment isolation, drains, vents, PSVs, isolation and bypass of control valves, battery limits, sample collection. These typical arrangements must be defined at the start of the Project, shown on the **Typical P&IDs** and then applied on each concerned P&ID.

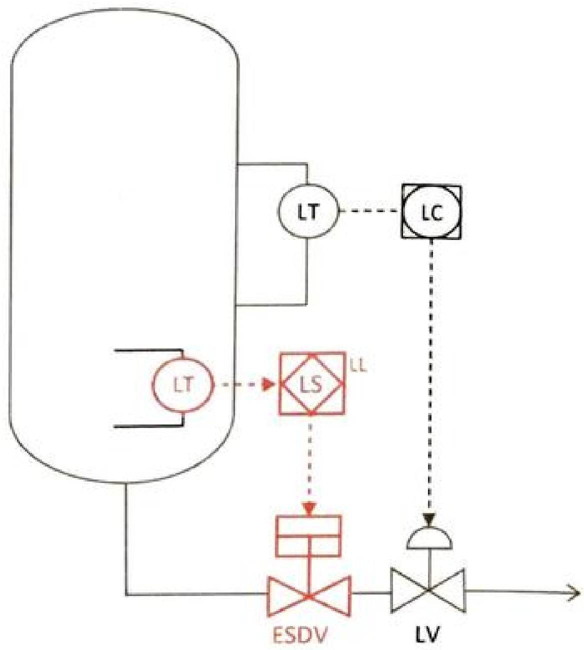


P&IDs are the documents through which Process communicates its requirements to Instrumentation & Piping disciplines. They shall show:

- **All itemized equipment,**
- **Item number and service description of each equipment with relevant design condition,**
- **Pertinent interior arrangement of equipment, e.g., distributor, weir, etc.**
- **All lines (process, utilities, start-up, maintenance), with indication of diameter, rating, material, service, line number, piping class, piping class break/change, external finishing (such as insulation, personal protection, tracing...),**
- **Battery limits between Parties, e.g., contractor and vendor,**
- **All valves for operation, start-up, maintenance, including isolation valves, check valves, etc. with indication of valve type,**
- **All instruments with detailed control loops, drawn as per ISA symbols, tagged as per the Project united numbering system, local instruments or instruments on local panel, sequences and interlocks (with brief description, e.g., start/stop, permissive to start, etc.),**
- **Control valves, ON/OFF valves,**
- **Safety valves (with set point and inlet/outlet size),**
- **Electrical controls, such as pump local or remote start/stop, emergency shutdown,**
- **Control and monitoring signals for rotating equipment and electrical motors,**
- **Requirements related to line routing/supports: straight lengths, slope, no pocket, minimum distance, symetrical arrangement, safe location requirement for vents, 2 phase flow, etc.**

The P&IDs are the main documents that show the facility's process, in particular to its future Operator. A P&ID review meeting between the Engineer and the Owner is held at an early stage of the Project, to collect the requirements of the Owner. The P&IDs are then revised to incorporate these requirements and receive the Owner's Approval. This constitutes a major step in the design. At this point, indeed, the P&IDs are "Issued For Design" for the other engineering disciplines, in particular Piping and Instrumentation, to develop their design.

Process designs the Process Shutdown System (PSS), which consists of instrumented safeguards to protect against failure of the Process Control System (PCS) leading to deviation of process parameters. The PSS is an altogether different system from the Process Control System. It has separate sensors, processors, cables and final elements (shutdown valves). In such a way, the PSS acts as as a back-up in case of failure of the function of the PCS.



LT	Level Transmitter
LC	Level Controller
LV	Level control Valve
ESDV	Emergency Shutdown Valve
LS	Level Switch

The level controller "LC" shown here is part of the PCS. It maintains the level in the vessel by opening/closing the control valve.

Should it fail, the PSS will, upon detection of very low level in the column, close the shutdown valve located upstream of the control valve in order to prevent loss of liquid level in the vessel and gas escape through the liquid outlet line. The very low level sensor and shutdown valve are part of the PSS.

The logic of operation is described in the Safeguarding Narrative which includes Cause & Effect Diagrams, also called SAFE (Safety Analysis Function Evaluation) Charts.

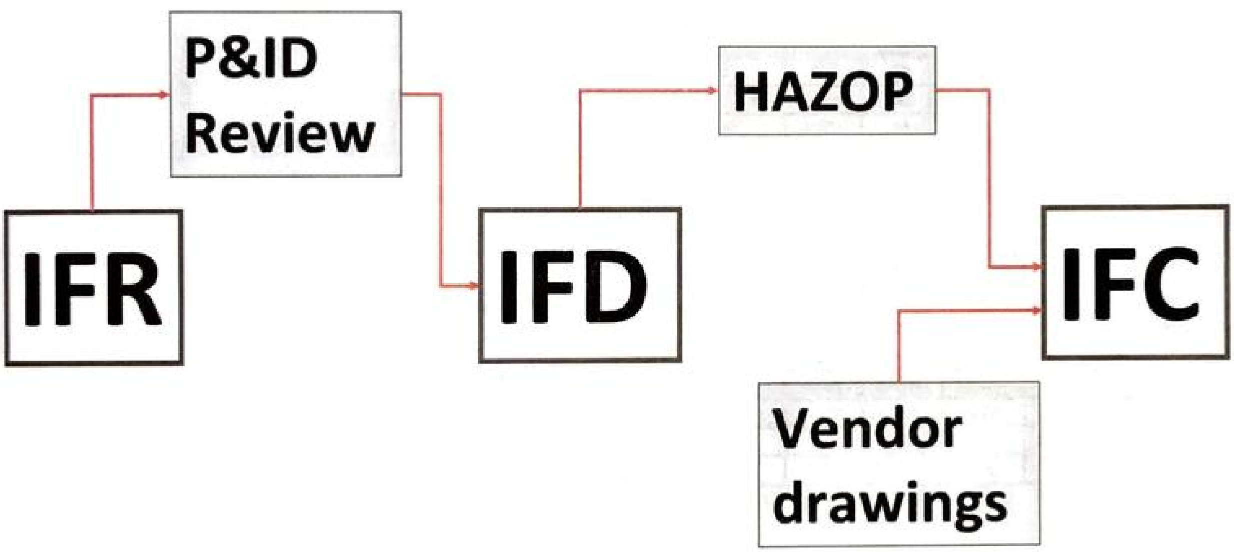
CAUSE AND EFFECT CHART

CAUSE: SERVICE – EQUIPMT	CAUSE: SERVICE – DESCRIPTION	TAG No.		EFFECT: 82-ESDV 1241 Sour water from V1201	EFFECT: 82-LV 1241 Sour water from V1201 to U19	EFFECT: 82-ESDV 1242 Reflux from V1201
				18	19	20
82-C1203	Gasoil Product Pump Shutdown	82-HS 1232A/B	11			
82-V1201	LSLL in 82-V1201	82-LSLL 1244	12			
82-V1201	LSLL in 82-V1201	82-LSLL 1243	13	C	C	
82-V1201	82-V1201 H/C Outlet Isolation	82-HS 1244	14			C
82-V1202	LSLL in 82-V1202	82-LSLL 1247	15			

Following the review of the P&IDs with the Client and incorporation of the required changes, the P&IDs are submitted to an Audit related to the Process Safety, called **HAZard and OPerability (HAZOP)** review. The main puropose of the HAZOP is to check that all required Process ShutDown devices, to protect against deviation of process parameters outside their acceptable range, are provided.

Even though the HAZOP is purely related to the safety of the process, the HAZOP session is usually organized by Safety discipline. Please refer to chapter 6 for details.

The P&IDs are revised, further to the HAZOP, to incorporate the design changes required following the HAZOP and information from Vendors: Equipment/packages piping connections, control system interfaces with equipment/packages, precise limits of supply, utility lines for packages, etc.



Contents of P&ID revisions

IFR	IFD	IFC
➢ Exercised contract option(s) ➢ Diameter of process lines	➢ Client comments ➢ Diameter of utility lines	➢ HAZOP actions ➢ Finalized interfaces with equipment and packages ➢ Size, number of PSVs and control valves

Process produces the Process fluids list, which shows the various fluids, their conditions (pressure, temperature) and the material suitable for the service and to prevent corrosion. The required piping material classes will then be identified by joint discussion between Process and Piping with the aim to standardize piping materials.

Process Fluids List

FLUID	SYMBOL	OPERATING & DESIGN CONDITIONS T °C MAX/DESIGN		bar MAX/DESIGN		MATERIAL
Drain	BD	30	50	atm	19	CS
Drain	BD	30	50	atm	98,5	CS
Drain	BD	50	70	atm	265	CS
Fuel Gas	FG	30	50	8	9	SS
Fuel Gas	FG	40	60	45	49	SS
Fuel Gas	FG	55	75	98	98,5	CS
Diesel fuel	FO	amb	50	2	3	CS
Fire Water	FW	amb	50	11	12	HDPE
Fire Water	FW	amb	50	11	12	CS
Lube Oil	LO	30	80	4,2	5	GALVAN
Methanol	ME	20	50	atm	3	SS
Methanol	ME	20	50	254,5	265	SS
Open drain	OY	amb	50	atm	3	CS
Hydrocarbon Gas	P	30	50	atm	19	CS
Hydrocarbon Gas	P	30	50	98	98,5	CS
Hydrocarbon Gas	P	-40/30	-46/50	atm	2	LTCS
Hydrocarbon Gas	P	-40/30	-46/50	98	98,5	LTCS
Hydrocarbon Gas	P	138	160	253,5	265	CS
Hydrocarbon Gas	P	50	70	253,5	265	CS
Hydrocarbon Gas	P	138	160	253,5	291	CS
Hydrocarbon Gas	P	-40/138	-46/160	253,5	291	LTCS
Hydrocarbon Gas	P	-40/50	-46/70	253,5	265	LTCS
Utility Air	UA	30	50	11	12	CS
Utility Water	UW	amb	50	3	4	GALVAN

List of Piping Classes

Class	Material	Rating	Pbara/T°C Design
11A	CS	150	19 / 50
15A	CS	600	98.5 / 75
18A	CS	2500	265 / 160
21A	LTCS	150	2 / -46 TO 50
25A	LTCS	600	98.5 / -46 TO 50
28A	LTCS	2500	265 / -46 TO 70
31A	304LSS	150	9 / 50
35A	304LSS	600	49 / 60
38A	304LSS	2500	280 / 50
91A	CS GALVA	150	5 / 80

Process assigns a number and a piping class to each line and calculates its diameter. The diameter is calculated based on hydraulic requirements, for a few concerned lines, but for most lines using formula limiting the velocity to prevent erosion, vibration and excessive noise. Corresponding calculations are recorded in the Line sizing calculation note. The diameter of Process critical lines, i.e., lines whose pressure drop shall be limited (PSV inlet lines, pump suction lines) is checked by Process once the isometric drawing is issued by Piping.

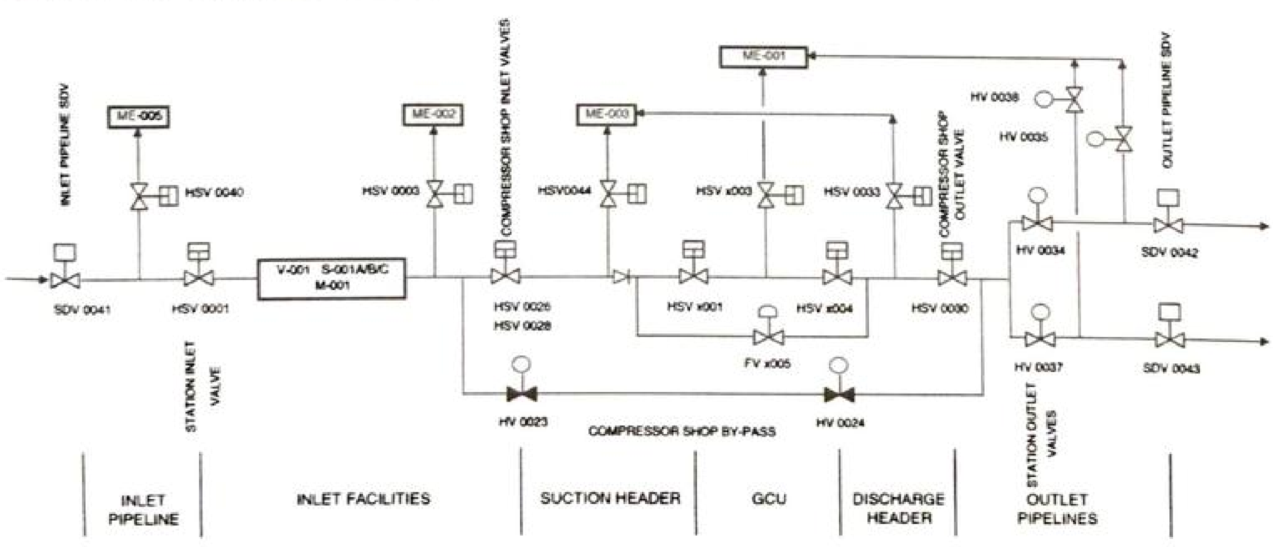
The Process line list shows the process conditions in all lines. The operating temperature will be used by Piping to calculate the line thermal expansion. The design pressure will set the hydrostatic test pressure.

Line Number			Line Size	Class	Insulation		P&ID Dwg. No.	Line Connection		Fluid Phase	Operating Condition		Density	Design Condition			Full Vacuum
Fluid Code	Unit Code	Seq No.			Code	Thk.		From	To		Press	Temp		Press	Temp (Max.	Temp (Min.	
											barg	degC	kg/m3	barg	degC	degC	(Y/N)
GN	71	61106	22	3C3AS1	N	NO	80-212	LNG STORAGE	UNIT 93	V	27.6	55	18.2	34.5	100		N
GN	71	61106	20	3C3AS1	N	NO	80-212	LNG STORAGE	UNIT 93	V	27.6	55	18.2	34.5	100		N
GN	71	61106	12	3C3AS1	N	NO	80-212	LNG STORAGE	UNIT 93	V	27.6	55	18.2	34.5	100		N
LNG	71	60001	32	3R0JLL	6	180	80-302	668-P001 A/B/C	LNG RUNDOWN HEADER	L	11.1	-159	439	30	80	-167	N
LNG	71	60001	22	3R0JLL	6	170	80-302	668-P001 A/B/C	LNG RUNDOWN HEADER	L	11.1	-159	439	30	80	-167	N
DOW	72	63000	0.75	1P1	N	NO	72-204	72-P061A	72ET-60105	L	0	48	1000	2	82		N
DOW	72	63001	0.75	1P1	N	NO	72-204	72-P061B	72ET-60105	L	0	48	1000	2	82		N
DOW	72	63002	0.75	1P1	N	NO	72-204	72-P062A	72ET-60105	L	0	48	1000	2	82		N
DOW	72	63003	0.75	1P1	N	NO	72-204	72-P062B	72ET-60105	L	0	48	1000	2	82		N

The Process Shutdown System described above isolates individual lines and shuts down individual equipment upon deviation of process parameters outside the acceptable range. A system is also required to isolate and shut down an entire section of the Plant, or even the whole Plant, in case of an emergency, mainly in case of gas leak or fire. This system is called the Emergency ShutDown system (ESD). It is also designed by the Process Engineer.

The system comprises emergency isolation valves, called ESDV (Emergency ShutDown Valves), to isolate the Plant in sections, shutting the flow of process fluids to an area where gas leak/fire have been detected and limiting the inventory of flammable fluids.

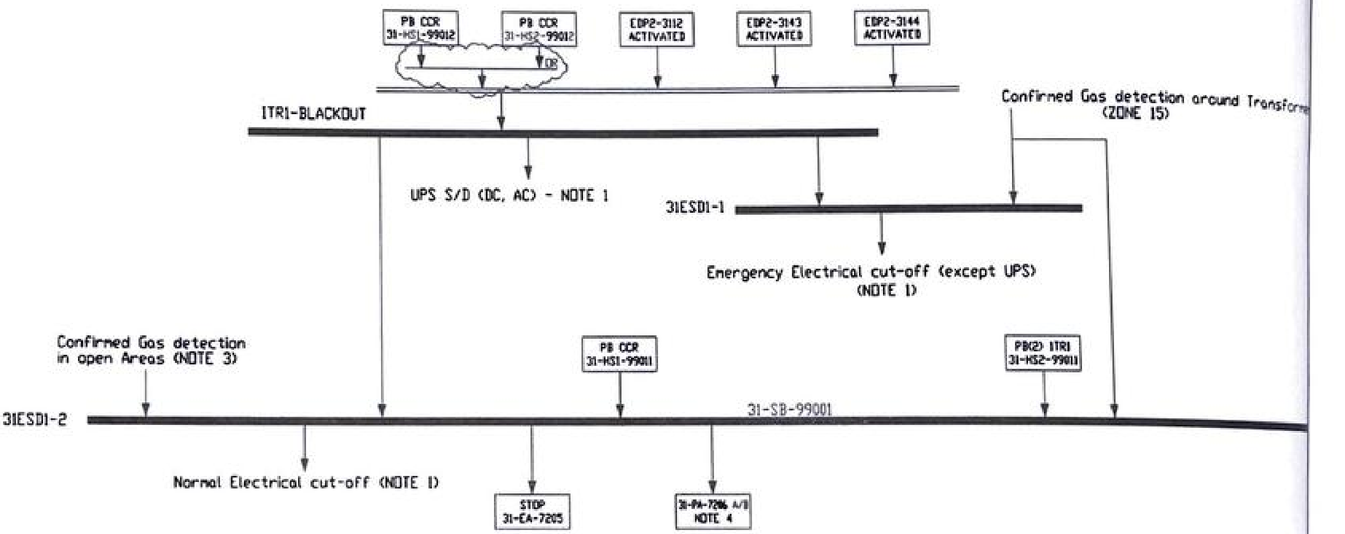
The ESD Block Diagram provides an overview of how the Plant can be isolated in various sections.



Emergency depresurisation valves are provided to depressurize each section of the Plant. These valves are also shown on the ESD Block Diagram.

The philosophy of isolation and depressuirsation of the Plant in an emergency is described in the **Emergency Shutdown and Depressurization philosophy**. Different levels of emergency shutdown are defined. The highest level shuts down and depressurizes the whole Plant while the lower levels shut down a single unit only.

The logic of activation of the various levels of the Plant Emergency Shutdown system, and their actions, is shown on the **ESD logic diagrams**.



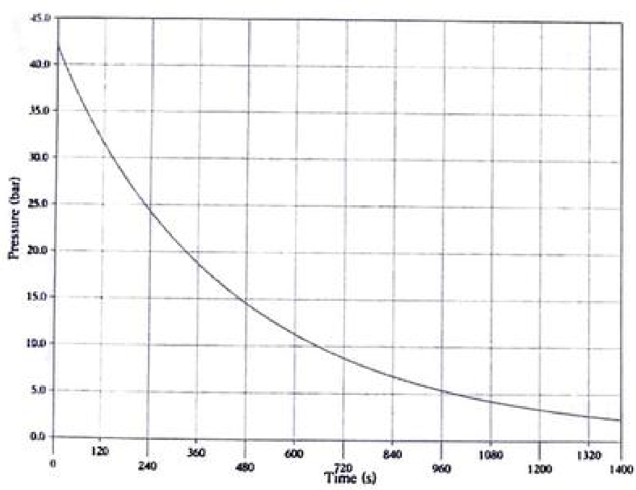
The above logic is also shown on Cause & Effect diagrams. The logic diagram is nevertheless easier to read.

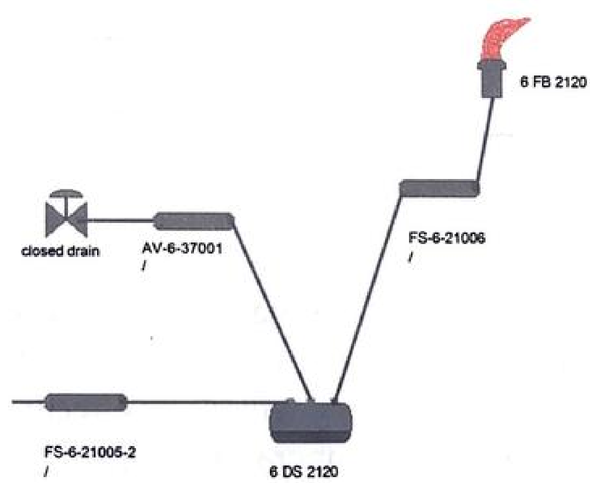
The emergency depressurisation of the Plant requires a relief system. Such system might be a cold vent, in which case gas is released to the atmosphere without being ignited, or a flare.

Process discipline is in charge of designing the pressure relief system. The design starts with the inventory of all relieving devices and scenarii. All relieving devices (emergency depressurization valves, pressure control valves, equipment pressure safety relief valves) and released flow in all scenarii (emergency, fire, loss of electrical power, loss of cooling medium, etc.) must be considered. The relieving devices and flow are shown in the **Relief Load Summary**.

ITEM	LOCATION	SET PRES. bar g.	INDIVIDUAL AIR-COOLED CONDENSER FAILURE t/h	GENERAL ELECTRICAL POWER FAILURE t/h	FIRE t/h	COOLING WATER FAILURE t/h	OTHER CASES (as specified) t/h	REMARKS
PRV-12116	82-C1201	6.0	499	182	23.5	-	542	Reflux loss
PRV-12136	82-V1203	20.5	-	-	38.1	-	-	
PRV-12160	82-V1206	7.5	-	-	8.6	-	-	
PRV-12117	82-C1204	3.5	14.1	5	2.5	1.4	35.0	Pumparound Pump P1217 Failure
PRV 12122	82-V1207	3.5	-	-	0.7	-	0.01	Blocked Outlet
Maximum Flare Load			499	187	38.1	-	542	

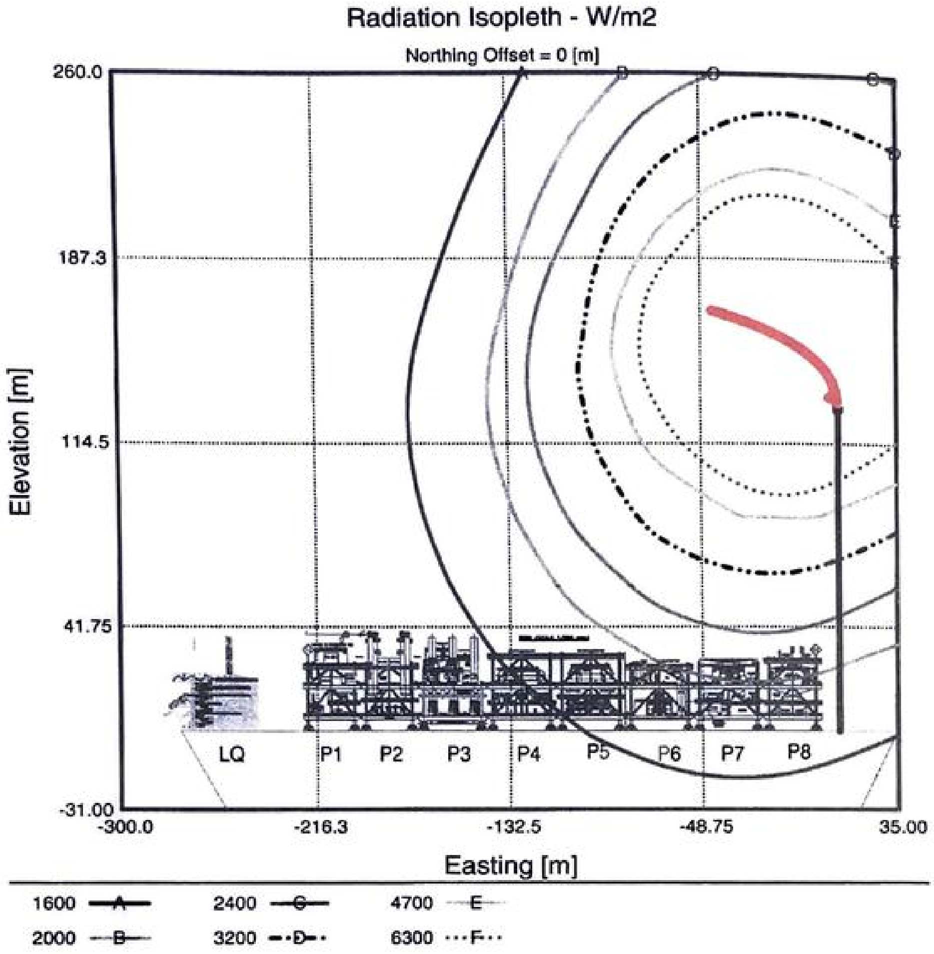
Process then sizes the relief system: diameter of relief lines, design pressure of liquid collection vessel (flare knock-out drum), capacity of flare tip, etc. The relief system design criteria are given by codes or Owner requirements, such as the requirement to depressurize the Plant to 7 bars in less than 20 minutes that is commonly applied to Off-Shore facilities.

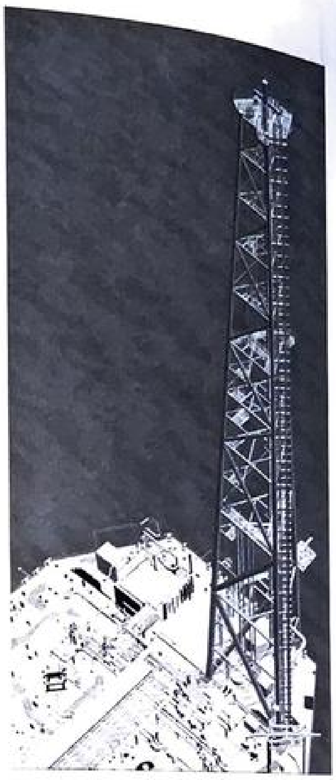


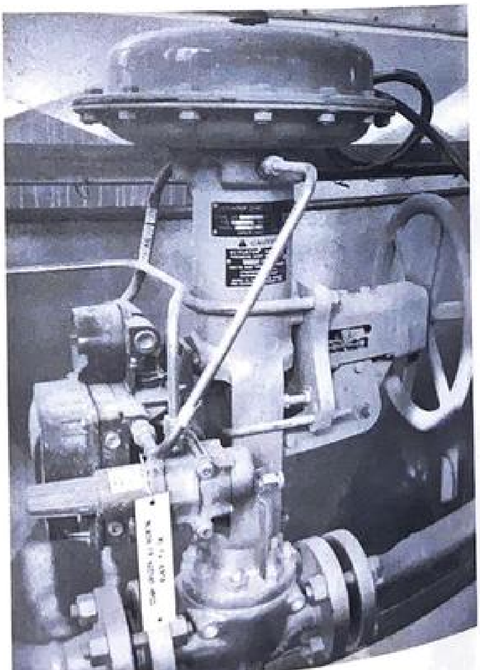


The **Flare Report** details the relief calculations and results, including the levels of low temperature reached in the pressure vessels and relief lines during depressurization. Very fast depressurization from high pressures to very low pressure in a few minutes leads to very low temperature. The depressurization conditions determine the low design temperature of the pressure vessels and the flare system. It may dictate the use of special materials such as low temperature carbon steel, or even stainless steel.

Flare heat radiation calculations are done as part of the flare study, to define the height of the flare stack. The required stack height is the one that gives low enough a level of heat radiation at grade/closest operating areas.



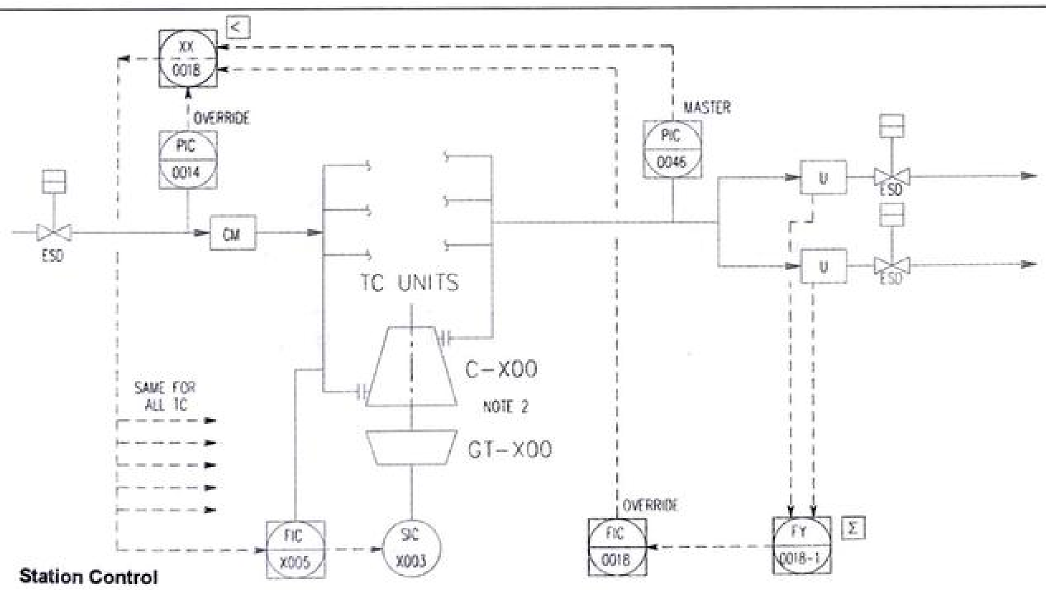




Instrument Process Data Sheets are issued for control valves. They indicate the extreme operating cases for the selection of valves whose size will allow effective control over the whole operating range.

CONTROL VALVE PROCESS DATA SHEET					PCV-0041
QUANTITY 1	LINE n°	2"-FG-005-15A-B	PID n°		P-3-08590
FLUID CHARACTERISTICS					
FLUID STATE	1 [X] GAS	2 [ ] LIQUID	[ ] STEAM		
DENSITY				kg/m³	66.3 / 45.3
MOLECULAR WEIGHT (GAS)				g/mole	16.5
VAPOUR ABS. PRESSURE AT T (OPERATING TEMPERATURE)				MPa	N/A
CRITICAL ABS. PRESSURE				MPa	N/A
DYNAMIC VISCOSITY				cP	N/A
COMPRESSIBILITY FACTOR (GAS)				-	0.90 / 0.92
RATIO OF SPECIFIC HEATS (GAS)				-	1.54 / 1.45
OPERATING CONDITIONS					
OPERATING CASE		Max. Flowrate Max. Pressure	Min. Flowrate Min. Pressure		
FLOW AT P1 AND T	kg/h	60	20		
UPSTREAM ABS. PRESSURE	MPa	9,7	6,8		
DOWNSTREAM ABS. PRESSURE	MPa	0,8	0,8		
UPSTREAM TEMPERATURE	°C	50	50		
DONNEES DE CONSTRUCTION / CONSTRUCTION DATA					
MAX. ABS. PRESS.	9,95 MPa	MAX. TEMPERATURE		60	°C
MAX. DIFFERENTIAL PRESSURE WHEN CLOSED VALVE (FOR ACTUATOR SIZING)				9,85	MPa
ETIGHT ACCORDING		CLASSE / CLASS	ΔP		MPa
ON POWER FAILURE, VALVE TENDS TO	FO [ ] OPEN	FC [X] CLOSED	FL [ ] LOCKED	FI [ ] INDETERMINATE	
PLUG CHARACTERISTIC	EQUAL % [ ]	LINEAR [ ]	OTHER [ ]		
NOISE LEVEL AT 1 m		MAXIMUM ALLOWED		80	dBA
HAND WHEEL		YES [X]	NO [ ]		

The Operating and Control Philosophy, or a dedicated Functional analysis, describes the Process controls and is used to program the Process control system.



Station Control

Control of the station shall be carried out, manually or automatically, by adjusting the revolutions of the units, controlling the most critical of the following parameters:

- suction gas pressure (override);
- discharge gas pressure (master);
- gas flow rate (override).

Complex control loops description, describing the control loops other than simple direct acting controllers, are issued to Instrumentation & Control discipline to facilitate the understanding of the control function.

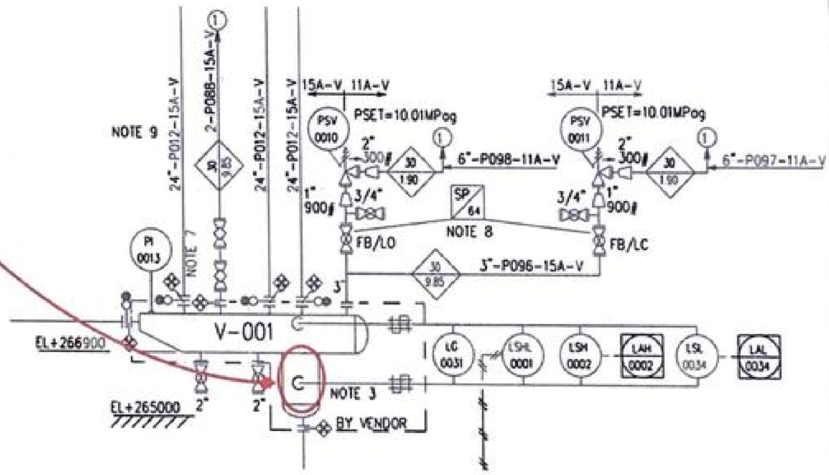
Finally, Process issues the **Operating Manual**, containing a detailed description of the facilities, of the Operator interface with the Plant systems, detailed instructions for start-up, operation and emergency.

4.1.1.3.3 Slug catcher lining-up and liquid sealing

Refer to the following Piping & Instrument Diagram:

- *P-3-08512 : Liquid disposal system*

- Fill bottom of boot with diesel oil through connection of one of non installed instruments (LSH or LSL) at least up to LSL-0001 (Level Switch Low) in order to avoid gas blow-by through drain line as transported gas expected quality is dry. Blind the connection again. Check that LV is still closed.
- Ensure that all spectacle blinds (one at drum inlet, three at drum outlet) around slug catcher are in open position.
- Close the two 2" plug valves on vent line.
- Close the two 2" plug valves on each drain.
- Ensure that mechanical interlock between the PSV is in right position, i.e. the closure of one isolation valve



The operating manual provides reference information such as the capacity of all vessels, set-points of controllers, alarms, safety switches, etc.

TAG	Position	Control device	PID	Unit	Set point	Alarm low	Alarm high	Range
PCV0001	Pilot gas for level valves	LVs	8513	bar	11			
LSHL0001	Slug catcher D-001 boot	LV-0001	8512	mm	-150/50			
LAH0002	Slug catcher D-001 boot		8512	mm			200	
LAL0034	Slug catcher D-001 boot		8512	mm		-450		
PIC0014	Header inlet filters separators S-001		8550	bar	67			
PAL0017	Inlet gas filters S-001 inlet header		8512	bar		64,5		50 - 70

The operating manual contains information about the *Plant* systems (process, utility, emergency shutdown). Information on the operation and maintenance of individual equipment are found in the equipment vendor documentation.

Chapter 4

Equipment/Mechanical

Besides the process duty indicated on the Process Data sheet, a number of additional requirements must specified, to ensure Equipment quality, safety, long uninterrupted service, low maintenance, adequacy to Site conditions, etc.

These requirements are defined by the Equipment (also called Mechanical) Engineer. As there are quite a few types of Equipment and each has a large degree of sophistication, which is evident when counting the number of pages of the corresponding industry codes, the Equipment discipline is split in specialties. There are 4 such main specialties:

- **Static equipment** (columns, drums, reactors, filters, separators, heat exchangers),
- **Rotating equipment** (pumps, compressors, turbines),
- **Fired equipment** (fired heaters, boilers, flare)
- **Package**: set of equipment ordered together performing a specified function: gas treatment, water treatment, air and nitrogen generation, chemical injection, solid handling, etc.

The Equipment specialist defines and gathers all requirements related to the Equipment in one "umbrella" document, the **Material Requisition (MR)**. Practices vary among Engineering contractors and this document may contain the information itself or make reference to document(s) containing the information instead. One MR is issued for each *type* of Equipment, e.g., centrifugal pumps, reciprocating pumps, columns, heaters, etc., as all Equipment of a given type is usually sourced from the same vendor. In any case, all of the following shall be present:

1) The process specification,
2) The list of applicable codes and standards,
3) The list of applicable Client specification(s),
4) The list of imposed suppliers, if any,
5) The list local regulations,
6) The detailed scope of supply & services,
7) The Site & Plant data,
8) The Mechanical data sheet,
9) The Engineering (guide) drawings,
10) A general or particular specification,
11) The extent of the shop assembly,
12) Inspection, tests and certification,
13) Packing,
14) Delivery terms,
15) Vendor Documentation Requirements and Schedule (VDRS),
16) Information to be submitted with the bid,

It is important that the Material Requisitions cover all above topics and that, for each topic, sound choices are made and critical points covered, as described below. This ensures that the received bids are as close as possible to the final ones. It reduces the duration of clarifications and allows placing Equipment purchase orders early, which, as explained in chapter 16, is critical to the Project execution.

1) The Process specification

Some Equipment are *designed*, i.e., sized, by the Purchaser (the EPC Contractor) while others are only *specified* by the Purchaser, their design being done by the Equipment Vendor.

Equipment type	Designed (1) by the Purchaser	Designed (1) by the Vendor
Columns, Drums, Shell & tubes heat exchangers (2)	X	
Other types of heat exchangers, column internals		X
Fired Equipment, rotating equipment, packages		X

Notes:

(1) "Design" is used here with the meaning "Equipment sizing" and not mechanical design. The mechanical design is, in all cases, done by the vendor.

(2) The design of shell & tubes heat exchangers could be left to the vendors but this is not convenient as these vendors, which are pressure vessels manufacturers, do not all have the (thermal) design know-how. In addition, the thermal design is needed for Plant Engineering development as it defines the Equipment dimensions and the position of its nozzles.

The information found on the Equipment process specification is different depending on whether the Equipment is designed or specified by Process:

- The Process Data Sheets of columns and drums fully define the Equipment with all vessel dimensions, type and disposition of internals, nozzles, etc.
- Similarly, the Thermal Data Sheets of shell & tubes heat exchangers also fully define the Equipment: number and diameter of shells, shape (straight/U shaped), length, diameter and number of tubes, etc.
- On the other hand, the Process Data Sheets of other Equipment types, or the duty specification for packages, is functional. It indicates the properties of the inlet and outlet streams to be achieved by the Equipment.

2) Applicable codes & standards

Codes and standards have been developed for all types of Equipment found in Oil & Gas facilities. The American Petroleum Institute (API) has developed standards based on operational feed-back from end-users and suppliers. These standards contain comprehensive requirements related to the design, material selection, manufacturing, auxiliaries, inspection, testing and documentation.

The choice of the applicable code determines to a large extent the Equipment cost. API standards contain a number of optional requirements to be decided by the Purchaser. These optional requirements are indicated by the words "if specified" in the standard. They are easy to identify as a bullet is shown in the left margin, as shown in the below extract of API 610 for centrifugal pumps:

	8.3.4.4	Complete Unit test
•	8.3.4.4.1	If specified, the pump and driver train, complete with all auxiliaries that make up the unit, shall be tested together.

These selected optional requirements shall be indicated on the Mechanical data sheet the Purchaser.

Industry standards, such as API, are subject to frequent revisions. The applicable edition of the standard shall therefore be indicated. It shall be the latest edition, as manufacturer products evolve according to the latest standards and manufacturers won't be able to produce according to outdated standards.

In all cases, manufacturers will take exceptions to some of the requirements of the API standards. These exceptions are discussed and agreed before placing the order.

For static equipment (pressure vessels, heat exchangers, boilers), the code mostly applied in the Oil & Gas industry is the ASME boiler and pressure vessels code.

There are standards applicable to both main Equipment and auxiliaries. A rotating equipment, for instance, might be subject to an API standard as a whole while its gear box, coupling, seals & lube oil systems might each be subject to another API standard. Furthermore, the Equipment of the auxiliary systems, e.g., lube oil cooler, pump, might be required to comply with industry standards or accepted as manufacturer standards.

3) Applicable Client specifications

Client specifications contain additional requirements to that of the codes, deriving from their operational experience. They also indicate choices, when left open to the user's choice in the code, such as the complete unit test of the pump shown above.

Clients have developed specifications for each type of commodity.

On top of the Client specification related to the main equipment, Client specifications related to individual components may be applicable: electrical motors, auxiliaries, structural steel, piping, electrical, instrumentation, materials of construction, welding, etc. Other Client specifications include painting, final documentation, spare parts list, etc.

The painting spec is often onerous. Whereas it is easy – even if costly – for the Equipment vendor to apply the painting specification to its own supply, i.e., the Main Equipment, it is difficult if not impossible to have it applied for standard off-the shelf items such as electric motors. In this case an industry standard, such as ISO 12944, or the manufacturer standard should be proposed to the Client as alternate.

4) Restricted suppliers list, also called Approved Vendors List (AVL), and standardisation

Most Oil Companies have their approved suppliers list. In addition, some impose standardisation. This is typically the case for electric motors, instruments, Programmable Logic Controllers (hardware and software).

There could also be restrictions in country of origin of manufacturing or, much more difficult to follow, raw materials.

5) Regulatory requirements

Some codes specific to the country of installation of the equipment need to be complied with, by law. Examples are codes for pressure vessels (ASME in US, PED in EU), explosion protection, Electrical code (NEC in the US, IEC in EU), etc.

6) Scope of supply & services

It is important to precisely define the scope of supply. Limit it to the supplier's core business while keeping your interfaces simple.

- Avoid "packaging", i.e., bundling equipment together and buying from a single vendor. This costs more than buying equipment separately, as it limits the competition (few vendors are able/willing to supply a package) and restricts your controls over the sub-vendors.

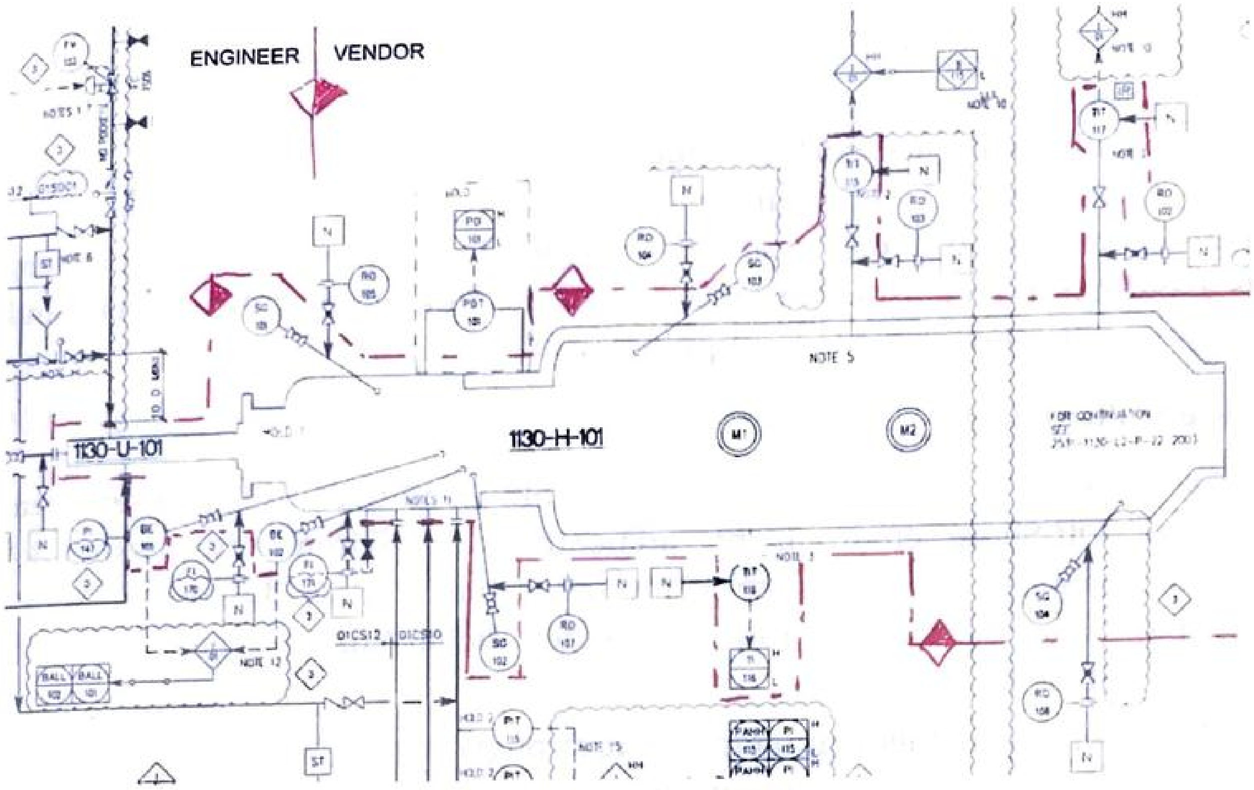
- Equipment with complex controls, e.g., gas turbines, or controls critical to the equipment integrity, e.g., compressors, shall be supplied with their Unit Control System (UCS). Equipment and packages with simpler and non-critical controls shall be controlled by the Plant ICSS. Please refer to chapter 11 for details.
- Leave items which are not the Equipment vendor's core business, and which are not linked to equipment design or integrity, outside the scope of supply. Examples: valves, piping, piping items, instruments, etc.
- Purchase the Machinery Monitoring System, when required for rotating Equipment, complete with its sensors from the Equipment supplier, who is the one defining its functional requirements.

For packages, it is convenient to define the scope of by means of a matrix.

DESIGNATION	DESIGN		SUPPLY		INSTALLATION	
	P	V	P	V	P	V
Instrument air supply at battery limit	X		X		X	
Instrument air distribution inside BL		X		X		X
Instruments inside BL		X		X		X
Junction boxes at BL		X		X		X
Cables between instruments and JBs		X		X		X
Fire & Gas detectors inside BL	X		X		X	

P = Purchaser, V = Vendor, BL = Battery Limits, JB = Junction Box

A P&ID mark-up is also effective to define the scope of supply of packages.



The scope of services must also be defined, including HAZOP for packages, vibration studies for reciprocating rotating equipment, etc.

The Mechanical Warranty shall be part of the scope of work and services. Its duration shall be stated and identical, as far as possible, to the one given by the Engineering Company to the end user.

For what concerns spare parts, 2 sets are usually defined:

- "Commissioning & start-up" spares, which are always included in the vendor's scope of supply. They include spares needed during construction for loss or breakage (nuts, bolts, gaskets, gauge glasses, connectors, extra pipe, bulk materials, etc.) and during pre-commissioning, commissioning and start-up (filter elements, strainers, mechanical seals, repair kits, fuses, thermocouples, instrument probes, transmitters, etc.).
- "2 years operating spare parts" are normally supplied as option. The list and price of these spare parts cannot usually be defined at the time when the purchase order is placed as the precise contents of the supply, and the selection of sub-suppliers, are not known yet. The cost of these spare parts could be significant, typically 10-15% of main equipment cost for pumps.

Once the scope of supply has been clarified with the vendor during clarifications, i.e., in "For Purchase" revision of the Material Requisition, the scope of supply shall be split by delivery lot. Equipment do not come on their own but with auxiliaries, such as a lube oil or cooling water skids, accessories, for instance Unit Control System, spare parts, etc. Each lot is usually delivered separately and at a different location. Arranging the scope of supply in delivery lots avoid missing items, for instance interconnecting piping between main and auxiliary skids, if required to be supplied (usually not).

7) Site & Plant data

The Equipment need to be suited to the Site conditions (dusty desert area, corrosive Off-Shore environment, arctic/tropical environment, maximum/ minimum air temperature), the Plant (available utilities: is cooling water available?) and the location (outdoor/under shelter/inside heated building) where it will be located.

The maximum ambient air temperature strongly impacts the power delivered by gas turbines. The maximum air temp to be considered for air-coolers must also be defined. It is lower than the maximum ambient air temperature as it does not make sense to design the air-coolers for such extreme case.

The minimum temperature expected in service determines Equipment materials of construction and impact test, which have a significant cost impact.

This temperature does not need to be the minimum ambient Site temperature. Indeed, the Equipment could be started-up slowly so that it warms up while its internal pressure is raised.

The minimum Site ambient air temperature determines the requirements for "winterisation", i.e., heat tracing to prevent freezing of process or utility fluids.

The wind speed and seismic level impact the thickness of tall low pressure columns.

If a Quantitative Risk Assessment (see Safety chapter) has been done and a blast resistance level has been specified for some Equipment, it must be specified. It could have a significant impact for large vessels.

The Plant data includes the Electrical voltage levels and frequency. The voltage level significantly impacts the cost of electric motors. Medium voltage motors are more expensive than low voltage motors. Usually the Client specification specifies a maximum power, typically from 150 to 300kW, for low voltage motors. This must be indicated to Vendors.

The following must be indicated as well:

- Available cooling medium, quality, supply and return conditions. The cooling water quality (presence of chlorides, fouling factor) determines the material and sizing of heat exchangers.
- Availability and conditions of supply of other fluids (fuel gas, nitrogen, instrument air, steam).
- Availability of a relief system (flare) and back pressure.

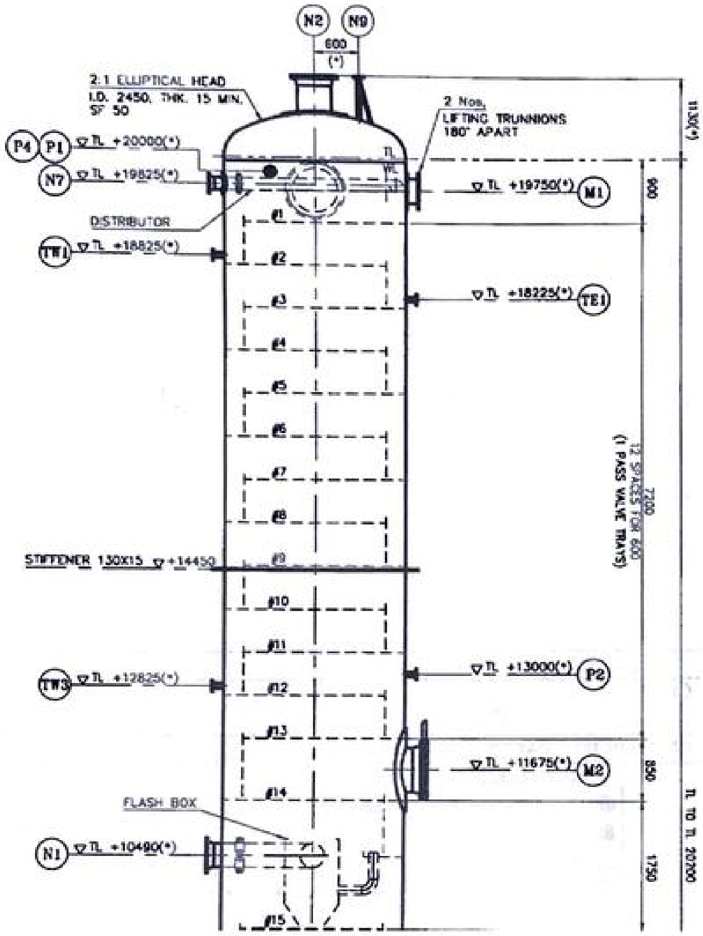
8) Mechanical data sheet (MDS)

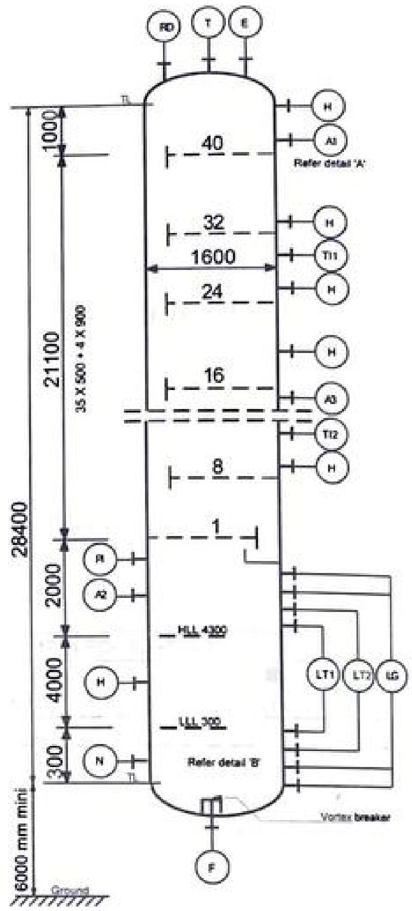
Templates of mechanical data sheets are included in API standards for rotating equipment. The data sheet is filled by both the Purchaser and the Vendor. Purchaser communicates technical data, requirements and assigns responsibility for the scope of work and supply. The Vendor indicates characteristics of offered equipment.

CENTRIFUGAL COMPRESSOR (API 617-7TH)	SERVICE RECYCLE COMPRESSOR
APPLICABLE TO: ● PROPOSAL ○ PURCHASE ○ AS BUILT	
NOTE: INFORMATION TO BE COMPLETED: ○ BY PURCHASER	☐ BY MANUFACTURER
CONSTRUCTION FEATURES	
☐ SPEEDS:	SHAFT SEALS:
MAX. CONT. ______ RPM TRIP ______ RPM	● SEAL TYPE (2.8.3) Dry gas seal
MAX. TIP SPEEDS ______ m/s @ 100% SPEED	● SETTLING OUT PRESSURE (BARG) 28,5
☐ LATERAL CRITICAL SPEEDS (DAMPED)	○ SPECIAL OPERATION (2.8.1)
FIRST CRITICAL ______ RPM ______ MODE	○ SUPPLEMENTAL DEVICE REQUIRED FOR CONTACT
SECOND CRITICAL ______ RPM ______ MODE	SEALS (2.8.3.2) TYPE ______
● TRAIN LATERAL ANALYSIS REQUIRED (2.9.2.3) (23)	● BUFFER GAS SYSTEM REQUIRED (2.8.7) ○ MANIFOLD (3.5.1.6)
● TRAIN TORSIONAL ANALYSIS REQUIRED (24)	● TYPE BUFFER GAS Nitrogen

The MDS gathers all information related to the Equipment: Process data, Site and Plant data, design, performance, materials of construction, hazardous area classification, selected type of auxiliaries, instrumentation, inspections & test, type of delivery.

9) The Engineering drawing (for Pressure Vessels and shell & tubes heat exchangers)

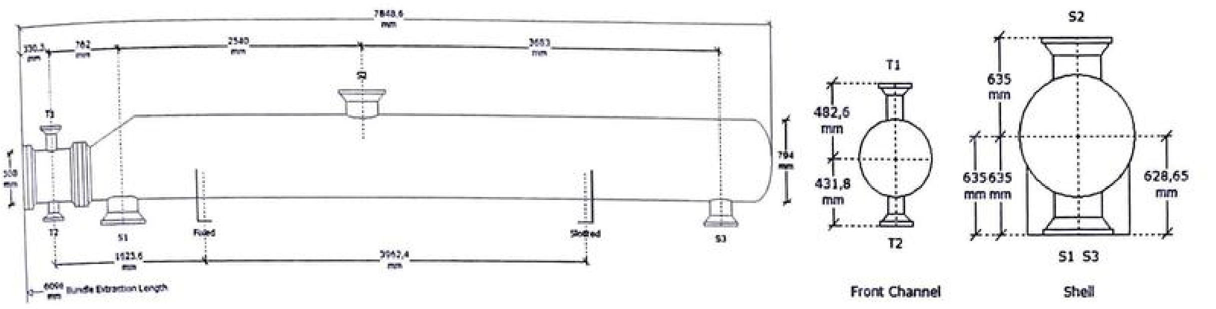




The Process Data Sheet only includes a skeleton drawing of a vessel, as shown above to the right. In order to allow the Plant design to proceed, in particular Plant Layout (design of access platforms) and Piping (routing of connected lines), additional information must be defined: the elevations and positions of nozzles and manholes. To this end, an Engineering Drawing is produced by the Equipment Engineer, as shown above to the left.

This drawing is sometimes called a Guide Drawing as it does not show the final position of nozzles, which could indeed be slightly changed as a result of the Equipment mechanical design performed by the vendor. It nevertheless allows the Plant design to proceed, requiring only minor adjustment once the final positions of nozzles are defined on the General Arrangement Drawing issued by the vendor.

Similarly, an Engineering drawing is issued for shell & tubes heat exchanger, upon completion of the thermal design by Process.



The Purchaser does not need to do the mechanical design of the vessel, i.e., the specification of the material grades and the calculation of the thickness of the vessel parts.

10) A general or particular specification

A general specification applies to all equipment of a given type, e.g., shell & tubes heat exchangers. It supplements the applicable, e.g., API, standard with Purchaser's choices related to optional requirements as well as additions/ modification to the standard. For this reason it makes reference to the numbering of the sections and sub-sections of the standard.

A particular specification is specific to a particular equipment item. It is issued for complex supplies with extended scope of supply, such as turbo-machinery and packages. It contains all sections 1) to 16) listed here along with design requirements in all disciplines: structural, instrumentation, electrical, piping, etc. for all such requirements, it is more effective to shortlist and include directly the applicable requirements in the particular specification rather than to make reference to the project specification and rely on the vendor to read them all!

11) Shop assembly

Equipment shall, as a rule, be assembled at the manufacturer's workshop up to the maximum extent allowed by transport dimensions. This allows to maximize the extent of testing at the manufacturer's and to minimize Site works.

Air-cooled heat exchangers, for instance shall be delivered as modules, as shown here.

The only parts to be shipped separately are walkways and ladders.

Such pre-assembly increases the cost and must therefore be clearly specified in the inquiry documents.

Rotating equipment and packages shall be supplied, wherever possible, skid mounted, i.e., with main and auxiliary equipment mounted on one skid with piping, valves, instruments, local panels installed and connected both mechanically, electrically and pneumatically.

12) Inspections, tests & certifications

Manufacturers have standard inspection & tests schedules which cover the needed tests as it is in their interest to prevent any issue at start-up and during the warranty period. The manufacturer Inspection and Test Plan could therefore be considered as sufficient.

API standards define inspections and tests but leave some optional, to be decided by the Purchaser. Any such optional inspection and tests, particularly if they are to be witnessed by the Client, must be specified as they impact the cost and schedule. This could be done by including an Inspection & Test Schedule as part of the Material Requisition. Extensive testing will be specified for Equipment for Off-Shore or remote Site to maximize troubleshooting, if required, at the vendor premises, where it can easily be done.

Third party certification and stamp, such as ASME U stamp for pressure vessels, might be required by law or Client. Third party certification increases the cost and schedule as the submission of documents to the certification party and its attendance to inspections and tests are required.

13) Packing

The type of packing depends on the type of commodity, the type of transport and storage (sheltered/unsheltered) at Site prior to installation.

Pressure vessels are transported open (or wrapped in plastic film) on wooden saddle. Shell & tubes heat exchangers are transported in wooden cage while the more fragile Plates & Frame are boxed up. Machinery and air-coolers are boxed up. If transported by sea or subject to long duration outside storage, a sealed box is required.

If size allows and transport is by sea, containers are ideal.

Reference to a standard, e.g., SEI 4C for sealed box for maritime transport, is best to specify what is wanted.

14) Delivery terms

Delivery conditions shall be specified by reference to a standard, typically Incoterms 2010.

The Equipment is usually delivered at the Manufacturer's works, loaded on to the Purchaser's vehicle. These terms (FCA loaded) are preferable to Free-On-Board (FOB) from the vendor's perspective. Indeed, in the case of the FOB, the supplier does not have control of the date of arrival of the ship.

15) Documentation

Documents to be supplied by Equipment vendors are of several types: Engineering, Manufacturing, Inspection and Expediting. They include:

- Vendor internal engineering documents, such as calculation notes, assembly drawings,
- Interface documents, showing the equipment interfaces with the Plant in all disciplines: equipment dimensions and required clearance for maintenance, equipment setting plan and loads on foundations, piping connections positions and rating, electrical and instrumentation connections, etc.

- Manufacturing documents such as welding and testing procedures, inspection and test reports, material certificates, etc.
- Documents required at the construction Site: preservation procedure, list of components that will be delivered (packing list), lifting instructions, commissioning and start-up instructions
- Documents to be retained by the Plant Owner: manufacturing records, Operating and maintenance manual, list, references and drawings of spare parts, regulatory documents (A-1 forms for pressure vessels, technical passports)

The **interface documents** are the most critical for the Plant Engineering development. There are not that many such documents and it is essential to focus on their timely submission and finalisation by vendors to prevent delays of Engineering.

These documents are listed hereinafter for the case of a package, which covers all possible interface documents. For other Equipment type, the interface documents are a sub-set of the documents listed below.

The MR shall include the Vendor Documents Requirement Schedule (VDRS), identifying the interface documents as critical and specifying submission dates consistent with the Engineering schedule.

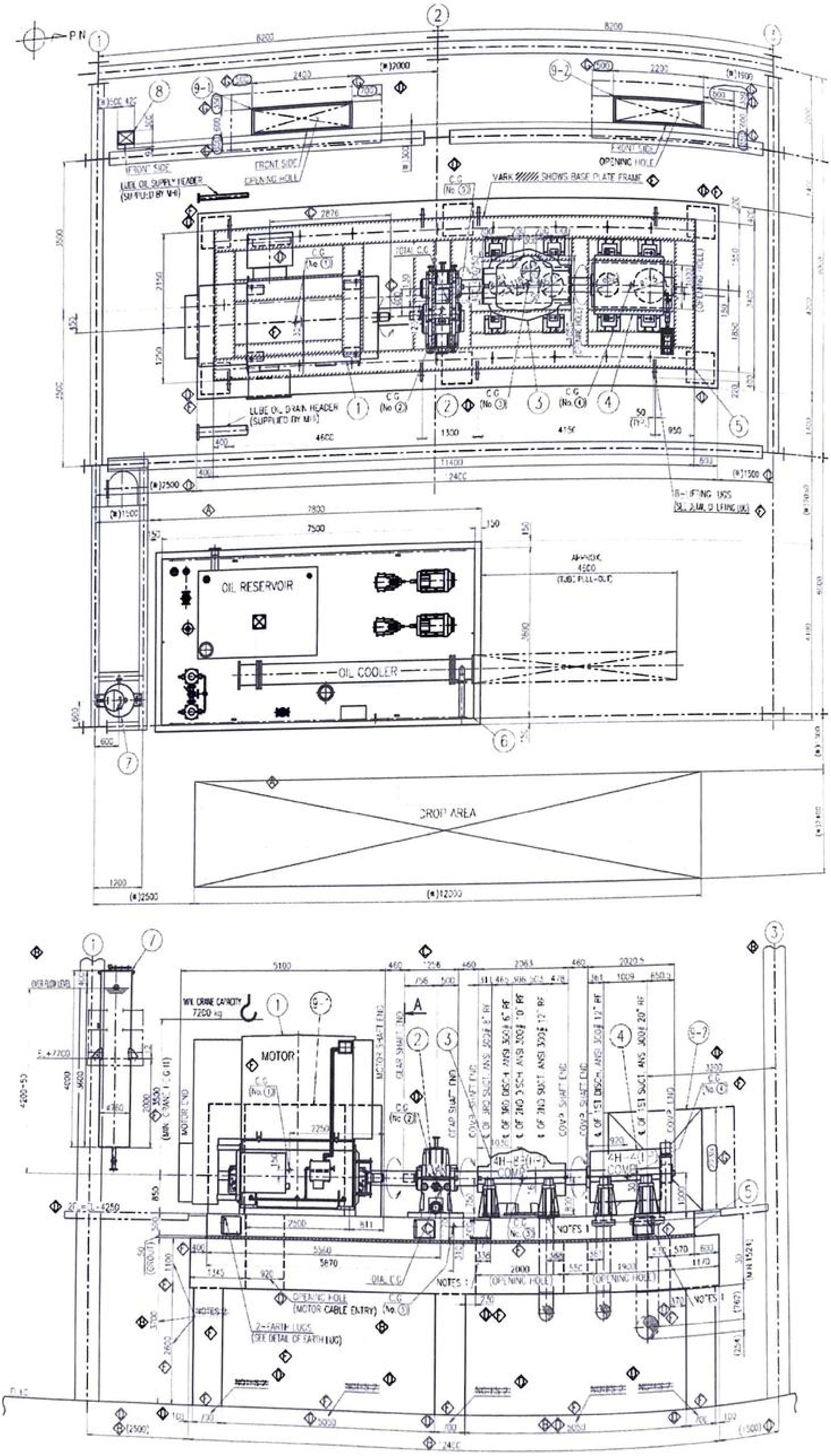
Item	Document	1st Issue Days after PO	2nd Issue Days after PO	Final Issue Days after PO	Document subject to LDs
1	General Arrangement with connections	30	60	90	Yes
2	Foundation Plan & loads	30	60	90	Yes
3	P&IDs	45	90	135	Yes
4	Electrical consumers list	45	75	105	Yes
5	Utility consumption list	60	90	120	Yes
6	Logic, sequence and control description & diagrams, cause & effects	105	165	185	Yes
7	I/O list	75	N/A	115	Yes
8	Instruments and JB layout	150	N/A	210	Yes
9	JB wiring diagrams	150	195	240	Yes

The time period for Purchaser's review of vendor documents shall be specified.

To ensure that interface documents are fit for purpose, their contents must be specified, as follows:

General Arrangement with connections list (see sample on the next page):

- <u>1st issue</u>: Issue for comments: overall preliminary dimensions & weights, nozzle size & positions,
- <u>2nd issue</u>: Issue for Detail Design: Equipment and auxiliaries dimensions, weights, nozzles positions, free areas required for maintenance and disassembly, connections list at battery limits with position, size, rating, facing,
- <u>Final issue</u>: Including all sub-vendors information


OIL RESERVOIR
OIL COOLER
DROP AREA
MOTOR
LUBE OIL SUPPLY HEADER
LUBE OIL DRAIN HEADER
FRONT SIDE
OPENING HOLE
TOTAL C.G.
MOTOR END
MOTOR SHAFT END
GEAR SHAFT END
NOTES 1
OPENING HOLE
(MOTOR CABLE ENTRY)
2-EARTH LUGS
(SEE DETAIL OF EARTH LUG)

Foundation plan:

Plan and elevation views showing all information on anchor bolts (size, location, grouting details), static & dynamic loads, for both main and auxiliary equipment.

- ◊ 1st issue: Preliminary loads
- ◊ 2nd issue: Final loads
- ◊ Final issue: Including all auxiliaries, pipe supports and sub-vendor information

P&IDs:

- ◊ 1st issue: P&IDs with all diameters excluding utility, vent and drain lines,
- ◊ 2nd issue: P&IDs with all diameters, all items numbered, specified and shown as per project standards,
- ◊ Final issue: Fully mechanized P&IDs, including all line item diameters

I/O list

- ◊ 1st issue: 95% of the instruments
- ◊ Final: indication of measuring range and set values for alarms and trips

Electrical consumers list

- ◊ 1st issue: Preliminary load list in Purchaser's format: quantity, type (normal/essential) and "not to exceed" installed power
- ◊ 2nd issue: Load list with final quantity, type and installed power (uncertainties on the individual installed power +/-5% max)

To ensure the timely deliveries of the interface documents by vendors, an incentive system must be put in place that shall be twofold:

- Payments must be subject to submission of critical documents,
- Liquidated damages must be applicable in case of late submission,

The above must be specified in the Purchase Order prepared by Procurement.

Vendors of rotating equipment and packages do not manufacture themselves all the items of the scope of supply. They typically purchase parts, such as gear box, electric motors, auxiliary skids, from sub-suppliers. This delays the availability of information (dimensions, power supply and utility consumption) related to the sub-supplied parts. It is therefore critical to specify that interface documents shall not only include main equipment but also auxiliaries.

16) Documentation to be submitted with the bid

This section is only present in the MR issued for Inquiry, it will disappear in the "For Order" issue of the MR. It shall list the documents needed to review the bid.

As part of documents to be submitted with the bid, vendors shall be requested to submit the filled Technical Bid Tabulation (see following section). This ensures that the vendor reviews the technical requirements which are grouped in the TBT and confirm compliance to each one.

For extended scopes of supply, ask for a P&ID to clearly identify the scope of supply, and a GAD.

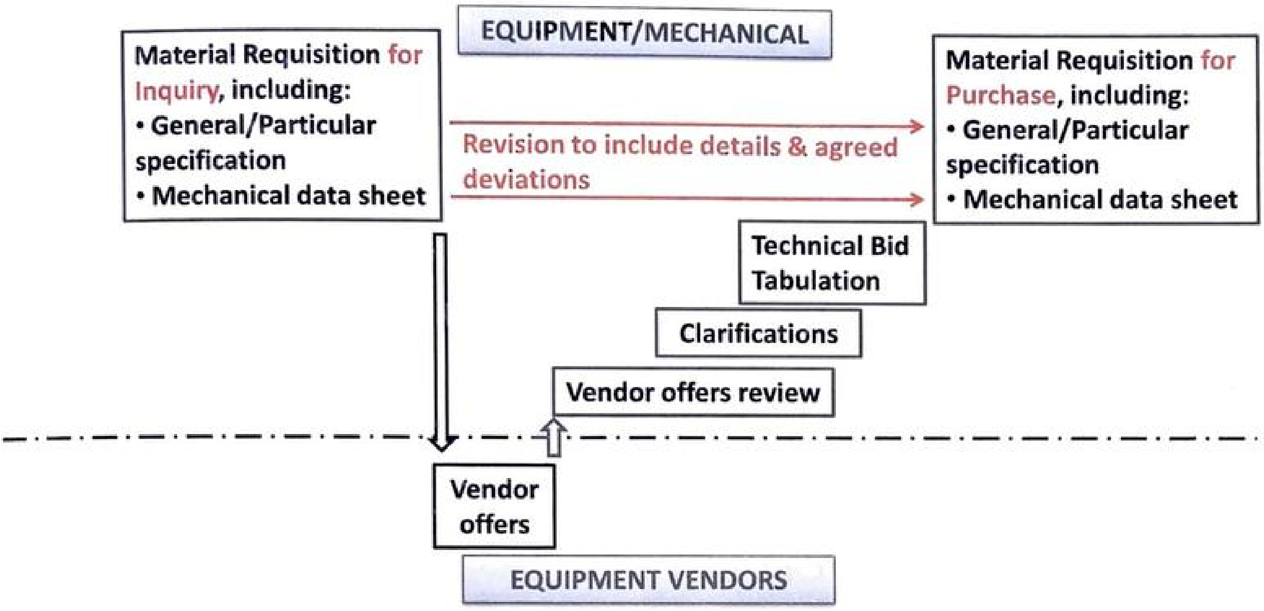
Lastly, request the vendor references list of Equipment with similar service conditions, e.g., power/rotating speed for compressors, types of materials, thickness and manufacturing method for pressure vessels.

Once offers are received from vendors, they are reviewed and clarifications held with vendors to confirm compliance with technical requirements.

Following the clarifications, the Equipment Engineer issues the Technical Bid Tabulation (TBT). The TBT is a list of all requirements (scope of supply, performance guarantees, design and fabrication code, inspection and quality requirements, extent of shop assembly, supplier's references in similar supplies, etc.) which indicates what is offered by each vendor.

			Requirements	Supplier 1	Supplier 2
1 -SCOPE OF SUPPLY SUMMARY (continued)					
1.6 Piping / Structure / Painting / Misc.					
Piping:					
Interconnecting piping between skids or equipement (fuel, lube oil, water, steam, etc..)			included	included	included
Painting					
Non insulated equipment (motor, valves, steel structures, platforms, etc..)			Max. at shop		up to final coat
Boiler block			Max. at shop	sandblasting & primer + insulation at shop	Primer + insulation/lagging at shop
1 -SCOPE OF SUPPLY (continued)					
1.7 Services					
Shop inspection and tests (as a minimum)				included	
Superheater			As per ASME	Hydrotested before shipping	Hydrotested before shipping
Boiler			As per ASME	Hydrotested before shipping	Hydrotested before shipping
1 -SCOPE OF SUPPLY (continued)					
1.8 Codes & standards					
Boiler presure parts & safety valves			ASME I	ASME I with S stamp	ASME
Pressure parts materials			ASME I	ASME I with S stamp	ASME
2 -OPERATING CONDITIONS					
2.1 Design conditions					
Feed Water Temperature @ BL	(MCR/Peak Load)	°C	120	120	120
Feed Water Pressure	(Mini required / Mecha desi	barg	68 / 90	65 / 90	Yes
2.2 Guaranteed performances					
Steam Flow	(MCR)	t/h	240	240	240
Steam Outlet Temperature at BL		°C	384 +/- 5	384 +/- 5	384 +/- 6
Steam Outlet Pressure at BL		barg	41,3 +/- 1	41,3 +/-1	41,3
3 - CONSTRUCTION DATA					
3.1 General					
Boiler area dimensions	W x L (w/o eco / w eco)	m	By Vendor	~16000x25000 / ~17000x25000	~24076x27147 / ~25231x26916
Boiler dimensions	W x L x H	m	By Vendor	12500 x 15500 x 10500	8670 x 19000 x 10250
3.2 Steam Drum					
Pressure	operating / design	barg	As per ASME	47,5 / 54,0	tbd / 56,54
Temperature	operating / design	°C	By Vendor	262 / 295	352 / 343
Length (TL-TL)		mm	By Vendor	14200	14833

At the bottom of the technical bid tabulation the technical compliance (Yes/No) of each vendor is stated. Once the most competitive technically acceptable bidder is selected, the material requisition is revised "For Purchase", to reflect what has been agreed during the clarifications, such as deviations, etc.



The purchase order is then placed on the basis of the "Issued for Purchase" Material Requisition. The vendor acknowledgment of the purchase order is requested as confirmation of compliance to all dispositions of the purchase order.

Once the equipment is purchased, the vendor submits its documents to Engineering for review and approval. Approval of key documents, such as mechanical design calculation note for pressure vessels, is required before the Vendor is allowed to proceed with fabrication.

Vendor documents concerning several disciplines are circulated and the comments are consolidated by the Equipment engineer that issued the Material Requisitions. The reviewed documents are returned to Vendors with a review code.

COMMENT STATUS : THE APPROVAL OF THIS DOCUMENT DOES NOT RELIEVE THE SUPPLIER OF ITS CONTRACTUAL RESPONSABILITIES				
1	NO COMMENT OR FORMAL COMMENTS PROCEED WITH FABRICATION RESUBMIT WITH UPPER REVISION STAMPED APPROVED FOR CONSTRUCTION		4	FOR INFORMATION REFERENCE ONLY
2	APPROVED AS NOTED PROCEED WITH FABRICATION IN ACCORDANCE WITH COMMENTS RESUBMIT CORRECTED DOCUMENTS FOR APPROVAL WITH UPPER REVISION		5	FINAL DOCUMENT
3	DISAPPROVED DO NOT FABRICATE RESUBMIT CORRECTED DOCUMENT FOR APPROVAL WITH UPPER REVISION			
			CHECKED BY :	DATE :

The **Project Equipment List**, that has been initiated by Process, is completed with information from vendors: Equipment dimensions and weights, etc.

TAG	SERVICE NAME	MATERIAL REQUISITION NO.	VENDOR NAME	TYPE	QUANTITY	DUTY /DRIVER kW	CAPACITY [m3/h unless specified]	HEAD [m]	POSITION	DIMENSIONS [mm] I. DIA / WIDTH [m]	DIMENSIONS [mm] LENGTH / HEIGHT [m]	WEIGHT (ton) EACH	INSULATION	FIRE PROOFING
P-1 A/B	MDEA TRANSFER PUMP	MR-1	A	Centrifugal	2		32.0	103.2	H	1,50	2,10	1,3		
PM-1 A/B	MDEA TRANSFER PUMP MOTOR	MR-1	A	Motor	2	37 (rated power)								
C-1	MDEA Absorber	MR-2	B	Vessel	1				V	6,51	21,95	1 007,4	Y	Y
C-1-X	MDEA Absorber internal	MR-3	C	Internal	1							34,0		
D-1	DESUPERHEATER	MR-4	D	In-line	1									
S-1	MDEA Solution Filter	MR-5	E	Filter	1		286		H	0,73	2,09	3,8		
Y-1	FILTRATION PACKAGE	MR-5	E		1					7,00	12,00	80,5		
E-1	THERMAL REACTOR WASTE HEAT BOILER	MR-6	F		1	59540	3200.7 t/h steam	-	H	3.7 / 4.6 channel	(*)	186.46		
F-1	IN-LINE HEATER FURNACE	MR-7	G	Vessel	1	-	-	-	H	3,30	11,20	54,0		
X-1	STEAM EJECTORS	MR-8	H	Ejector	1	-	4365 kg/h	-		-	-	0,4		
X-2	PRV4901A Silencer	MR-9	I	Silencer	1					0,61	0,76	0,18		
Y-2	PHOSPHATE MIXER	MR-10	J	Mixer	1	-	-	-		-	-	(*)		

It gathers all information related to Equipment: Reference of Material Requisition and Purchase Order, Vendor name, Equipment dimensions and weights, insulation and fire proofing requirements, etc.

It serves a number of functions, including that to identify the capacity of cranes required to install the Equipment at Site and place the erection contract.

Chapter 5

Plant Layout

Once the Plant equipment is defined, upon completion of the Process Flow Diagrams (PFDs), Plant Layout discipline performs layout studies, which consist of defining the spatial organisation of the facility.

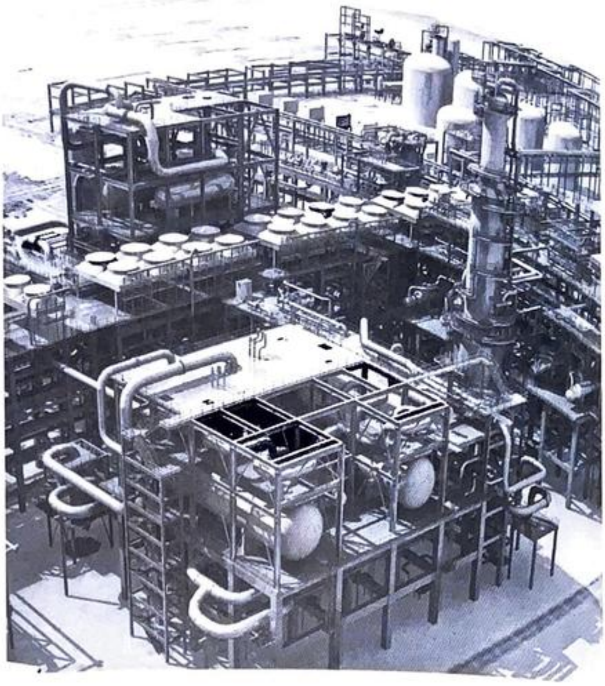
An industrial facility is usually split into 3 zones: Process, Utilities and Offsite.

- The Process units are where the feedstock is processed into products,
- Utilities units include electrical power generation, production and handling of utility fluids such as steam, heating/cooling medium, water, compressed air, nitrogen, treatment of the waste fluids such as rain and oily water, drains, waste gas, etc.
- Offsites are product storage and shipping facilities,

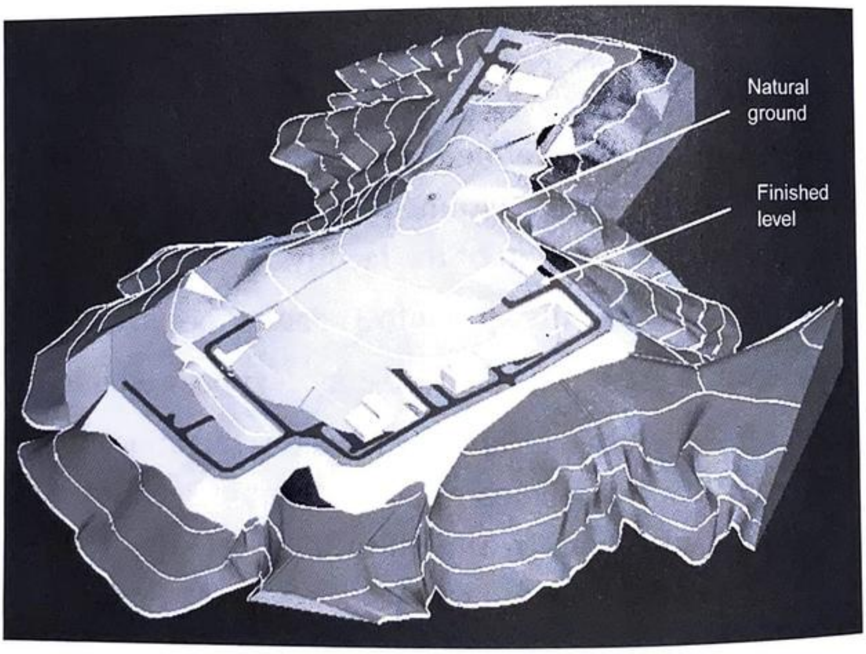
An off-shore facility also comprises living quarters (LQ) and a helicopter landing pad, located as far as possible from the process units.

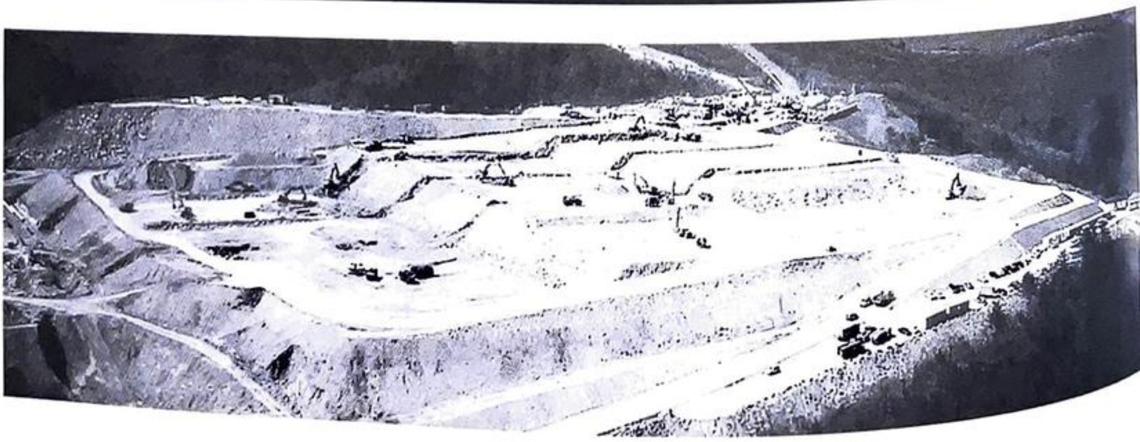
The Site where the Plant is to be built impacts its layout:

A restricted land plot size imposes a vertical stacking of the equipment rather than their horizontal spread.



A sloped relief promotes a terraced arrangement to minimize earthworks.





Plant layout takes into account the Plant environment: location of access/exit roads, external connecting networks: pipelines, electrical grid, water supply, etc.

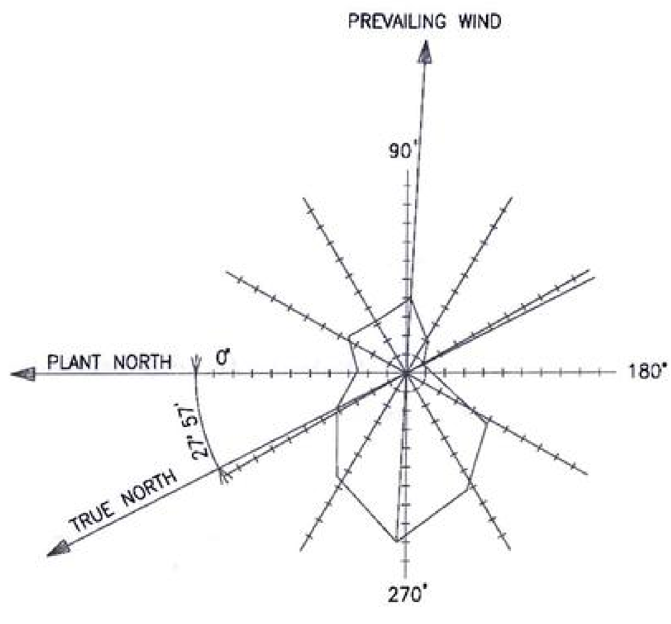
Process units are segregated and located away from utility units and buildings with permanent human occupation. Flammable storage is reduced to a minimum within Process units and relocated outside.

Ignitions sources, such as open flame fired heaters and electrical sub-stations, are located upwind of process units.

This prevents a gas cloud developing from a leak in process units to reach an ignition source.

The prevailing wind direction at Site is considered.

Separation distances are provided between Process units. They limit the risk to adjacent facilities, as heat radiation reduces quickly with distance. They also reduce the impact of an explosion, in one process unit on the other units, as the blast overpressure also reduces quickly with distance.



WIND ROSE

Separation distances between process units are usually set according to the GE GAP[1] Guidelines, unless more stringent legal regulation applies. The first step is to rate the fire/explosion risk of each Process unit.

The risk is that of release and ignition of flammable material. It derives from the fluid handled, the type of process (non-reactive such as distillation, endothermic reaction or exothermic reaction for which runaway is possible) and the operating conditions: pressure and temperature. The risk level is classified as High Hazard (HH), Intermediate Hazard (IH) or Moderate Hazard (MH).

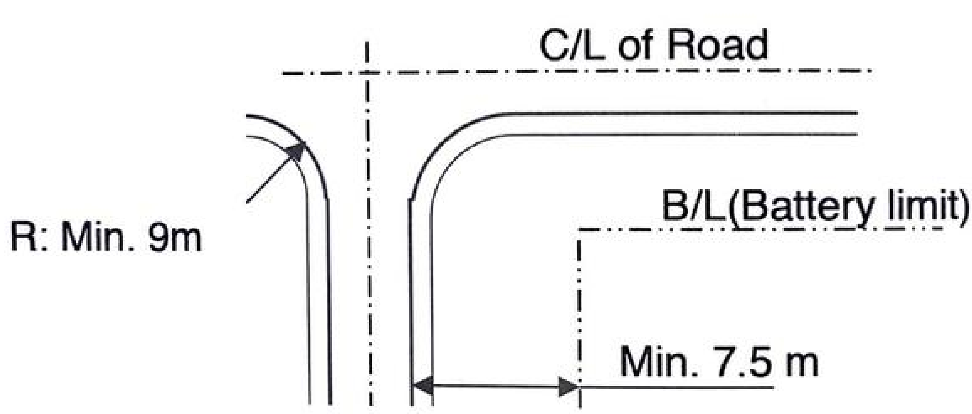
1. GE Global Asset Protection Services, Oil & Chemical Plant Layout and Spacing recommendations, ref. GAP.2.5.2

UNIT	UNIT NAME	Hazard Classification
10	Crude Distillation (CDU)	MH
11	Vacuum Distillation Unit (VDU)	MH
12	Naphta Hydrotreater (NHT)	IH
13	Continuous Catalytic Reformer (CCR)	IH
14	Vacuum Residue Hydrodesulphurization Unit	HH
15	Hydrocracker Unit	HH

The code specifies minimum distances between two units as per the combination of risk:

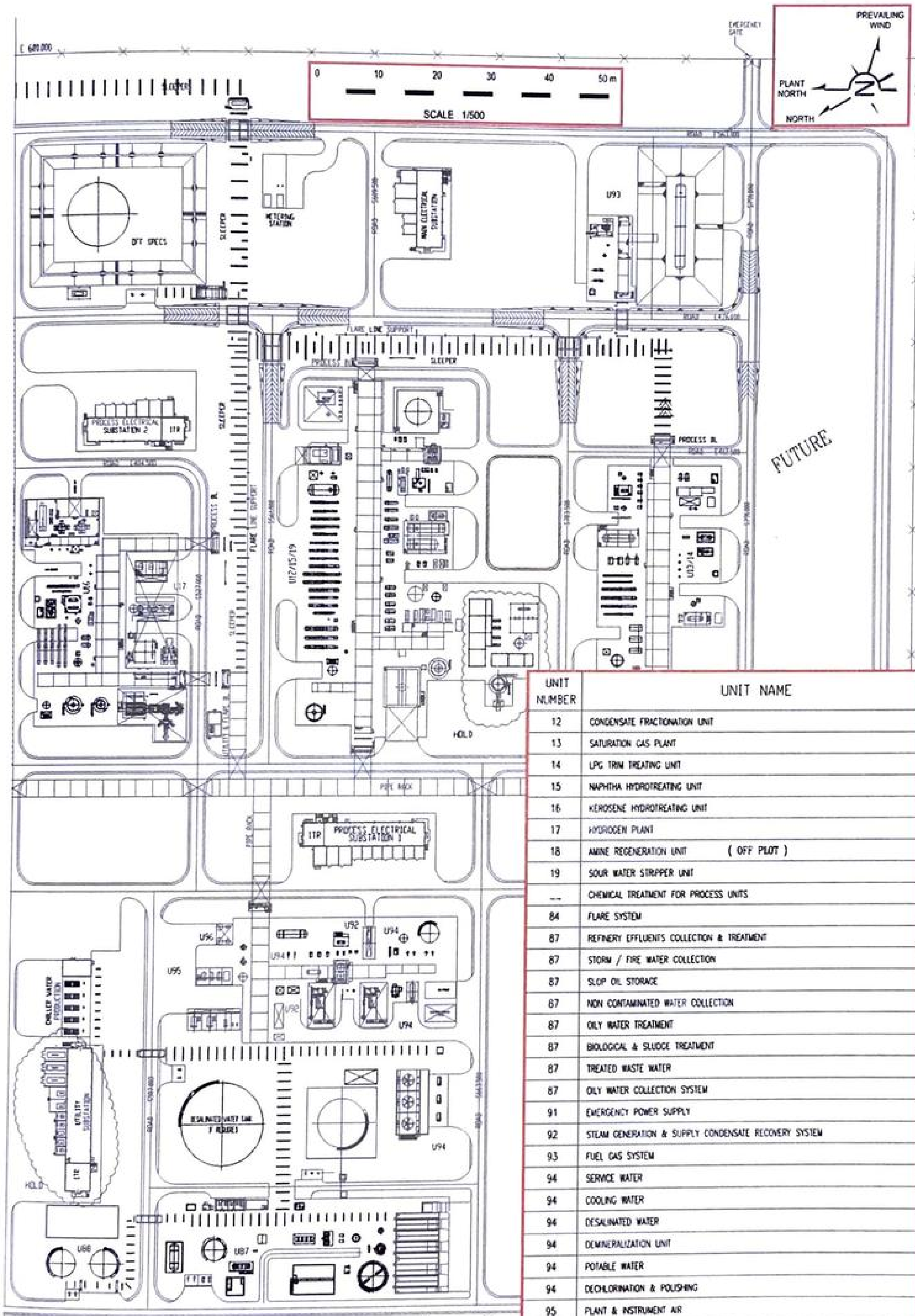
(in m)	MH	IH	HH
MH	15	30	60
IH		30	60
HH			60

Other rules are applied to establish the Plant layout, as defined in the Plant Layout guidelines specification.



The General Plot Plan shows the entire Plant territory, up to its fence, the location of the various units, buildings, as well as the connections of the Plant with its surroundings: access roads, etc.

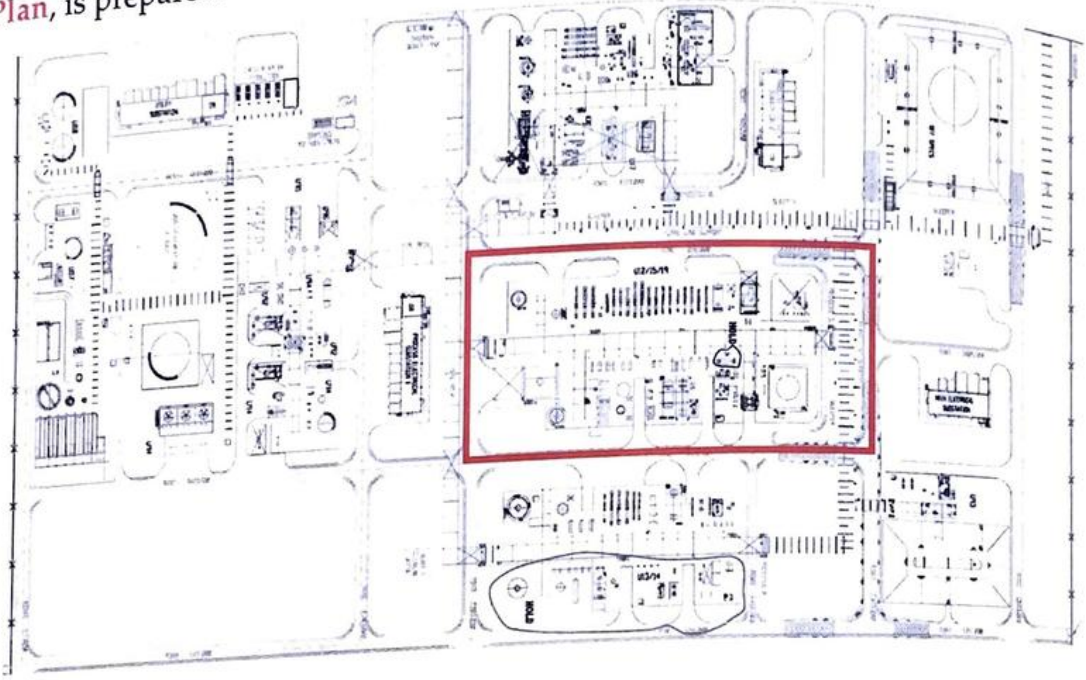
5. Plant Layout



UNIT NUMBER	UNIT NAME
12	CONDENSATE FRACTIONATION UNIT
13	SATURATION GAS PLANT
14	LPG TRIM TREATING UNIT
15	NAPHTHA HYDROTREATING UNIT
16	KEROSENE HYDROTREATING UNIT
17	HYDROGEN PLANT
18	AMINE REGENERATION UNIT (OFF PLOT)
19	SOUR WATER STRIPPER UNIT
--	CHEMICAL TREATMENT FOR PROCESS UNITS
84	FLARE SYSTEM
87	REFINERY EFFLUENTS COLLECTION & TREATMENT
87	STORM / FIRE WATER COLLECTION
87	SLOP OIL STORAGE
87	NON CONTAMINATED WATER COLLECTION
87	OILY WATER TREATMENT
87	BIOLOGICAL & SLUDGE TREATMENT
87	TREATED WASTE WATER
87	OILY WATER COLLECTION SYSTEM
91	EMERGENCY POWER SUPPLY
92	STEAM GENERATION & SUPPLY CONDENSATE RECOVERY SYSTEM
93	FUEL GAS SYSTEM
94	SERVICE WATER
94	COOLING WATER
94	DESALINATED WATER
94	DEMINERALIZATION UNIT
94	POTABLE WATER
94	DECHLORINATION & POLISHING
95	PLANT & INSTRUMENT AIR
96	NITROGEN SYSTEM

The General Plot Plan is reviewed during the HAZID. The results of this review might include the relocation of some units, e.g., product storage upwind of process units, etc.

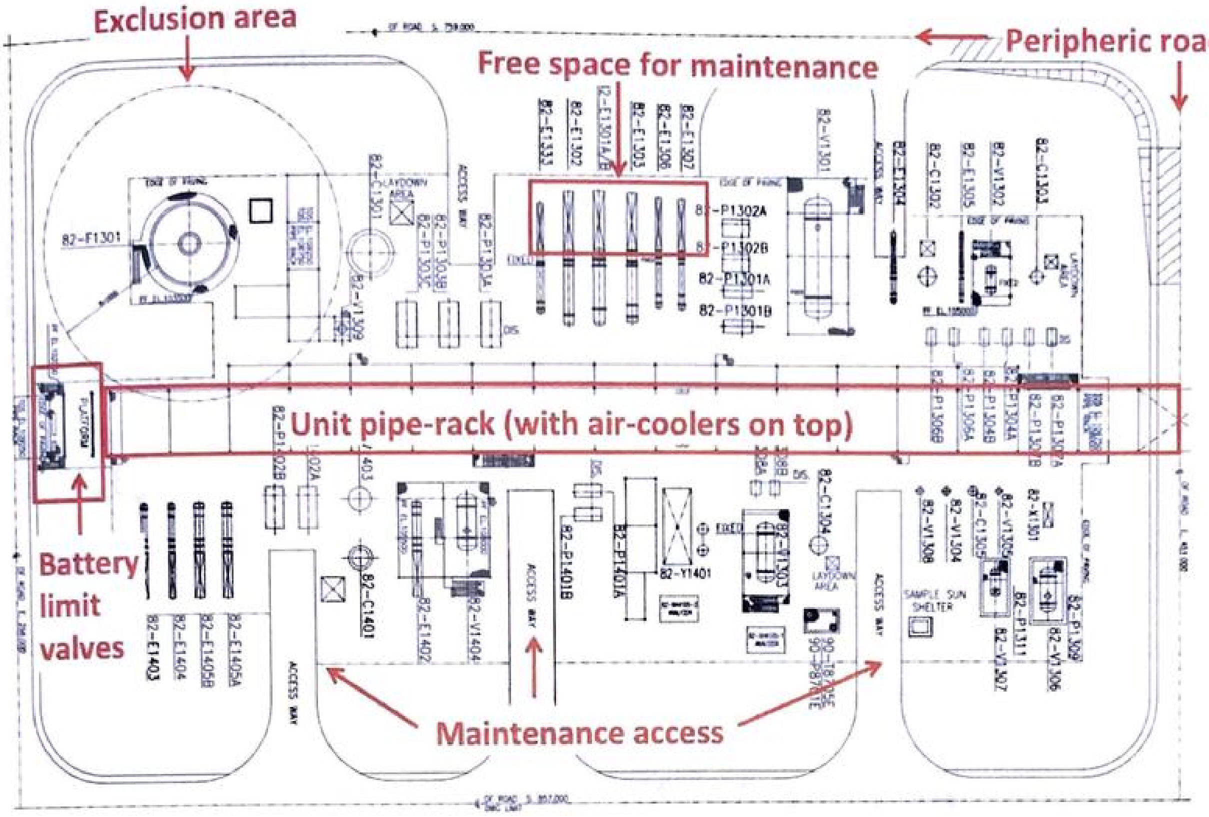
Once the layout of Process and Utility units within the Plant, i.e., the General Plot Plan, is defined, the layout of equipment within units, i.e., the Unit Plot Plan, is prepared.



To establish the Unit Plot Plan, the Plant Layout Engineer starts with 2 documents issued by Process: the Unit Process Flow Diagram and Sized Equipment List.

The layouts of Units are standard. They usually include a peripheric road, for easy access by vehicles for operation, maintenance and fire fighting. The Unit Equipment are located on both sides of a central piperack which supports the lines interconnecting equipment, the utility headers and the Unit/Plant interconnections. Battery limit valves are provided on each interconnection, to allow easy isolation of the Unit from the Plant in an emergency.

The Unit piperack shape (straight, "L" or "T" shape) and position are determined to suit the location of the Plant/Unit interconnections and the location of the Instrumentation and Electrical Equipment room.

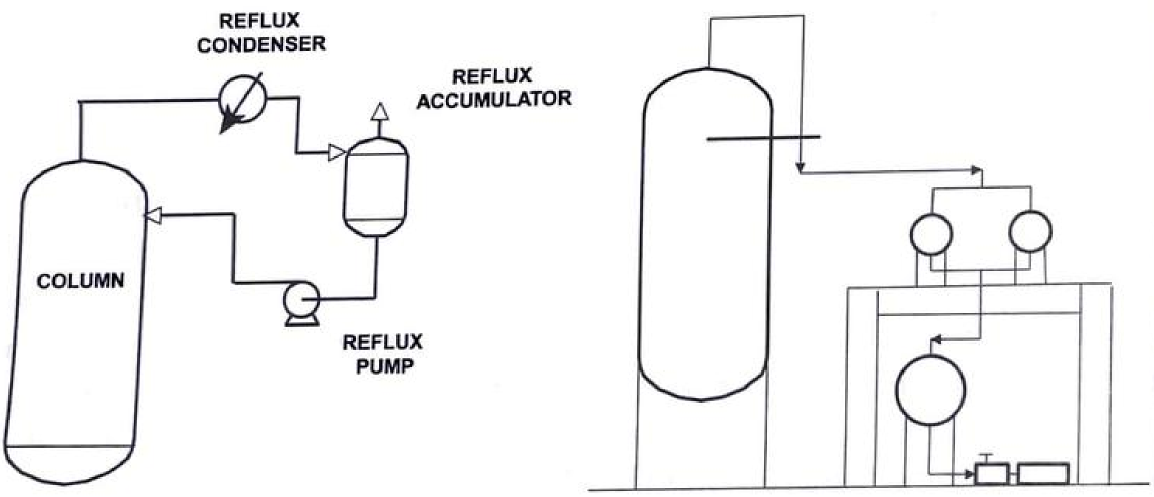


Equipment positions are set considering a number of requirements that include:

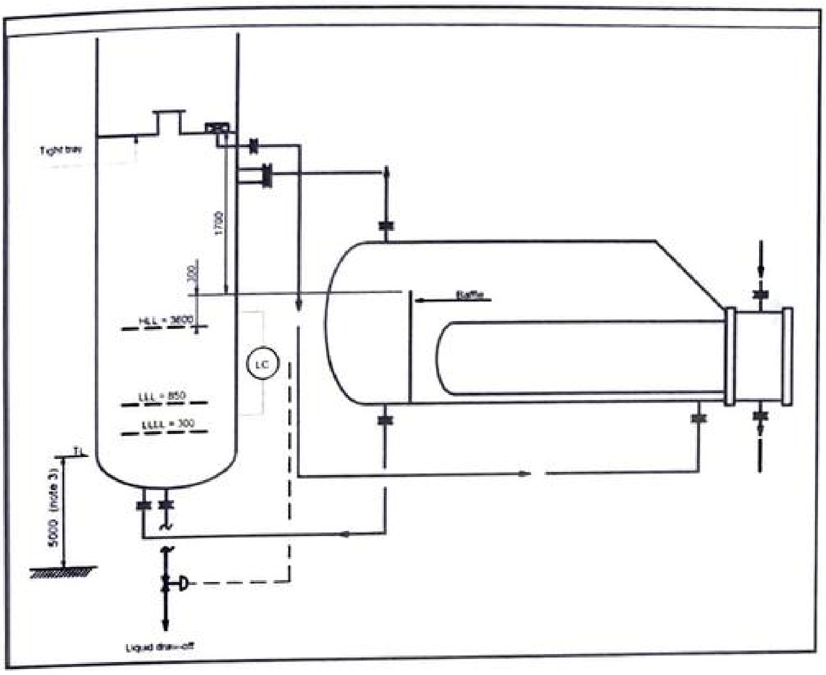
- Separation distances are provided between Equipment with a high fire/ explosion hazard, if any. GE GAP.2.5.2/2A provides criteria for hazard level classification. For instance, pumps handling flammable or combustible liquids at high temperature and high pressure, are classified High Hazard (HH) and all other pumps handling flammable or combustible liquids, are classified Intermediate Hazard (IH). Separation distances are kept between these Equipment as shown in the table below. These distances do not apply to running/spare equipment.

Minimum distance between equipment (meters)	Compressors	Intermediate Hazard (IH) pump	High Hazard (HH) pumps	High Hazard (HH) reactor	Columns, drums	Fired Equipment	Air-cooled heat exchangers
Compressors	10						
IH pumps	10	1.5					
HH pumps	15	1.5	1.5				
HH reactors	15	3	5	7.5			
Columns, drums	15	3	5	15	5		
Fired Equipment	15	15	15	15	15	7.5	
Air-cooled HX	10	5	5	7.5	3	15	None

- Large and heavy equipment which are installed using a heavy lift crane having a large footprint are suitably located on the outskirts of the Unit in order that the Unit construction is not prevented prior to their installation.
- Avoid locating equipment A behind equipment B in a way that requires equipment A to be installed before equipment B, as it could create a schedule constraint and potential delay at Site.
- An exclusion area is kept around open flame furnaces, where no equipment/valve/flange which could be a leak source shall be installed,
- Equipment are grouped, on the Process Flow Diagrams, by functional sub-units, such as a column overhead system shown here, and located as per their sequence in the Process,



- *The dimensions of Equipment are taken from the Process Equipment list, as shown in Chapter 3. Process determines the size of only a few Equipment. It does not determines the size of air-cooled heat exchangers, which have a large footprint hence impact on the plot Plan, rotating equipment and their auxiliaries, including required clearance for dismantling, fired heaters, package, etc. The space occupied by these equipment must be estimated based on Equipment of similar duty on previous jobs.*
- *Shelters/buildings are usually required to house machinery. Corresponding space must be allocated, along with inside laydown area.*
- *The elevation of Equipment is dictated by Process requirements, which are shown on the P&IDs and/or the equipment process data sheets:*



– Vessels feeding pumps are elevated to give the pump sufficient head to avoid cavitation. The required elevation is determined by Process based on the type of liquid and its condition: boiling liquid require NPSH of several meters.

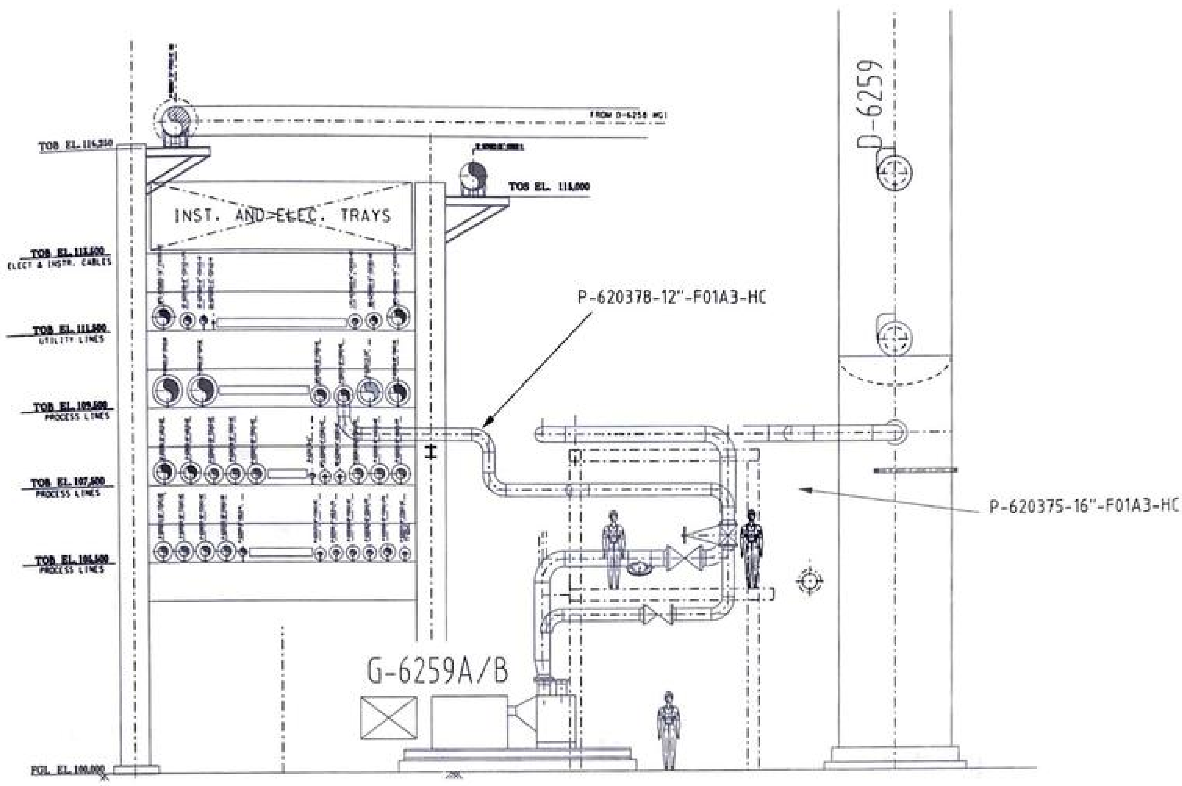
– Gravity flow must be ensured between equipment where required, e.g., between a condenser and the downstream vessel, between a column and reboiler as shown here, etc.

–Drain vessels, which col-lects drains by gravity for all other vessels are usually located underground in a pit.

- Valves discharging to the flare (PSVs, PCVs, BDVs) must be located above the flare header so that any condensed liquid flows to the flare KO drum. The position of the flare header therefore determines the elevation of the platforms where the PSV/PCV/BDV will be installed. When this would result in too high a position, a dedicated Unit flare header and KO drum is provided.
- Hydraulics may also play a role in equipment elevation. The Plant cooling water, if available at 4 barg at the Unit battery limit 6m above grade, would be at 3 barg only at elevation of 16 meters!
- It is common to locate air-cooled heat exchangers on top of the Unit pipe-rack to save space on the ground. A service platform is provided underneath, allowing motors, fans, bearing to be dismantled and rolled on

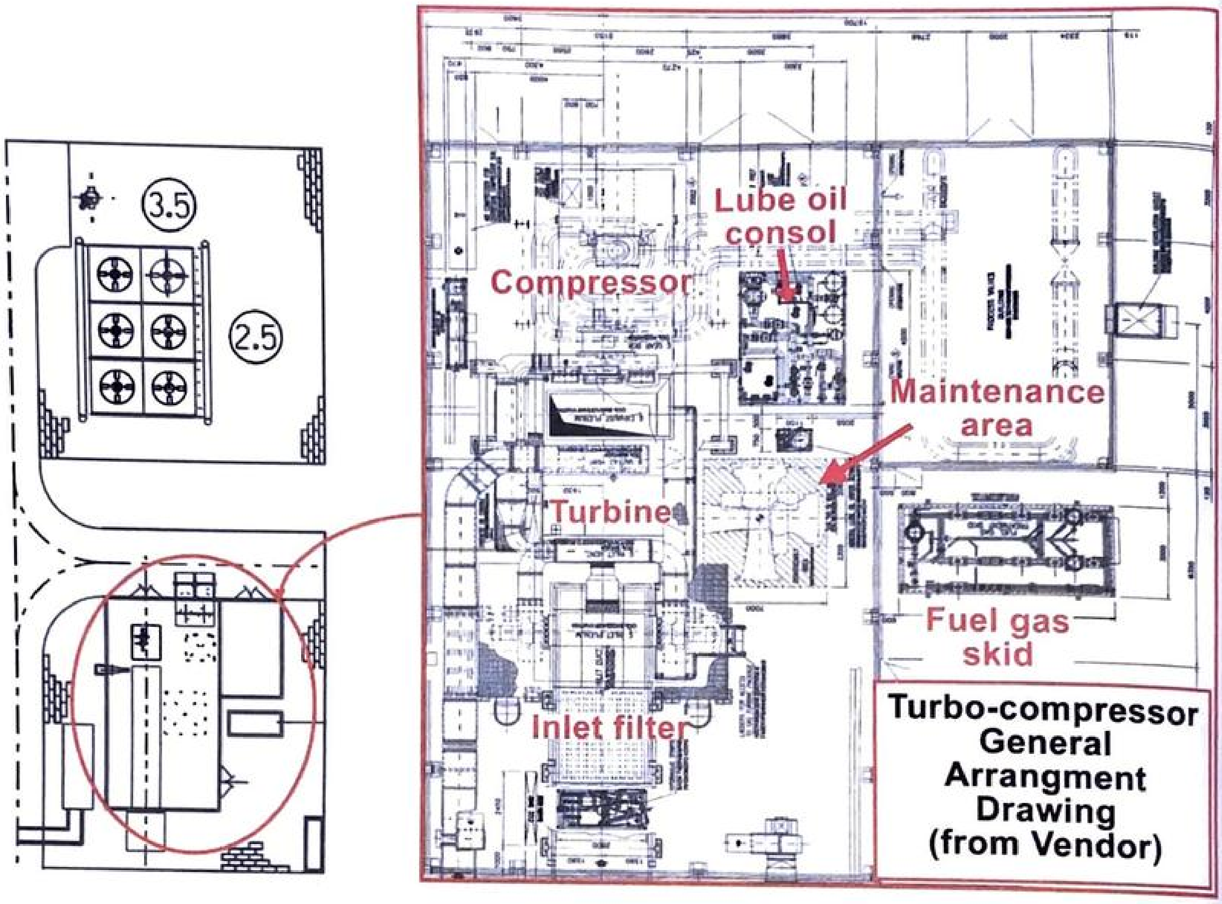
a trolley to an area accessible by crane/davit wherefrom they can be lowered to grade. The width of the pipe-rack is therefore set to the air-cooler column spacing, typ., 9 m, or, if not economic, a side structure is added, i.e., 6m+3m.

- Equipment requiring frequent maintenance are best located at grade.
- Rotating equipment are best located on foundation at grade rather than on elevated structures. The large weight of the foundation indeed prevents vibration. Electrical motors, which are the heaviest piece of equipment to be dismantled on pumps/compressors, are located towards the outer edge.
- Stair towers must be provided to access process structures. It is best to locate their exit towards the outside of the Unit.
- Platforms directly supported on Equipment, such as columns, horizontal vessels, are used to support instruments, lines and fitted with ladders. This is not used for reactors which operate at elevated temperature, for which surrounding independent access structure supporting access platforms, lines, valves. This independent structure prevents stress due to differential thermal expansion and avoids a complex interface between the equipment and its environment (positions and loads of platforms and pipe supports on the shell).
- Access by road (for crane) is provided for maintenance of the following Equipment: columns/reactors (change of internals/catalyst), rotating equipment (pumps/compressors), air-coolers (bundle removal), shell & tube heat exchanger (bundle removal).
- Large diameter and exotic material lines are identified and their length minimized.



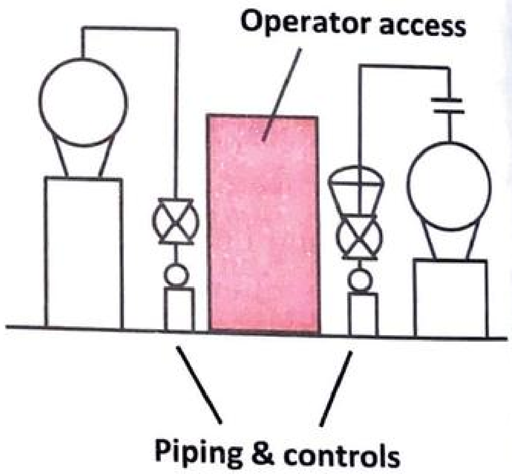
- Space is also provided, next to pumps and compressors, for the special arrangement of their inlet and discharge lines, including straight lengths, strainer, valves, special supporting requirements.
- Space for routing Electrical & Instrumentation cables is allocated, either on the piperack, as shown above, in case of above ground cable installation, or underneath the pipe-rack, in case of underground installation.
- The Piping Line Diagram is drawn (see Piping chapter) to check that the Process sequence has been followed when locating equipment so that the length of interconnecting lines is minimized.
- A 3 meter clearance is kept where fork lift access is required.
- Space shall be foreseen for locating of the buried fire water ring main, on the road side, together with fire hydrants and monitors.

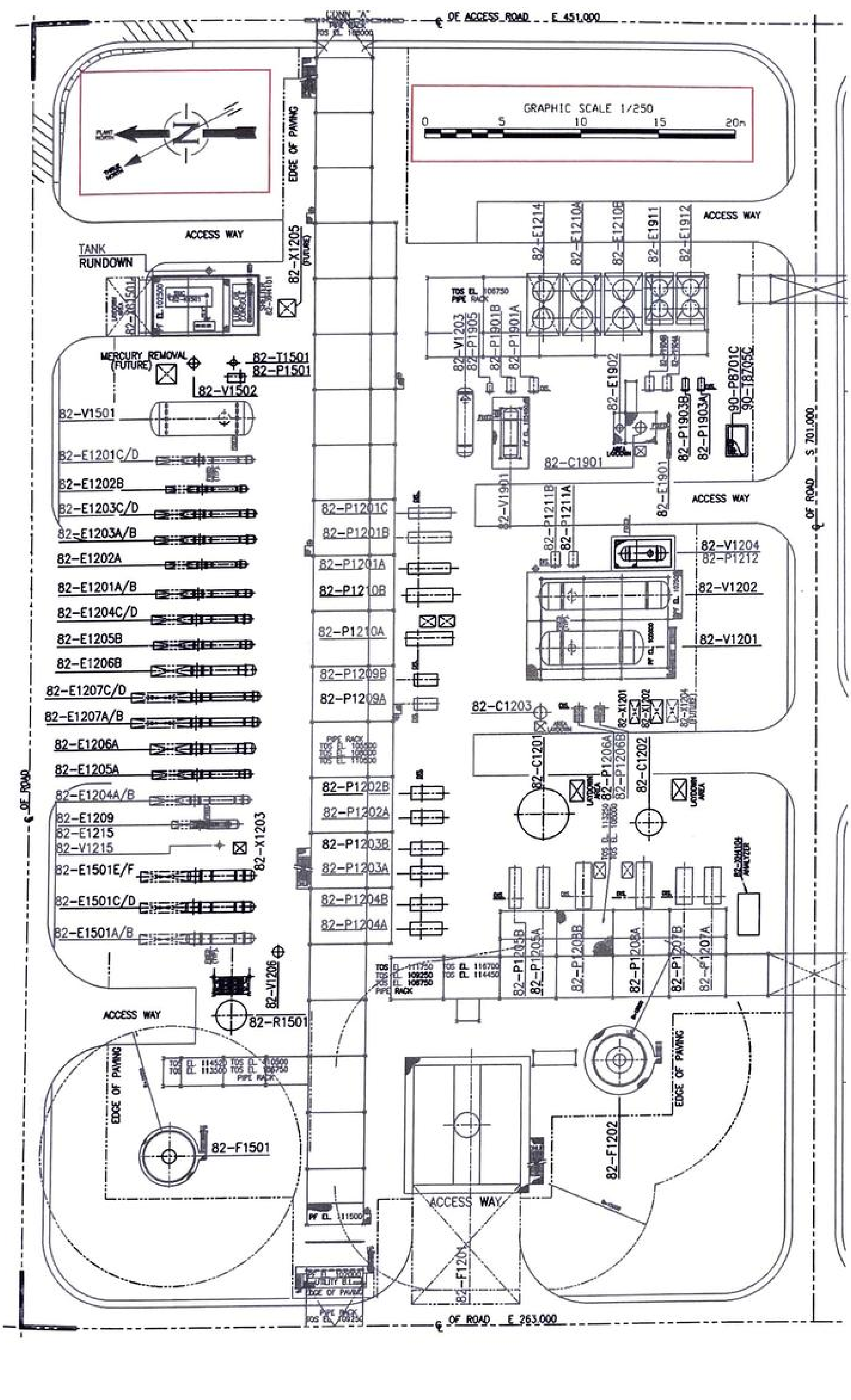
The dimensions of rotating equipment and that of their auxiliaries will only be known once the order is placed and the GAD is received from the Vendor.



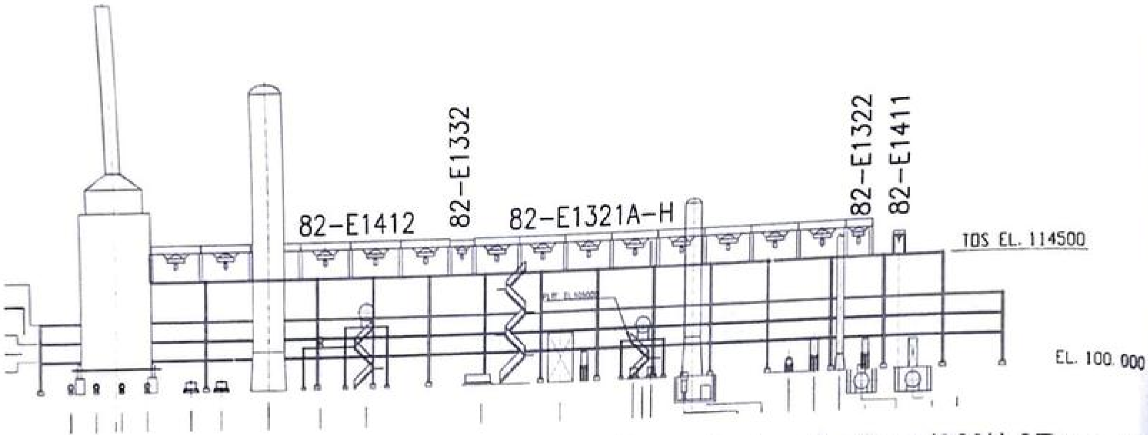
Plant layout takes a lot of experience: One needs to have a vision of the completed equipment environment, including all pipes, valves, small bore lines and access platforms before they are designed in order to provide enough free space for these future developments.

The typical **Unit Plot Plan** of a Process Unit is shown on the next page.



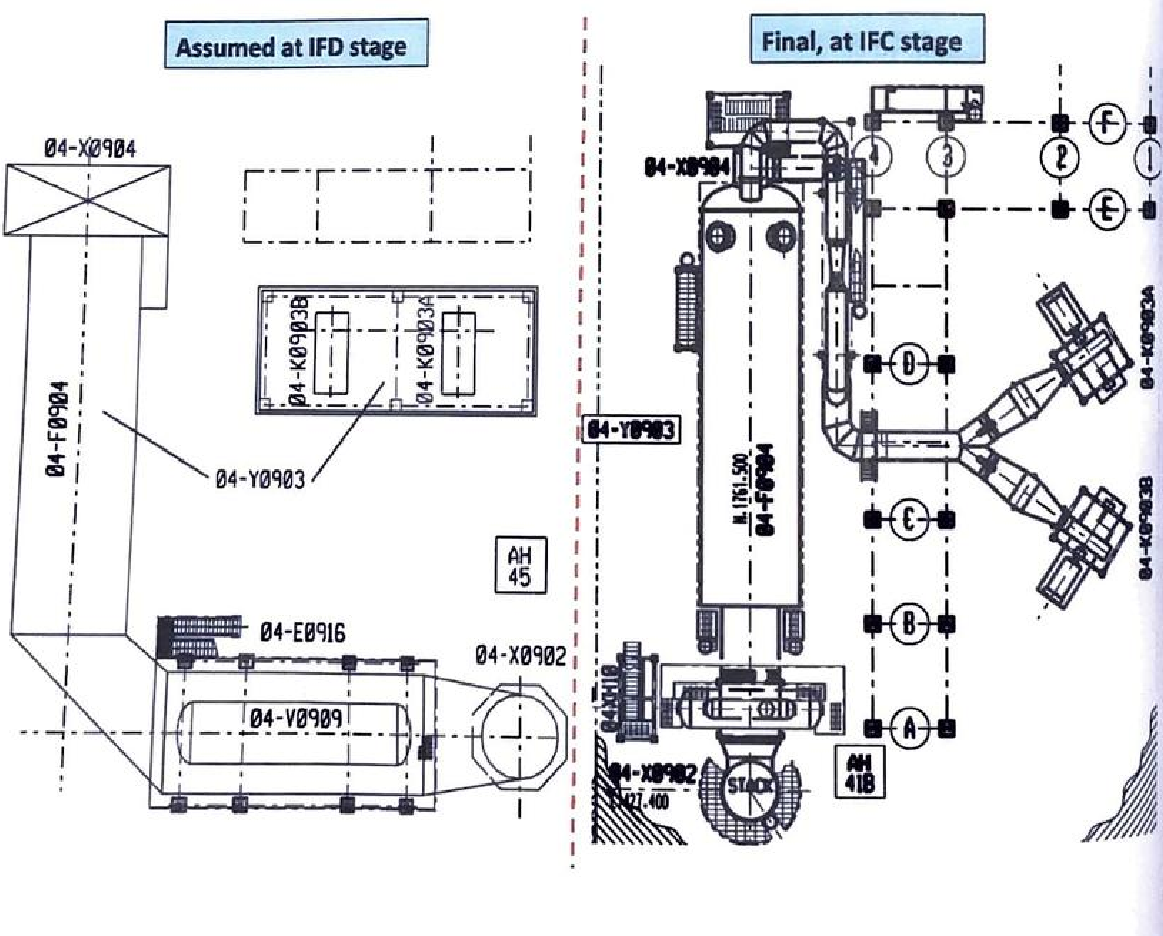

OF ACCESS ROAD E 451,000
GRAPHIC SCALE 1/250
0 5 10 15 20m
EDGE OF PAVING
ACCESS WAY
TANK RUNDOWN
82-X1205 (FUTURE)
82-E1214
82-E1210A
82-E1210B
82-E1911
82-E1912
82-V1203
82-P1905
82-P1901B
82-P1901A
82-E1902
90-P8701C
90-T8705C
MERCURY REMOVAL (FUTURE)
82-T1501
82-P1501
82-V1502
82-V1501
82-E1201C/D
82-E1202B
82-E1203C/D
82-E1203A/B
82-E1202A
82-E1201A/B
82-E1204C/D
82-E1205B
82-E1206B
82-E1207C/D
82-E1207A/B
82-E1206A
82-E1205A
82-E1204A/B
82-E1209
82-E1215
82-V1215
82-X1203
82-E1501E/F
82-E1501C/D
82-E1501A/B
82-C1901
82-P1903B
82-P1903A
82-E1901
S 701,000
OF ROAD
82-V1901
82-P1211B
82-P1211A
82-P1201C
82-P1201B
82-P1201A
82-P1210B
82-P1210A
82-P1209B
82-P1209A
82-V1204
82-P1212
82-V1202
82-V1201
82-C1203
82-X1201
82-X1202
82-C1201
82-P1206A
82-P1206B
82-C1202
82-P1202B
82-P1202A
82-P1203B
82-P1203A
82-P1204B
82-P1204A
82-P1205B
82-P1205A
82-P1208B
82-P1208A
82-P1207B
82-P1207A
PIPE RACK
82-V1206
82-R1501
82-F1501
82-F1202
82-F1201
ACCESS WAY
OF ROAD E 263,000

Elevation views are produced in addition to the plan view.



The Unit Plot Plan is reviewed with the Client, during the first (30%) 3D model review. Once review comments are incorporated, the Plot Plan is issued for design (IFD). All Engineering disciplines develop their design on this basis.

The Plot Plan can only be finalized with dimensions of Vendor designed equipment, which might be very different from those assumed originally, as shown for this package (incinerator with waste heat boiler, stack and air blowers).



Chapter 6

Safety & Environment

Health, Safety and Environment (HSE), also called Loss Prevention Engineering or simply "Safety", works at preventing the likelihood and minimizing the consequences of fire and explosion resulting from leaks.

Safety is involved in several aspects of the design:

- Plant Layout
- Plant Emergency shutdown depressurization
- Hazard identification
- Risk assessment
- Fire protection & fire fighting
- Fire & gas detection
- Hazardous area classification
- Escape & evacuation

The Safety Concept describes the design activities that will be carried out in all the above areas. This chapter follows the sections of the Safety concept.

The Safety of the Plant Layout is ensured by applying the layout principles explained in Chapter 5: separation distances between units and equipment, location of ignition sources upwind or crosswind of potential flammable gas leak sources, etc. The review of the layout is part of the Hazard identification (HAZID).

The Plant Emergency shutdown and depressurization system is designed by Process, as described in Chapter 3, in co-ordination with Safety.

The **HAZID** (HAZard IDentification) review looks at both the hazards that could face the Plant, from external causes, due to its location and at the hazards created by the Plant itself.

A multi-disciplinary team looks at the following categories of hazards:

- Environment hazards: is the Plant suitably designed for climate extremes (heavy rain, strong wind), earthquake, tsunami, etc.

- Human hazards: can the Plant be affected by adjacent human activity/land use (industrial, farming, traffic, etc.)?
- Process hazards: what type of fluids does the Plant handle? What type of hazard do they create: fire? Explosion? Toxic hazard to people? Risk of pollution?
- Facility operation hazard: what type of hazard come from the operation of the Plant, such as storage of products, overhead lifts for maintenance

The team looks mainly at the Plant Layout (Plot Plan) and Process scheme (Process Flow Diagrams and Heat & Mass balance) and proceeds by Plant area.

The HAZID team raises questions or provides recommendations, which are recorded on HAZID action sheets issued as part of the **HAZID report** to the Engineer.

ACTION ON:	RESPOND BY: A.S.A.P
ACTION NO: 67	MEETING DATES:
DRAWINGS AND DOCUMENTS: OVERALL PLOT PLAN	
ITEM: OFF SPEC TANKS	
CAUSE: Tank bottom corrosion	(Discharge to soil Accidental/Emerg)
CONSEQUENCE: Soil and underground contamination.	
SAFEGUARDS: -Tank leak detection system, -Tank bottom is sloped to drain detection point, - Material selection.	
ACTION: To ensure that there is an internal epoxy coating.	
RESPONSE: (Action 67)	DATED:
SIGNED:	
ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO: PROJECT:	

The Engineer answers the action sheets up to close-out by the Client.

The HAZID is also called Qualitative Risk Assessment. Indeed, no risk rating nor quantitative evaluation of hazard likeliness or consequence is done.

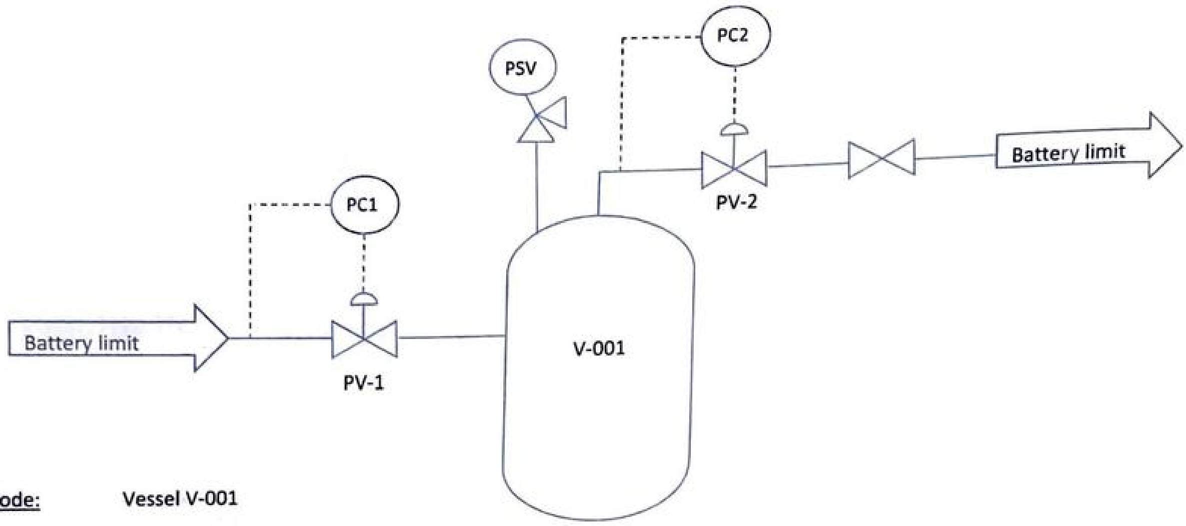
The **HAZOP** review team verifies that safeguards are built in the design to protect the integrity of the Plant against those process upsets.

A very systematic method is used by which all possible process upsets are reviewed:

- Too much or too little pressure,
- Too much or too little temperature,
- Too much or too little flow, no flow, reverse flow or misdirected flow,

At each point – called node – of the process, the team looks at the possibility to have any of the above deviations. If a deviation is possible, the team identifies what could be the consequence and whether a safeguard is present.

When scrutinizing the too much pressure deviation in the vessel below, for instance, the HAZOP team will fill the table shown.



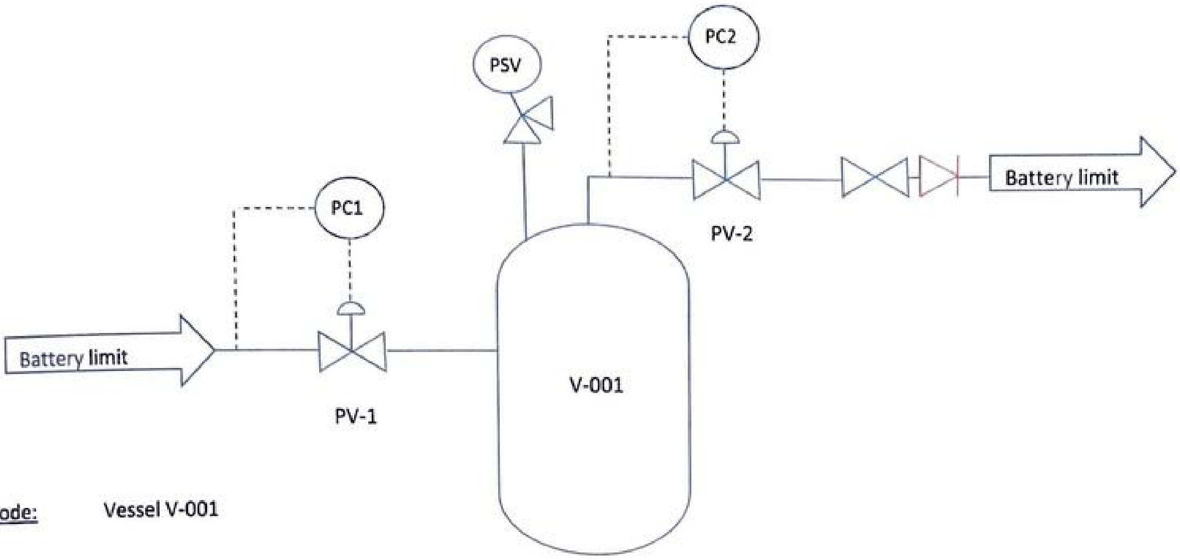
Node: Vessel V-001

Deviation: **Too high pressure**

Cause	Consequence	Safeguard	Recommendation
Failure of PC2/PV-2	V-001 overpressure and rupture	PSV	-
Closure of outlet valve	V-001 overpressure and rupture	PSV	-

As, in the above case, a safeguard is already provided in the design (the Pressure Safety relief Valve), no recommendation is made.

Should there be no safeguard, such as for the case of reverse flow below, a recommendation would be made.



Node: Vessel V-001

Deviation: **Reverse flow**

Cause	Consequence	Safeguard	Recommendation
Reverse flow from battery limit	Contamination of vessel V-001	None	Add a non-return valve

The HAZOP team fills an HAZOP Action sheet with the recommendation.

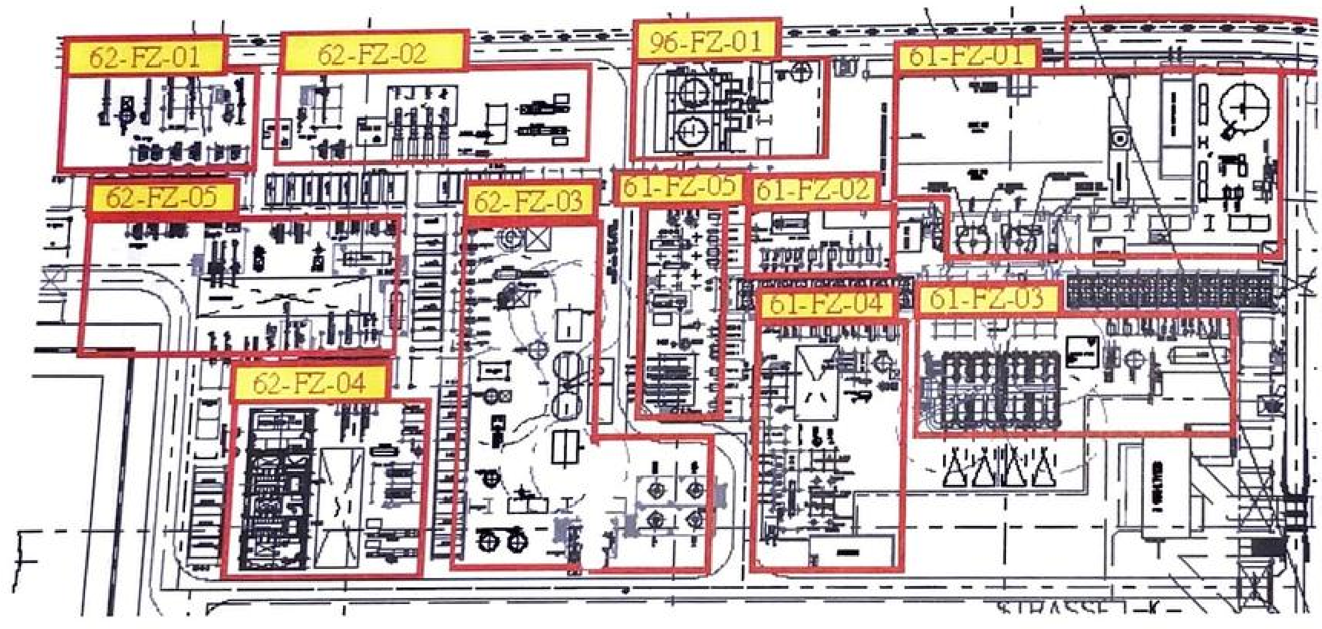
ACTION ON: TECHNIP	RESPOND BY: A.S.A.P
ACTION NO: 1	MEETING DATES: Tuesday 28th November 2006
DRAWINGS AND DOCUMENTS: XXX-32-00113-PID-210-0001 REV B - Neutralizing & Corrosion inhibitor injection	
ITEM: Neutralizing & corrosion inhibitor injection PK-201	(Hazop Node 201)
CAUSE: 3. Tank refilling.	(Flow Reverse)
CONSEQUENCE: Potential nitrogen back-flow through the filling line.	
SAFEGUARDS: None	
ACTION: Ensure there is a non-return device either on the tank side hose connection or on the tank TK-241 filling line.	
RESPONSE: (Action 1)	DATED:
SIGNED:	
ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO:	

The HAZOP action sheets are issued as part of the **HAZOP report** to the Engineer who fills the answer until close-out by the third party having chaired the HAZOP or, more often, the Client.

HAZOP reviews are usually conducted by a third party to avoid conflicts of interest between the Engineer and the Client. Indeed, the recommendations made in HAZOP could indeed imply significant re-work.

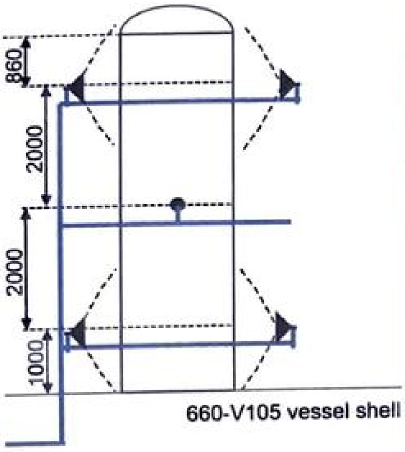
The HAZOP review does not assess the reliability of the safeguards. It considers that when there is a safeguard, the safeguard will not fail to operate. Indeed failure of the safeguard at the same time as the process upset would be a double jeopardy with a remote probability of occurrence. The review of the reliability of safeguards is the subject of the SIL review discussed in the Instrumentation & Control section.

Second only to the safety of the Plant process is the safety of the Plant layout. As explained in the Plant Layout Chapter, separation distances are provided between the Plant Units. This limits the extent of a potential fire to a certain area, called a fire zone. The Plant **Fire Partitioning Drawing** shows the extent of the Fire Zones.



Such partitioning allows to consider the scenario of a fire in a limited area – one fire zone – only and to set the fire water pumps and storage capacities accordingly.

The largest fire water water needs in any Fire Zone is taken into account, considering the operation of all fire fighting equipment: deluge, fire monitors and hydrants in this area. These calculations are detailed in the **Fire Water demand calculation note**.



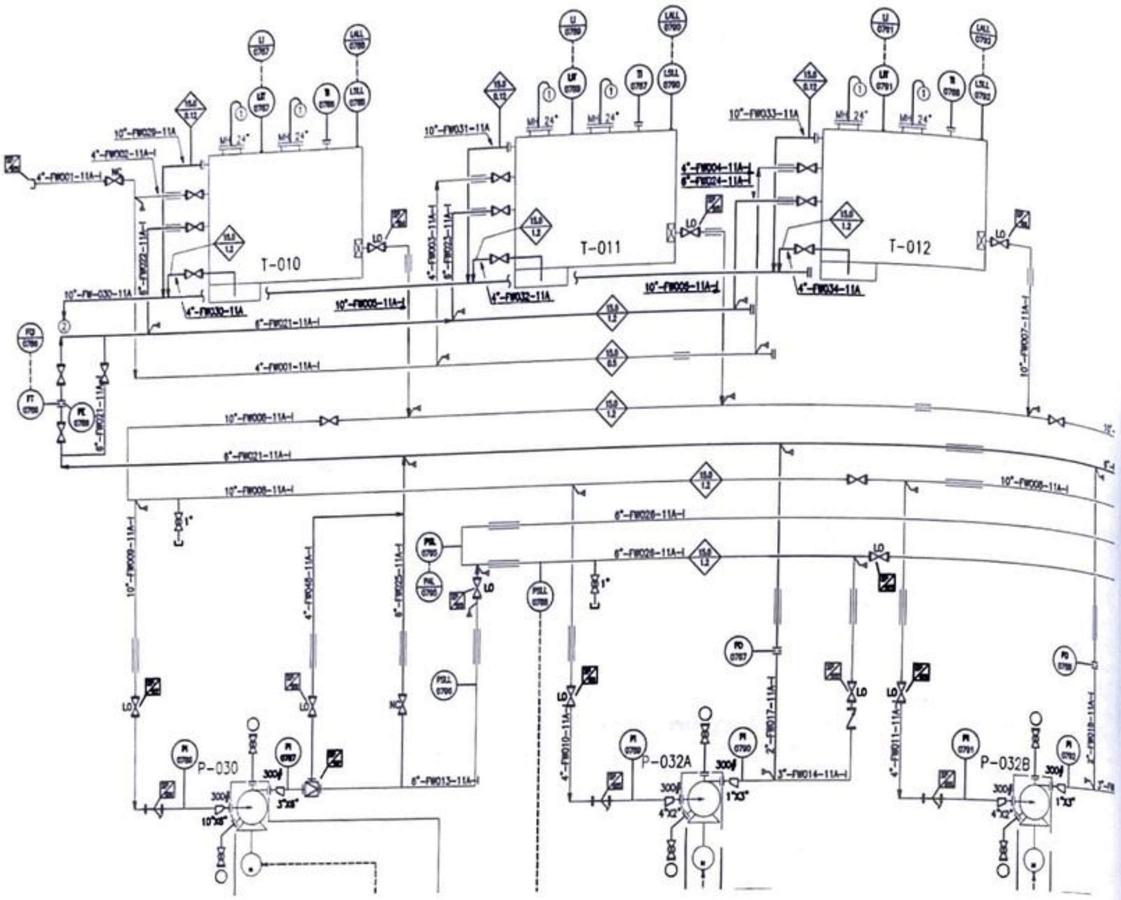
Item	Calculated flow rate
Maximum flowrate for spray and deluge system	141 m^3/h
Flowrate for monitors (2)	228 m^3/h
Flowrate for hoses (2)	114 m^3/h
BOG booster compressor area total firewater demand	**483 m^3/h**

The deluge system consist of spray nozzles (sprinklers) arranged around selected[1] process equipment, that automatically spray water on the equipment upon detection of fire. The purpose of the water spray is either to absorb the heat generated by the fire or to cool down the equipment, for instance a pressure vessel, to prevent the steel from loosing its strength at elevated temperature which could lead to loss of containment. The deluge water demand is calculated from the number of sprinkler nozzels, itself a function of the the surface areas of the protected vessels.

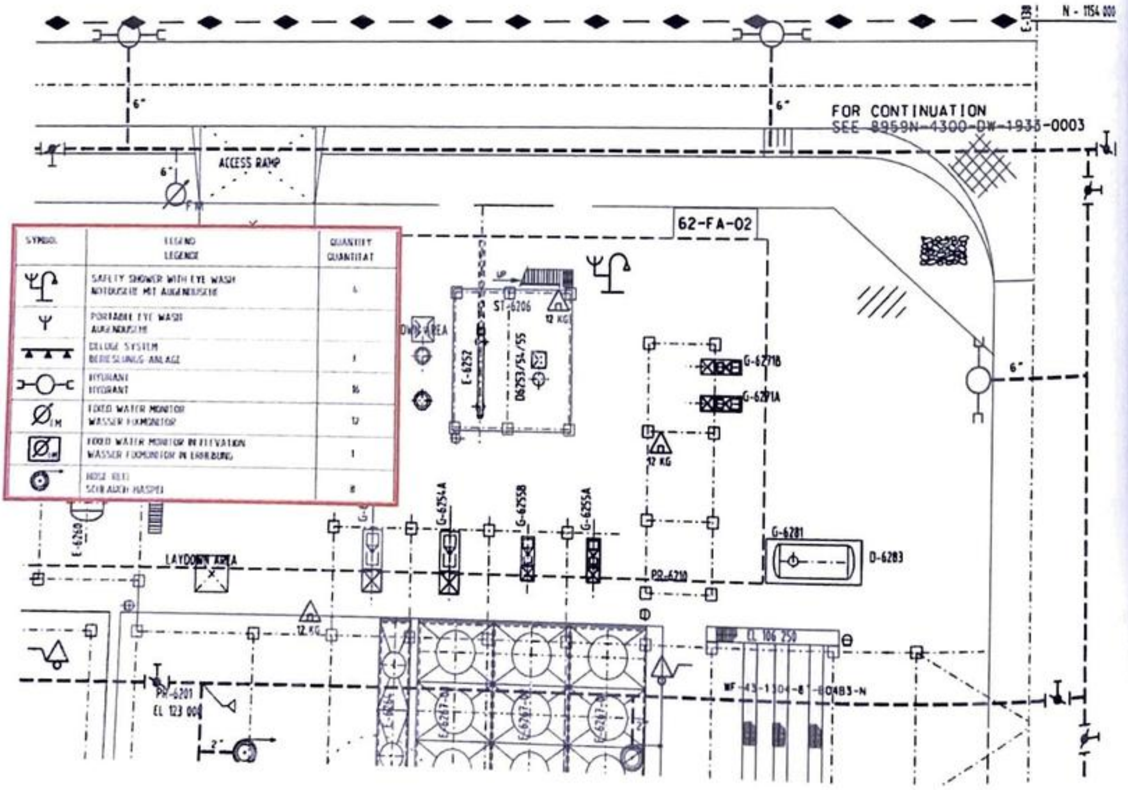
The fire water demand calculation leads to the sizing of the fire water storage and pumps, for which Safety issues "Process" Data sheets.

1. Almost all equipment of Off-Shore facilities but only a few, the ones which create a high fire hazard or that are not accessible by fire monitors, On-Shore

The fire water system is depicted on the **Fire Water P&IDs**.

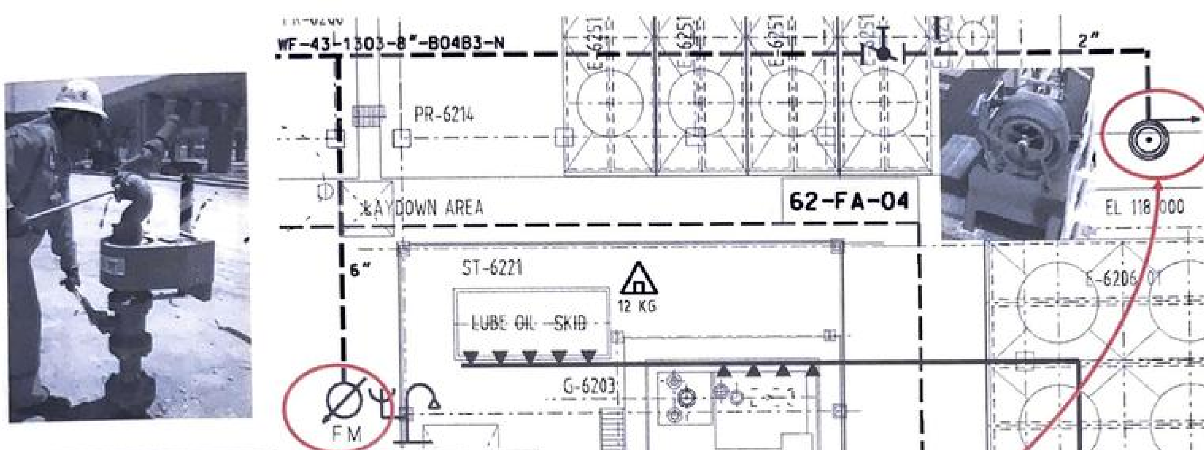


The fire water distribution piping is routed around the areas to be protected, with valves to isolate its sections, as shown on the **Fire Protection drawing**.



Isolation valves are provided to allow isolation of any damaged part while maintaining supply on the rest of the network. The ringed arrangement allows to supply fire water to any area from two sides. The combination allows to supply fire water to any area even if part of the fire water distribution network is damaged.

The Fire Protection drawing also shows the Fire fighting equipment location.

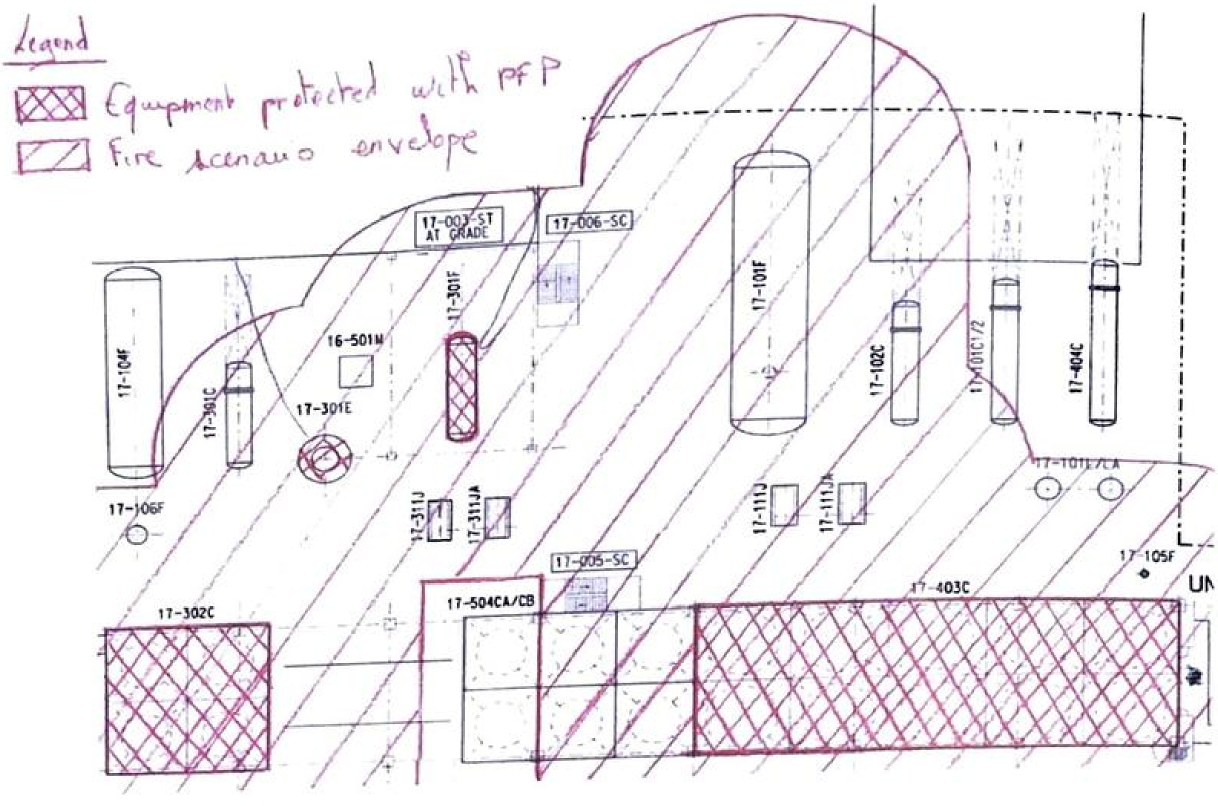


SYMBOL	LEGEND	QUANTITY
	FIRE AREA	5
	SAFETY SHOWER WITH EYE WASH	4
	PORTABLE EYE WASH	-
	DELUGE SYSTEM	3
$\varnothing_{FM}$	FIXED WATER MONITOR	12
	FIXED WATER MONITOR IN ELEVATION	-
	HOSE REEL	8
X KG	PORTABLE DRY POWDER A/B/C EXTINGUISHER(12KG)	37

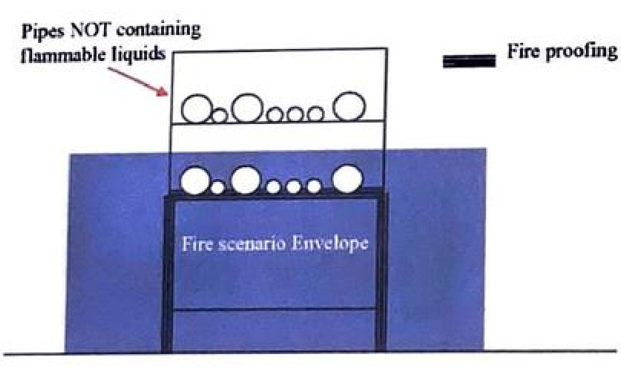
Passive fire fighting, i.e., fireproofing, is applied to structures supporting equipment and pipes. Protection of the such structures prevents/delays the fall of critical equipment or pipes if the structure is engulfed in a fire, avoiding the escalation of the incident.

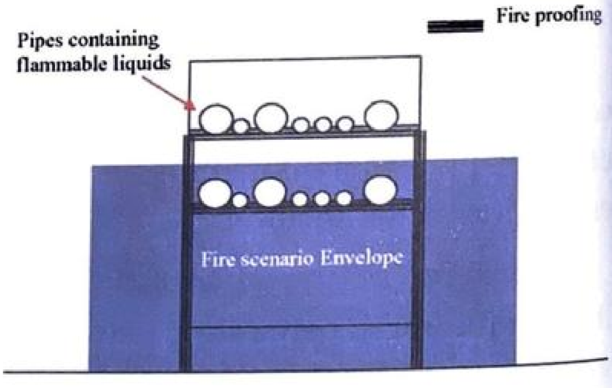
In order to define which structures shall be fireproofed, Safety establishes the list of equipment generating a fire hazard, i.e., equipment containing a significant volume of flammable fluids.

Each such equipment creates a "fire scenario envelope" in its surroundings. The various envelopes are consolidated on the **Passive Fire Protection (PFP) drawings**.



Equipment within the fire envelope that contain hydrocarbons are identified and their supporting structures fire proofed. The etxent of fireproofing is defined by means of typical drawings.



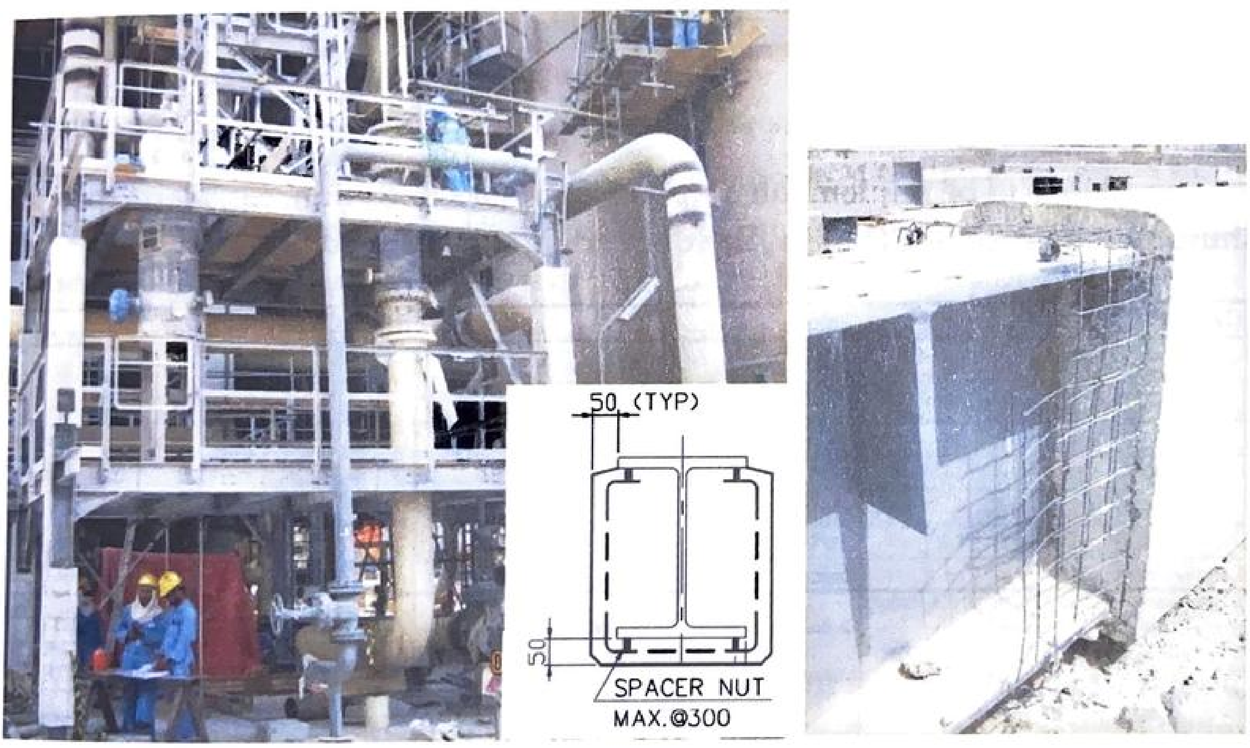


A deterministic approach used to be applied to define the extent of fire proofing. The fire envelope extent was determined by integrating individual equipment fire envelope, whose extent was given by applying standard distances given by the code based on the equipment inventory. The code prescribed which equipment to protect within the fire envelope, applying coarse criteria: all equipment having flammable inventory of causing domino effect if collapsing had to be protected.

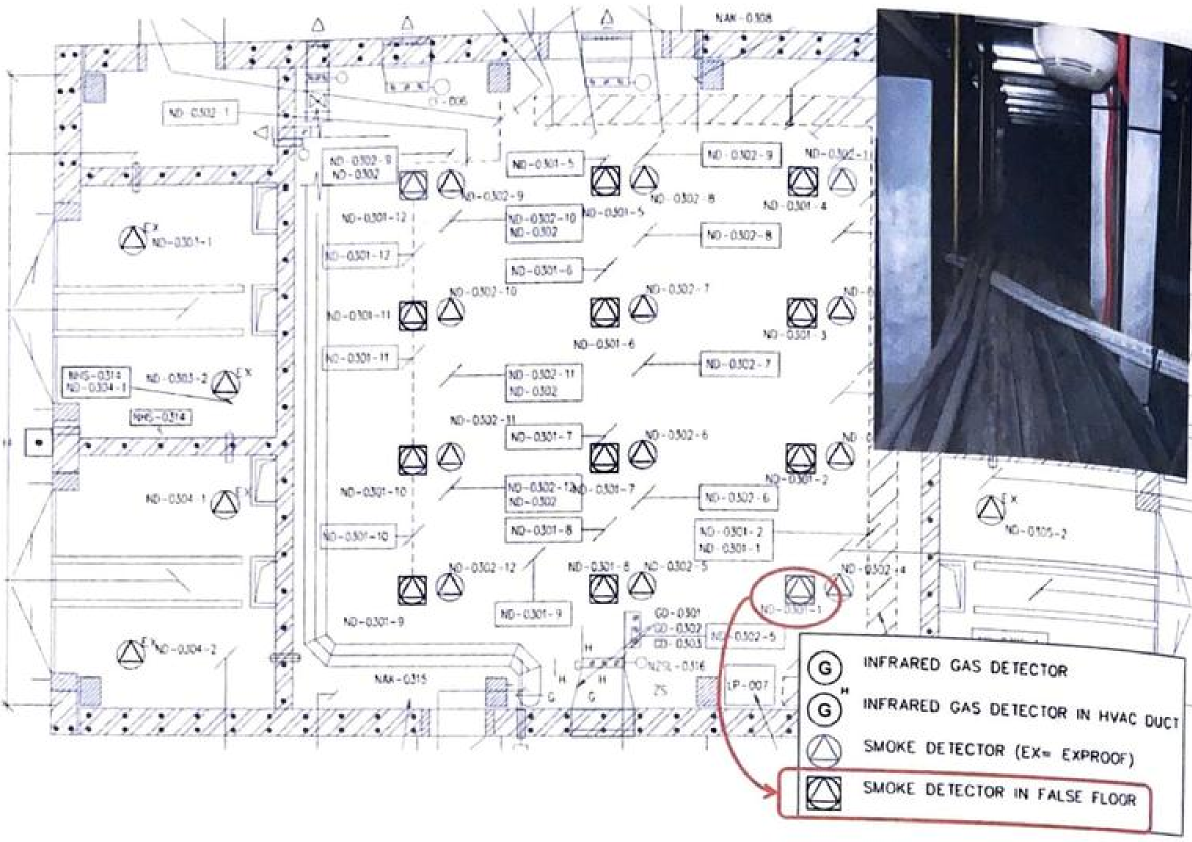
Such rule based approach is now replaced by what is called a risk based design. The risk level, i.e., the product of the probability and the severity of the consequences, of a fire originating from each equipment is evaluated. Passive fire protection is prescribed in the area affected by such fire only if the risk level is higher than a given threshold, typically one fatality every 10,000 years of operation.

Such risk based approach, which entails the performance of a QRA, allows to significantly reduce the PFP quantities.

Fire proofing is done by concrete (On-Shore) or lighter (Off-Shore) coating. Concrete coating of beams is done as per a standard issued by Civil.



The **Fire and Gas detection system** activates alarm and perform automatic actions, such as emergency shutdown of the process, in case of fire or gas detection. The number, location and type of Fire and Gas detectors in defined by Safety and shown on the **Fire & Gas detection layout drawings**.

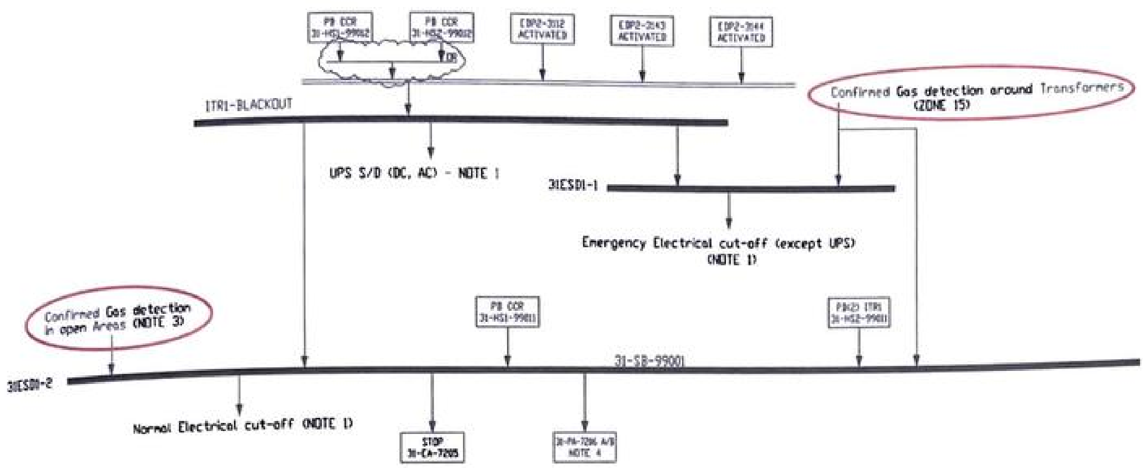


The actions to be implemented upon Fire or Gas detection, e.g, alarm, process shutdown, release of CO2, etc., are defined on the Fire and Gas Matrix.

CAUSES				EFFECTS							
Location	Causes	Voting	Setpoint	Local F&G panel	Master F&G panel	Gate house F&G panel	Fire building F&G panel	Audible and visible Fire alarm	Audible and visible Gas alarm	SD-2	Close electrical substation 27.1 fire dampers and stop HVAC
Compressor unit 27.1 - Electrical substation											
Transformers	Optical smoke detector	1 out of 2		X	X	X	X				
		2 out of 2		X	X	X	X	X			
	Manual Fire Alarm Station	1 out of 1		X	X	X	X	X			
HVAC inlet	Infrared gas detection	1 out of 3	10% LFL	X	X	X	X				
		1 out of 3	20% LFL	X	X	X	X				
		2 out of 3	10% LFL	X	X	X	X		X		
Electrical room and false floor		2 out of 3	20% LFL	X	X	X	X		X		X
	Optical smoke detector	1 out of 2		X	X	X	X				
		2 out of 2		X	X	X	X	X			X
	Manual Fire Alarm Station	1out of 1		X	X	X	X	X			

In the example shown above, detection of gas in the air inlet duct of the building ventilation system causes the ventilation fan to stop and the damper (shutter of the ventilation duct) to close. Indeed, the equipment located inside buildings is not designed to work in an explosive atmosphere.

The same information is shown, in a more synthetic and easy to read way, on the **ESD logic diagrams**.



Safety prepares the **Hazardous area classification drawings** which show areas where an explosive atmosphere could be present along with the likeliness of its presence (zone 0: always present/ zone 1: likely present in normal operation/ zone 2: present in abnormal conditions only).

The 1st step is to define the code to be used for the classification, e.g., API RP 505. The 2nd step is to make the inventory the process fluids and tabulate their properties, in particular flash point of liquids and flammability of gas.

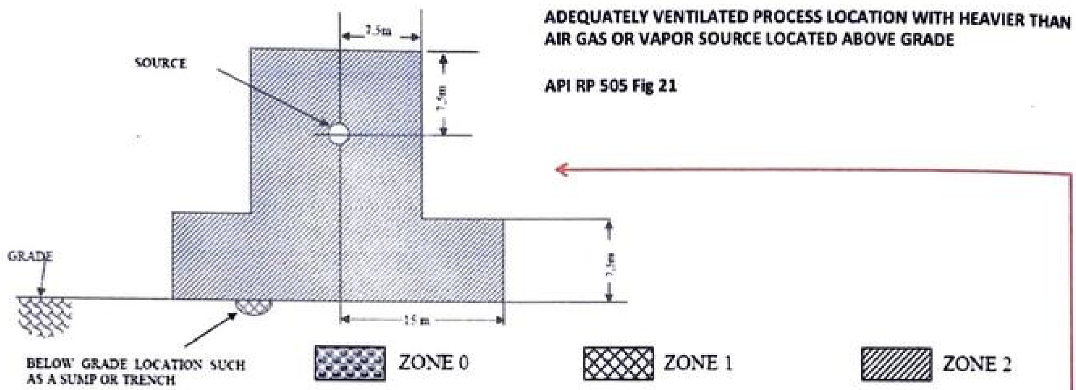
N°	Name	PRODUCT Composition (vol%)								MOL. WEIGHT (g/mol)	FLASH POINT (°C)	AUTOIGN. TEMP. (°C)	FLAM. LIMITS LFL (%vol)	FLAM. LIMITS UFL (%vol)	DENSITY Liq	DENSITY Gas	IEC GROUP OF GAS	TEMP. CLASS
1201	CONDENSATES FROM U76	C4H10 5.00	C5H12 8.00	C6H14 4.00	C7H16 10.00	C8H16 10.00	C8H18 6.00	C9H18 57.00		123	<37.8	241	1,2	7,2	L	H	IIA	T3
1206	C1201 OVHD	H_2O 8.00	C4H10 6.00	C5H12 5.00	C6H14 31.00	C7H16 15.00	C8H16 10.00	C8H18 10.00	C9H18 6.00	87	<37.8	239	1,2	7,4	L	H	IIA	T3
1207	CRUDE FROM FURNACE	C_4H_{10} 5.00	C_7H_{16} 10.00	C_8H_{18} 9.00	C_8H_{18} 5.00	C_9H_{18} 4.00	C_9H_{20} 4.00	$C_{10}H_{22}$ 3.00	$C_{11}H_{24}$ 60.00	130	<37.8	235	1,1	6,8	L	H	IIA	T3
1208	COND TOWER OVHD NAPHTA	C_3H_8 5.00	C_4H_{10} 13.00	C_5H_{12} 1.00	C_5H_{12} 15.00	C_6H_{14} 66.00				94	<37.8	225	1,2	7	L	H	IIA	T3
1608	FUEL GAS	H_2 69.00	H_2S 18.00	CH_4 2.00	C_2H_6 2.00	C_3H_8 2.00	C_4H_{10} 3.00	C_5H_{12} 1.00	C_6H_{14} 1.00	16	Gas	377	3,8	48,0	L	L	IIC	T2
1904	REFLUX SOUR WATER STRIPPI	H_2O 90.70	NH_3 4.70	H_2S 1.60						18	/	Unflammable mixture						

The 3rd step is to identify the process conditions of these streams throughout the Plant. As process conditions changes at Equipment, this identification is done by Equipment.

EQUIPMENT				FLAMMABLE MATERIAL			
Item	Name	Product N°	Operating temperature (°C)	Operating pressure (bara)	State	Relative density to	Group of gas (IEC)
82E1210A/B	Light gasoil cooler	1213	132/58	13,3/12,5	L	-/L	IIA
82E1212A-D	First stage condenser	1206	151/131	3,6/3,1	V	H/L	IIA
82E1213A-H	Second stage condenser	1217	105/58	3,1/2,7	M	H/L	IIA
82E1214	Heavy gasoil product air cooler	1220	160/65	12,8/12,1	L	-/L	IIA
82E1216	LVGO pumparound aircooler	1221	183/58	9,2/7,5	L	-/L	IIA

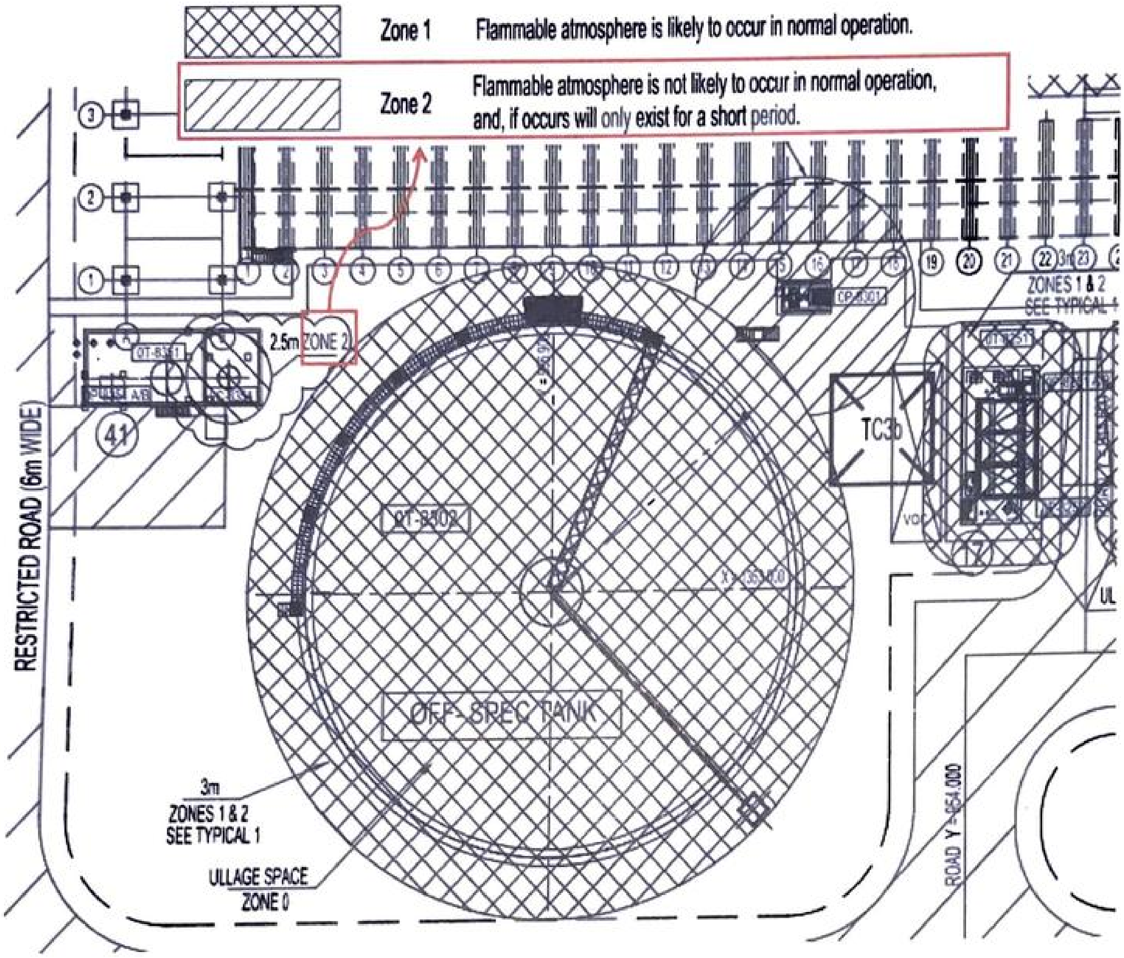
A hazardous area is created by release sources near these Equipment: flanges, process vents, relief valves and rupture disks, pumps and compressor seals.

The shape and extent of the explosive atmosphere depends on the fluid density (gas lighter/heavier than air) and degree of confinement.



EQUIPMENT				FLAMMABLE MATERIAL				VENTILATION & LOCATION	ZONES CREATED BY THE EQUIPMENT			
Item	Name	Product N°	Operating temperature (°C)	Operating pressure (bara)	State	Relative density to air/water	Group of gas (IEC)		Boundary of zone 1 (m)	Boundary of zone 2 (m)	Additional zone 2 (m)	Ref fig of job spec (API RP 505)
82E1210A/B	Light gasoil cooler	1213	132/58	13,3/12.5	L	-/L	IIA	O	/	15	/	FIG 1-1 (21)
82E1212A-D	First stage condenser	1206	151/131	3,6/3,1	V	H/L	IIA	O	/	15	/	FIG 1-1 (21)
82E1213A-H	Second stage condenser	1217	105/58	3,1/2,7	M	H/L	IIA	O	/	15	/	FIG 1-1 (21)
82E1214	Heavy gasoil product air cooler	1220	160/65	12,8/12.1	L	-/L	IIA	O	/	15	/	FIG 1-1 (21)
82E1216	LVGO pumparound aircooler	1221	183/58	9.2/7.5	L	-/L	IIA	O	/	15	/	FIG 1-1 (21)

The Hazardous area classification drawings sum-up the individual hazardous zones.



Electrical equipment located in hazardous areas must be of a special design, called explosion protection, so that they cannot be a source of ignition. The required degree of protection is determined by the classification (zone 0>1>2) of the area.

Protection could be achieved in by different designs such as:

- explosion proof "d": the equipment is enclosed inside a heavy duty enclosure, as shown here, that would contain an explosion and avoid its propagation,
- increased safety "e": the equipment is designed not to generate any spark,
- intrinsic safety "i": the amount of energy created by a spark in the equipment is not high enough to ignite the explosive atmosphere.

Besides this level of explosion protection, Safety identifies the nature of the explosive atmosphere in which the equipment could be present. It has indeed a direct impact on the minimum ignition energy. An atmosphere of hydrogen, such as the one that could develop in a battery room during charging, requires much less energy to ignite than a natural gas atmosphere for instance. The content of the atmosphere is specified by reference to a gas group, e.g., IIC for hydrogen.

Finally, Safety specifies the maximum temperature authorized on the equipment surface. Indeed, the explosive atmosphere would ignite if it comes in contact with a temperature above its self-ignition temperature. This again depends on the composition of the explosive atmosphere: methane self-ignition temperature is around 600°C whereas that of ethylene is 425°C.

The maximum equipment surface temperature is specified by means of a temperature class, e.g., T3 means maximum surface temperature of 200C.

Electrical equipment protected against explosion is clearly marked by means of an international label encompassing the information above and is supplied with an Explosion protection certificate.

The **Quantitative Risk Analysis (QRA)**, also called **Fire and Explosion Risk Analysis (FERA)**, defines the protections of personnel/asset from explosion and fire that must be incorporated in the Plant design. Instead of a determinist approach, such as the one used for defining Fire Proofing as explains above, such analysis is a probabilistic approach.

It considers both the probability and severity of events. The severity level derives from the level of radiation (fire) or overpressure (explosion), e.g,

- Minor: no effect on people and no damage the Plant
- Significant: effect on Plant personnel, no effect on the public, damage to plant <10M USD
- Sever: fatality among Plant personnel, health effect on the public, damage to asset >10M USD

- Major: fatality among Plant personnel or public, damage to asset >100M USD,

The product of the probability and the severity of an accidental event is the risk. Companies define tolerable risk area by means of a risk matrix.

FREQUENCY (events/year)

1.0E-02				
1.0E-03				
1.0E-04				
1.0E-05				
1.0E-06	Minor	Significant	Severe	Major

SEVERITY

Unacceptable risk area

"ALARP" area

Acceptable risk area

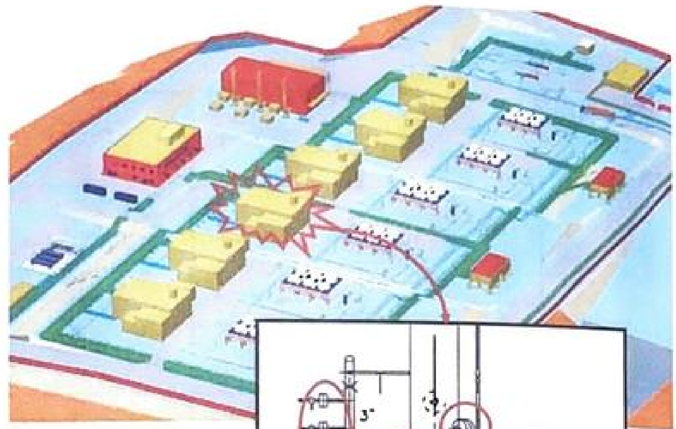
A design change is required for any event falling in the "Intolerable Risk Area" of the matrix. Its frequency or consequences must be reduced to bring it into the "ALARP (As Low As Reasonably Practicable)" or "Acceptable" risk areas, through risk reduction measures.

The first step of the QRA work process is to identify the relevant hazards.

In the example that follows, the hazard identified is an explosion due to gas leak inside an enclosure (a compressor building). The cause could be leaking flange, material defects, construction errors, corrosion, maintenance overlook, etc.

The frequency of the event is determined by making the inventory of all components which could be the source of the leak (flanges, pumps, valves, instruments...). The frequency of leak of individual components is taken from statistical data found in the Loss Prevention literature.

The sum of the individual component leak frequencies gives the overall frequency.



Case stuy: Gas leak from random piping component rupture

Cause: installation error, corrosion, material defect...

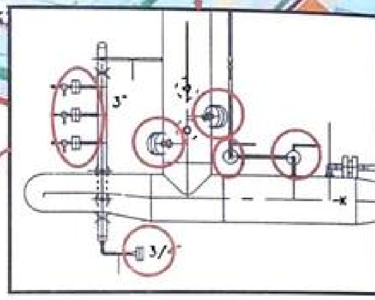
Possible consequence: Dispersion without ignition / jet fire / flash fire / explosion

Section considered: Compressor building

Step 1:

Identification and characterisation of initiating events

Σ risk components *failure rate (from statistics)

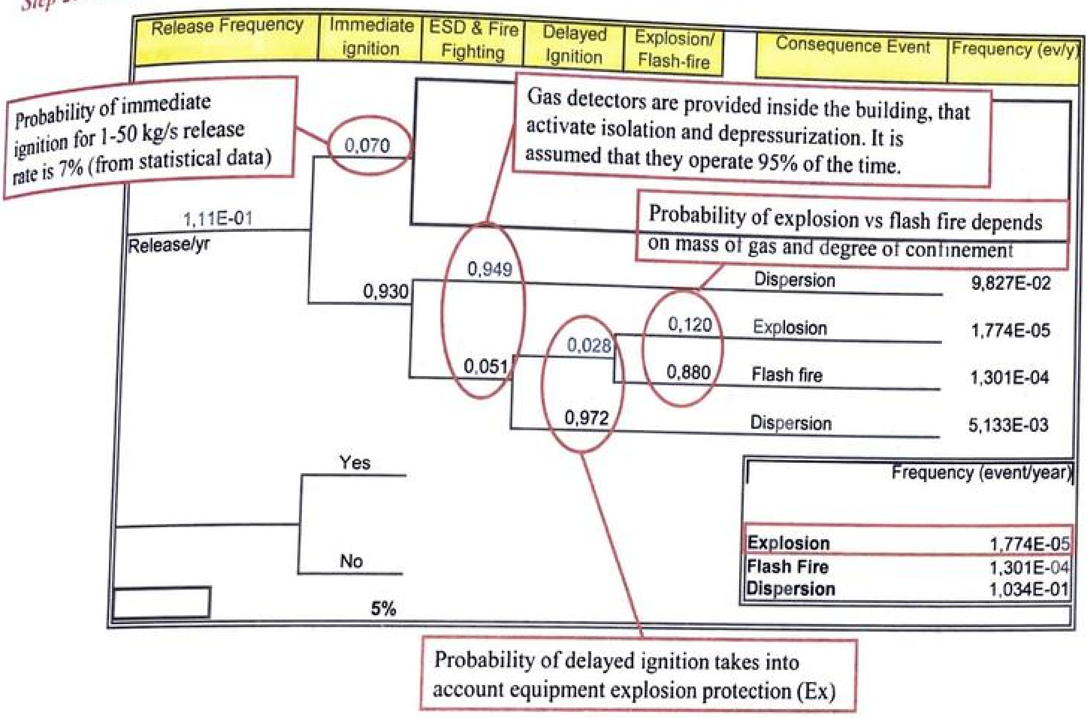


Gas leak inside compressor buidling due to component rupture	Hole size (% of component section)		
	5%	20%	Full
Frequency (event/year)	1,11E-01	5,06E-04	6,83E-05
Outflow rate (kg/s)	5,7	90,8	2270,0

Release of hazardous material to atmosphere can give rise to different effects, such as simple dispersion without harm or on the contrary fire, explosion etc. This depends on a number of factors, such the presence of ignition sources, the degree of confinement, etc. It is the purpose of the second step of the QRA to evaluate the probability of each possible consequence.

The various scenarios are shown on an event tree. The frequency of each event is factored by the probability of the subsequent one, resulting in the frequency of the various possible consequences

Step 2: Event tree analysis

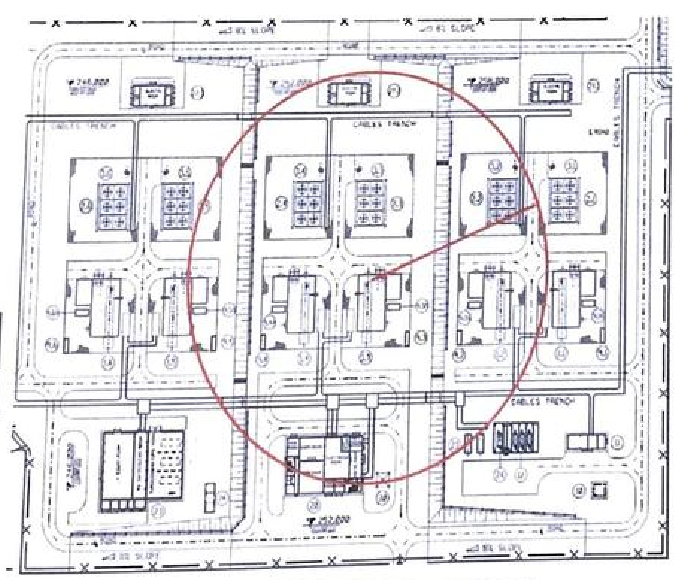


The third step of the QRA is to evaluate the effects of each accidental scenario in terms of reference values of overpressure, heat radiation, etc.

Step 3:

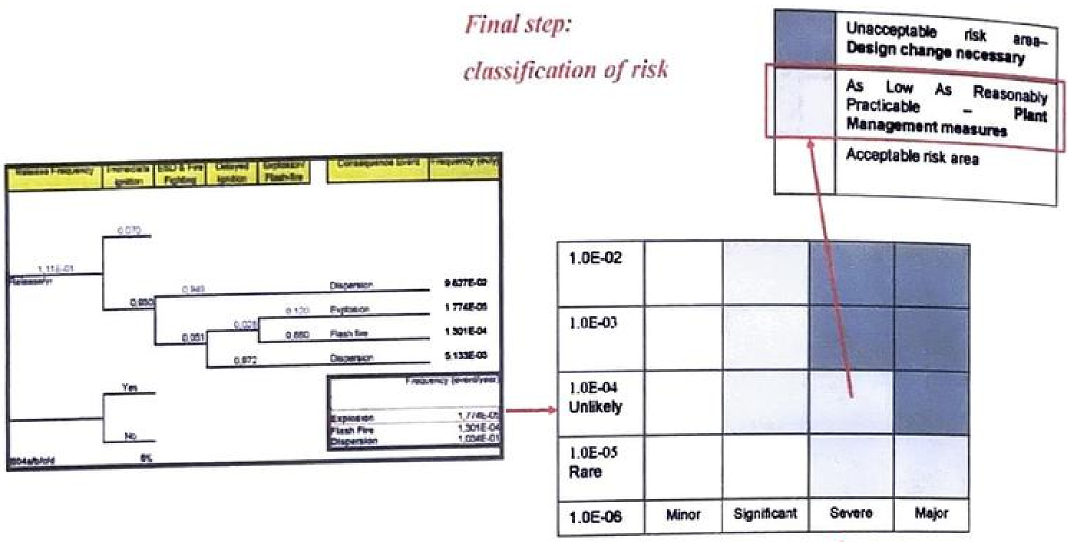
Consequence evalutation

Overpresssure (bar)	0.2	0.1	0.01
Distance (m)	96	167	1270



CONSEQUENCE CLASS	QUANTITATIVE CRITERIA	EFFECTS
MINOR	≤0.1 bar locally (within 10m)	No effect, no damage
SIGNIFICANT	≤0.1 bar locally (within 50m)	Limited damage to plant and operators
SEVERE	> 0.1 bar within plant	Damage to plant and operators
MAJOR	> 0.1 bar on populated areas	Damage to plant, operators & public

The consequence and probability are plotted on the **Risk Matrix** to check the acceptability of the risk.



CONSEQUENCE CLASS	QUANTITATIVE CRITERIA	EFFECTS
MINOR	?0.1 bar locally (within 10m)	No effect, no damage
SIGNIFICANT	?0.1 bar locally (within 50m)	Limited damage to plant and operators
SEVERE	>0.1 bar within plant	Damage to plant and operators
MAJOR	>0.1 bar on populated areas	Damage to plant, operators & public

Should the risk fall outside the acceptable area, design changes are required.

Such design changes could include requirements for blast resistance of buildings, reinforcement of structures supporting safety critical elements, etc. The results of the Risk Assessment studies tend to depend significantly on the party that performs them! Experience shows that for a similar Plant, requirements for fire proofing and blast resistance can greatly vary

The flare radiation calculations described in the Process chapter, along with dispersion studies in case of flare flame loss result in the definition of the restricted and impacted areas. The **restricted area** around the flare/cold vent, to be fenced off to prevent operator access, is determined based on the level of heat radiations and exposure to toxic substances. The concentration of toxic substances is determined by dispersion studies, for all relief scenarii and meteorological conditions.

- The restricted area extends up to the limit of concentration of toxic substance, and heat radiation, allowed for short term exposure in normal flare operation.

- Abnormal flare operation, i.e., flare flame out, is also considered. As the operation is abnormal, the restricted area determined in these conditions extends to the limit of lethal concentration.

The much wider impacted area is also determined in these abnormal conditions. It extends to the limit of concentration of toxic substance creating irreversible effect on health. Should it extend beyond the Plant fence, an emergency response plan must be developed for the evacuation of the public.

The various impacts of the Plant on the environment are identified and evaluated by HSE discipline.

An ENVID (ENVironmental aspects IDentification) review is performed to identify all such impacts.

Aspect	Health	Air	Water		Raw material	Waste
		Gaseous emissions	Resource Consumption	Liquid effluents	Petroleum/gas /Chemicals	
Relief (flare/vent)	Noise*	CO, NO_X, PM, SO_2, VOC				
Power generation		CO, NO_X, PM, SO_2			Fuelgas	
Gas compression	Noise*	Fugitive VOC			Gas	
Fresh water	Potable		X			
Cooling water	Legionella		X	Effluent Water Temperature	Biocides, pH Control	
Effluent water (open drains/ treatment Plant)				Hydrocarbons, Suspended Solids		Biosludges, Oily sludge

The review covers, for each aspect, the corresponding environmental concerns (noise, NOx emission, energy consumption, waste generation…) and the measures that are implemented in the design to control the environmental impact.

The Health and Environment Requirements specification states the requirements for each of the identified environmental aspect, the emissions and discharge constraints imposed by law, the design dispositions to limit/monitor pollutants for each type of emission/discharge, ambient air quality, noise limits, the dispositions for disposal of hazardous waste, etc.

Effluent Quality Criteria for Discharge into Sea 3. Organic Species				
Parameter	**Symbol**	**Units**	**Monthly Average**	**Maximum Allowable**
Oil & Grease		mg/l	5	10
Phenols		mg/l	0.1	0.5
Total Organic Carbon	TOC	mg/l	50	75
Halogenated hydrocarbons and Pesticides		mg/l	***	

The requirements identified in the Health and Environment Requirements specification are fed back into the design of the Plant (water treatment system, exhaust stacks Continuous Emissions Monitoring System), and incorporated in Equipment specifications (limits of CO and NOx for gas turbines, fired heaters, height of stacks, etc.).

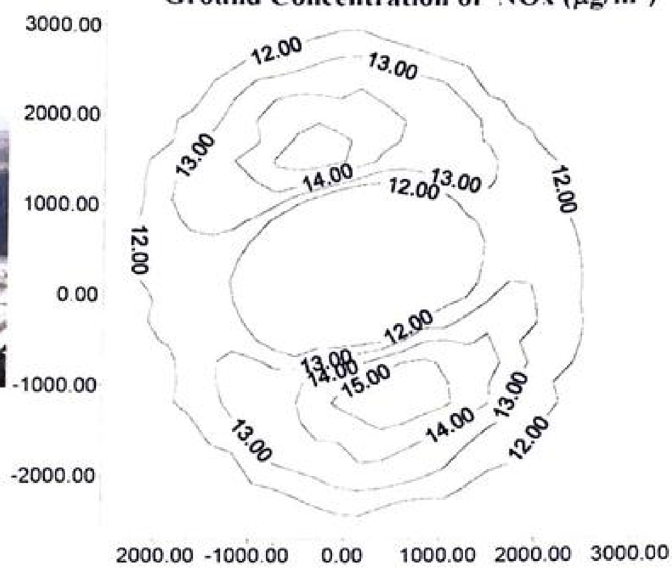
The **Environmental Impact Assessment (EIA)** is performed to verify and prove that the design complies with the legal requirements and is required to obtain the Plant construction permit. It is done by a specialized third party using baseline surveys of the area that often require gathering at least two seasons of data. The EIA includes an analysis of the dispersion of pollutants released by the Plant to evaluate its impact on the surroundings. For gaseous emissions, it entails an inventory of all sources of emissions (machinery exhausts, etc.), and the modelling the atmospheric dispersion according to local meteorological data. It results in the calculation of the levels of ground concentration of atmospheric pollutants at various distances from the Plant, e.g., within the facility, in nearby populated areas, etc.

Sources description

SOURCE NAME	Stack Height (m)	Stack diam (m)	Flue gas temp (K)	Flue gas velocity (m/s)	Q (Nm³/h)	NOx (g/s)	CO (g/s)
Turbocompressor TC-100	15	[illegible]	[illegible]	28	206000	2.87	8.60
Turbocompressor TC-200	15	[illegible]	[illegible]	28	206000	2.87	8.60
Turbocompressor TC-300	15	[illegible]	[illegible]	28	206000	2.87	8.60
Turbocompressor TC-400	15	[illegible]	[illegible]	28	206000	2.87	8.60
Turbogenerator TG-001	15	1.58	806	28	15000	0.63	1.88
Turbogenerator TG-002	15	1.58	806	28	15000	0.63	1.88

Coordinates of the sources

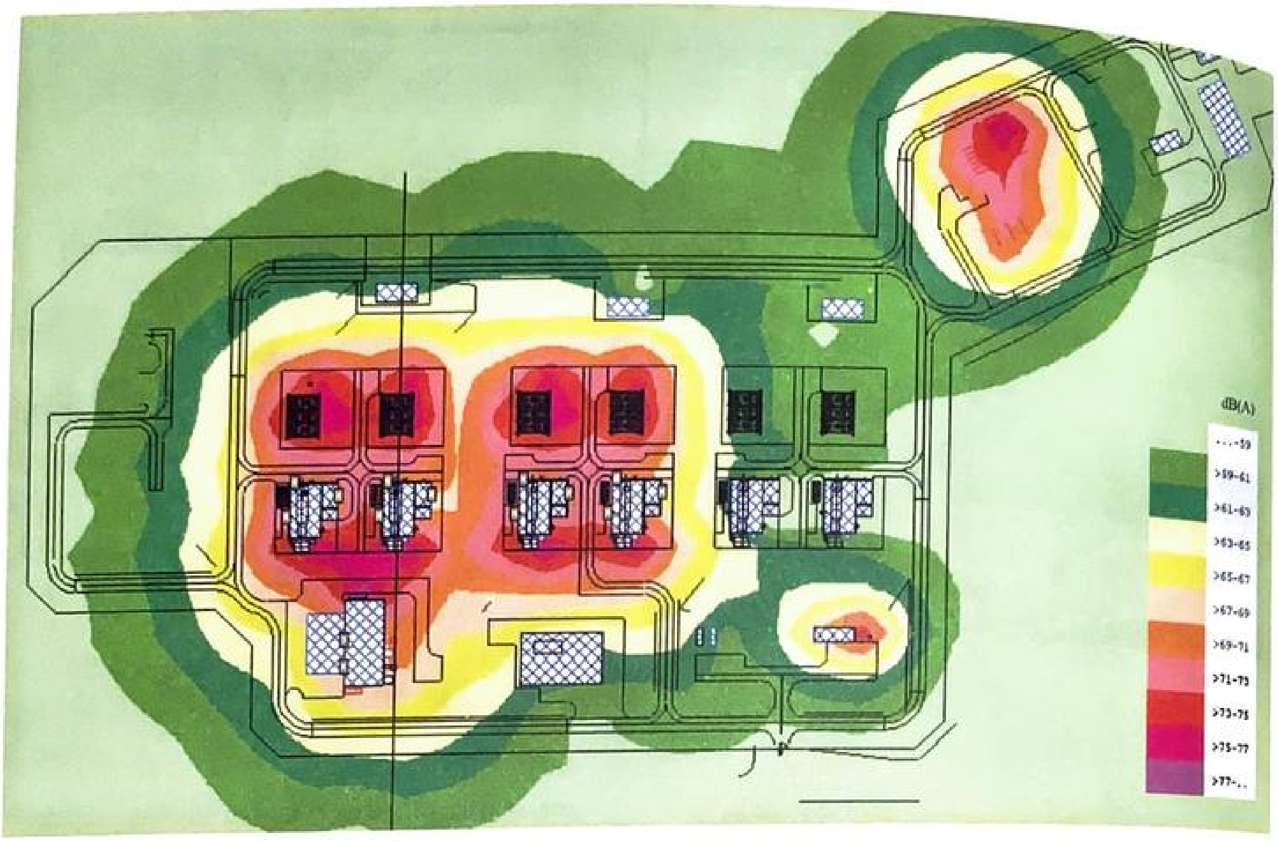
	X (m)	Y (m)
Turbocompressor TC-100	[illegible]	[illegible]
Turbocompressor TC-200	[illegible]	[illegible]
Turbocompressor TC-300	[illegible]	[illegible]
Turbocompressor TC-400	[illegible]	[illegible]
Turbogenerator TG-001	[illegible]	[illegible]
Turbogenerator TG-002	[illegible]	[illegible]



The scope of the Environment Impact Assessment covers emissions in normal operation only. Accidental emissions and their impact on the facilities or populations is out of the scope and is covered in the Quantitative Risk Assessment (see below).

The environmental impact assessment also includes a **Noise study**. It starts with the inventory of all noise sources. Noise levels are obtained from reference data base during preliminary studies, then from each equipment vendor after purchase. A computer is used to run a model of the noise dispersion. Both noise sources and barrier elements, with noise screen effect such as buildings, are entered in the model. The noise level at each location of the plant is then evaluated. Verification is done that noise level in working areas, and at the facility's boundaries, are within the safe/legal limits.

The noise study records the bases and results of noise calculations. Equipment noise insulation requirements are derived from the noise study. The results of the noise study are shown on the **Noise map**.



Finally, the Environmental Impact Assessment includes a waste management study. The wastes generated by the Plant are inventoried and the possible options for recycling, treatment or disposal are studied based on existing local waste recycling/treatment/disposal facilities. This study allows to design the temporary waste storage area required on site.

Chapter 7

Civil Engineering

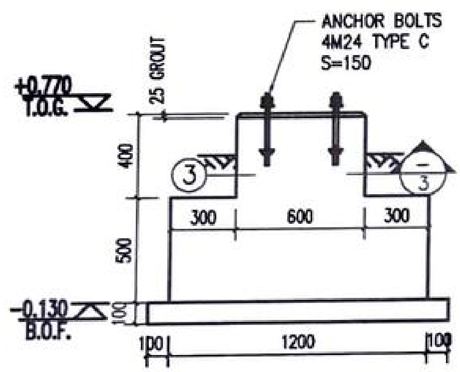
The first step of civil engineering for an on-shore Plant is to know the Site and the type of soil on which it will be built. A survey is required to collect topographical, hydrological, geological and geotechnical data. A **Soil Investigations Specification** is prepared by the Geotechnical Engineer to define the scope of this survey. The survey includes soil investigations, by means of geotechnical and geophysical methods, to collect a good understanding of the type of soil and its variability over the Plant area. The type of soil determines the type of equipment required for excavations (excavators/explosives) and the type of foundations (shallow/deep) of Plant equipment.

The survey also includes the identification of any local geo hazards, such as seismic hazard, collapsible soil, underground cavities, underground water level, etc. The soil characteristics including the bearing capacity are defined, after soil investigations, in the **Geotechnical Survey Report**. The bearing capacity of soil is one of the key information which shows the load versus settlement capacity of the soil. The information of this report provides the geotechnical parameters and data needed to design foundations.

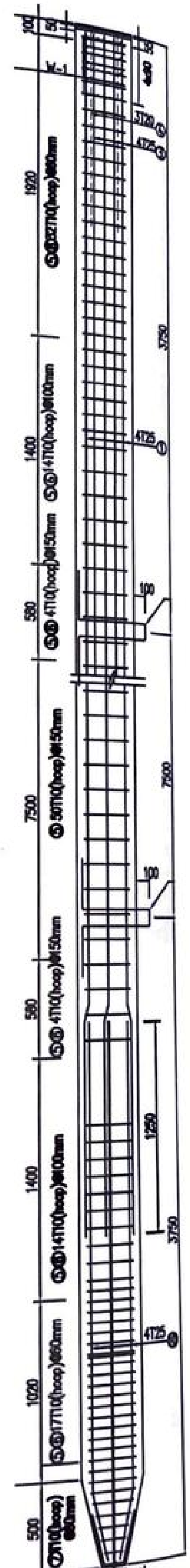
Foundations are structural elements that connect a structure to the ground that supports it and are typically composed of reinforced concrete and steel.

Foundations can generally be classified into two broad categories: shallow foundations and deep foundations.

Deep foundations transfer some or the entire load to deeper soils, and are considerably more expensive and complex than shallow foundations. Deep foundations are used for structures or heavy loads when shallow foundations cannot provide adequate capacity, due to size and structural limitations. They may also be used to transfer superstructure loads past unsuitable soil layers. While shallow foundations rely solely on the bearing capacity of the soil beneath them, deep foundations can rely on end bearing resistance, frictional resistance along their length, or both in developing the required capacity.



Shallow vs deep foundations



Examples of deep foundations include piles, drilled shafts, and caissons.

The selection between these two types is varying regarding the situation and economic measures, and normally, the shallow foundation is the first choice because it is simpler and more economic.

Sometimes civil design team reduces the tension (pressure) beneath the shallow foundation by increasing the size of it to maintain the tension under bearing capacity of the soil, however, depending on type of the load (dynamic/static or lateral), size of the load, soil characteristics and the settlement limitations, sometimes using deep foundation is not avoidable.

Since to select shallow foundation instead of deep foundation requires more concrete volume, time and cost estimation should be done for both alternatives to evaluate the economic measures, especially, in a situation where concrete material is hard to provide and expensive or the underground water is too high.

When a project encounters difficult foundation conditions, another possible alternate solution is to modify the existing ground. There are plenty of methods for **Soil Improvement** such as vibration, grouting, preloading, reinforcing earth, etc. Since these technics are generally expensive and their effectiveness completely depends on the soil conditions, a thorough study is required before selection of methodology and scope of application.

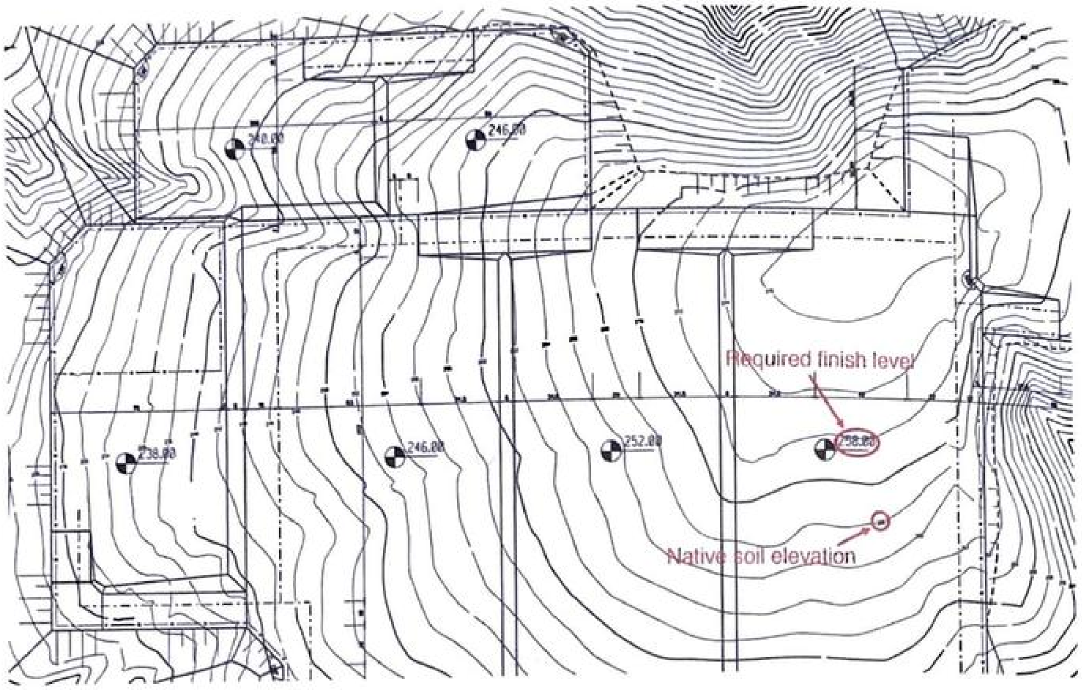
The **Specification for Topographical Survey** is necessary to clarify the type and scope of topographical survey and its deliverables. The outcome of this survey is the **Topography drawing** which is needed to decide about Site preparation elevations and cut/fill volumes. These measures are absolutely essential economically, for instance, any increase in volume of cut/fill leads to a rise in spending resources and time.

One of the key information to select the final level of the Plant is the **Hydrology Study** and its flood assessment. In some situations, for instance wetlands, a massive amount of fill material should be transported to Site and compacted layer by layer to level up the Plant, therefore, the hydrology study and elevation of the Site preparation impact the project time and cost noticeably.

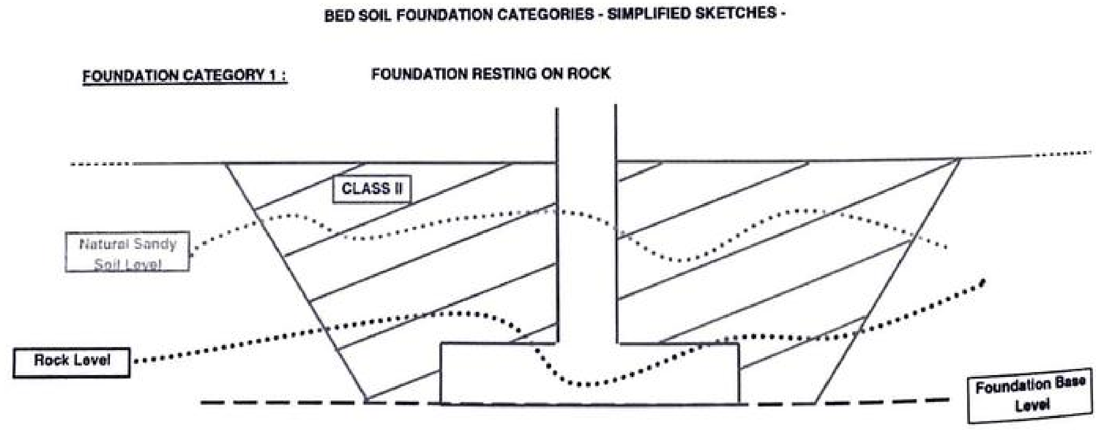
Earthworks equipment excavate/fill in order to reach the required finish level.

To provide suitable soil material or disposal of excavation surplus of the project borrow/disposal pits should be designated and prepared based on the Geotechnical Survey Report. The **Earthworks Specification** specifies tests and boreholes to be done in borrow pit locations to make sure that the soil is proper for the project.

The Grading Plan shows the natural ground and final desired elevations.



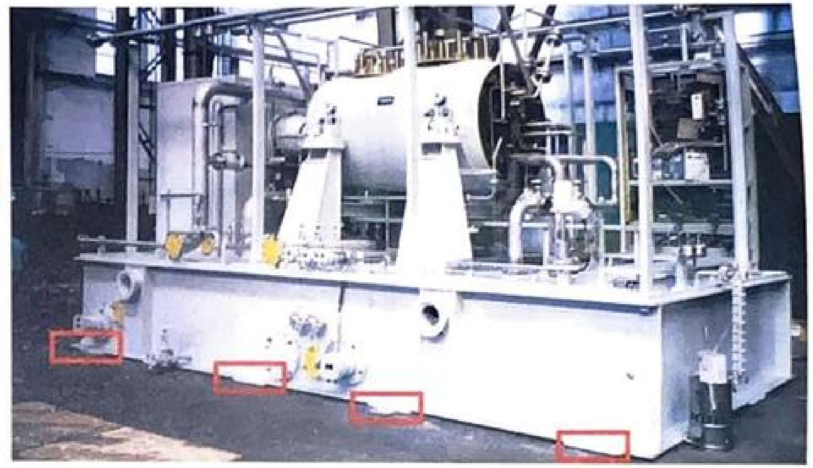
The geotechnical investigations report provides the design basis for foundations: foundation type, expected depth of selected bed soil at different locations of the Plant territory, soil bearing capacity, ground water level. This is recorded in the Civil Design Criteria, which also specifies the applicable codes, safety factors, materials (rebars, anchor bolts, concrete), loads (wind, seismic, live loads), load combinations as well as any specific design requirement, e.g., minimum concrete cover, etc.

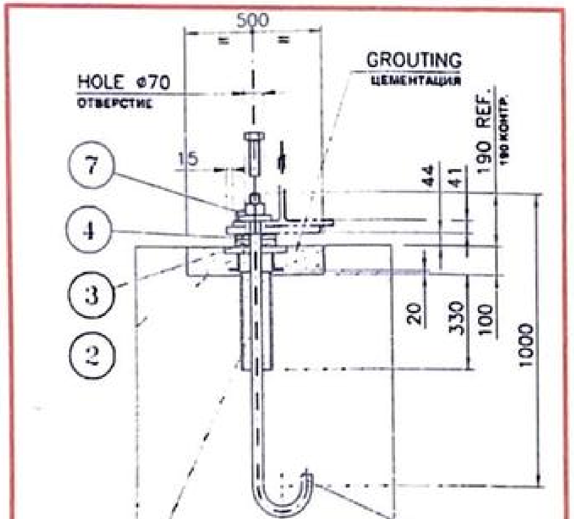


Design of equipment foundation requires Vendor information: location of anchor bolts as well as static and dynamic loads. This information is received on a drawing called the Equipment setting plan or Equipment foundation drawing, shown hereafter.

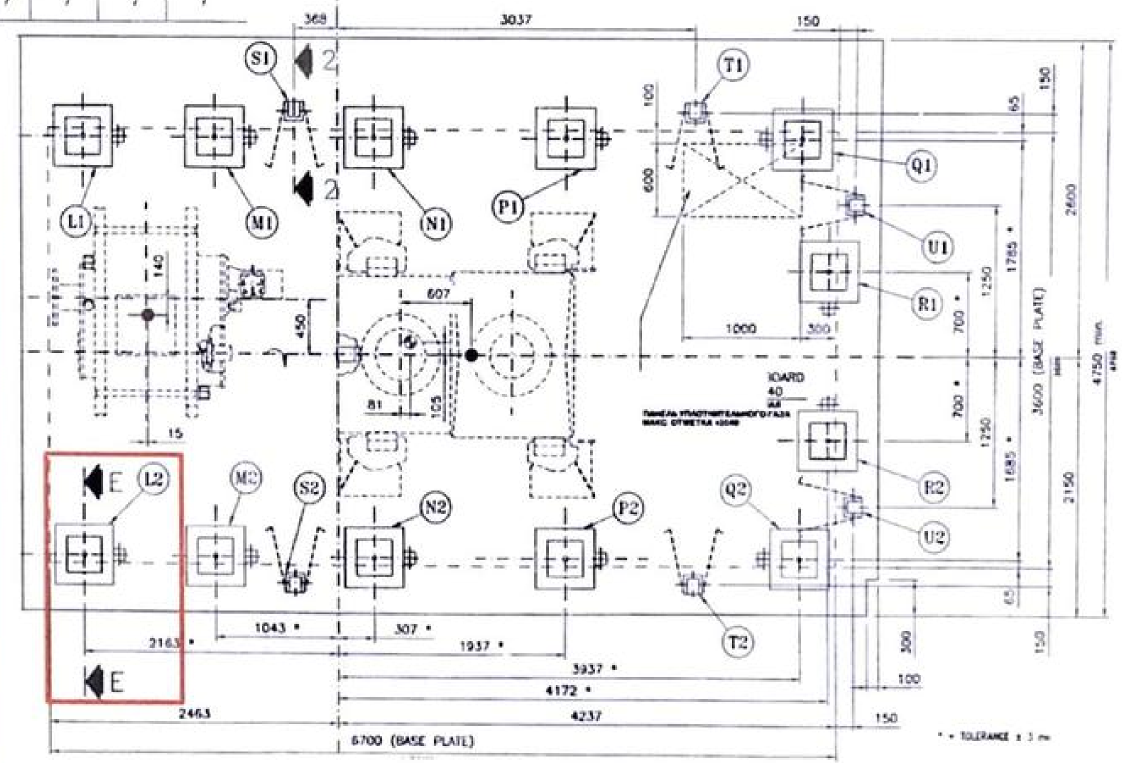
CENTRIFUGAL COMPRESSOR

REFERENCE AXIS / SUB-SOLE PLATE DENOMINATION	FOUNDATION LOADS (KGS.) EACH SUB-SOLE PLATE / НАГРУЗКИ (КГ) НА КАЖДУЮ ИЗ НИЖНИХ ПЛИТ ОСНОВАНИЯ ФУНДАМЕНТА — NORMAL OPERATION LOADS / НОРМАЛЬНЫЕ РАБОЧИЕ НАГРУЗКИ: STATIC LOADS	NORMAL TORQUE LOADS	FOUNDATION ANCHOR AND GUIDE SUPP. LOADS		NORMAL DYNAMIC LOADS 1		NORMAL DYNAMIC LOADS 2		EMERGENCY LOADS / АВАРИЙНЫЕ НАГРУЗКИ: SEISMIC LOADS		
	−Z	±Z	Y	Z	±Z	±Y	±Z	±Y	−Z	±Y	±X
L1−L2	4900-4300	/	/	/	330-370	230-270	48-52	48-52	5000-5400	900-860	900-860
M1−M2	4900-4300	/	/	/	330-370	330-370	48-52	48-52	5000-5400	950-860	900-850
N1−N2	8310-8620	/	/	/	/	/	65-70	65-70	9900-10250	1670-1730	1670-1730
P1−P2	8310-8620	/	/	/	/	/	65-70	65-70	9900-10250	1670-1730	1670-1730
O1−O2	3330-3820	/	/	/	/	/	/	/	4050-3350	680-570	680-570
R1−R2	3330-3820	/	/	/	/	/	/	/	4050-3350	680-570	680-570
S1−S2	/	/	-5300/+5300	/	/	/	/	/	/	/	/
T1−T2	/	/	-5300/+5300	/	/	/	/	/	/	/	/
U1−U2	/	/	/	-5300/+5300	/	/	/	/	/	/	/

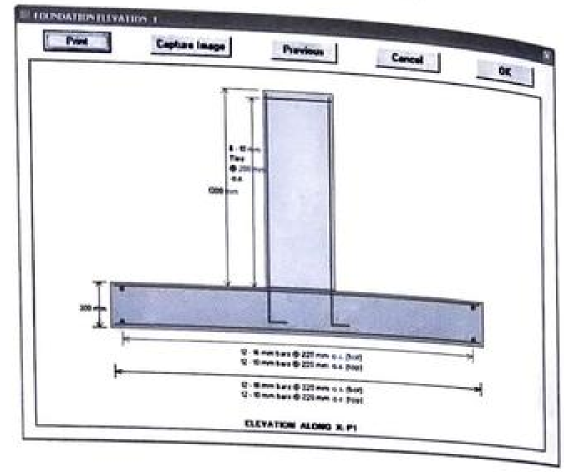




Section E-E
TYPICAL 12 PLACES FOR
CENTRIFUGAL COMPRESSOR BASEPLATE ANCHORAGE



The civil engineer designs the foundation using computer software.



Equipment foundations are sized to prevent Equipment from sliding or overturning while not exerting on the soil a pressure higher than its bearing capacity. Equipment static (dead, live, test) and dynamic loads, loads from external environment (wind, seismic action) are taken into account using combinations prescribed by the code. Stability formula given by the code must be satisfied, with the safety factor decided by the Project as part of the Civil Design Criteria, otherwise the foundation size needs to be increased.

Design bases and calculations results are recorded in the Foundation calculation note.

DESIGN CODE ACI 318 - 2002

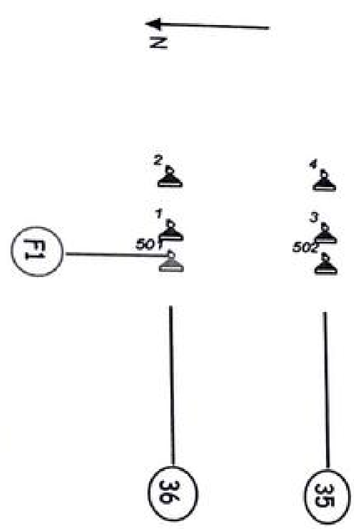
FOOTING DESIGN INFORMATION

CONCRETE PARAMETERS:		E-W Dim (mm)	2600.00
Compressive Strength (N/sq mm)	28.00	N-S Dim (mm)	2600.00
Unit Weight (kN/cu m)	24.00	Thickness (mm)	550.00
REINFORCING STEEL PARAMETERS:		Bottom Steel (Bot)	11 - 16 mm bars @ 225 mm o.c. (bot)
Yield Strength (N/sq mm)	420.00	Max Long Bar Size	20
Unit Weight (kN/cu m)	78.50	Min Long Bar Size	20
Modulus of Elasticity (kN/sq mm)	210.00	Max Tie Bar Size	10
		Min Tie Bar Size	10
SOIL PARAMETERS:		Max Ftg Bar Size	25
		Min Ftg Bar Size	12
Allowable Net Bearing Capacity (kN/sq r	350.00	Temp & Shrinkage Steel Ratio	0.0009
Unit Weight (kN/cu m)	18.00	**BUOYANCY CRITERIA:**	
MINIMUM FOUNDATION CRITERIA:		Consider Buoyancy:	No
Depth of Footing Below Grade (mm)	1450	Consider soil for buoyancy	No
Minimum Soil Cover (mm)	900.00	Water table below grade (	0
Grade Elevation (mm)	3000.00		

APPLIED LOADS

P8

Load Case	Axial (kN)	Shear E-W (kN)	Mom N-S (kN m)	Shear N-S (kN)	Mom E-W (kN m)
1 - Dead	63.99	-0.63	0.00	-3.65	0.00
2 - PDL	232.12	-4.64	0.00	-11.98	0.00
3 - POL	123.68	-6.98	0.00	-1.88	0.00
4 - TL	0.00	0.00	0.00	0.00	0.00
5 - PTL	0.00	0.00	0.00	0.00	0.00
6 - TF	166.61	-27.75	0.00	-34.21	0.00
7 - Wind_X	45.48	-0.90	0.00	-20.89	0.00



BEARING CAPACITY/STABILITY RATIO

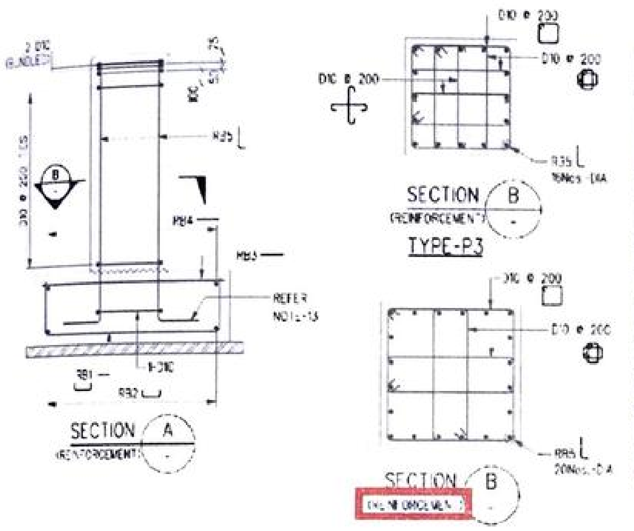
Load Comb	Max Pressure (kN/sq m)	All Pressure (kN/sq m)	S.R. N/S.	S.R. E/W	All S.R.	Rem
1 - Dead + PDL	84.97	376.09	25.83	76.61	2.00	
2 - Dead + PDL + PTL + BL	84.97	376.09	25.83	76.61	2.00	

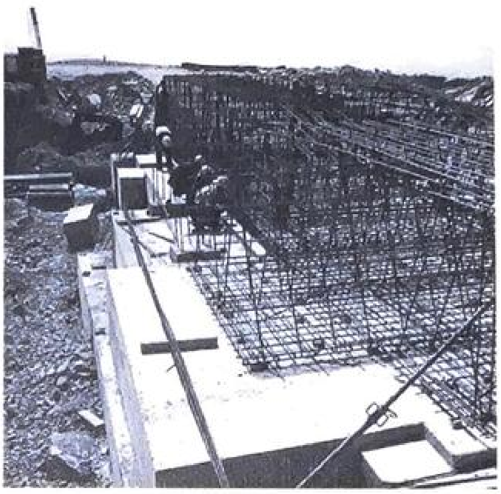
MAXIMUM SHEAR - E-W DIRECTION

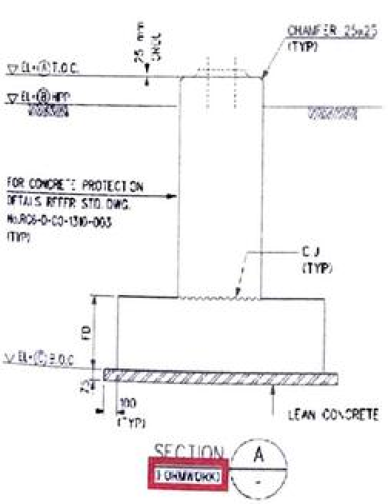
Load Comb	Left Dist (m)	Max Shear (kN)	Shear Stress (kN/sq m)	All Stress (kN/sq m)	Rem
1 - 0.9Dead + 0.9PDL + 0.45POL + 1.28Wind_X + 1.6BL	0.59	93.88	78.99	659.07	
2 - 0.9Dead + 0.9PDL + 0.45POL + -1.28Wind_X + 1.6BL	0.59	65.84	55.40	659.07	
3 - 0.9Dead + 0.9PDL + 0.45POL + 1.28Wind_Z + 1.6BL	0.59	158.35	133.24	659.07	

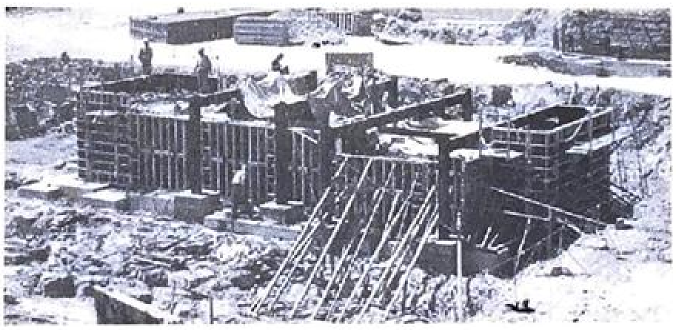
2 different type of construction drawings are issued for foundations, with associated Bill Of Quantities: the **Reinforcement drawings** and **Formwork drawings**. Also a pile layout and detail is needed for the pile foundations.

The position and elevation of the equipment are obtained from the Plant Layout discipline. Civil must also co-ordinate any other requirements, such as embedding sleeves for cables or pipes, with other disciplines.









Besides drawings, Civil issues **Civil works specifications**, for each trade, e.g., Site preparation, concrete works, roads, buildings, etc. which defines the materials to be used, how the work shall be done, the inspections and testing requirements, etc.

3 MATERIALS

3.1 Special requirements

3.1.1 Cement

Cement characteristics shall conform to BS 12, BS 146, BS 1370, BS 4027, BS 4246, BS 6588 or equivalent Russian code.
The type of cement to be used and the relevant strength shall be specified on the design drawings and/or in other contract documents.

3.1.2 Water

The water used for making concrete or cleaning out shuttering, curing concrete or similar purposes shall be taken from the mains supply wherever possible, and shall comply with the requirements of BS 3148: or equivalent Russian code. Where water is not available from the mains the Customer's approval shall be obtained before use.

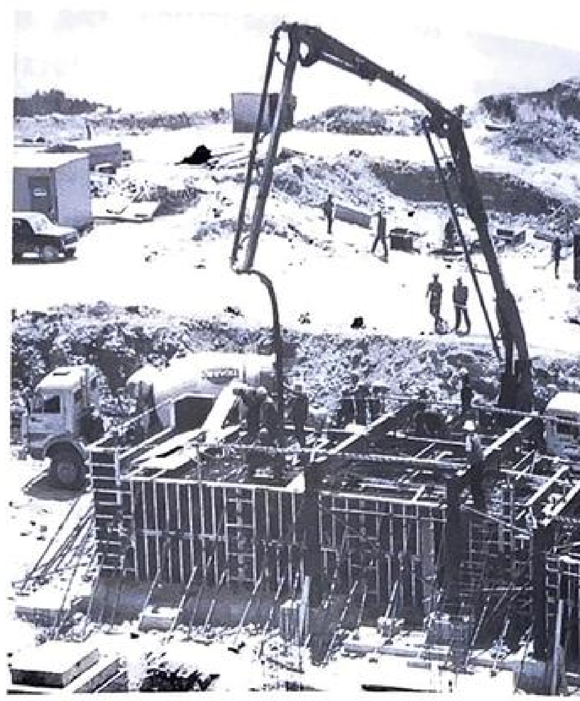
3.1.3 Sand (Fine aggregate)

Sand shall come from rivers, quarries, from natural sources or crushing of compact siliceous, quartz, granitic or calcareous rock. The sand shall be clean, free from silt and any other foreign matter that may affect the strength and/or the normal curing time of the concrete.
The grain size shall be well graded within the following range:

Sieve (BS 410)	% Passing (by mass)
10 mm	100
5 mm	95-100
2.36 mm	80-100
1.18 mm	50-85
600 µm	25-60
300 µm	10-30
150 µm	2-10

The content in fines (passing through a sieve of 75 µm) shall not exceed the following values:

- 3% by mass for natural sand
- 5% by mass for sand produced by crushing.



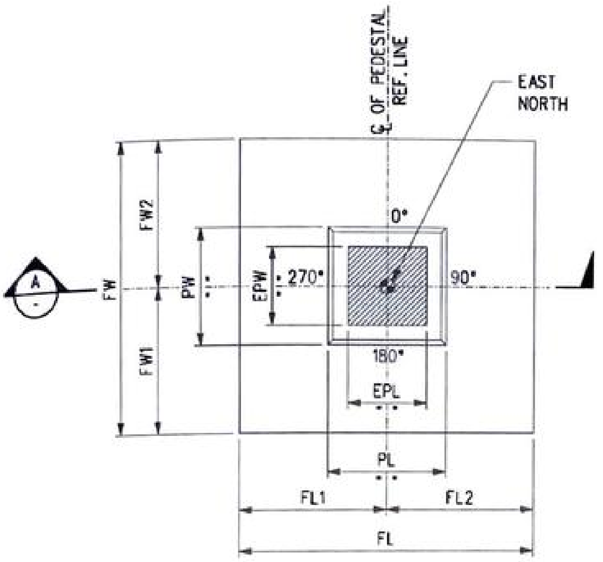
The range and number of Site works specifications vary according the requirements of the project and enterprise environmental factors. In some projects even the tile spec is prepared while in others the specs limited to some major items like earthworks, concrete and steel and other requirements are referred to standards and contractual obligations.

On the basis of the Site works specifications and the applicable codes and standards, **Inspection and Test Plans (ITP)** are prepared for each major Site activity. For concrete, for instance, tests and inspections are done before, during and after the concrete placement. The ITP specifies the required tests, the applicable codes, the acceptance criteria and the responsibilities of the parties (contractor, client). The objective of the ITP is to ensure that the required quality is achieved.

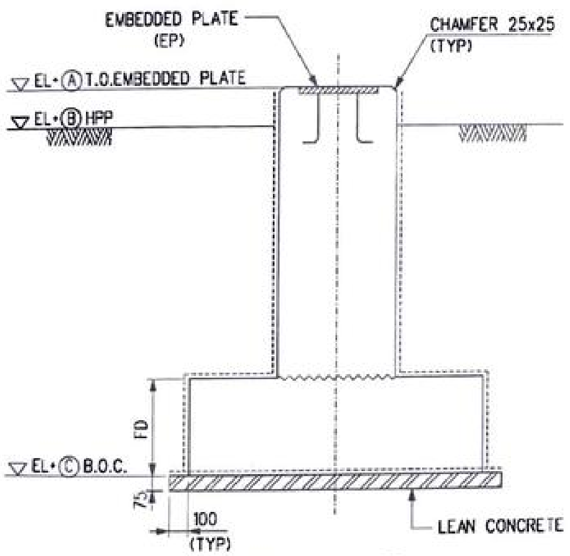
Pre-fabrication is done to the maximum possible extent in order to reduce installation time. Concrete indeed requires around 2 weeks to dry before it can be backfilled. For the case of a foundation cast in-situ for instance, the excavation, which occupies a large area, needs to remain open for those two weeks, which prevents other works to proceed in this area. Pre-fabrication of the foundation would avoid that and allow to backfill immediately after installation.

Small foundations, manholes, cable trenches are standardized.

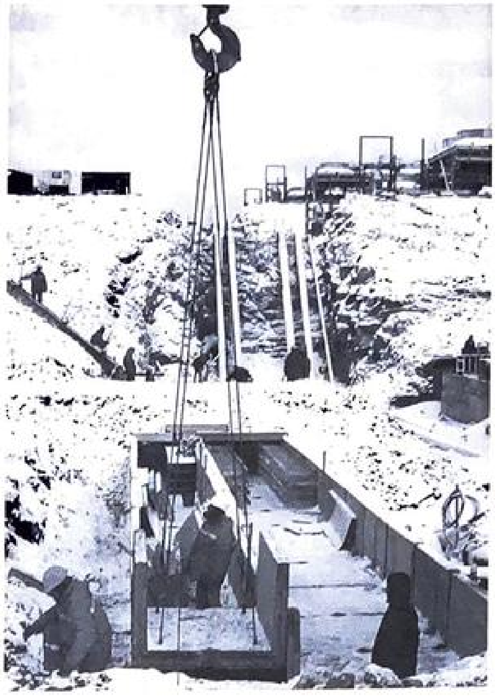
FOUNDATION TYPE-2



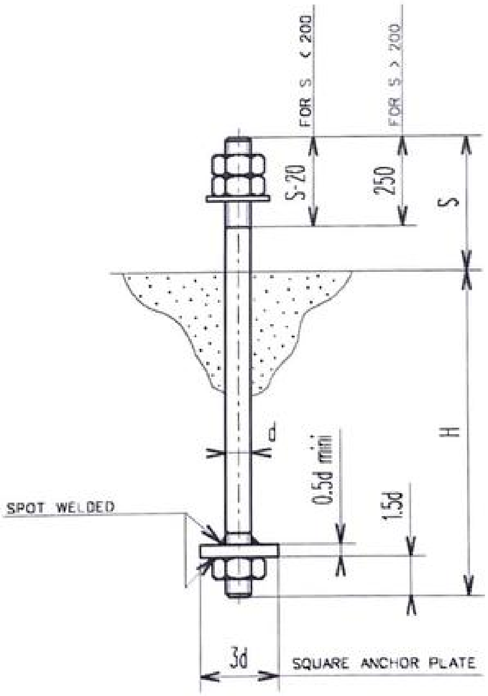
FOUNDATION PLAN



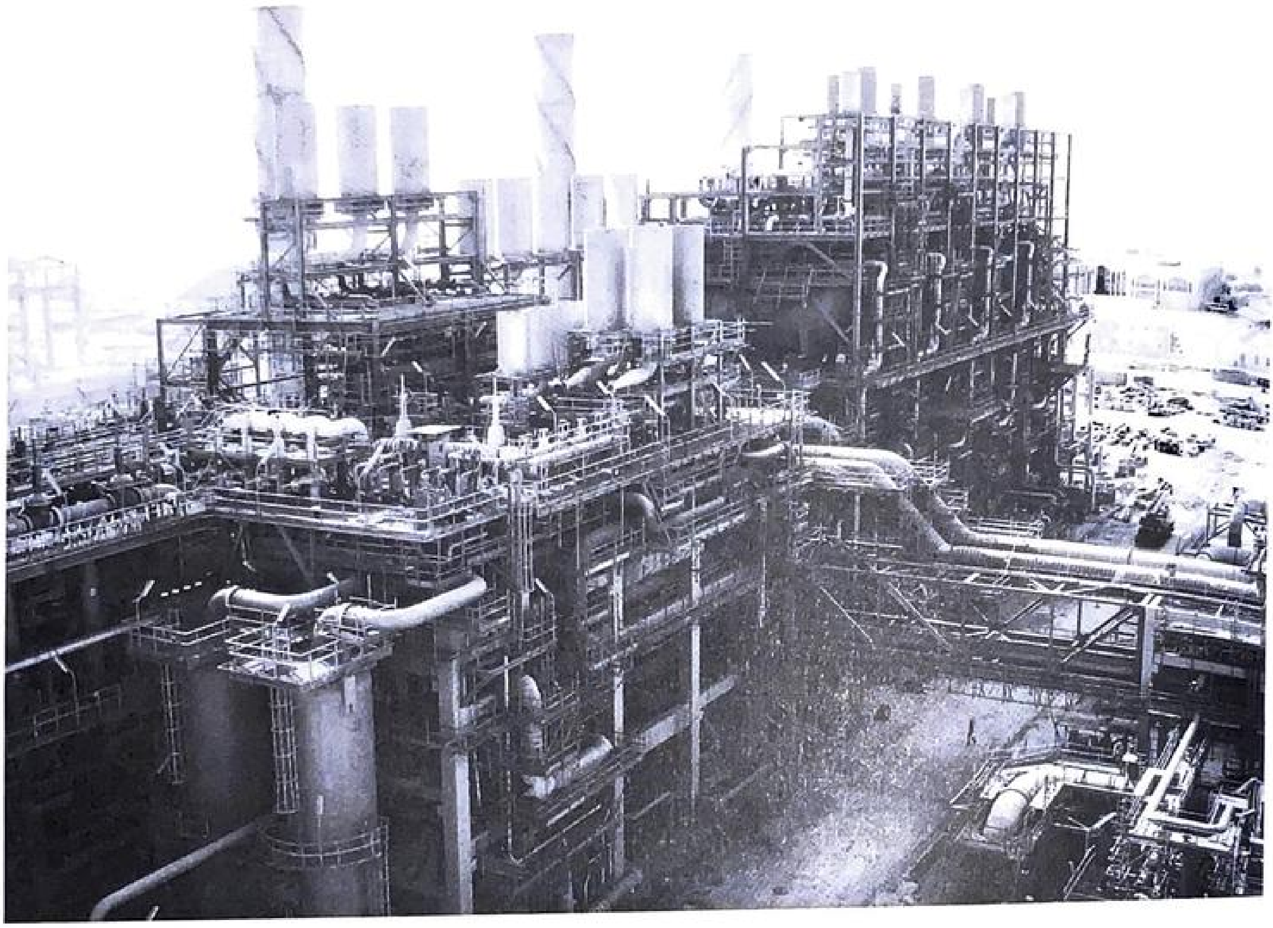
SECTION A
(FORMWORK)



The Concrete Standard Drawings show repetitive arrangements, such as that of anchor bolts, insert/levelling plates, etc., ensuring consistency of the design and construction.



Civil Engineering is also in charge of the design of steel and concrete structures supporting equipment and pipes.



The geometry of these structures, i.e., dimensions, number and elevation of levels, is defined by Plant Layout.

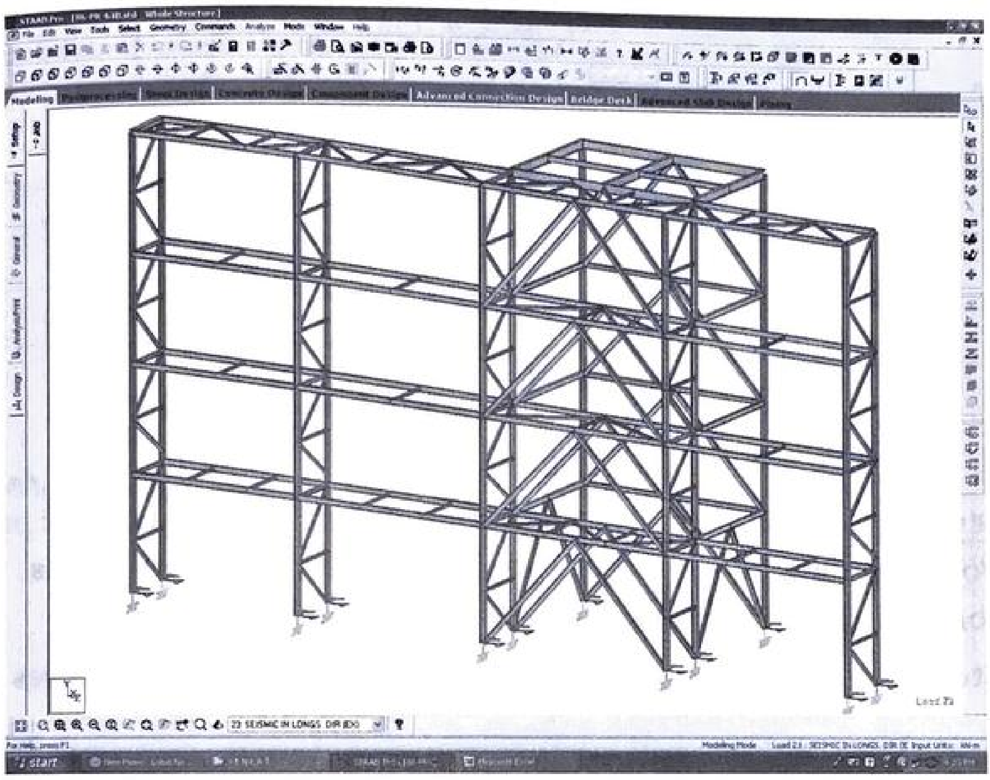
Inputs for the design of the structure include loads from equipment and piping, live loads, loads from wind and seismic action, if any.

Setting plan and loads of equipment are provided by vendors. Piping and valves support location and loads are provided by Piping. As piping routing is not finalized at the early stage at which structures must be designed to comply with the Project schedule, estimates are done and contingencies included.

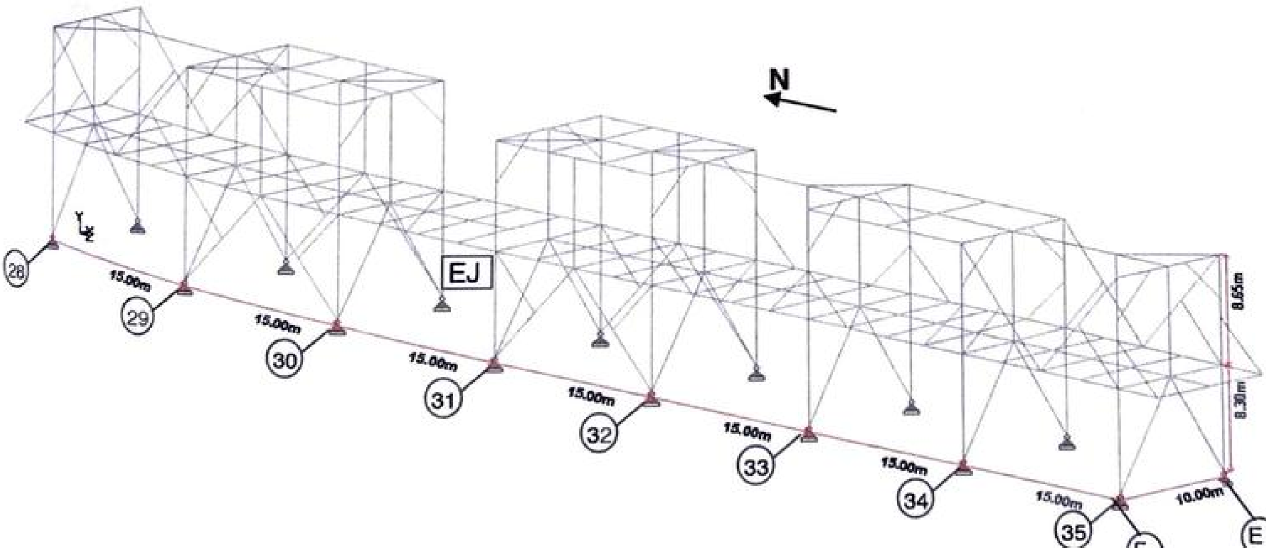
The structures are classified into two major types: steel structures and concrete structures. The selection between these two types are based on the construction schedule, differential cost between steel and concrete, function of structure, corrosion and maintenance, requirement for fire resistance, normal industry or Company practice.

The **steel structure design specification** must be issued by the Engineer and approved by the Client before the start of any design work. It states the design code that will be used, the loads and load combinations (wind, seismic, live loads) that will be considered, the grade of steel that will be used, and the maximum allowable deflection of structures.

The steel structure is modelled in the calculation software.



Loads are applied and the software calculates the stress in the various members for the various combinations of loads. The size of members is increased or additional members added until the criteria are met, i.e., deflection is less than the maximum allowed and stress in any member does not exceed the acceptable limit for the selected grade of steel.



The design basis and results extracted from the software are recorded in a Calculation Note.

Basic Design Data

Grade of Steel		= ASTM A36, BS EN 10025; 1993 Grade S275
Yield strength of steel	f_y	= 265 N/mm2 (RG6-S-00-1310-101, Clause 5.1(4))

Anchor Bolts

Anchor bolts grade		= ASTM A307
Allowable Tensile stress		= 138 N/mm^2
Allowable Shear stress		= 69 N/mm^2

Wind loads

Basic wind speed	V =	41 m/s
Exposure category	=	C
Importance factor	I =	1.0
Topographic factor	K_{zt} =	1.0

Seismic load

Seismic zone	=	1
Seismic zone factor	Z =	0.075
Soil profile type	=	S_b
Importance factor	I =	1.0

7 RESULTS AND CONCLUSION

Maximum lateral displacement of top-most tier at EL19.400m as obtained from "STAAD OUTPUT"

Elevation (m)	Node	Load case	Max. displace. in X- dir. (mm)	Max. displace. in Z-dir. (mm)	Ht. Above Base Pl. (H) (mm)	Allowable Deflection (H/200) (mm)	Ratio (Ht./Disp.)
19.4	96	913	35.68		16950	84.75	475.06
19.4	60	111		16.122	16950	84.75	1051.4

From above table, it is observed that lateral displacements are well within the allowable limit.

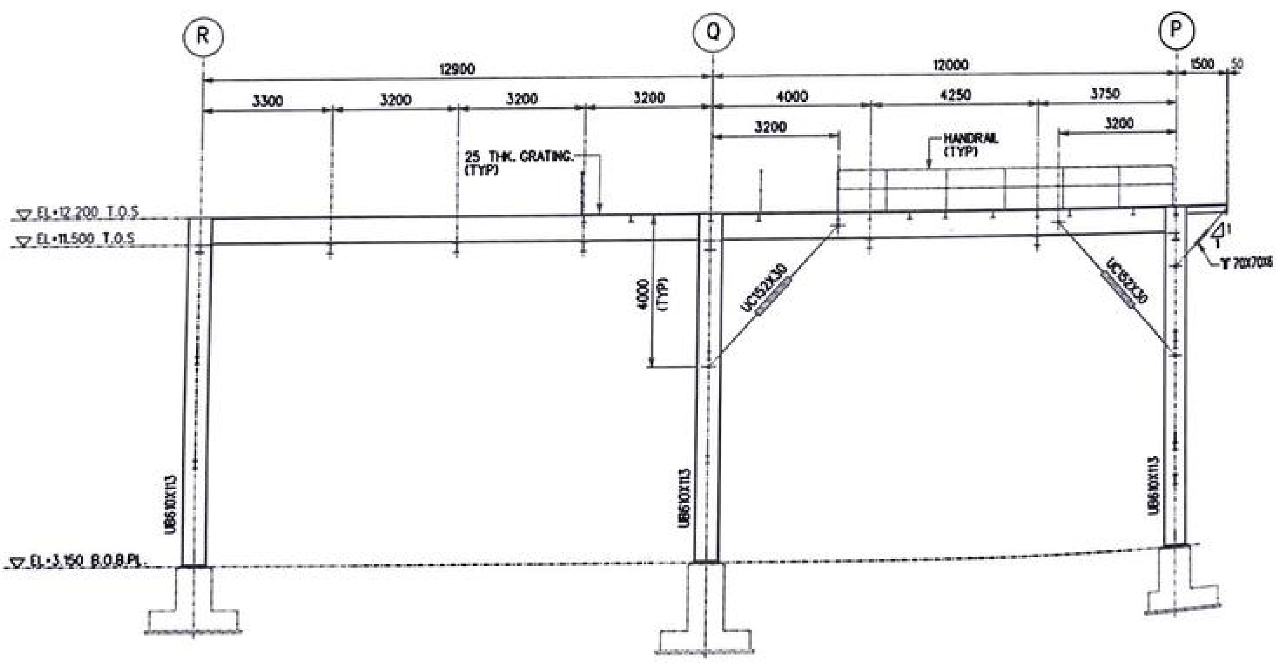
Maximum stress ratio as obtained from Staad Output is as follows

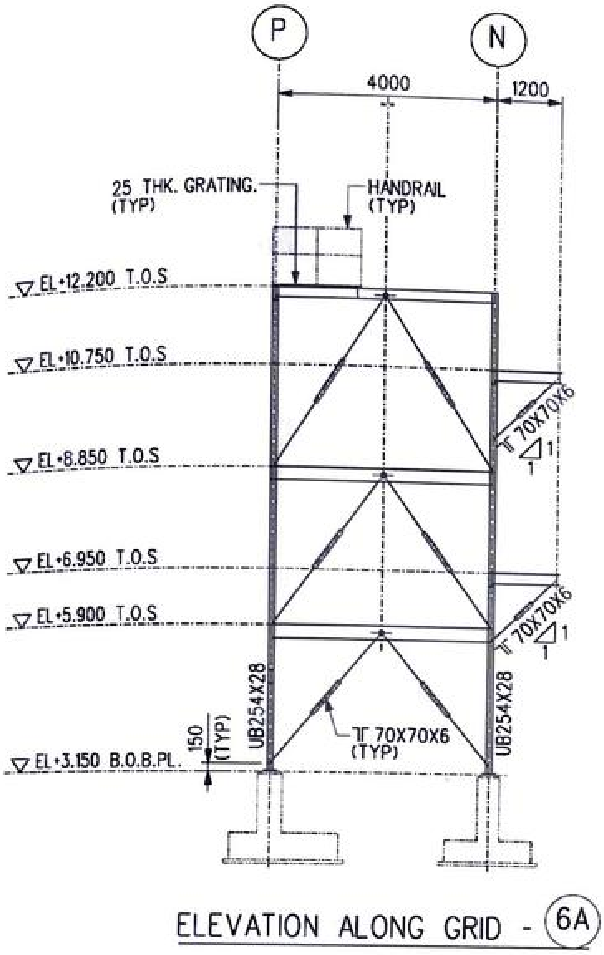
Description	Member	Max. Stress Ratio
GRID F - 29 to 30, 31 to 32	UB610X229X113	0.499
GRID E - 29 to 30, 31 to 32	UB914X305X253	0.882
GRID 33 to 34	UC254X254X73	0.415
PLAN BRACINGS AT EL 19.400	UC203X203X46	0.458
PLAN BRACINGS AT EL 19.400	2/UA90X90X8	0.538

STEEL Pipe Rack Structure 84-PR-65 is thus safe.

The calculation report extracted from the computer must include: printouts of model geometry, member sizes and properties, applied loads and load combinations, support reactions, member stresses and deflections:

Steel Structure Design Drawings are issued to the steel structures supplier.

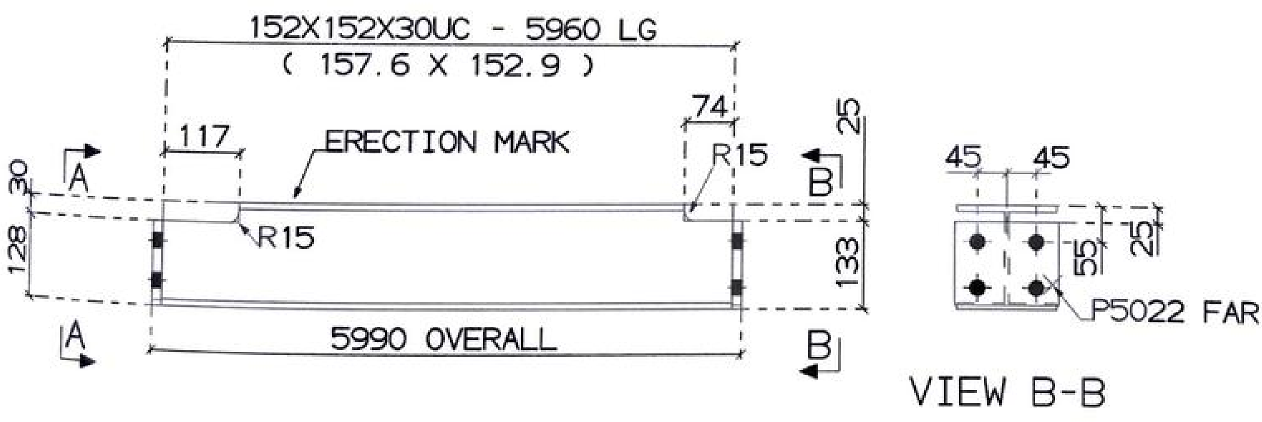




ELEVATION ALONG GRID - 6A

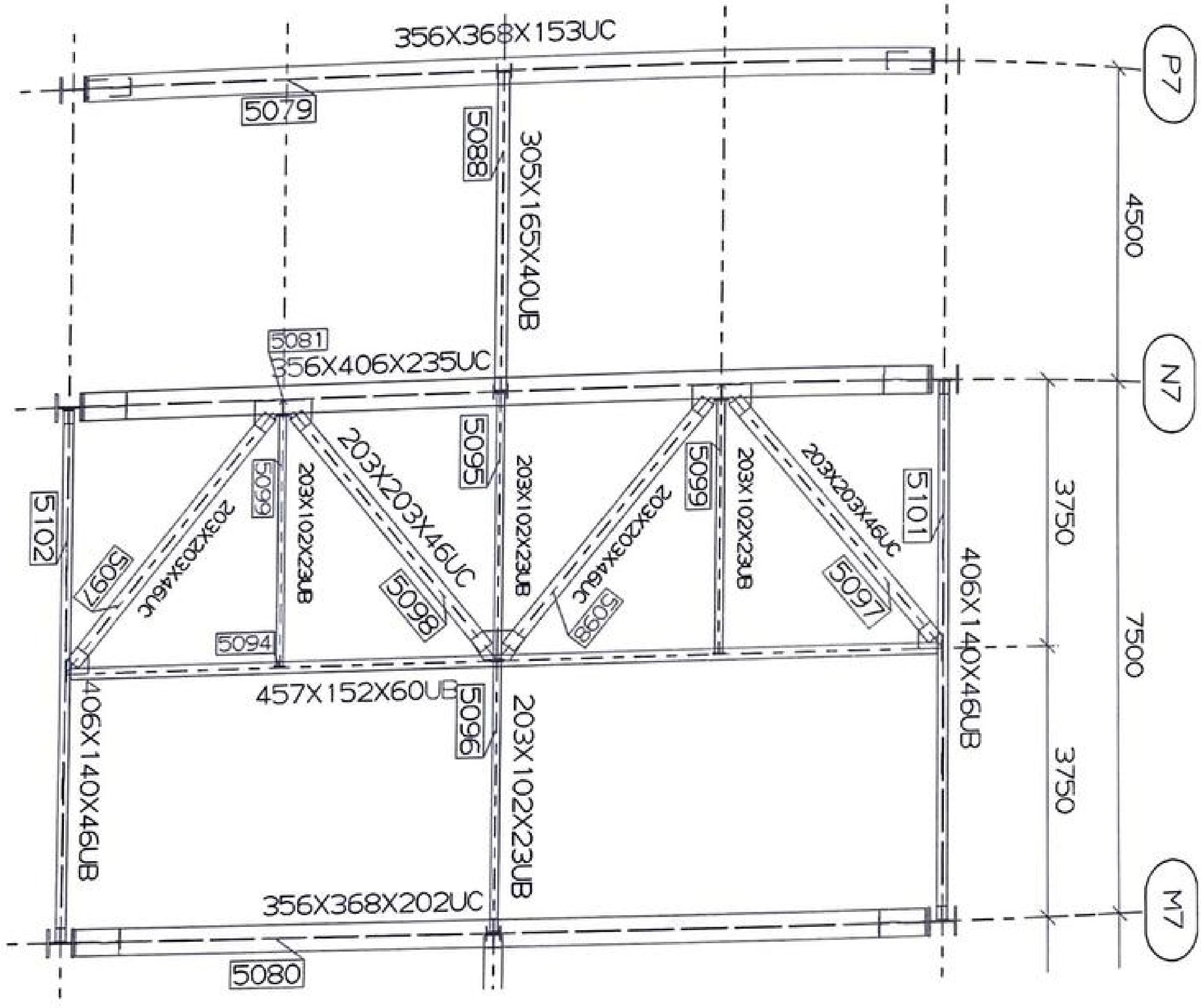
BILL OF QUANTITY				
ITEM No.	DESCRIPTION	D/M	UNIT	QUANTITY
A.3	PIPE RACKS [NON-FIREPROOFED]			
A.3.1	HEAVY (MORE THAN 75 kg/m)	M.1	Ton	10.71
A.3.2	MEDIUM (BETWEEN 30-75 kg/m)	M.1	Ton	14.17
A.3.3	LIGHT (LESS THAN 30 kg/m)	M.1	Ton	6.78
A.9	HANDRAILS	M.2	Ton	
A.10	LADDERS AND LADDER CAGES	M.2	Ton	
	TOTAL STEEL WORK		Ton	31.66

The steel structure manufacturer completes the design of the structure, in particular that of connections – on the basis of member end forces shown in the Engineer's calculation note – and issues **Shop Drawings** to its fabrication shop.



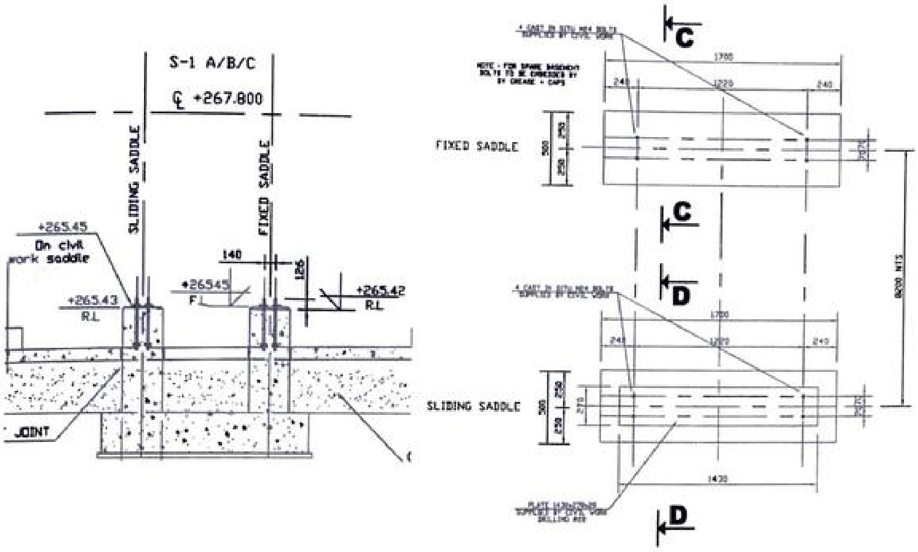
One shop drawing is produced for each structural member, showing all fabrication details, such as exact dimensions, position of gussets, positions and number of holes for bolts, etc. Manufacturing data is usually transferred automatically from the manufacturer design office to the numerical control fabrication machinery.

The manufacturer issues the **Erection Drawings**, which show the overall view of the structure, together with the arrangement of the various steel members, identified by their piece marks. Identification is critical. A given steel structure may come in as many as one thousand pieces, reaching the Site by several truck loads, stored in very extended lay down areas.



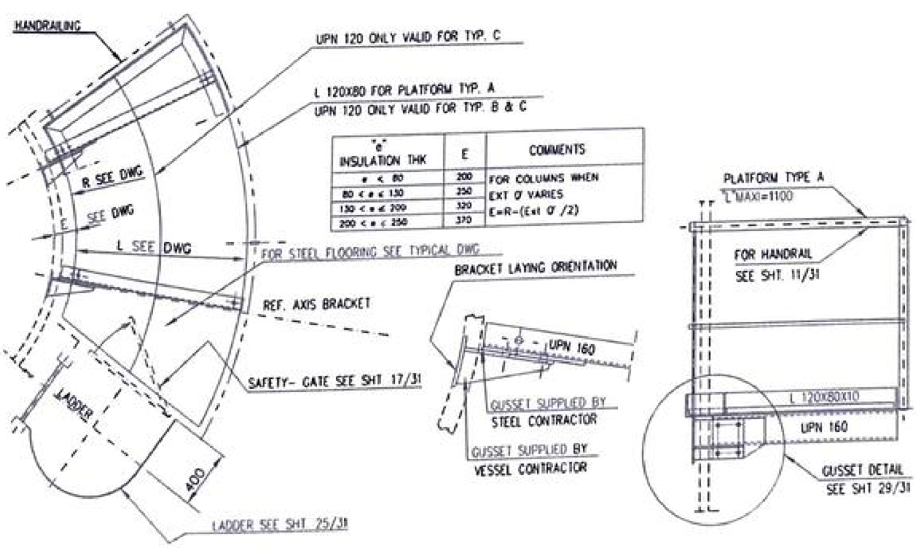
For concrete structure, the process is generally the same. The design entails the definition of the members (beams and columns) dimensions and required re-inforcement (rebars). The calculations are done using an analytical software model considering geometry of structure, internal and external loads, concrete strength (which is selected by design based on concrete specification), rebar steel grade.

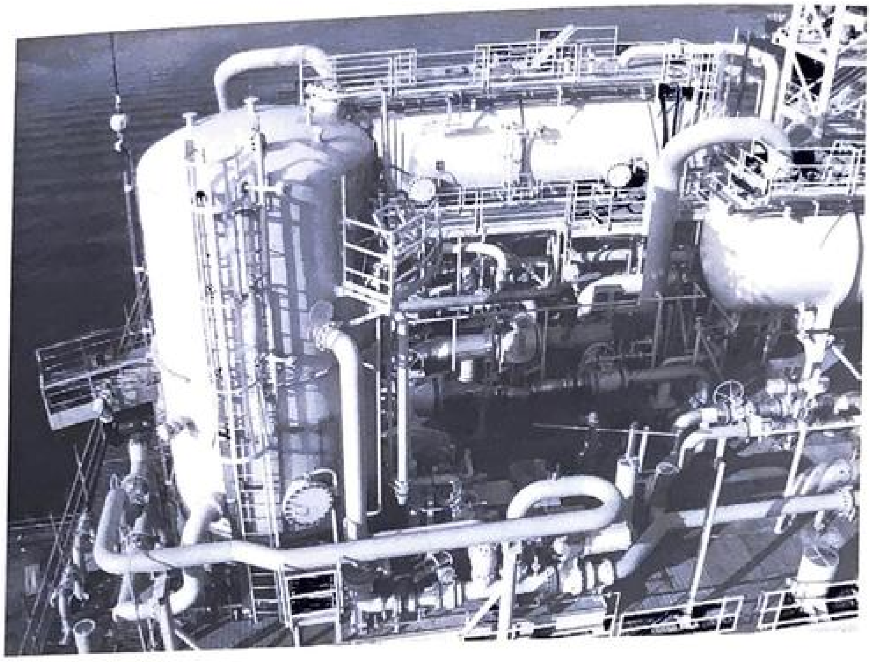
The Civil design described above shall, in many countries, comply with local codes. The Engineer may not be familiar with these codes. It is common, in such cases, for the Engineer to sub-contract the civil design to a local company. The Engineer then only produces **Guide Drawings**, showing dimensions, equipment setting plan and loads. The design, calculations and construction drawings are left to a local civil engineering sub-contractor.

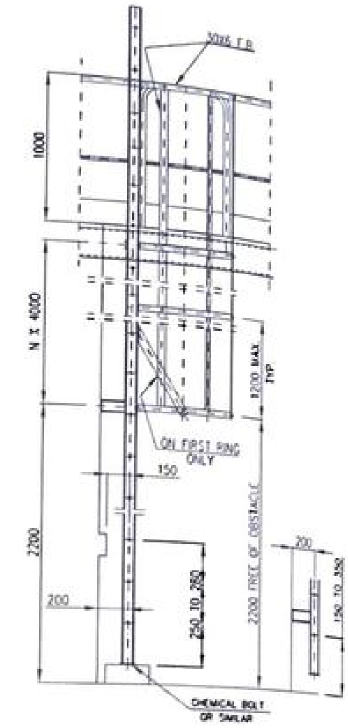


			Opération		Loads(hydrotest)		Empty loads	
			Anchor	Sliding	Anchor	Sliding	Anchor	Sliding
S1A	Fx	→		±3 300		±3 750		±3 000
	Fy	↓	-10 000	-10 000	-12 500	-12 500	-9 000	-9 000
	Fz	→						
	Mx	↷						
	My	↷						
	Mz	↷						

Civil designs small platforms for operator access (to equipment, instrument, valves, etc.) as instructed by Piping. They are designed according to **Standard drawings**.

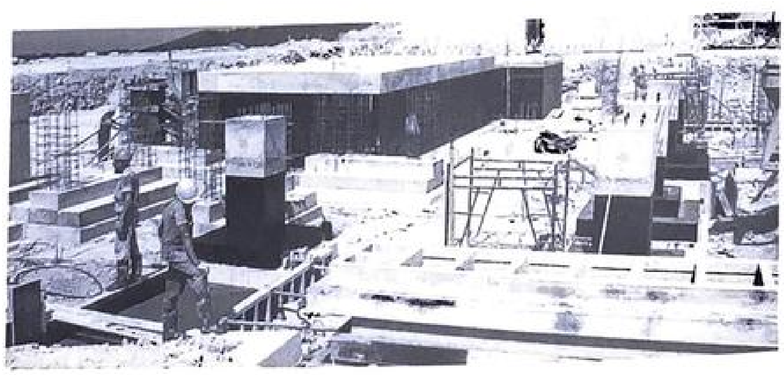




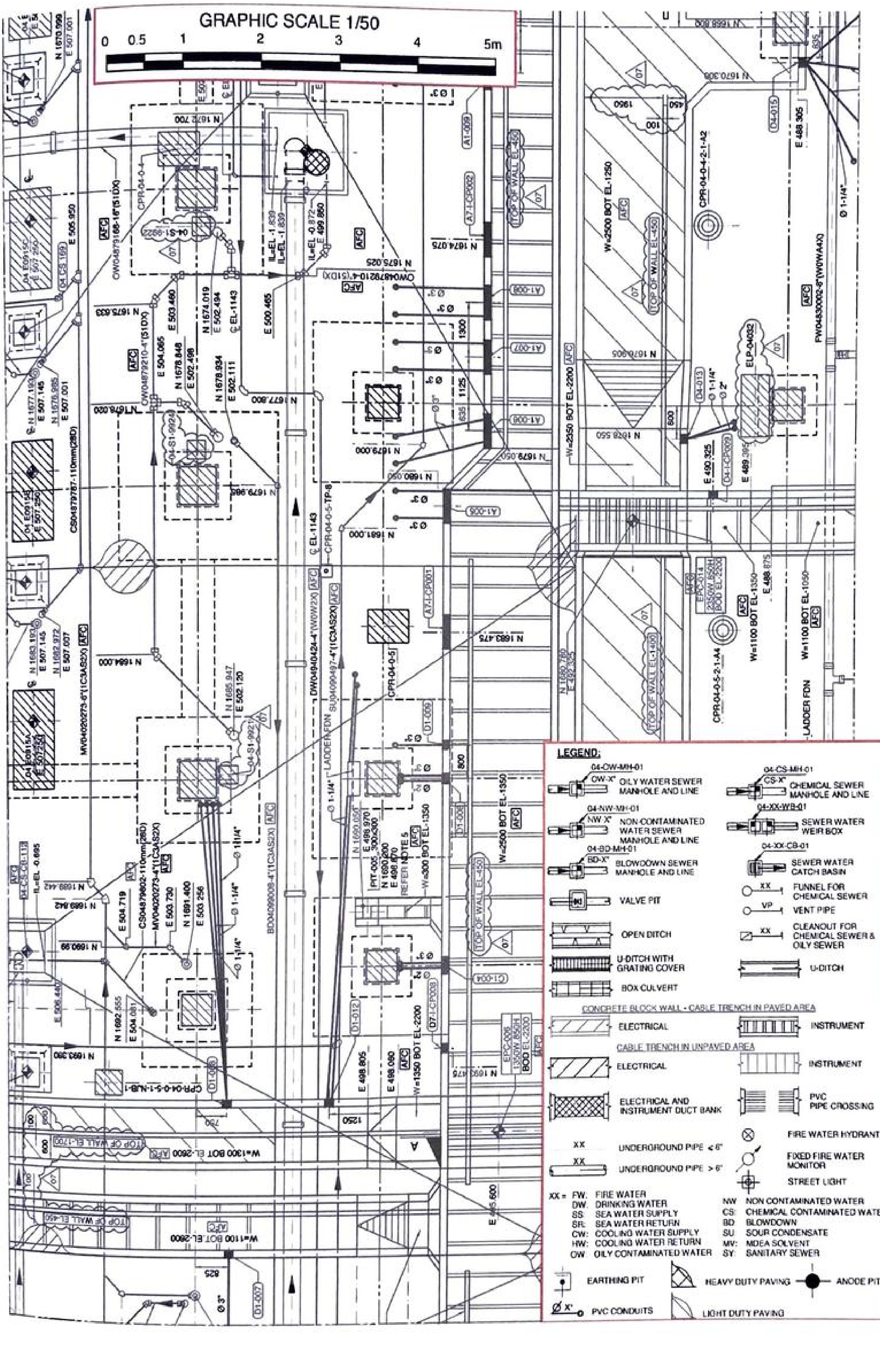


Drawings are then issued for each such platform, staircase, etc. based on this standard.

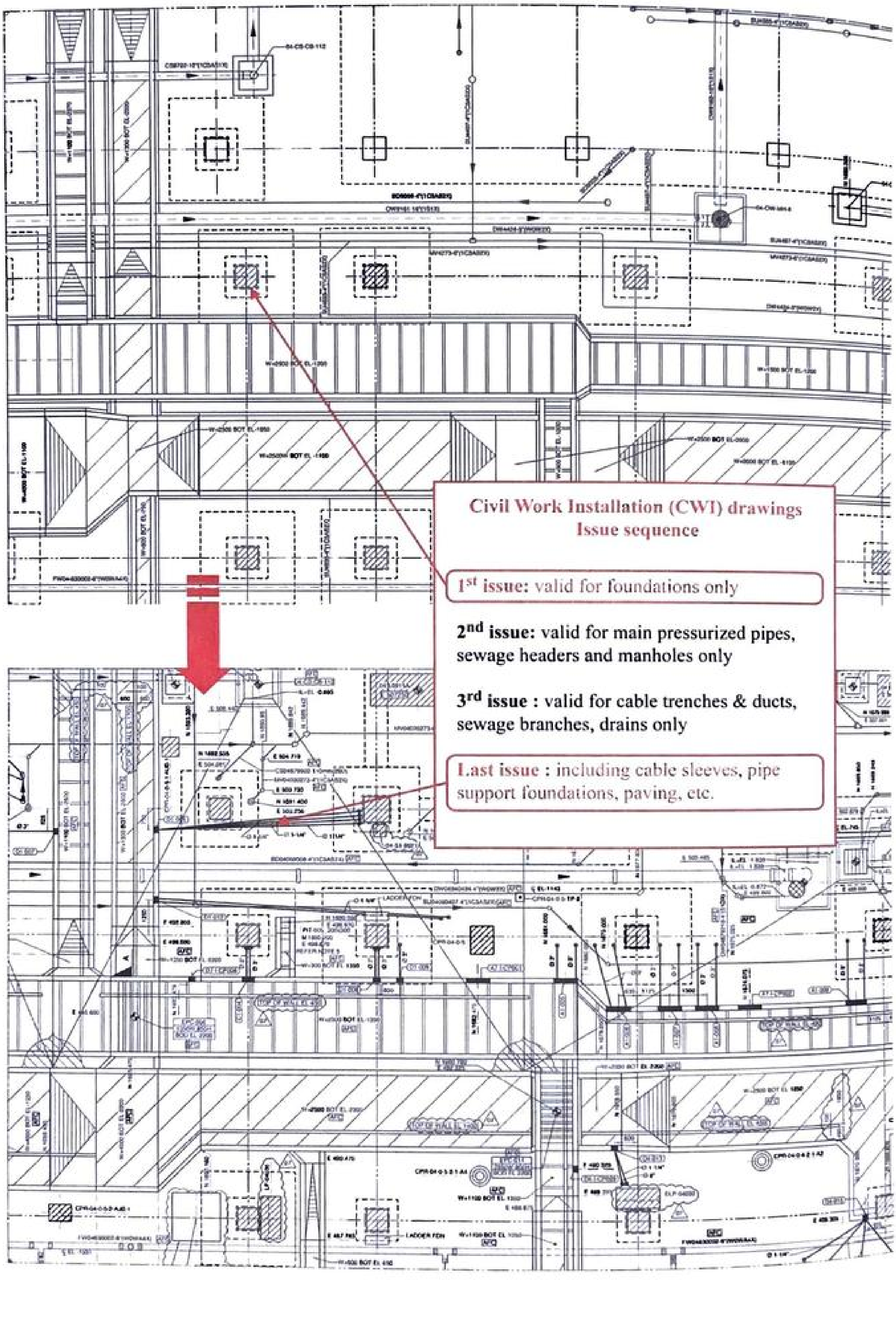
The Civil Engineer's responsibilities include all underground installations: equipment foundations, process and utility pipes, drains, rain water collection pipes and catch basins, fire water network, cable trenches, duct banks, cable sleeves, pits for underground equipment and valves, roads, ditch, paving, etc.



The General Underground Networks (GUN) drawing, also called the Underground composite drawing, shows, for the entire Plant area, the location of all underground constructions and systems.


GRAPHIC SCALE 1/50
0 0.5 1 2 3 4 5m
LEGEND:
04-CW-MH-01
OILY WATER SEWER MANHOLE AND LINE
04-CS-MH-01
CHEMICAL SEWER MANHOLE AND LINE
04-NW-MH-01
NON-CONTAMINATED WATER SEWER MANHOLE AND LINE
04-XX-WB-01
SEWER WATER WEIR BOX
04-BD-MH-01
BLOWDOWN SEWER MANHOLE AND LINE
04-XX-CB-01
SEWER WATER CATCH BASIN
VALVE PIT
FUNNEL FOR CHEMICAL SEWER
VENT PIPE
OPEN DITCH
CLEANOUT FOR CHEMICAL SEWER & OILY SEWER
U-DITCH WITH GRATING COVER
U-DITCH
BOX CULVERT
CONCRETE BLOCK WALL - CABLE TRENCH IN PAVED AREA
ELECTRICAL
INSTRUMENT
CABLE TRENCH IN UNPAVED AREA
ELECTRICAL
INSTRUMENT
ELECTRICAL AND INSTRUMENT DUCT BANK
PVC PIPE CROSSING
FIRE WATER HYDRANT
UNDERGROUND PIPE < 6"
FIXED FIRE WATER MONITOR
UNDERGROUND PIPE > 6"
STREET LIGHT
XX = FW: FIRE WATER
DW: DRINKING WATER
SS: SEA WATER SUPPLY
SR: SEA WATER RETURN
CW: COOLING WATER SUPPLY
HW: COOLING WATER RETURN
OW: OILY CONTAMINATED WATER
NW: NON CONTAMINATED WATER
CS: CHEMICAL CONTAMINATED WATER
BD: BLOWDOWN
SU: SOUR CONDENSATE
MV: MDEA SOLVENT
SY: SANITARY SEWER
EARTHING PIT
HEAVY DUTY PAVING
ANODE PIT
PVC CONDUITS
LIGHT DUTY PAVING

Civil Works Installation (CWI) drawings are issued several times according to the sequence of Site works. Each revision shows all the undergrounds but specifies that only a few are finalized and good for construction (IFC).



Timely issue of CWI drawings with all information is a co-ordination challenge. These drawings must indeed be issued at an early stage, as explained in the Schedule Chapter, and require information from several disciplines. For some of these disciplines, the underground systems are the last priority, for instance for Process whose underground systems are the drains. Electrical and Instrument cables must have been routed up to their terminal points for E&I to be able to advise Civil the number and positions of cable sleeves to install under the paving.

In order to inquire and contract construction activities Civil prepares the **Bill Of Quantities (BOQ)** showing the types and volumes of Civil works.

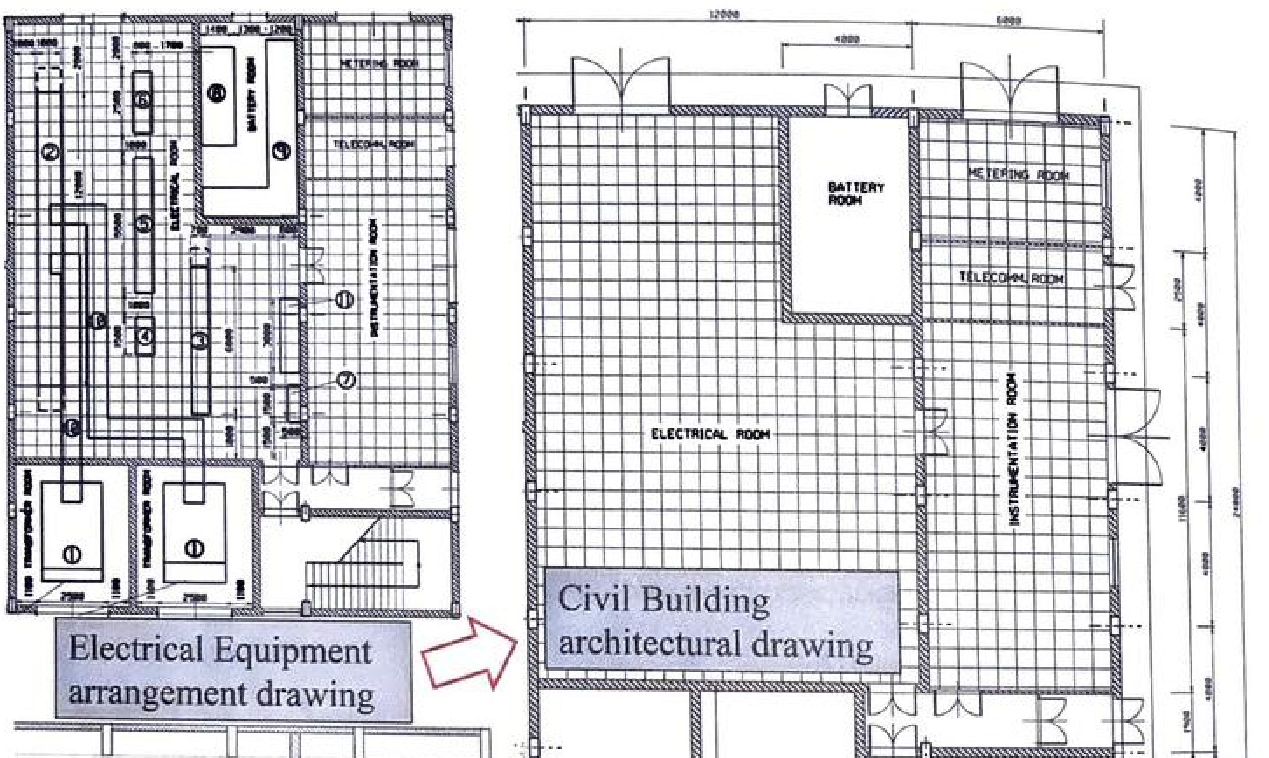
EARTHWORKS, TANK PAD, DIKES AND DITCHES		
General **Earthworks**	unit	qty
General excavation by machine		
General excavation by machine in loose or compact soil	cum	23 191
General excavation by machine in soft rock	cum	0
General excavation by machine in hard rock	cum	0
CONCRETE WORKS		
Supply and installation of deformed steel bars for concrete reinforcement		
Vertical equipment foundation	kg	56 801
Horizontal equipment foundation	kg	24 423
Pumps, compressors on pedestal, packages & skid foundation	kg	63 757
Ring wall foundation	kg	47 404
Raft foundations with concrete columns	kg	63 881
Foundation concrete		
Lean concrete		
Lean concrete 50 mm thickness	sqm	4 635
Lean concrete 75 mm thickness	sqm	0
Lean concrete 100 mm thickness	sqm	0
Foundation concrete		
Vertical equipment foundation	cum	632
Horizontal equipment foundation	cum	76
Pumps, compressors on pedestal, packages & skid foundation	cum	751

For the case of an EPC Project where Construction starts much before Engineering is completed estimates must be done by the Civil Engineer to complement the **Material Take-Off (MTO)** made from available drawings.

It is essential for the construction contractor to get accurate estimates of work volumes, for each type of work, in order to mobilize the right quantity of resources and equipment.

The design of buildings also falls within the scope of the Civil engineer.

The **Architectural Drawing** summarizes the requirements for the building, which come from the concerned discipline. For an Electrical sub-station, these requirements include the number and size of rooms, false floor for cable routing, floor/wall openings for cable entry, etc.



ROOM DESIGNATION	FLOOR FINISHING				WALL FINISHING			CEILING FINISHING	
	F1	F2	F3	F4	W1	W2	W3	C1	C2
METERING ROOM				X	X				X
TRANSFORMER ROOM	X						X	X	
INSTRUMENTATION ROOM				X	X				X
ELECTRICAL ROOM				X	X				X
BATTERY ROOM			X		X			X	

The building detailed design, which entails the production of numerous detailed drawings, bill of materials, etc., in all trades.

Discip.	Deliverable
PLUMBING	water and sewage pipe sizing
	water and sewage pipes layout
SAFETY	fire alarm logic diagram
	fire detection and alarm devices layout
	fire fighting calculations
	fire fighting equipment layout
STRUCTURAL	bill of material for concrete re-inforcement
	details drawings
	floor drawings
	foundation drawings
	structural design calculation note
TELECOM	public address and general alarm devices layout
	telecom equiment layout

Discip.	Deliverable
ARCHITECTURAL	doors and finishing schedules
	elevation views
	plan views
	section views
ELECTRICAL	cable sizing and schedule
	distribution board schedule
	distribution diagram
	grounding layout drawing
	illumination calculation note
	lighting equipment layout drawing
	socket layout drawing
HVAC	control logic diagram
	ductwork sizing
	equipment and ducts layour drawings
	equipment list
	equipment sizing
	air flow diagram

Building detail design is usually sub-contracted to the building construction contractor.

The **Heating, Ventilation and Air Conditioning (HVAC)** system is also part of the building design. The HVAC system is designed to provide the required climate inside the building/rooms.

Examples of climate control requirements are:

- Forced ventilation for mechanical equipment generating heat,
- Ventilation (heat evacuation) and air-conditioning (humidity control) in Electrical and Instrument equipment rooms,
- Overpressure maintenance in Electrical and Instrumentation buildings located inside process units (to prevent dust/flammable gas from entering the building),
- Heating (winter) & air-conditioning (summer) for permanently manned rooms,

The design of the HVAC system depends on the above requirements, the environmental conditions (min/max temperature, humidity) at the Plant location and the heat emissions from equipment, cables, etc.

Climatic Data

Warm season

Design Temperature for Ventilation Systems	+ 26.2 °C
Design Temperature for Air Conditioning Systems	+ 30.8 °C
Absolute Maximum Temperature	+ 41.0 °C
Specific Enthalpy for Air Conditioning System Design	+ 66.8 kJ/kg
Relative Humidity	60 %

Internal Design Condition

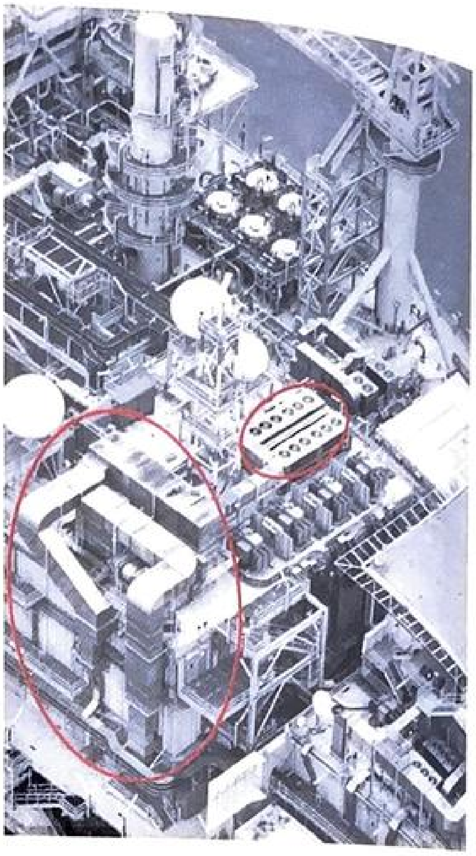
Warm season

Rooms with permanent working personnel	+ 24 °C

For Technological Control Rooms the following optimal rates shall be maintained round a year:

Temperature	22 ± 2 °C
Relative Humidity	50 ± 10 %

ESTIMATED HEAT EMISSION FROM EQUIPMENT (W/m^2 OF FLOOR AREA)	
CONTROL ROOMS	350
OFFICES, LABORATORIES, CLINIC	-
ELECTRICAL SWITCH ROOMS	50
KITCHENS	250
DINING AREAS	50
MAINTENANCE AREAS	15



Chapter 8

Materials & Corrosion

Materials & Corrosion discipline specifies materials to suit the various services. It also specifies how these materials will be protected against internal (from fluid) and external (atmospheric) corrosion.

Material selection is done on the basis of required material strength (ability to withstand pressure), adequacy with fluid temperature and resistance to corrosion from the carried fluid.

The most common material encountered is carbon steel, which is cheap and widely available. It comes in different grades. High strength grades are used for high pressure service, to reduce wall thickness. For very low temperature, such as depressurization lines and cryogenic service, alloy steels, such as stainless steel, are required.

STEEL TEMPERATURE RANGE Based on ASME B31.3 edition 2004

- 254°C	- 198	- 101	- 73	- 46	- 40	- 29	37,8	343	371	427	538	593	650	732	816°C
- 425°F	- 325	- 150	- 100	- 50	- 40	- 20	100	650	700	800	1000	1100	1200	1350	1500°F
SS	**9 Ni**		**3.5 Ni**	**LTCS**			**CS**				**Cr-Mo**			**SS**	

SS = Stainless Steel, LTCS = Low Temperature Carbon Steel, CS = Carbon Steel.

Materials are selected on the basis of the calculated corrosion rate.

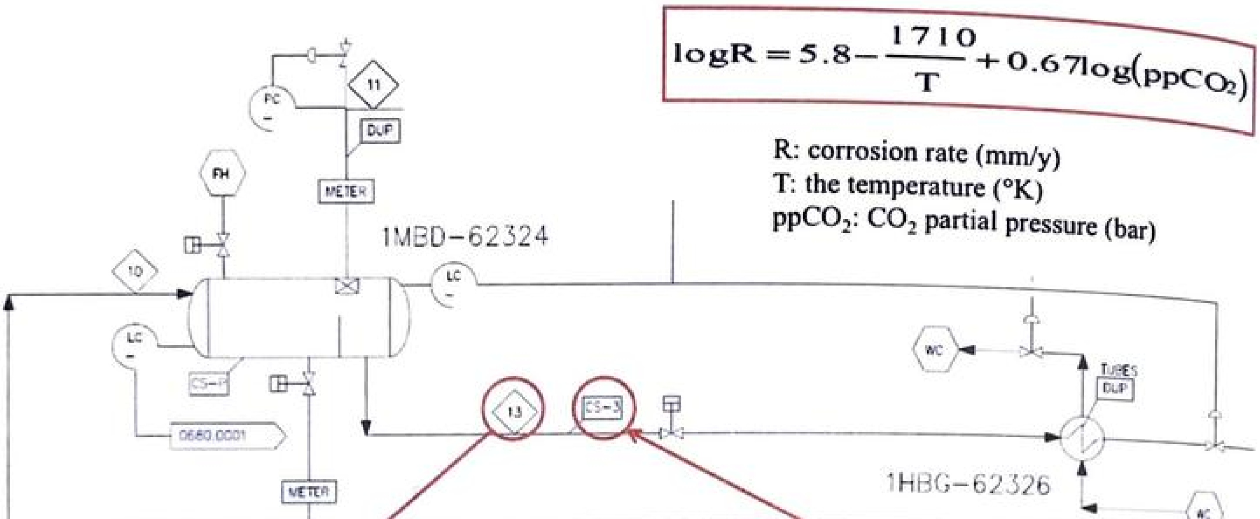
Steel pipes handling well stream effluent in oil and gas production facilities, for instance, are subject to corrosion by acid water. Indeed, the effluent from the wells contains a mixture of oil, water and gas. Gas contains CO_2, which makes the water acid. Acid water corrodes steel.

The total corrosion rate, i.e., loss of wall thickness, over the design life of the facility is calculated, based on the CO_2 partial pressure, fluid temperature, etc.

If such loss is only a few mm, then ordinary carbon steel "CS" is selected, with an increased thickness, called a corrosion allowance "CA", typically up to 6mm only.

$$\boxed{\log R = 5.8 - \frac{1710}{T} + 0.67\log(ppCO_2)}$$

R: corrosion rate (mm/y)
T: the temperature (°K)
$ppCO_2$: CO_2 partial pressure (bar)



Stream No.	Press (Barg)	Mole CO2	Temp (C)	R (mm/y)	Correction factor	Corrected corrosion rate	Material + CA (mm)
10	36.5	0.0035	93	3.25	0.02	0.06mm/yr	CS+3
22	36.5	0.0086	93	5.93	0.48	3mm/yr	Duplex SS
12	36.5	0.0001	93	0.31	0.20	0.06mm/yr	CS+3
13	36.5	0.0009	93	1.31	0.02	0.02mm/yr	CS+3
14	3.5	0.0009	66	0.07	0.85	0.06mm/yr	CS+3

If the wall thickness loss is too high, a corrosion resistant alloy steel must be selected, such as stainless steel.

In some cases, it is possible to inhibit corrosion by injecting a chemical, called corrosion inhibitor, to decrease the corrosion rate. In such case the pipes can remain in carbon steel but adequate corrosion monitoring, for instance by means of weight loss coupons and corrosion probes, must be put in place to ensure inhibition is effective.

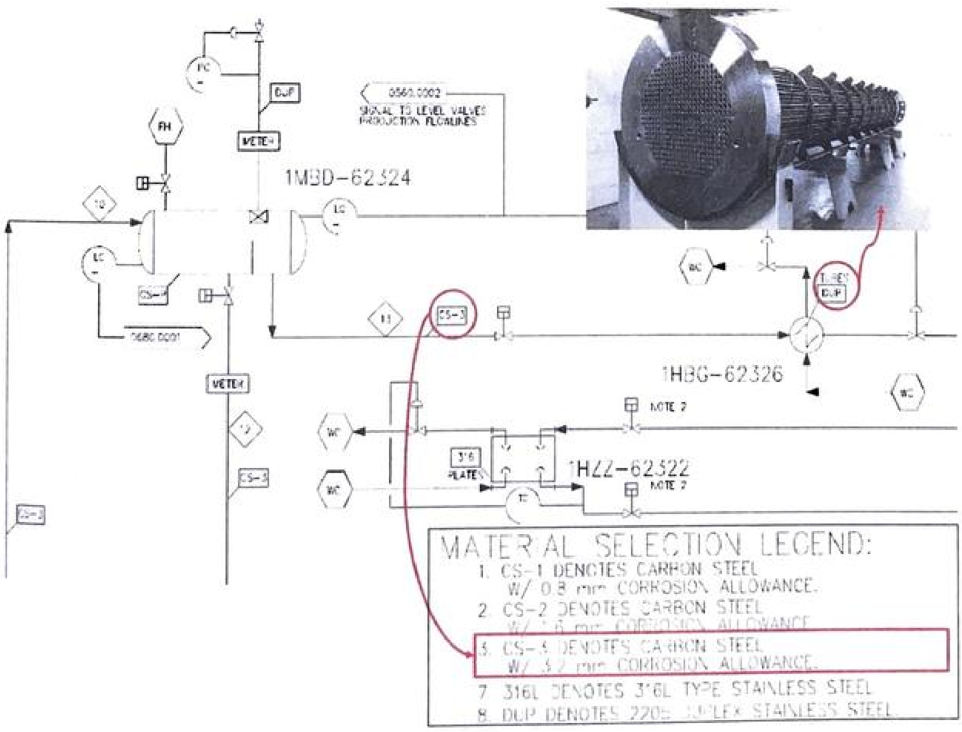
The selection of materials is done for each line and each equipment as conditions may be different. The method used and the results obtained are shown in the **Material Selection and Corrosion Control Report**.

This document consists of 2 parts.

- The first part gives the list of the corrosion phenomena and the basis used for calculating the corrosion rates: formula used, empirical corrosion rate given in publications, e.g., API RP 581, etc.
- The second part gives the corrosion rates and selected material for each line and equipment. Material selection for rotating equipment such as pumps makes reference to classes of materials for the various parts (casing, impeller, shaft, bearing, etc.).

Equipment	Operating Conditions	Composition	Corrosion Assessment	Material Selection
V-001 Rich Amine Surge Drum	T = 65°C P = 1barg	Rich amine	Risk of H2S-related cracking Risk of ASCC	*Shell & Head*: KCS severe wet H2S service + PWHT + 6mm CA *Internals*: SS 316L
P-001 A/B Rich Amine Pump	T= 65°C P = 6barg	Rich Amine	Risk of H2S-related cracking Risk of ASCC Erosion-corrosion	*Casing*: SS 316L *Impeller*: SS 316L API A-8

The results are also shown on the **Material Selection Diagrams**, which use the Process Flow Diagram as background.

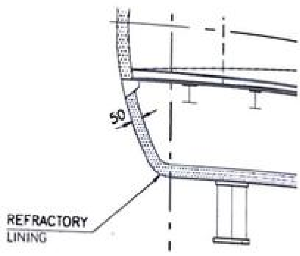


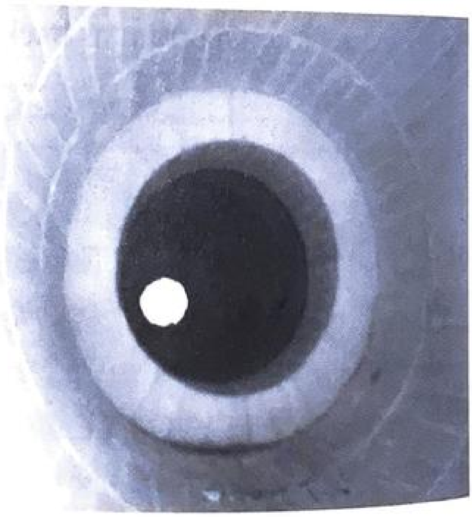
Specific requirements must be applied to materials in wet H_2S environment, called **Sour service**, to resist hydrogen induced cracking. The presence of H_2S in aqueous solution causes the steel to absorb a large amount of hydrogen. The steel is subject to cracking, called Sulfide Stress Cracking (SCC), above a critical concentration of hydrogen absorbed. The loss of containment that could result from this cracking causes a particularly severe hazard as H_2S is fatal in minutes.

A service is considered sour in presence of liquid water and above a certain, very small, H_2S concentration. Specific requirements shall be applied to piping and equipment in sour service: chemical composition, maximum hardness requiring Post Weld Heat Treatment (PWHT) of welds etc. The Equipment and lines in sour service are identified in the Material Corrosion Report.

Cracking is not, like corrosion, a phenomenon that develops over time. Hence sour service requirements shall be applied to materials even if they are only subject to sour service during upset conditions.

Steel strength rapidly decreases with increasing temperature. Vessels operating at high temperature, such as furnaces and reactors, are internally lined with **refractory**. The refractory reduces the temperature from the temperature inside the vessel, which could be higher than 1000°C in a furnace, down to a temperature (400°C) that allows the vessel shell to be in ordinary steel.





The refractory may be concrete, cast on the vessel wall and held by means of anchors, or, for heavier duties, refractory bricks (as shown on the picture here).

Many materials have the same visual appearance. In order to avoid confusion and prevent using the wrong type of material during construction, which could have catastrophic consequences, marking and inspection of materials are put in place.

Positive Material Identification (PMI) is done for alloy steels. PMI determines the chemical composition and allows to differentiate alloys.

DAILY POSITIVE MATERIAL IDENTIFICATION REPORT FOR PIPING

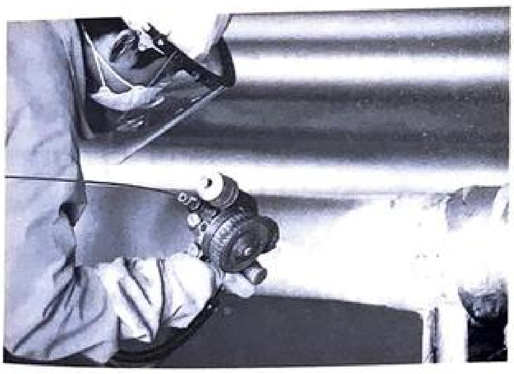
ISOMETRIC No. : F65A775RBD1016 3ROJL	✓	FOR ACCEPT	REPORT No : T7-7539	
	✗	FOR REJECT	PAGE No : 01	

MATERIAL TYPE	WELD METAL TYPE	PMI EQUIPMENT :
A: 304L B: 304H C: 316L D: NiCrMo4 E: Other Alloy	A : 308L B : 308H C : 316L D : NiCrMo4 E : Other Alloy	NITON XLI/XLT

SPOOL NO.	W.No. ~~SW~~ / FW ✓	BASE METAL 1	WELD METAL	BASE METAL 2	EXAMINED BY	DATE
	06	A ✓	A ✓	A ✓	AK	30-03-09

Mo	Nb	W	Ni	Fe	Mn	Cr	V	Ti
0.24 ± 0.07	0.03 ± 0.03	0.01 ± 0.28	8.46 ± 1.39	68.87 ± 2.15	2.26 ± 1.01	18.59 ± 1.25	0.25 ± 0.46	0.26 ± 0.57
0.26 ± 0.06	0.00 ± 0.01	0.00 ± 0.22	8.98 ± 1.13	67.51 ± 1.73	2.05 ± 0.78	19.31 ± 1.02	0.00 ± 0.51	0.55 ± 0.52
0.23 ± 0.09	0.02 ± 0.03	0.00 ± 0.36	8.79 ± 1.81	71.85 ± 2.81	0.63 ± 1.10	17.69 ± 1.57	0.22 ± 0.55	0.00 ± 1.10
0.28 ± 0.06	0.01 ± 0.01	0.00 ± 0.24	8.29 ± 1.11	70.00 ± 1.75	2.64 ± 0.80	18.20 ± 0.99	0.01 ± 0.29	0.00 ± 0.65

The corrosion engineer specifies the protection of structures and pipes against external (atmospheric) corrosion.



Protection of outdoor steel from corrosion is achieved by coating. The coating can be a metallic coating, such as Zinc (galvanizing) or Aluminium (very severe environment). For less severe requirements, steel is painted, after thorough surface preparation (sand blasting).

Painting is done following a painting systemn which defines the number, composition and thickness of each layer. Different painting materials are used for pipes in low temperature and high temperature service.

The **Painting specification** defines the surface preparation and paint system to be used for each application. Reference is made to an International code for the definition of the colors.

No.	Pipework Category	Painting System
1.	Pipes, factory bends, tees and other fittings with service temperature up to 80°C	*Epoxyvinyl System* Primer: inorganic zinc primer, DFT 75 μm min. Intermediates: two coats of epoxyvinyl paint, DFT 80+100 μm. Top coat for final color: epoxy paint, DFT 40 μm min. Total DFT 295 μm min.
2.	Pipes, factory bends, tees and other fittings with service temperature over 80°C	*Silicone System* Primer: inorganic zinc primer, DFT 75 μm min. Intermediates: two coats of silicone paint, DFT 25+25 μm. Top coat for final color: silicone paint, DFT 25 μm min. Total DFT 150 μm min.

Protection of submerged steel, e.g., internals of vessels, Off-Shore platform jacket, sealines, is done by means of sacrificial metallic attachments.

Such attachments, made of a less noble metal than steel, corrode first and, as they are electrically connected to the protected steel, prevent the corrosion of the latter. Sacrificial anodes are usually in zinc. They can be replaced once consumed.

Protection against corrosion of steel buried in the ground, e.g., underground piping services, is also achieved by coating. A mechanically stronger coating than painting is required for such application, usually in the form of a polymer applied at the factory on the straight pipes, fittings, etc. Field joints are coated at Site. The **Coating specification** defines the requirements of the coating, such as surface preparation, number, material and thickness of layers.

Buried steel pipes are usually protected against corrosion by an additional system, called the **cathodic protection** system.

Cathodic protection consists of maintaining the steel pipe at a low negative potential. This is done by flowing an electric current between the pipe and an anode buried close to it. Anodes are surrounded by material of low resistance, such as coke, in order to ensure the flow of the electric current. Reference electrodes measuring the pipe potential are provided to control that the pipe is effectively protected.

Electrodes used to monitor pipe potential

Cathodic protection

Coke breeze

Laying of flexible anode

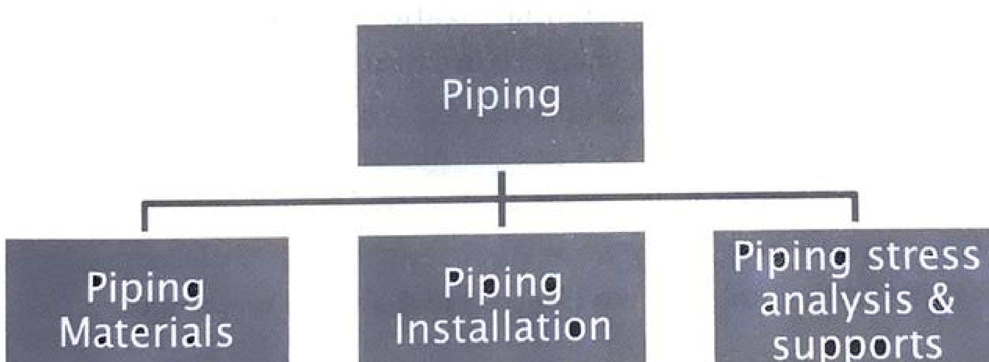
The **Insulation specification** covers the different types of insulation installed on equipment and piping: insulation for heat conservation, personnel protection and acoustic insulation. It specifies the insulation materials (such as mineral wool), thickness and provides detailed requirements for proper installation, ensuring in particular an adequate protection from the weather.

Chapter 9

Piping

Piping discipline is usually split in three specialities:

- **Piping Installation**, in charge of piping studies and layout,
- **Piping Materials**, in charge of the specifications of piping items,
- **Piping Stress Analysis and Supports**, in charge of calculations,



Based on the Process Fluids list obtained from Process, **Piping Materials** define different groups (called classes) of piping materials.

Fluids list

Pos.	FLUID	SYMBOL	OPERATING & DESIGN CONDITIONS T °C MAX/DESIGN		barg MAX/DESIGN		MATERIAL
1	Drain	BD	30	50	atm	19	CS
2	Drain	BD	30	50	atm	96,5	CS
3	Drain	BD	50	70	atm	265	CS
4	Fuel Gas	FG	30	50	8	9	SS
5	Fuel Gas	FG	40	60	45	49	SS
6	Fuel Gas	FG	55	75	98	98,5	CS
7	Diesel fuel	FO	amb	50	2	3	CS
8	Fire Water	FW	amb	50	11	12	HDPE
9	Fire Water	FW	amb	50	11	12	CS
10	Lube Oil	LO	30	80	4,2	5	GALVAN
11	Methanol	ME	20	50	atm	3	SS
12	Methanol	ME	20	50	254,5	265	SS
13	Open drain	OY	amb	50	atm	3	CS
14	Hydrocarbon Gas	P	30	50	atm	19	CS
15	Hydrocarbon Gas	P	30	50	98	98,5	CS
16	Hydrocarbon Gas	P	-40/30	-46/50	atm	2	LTCS
17	Hydrocarbon Gas	P	-40/30	-46/50	98	98,5	LTCS
18	Hydrocarbon Gas	P	138	160	253,5	265	CS
19	Hydrocarbon Gas	P	50	70	253,5	265	CS
20	Hydrocarbon Gas	P	138	160	253,5	291	CS
21	Hydrocarbon Gas	P	-40/138	-46/160	253,5	291	LTCS
22	Hydrocarbon Gas	P	-40/50	-46/70	253,5	265	LTCS
23	Utility Air	UA	30	50	11	12	CS
UW	Utility Water	UW	amb	50	3	4	GALVAN

Piping Classes

Class	Material	Rating	Pbarg/T°C Design
11A	CS	150	19 / 50
15A	CS	600	98.5 / 75
18A	CS	2500	265 / 160
18B	CS	2500	291 / 160
21A	LTCS	150	2 / -46 TO 50
25A	LTCS	600	98.5 / -46 TO 50
28A	LTCS	2500	265 / -46 TO 70
31A	304LSS	150	9 / 50
35A	304LSS	600	49 / 60
38A	304LSS	2500	280 / 50
91A	CS GALVA	150	5 / 80

Piping Material Classes allow to standardize piping materials by using the same for several services. In this way, material will be interchangeable at Site. Any excess material for any line of a given class can be used for any other line of the same class. Should there be a change at Site on one of these lines, it will be easier to find available material.

There is a trade-off between standardization and cost. While reviewing the above list of fluids, one weighs the benefits of using a different piping class for fluids # 18 and 20. If there are long lines carrying fluid #18 it will be worth to dedicate a piping class to fluid #18 rather than to use that of fluid #20. This will allow to reduce the thickness of pipes to that strictly required for the conditions of fluid #18, i.e., 265 barg, instead of overdesigning to 291 barg. This is indeed what was done in this case as two classes (18A and B) were made.

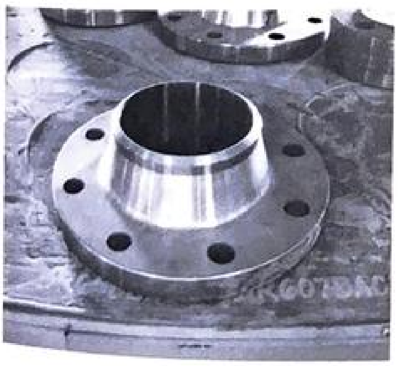
Piping involves a variety of components: straight runs, elbows, tees, flanges, reducers, valves, etc. Each of these components must be specified in order to be purchased. This is done in the **Piping Material Classes specification**.

SERVICE : DRAIN (BD) HYDROCARBON GAS (P)	GENERAL MATERIAL : CARBON STEEL **API 5L Gr. B, X52, X65**	RATING : **2500# RTJ**	PIPING CLASS : **18A**
	Corrosion Allowance = 0		Page : 1/3

CODE: ASME B31-8

Limits				
T °C	-29	38	121	160
P Barg	265	278	278	265

		DIA from	DIA to	Sched./ WT(mm) Rating	End	Material standard	Dimensions standard	DESIGNATION	NOTES
PIPE		1/2"	3/4"	160	BE	API 5L Gr.B-MDS-CS01	ASME B36.10	SEAMLESS PIPE	
		1"	1"½	XXS	BE	API 5L Gr.B-MDS-CS01	ASME B36.10	SEAMLESS PIPE	
		2"	2"	160	BE	API 5L Gr.B-MDS-CS01	ASME B36.10	SEAMLESS PIPE	4
		3"	3"	80	BE	API 5L Gr.X52-MDS-CS04	ASME B36.10	SEAMLESS PIPE	4
		4"	14"	120	BE	API 5L Gr.X52-MDS-CS04	ASME B36.10	SEAMLESS PIPE	4
		16"	24"	(*)	BE	API 5L Gr.X65-MDS-CS06	ASME B36.10	S.A.W. WELDED PIPE : (*) 16" thk = 25.4, 18" thk = 28,58 20" thk = 31.75 , 24" thk =38.1	4
FORGED STEEL FITTING	B.W	1/2"	2"		BW	ASTM A105-MDS CS01	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
		3"	14"		BW	A694- F52-MDS CS03	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
		16"	24"		BW	A694- F65-MDS CS05	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
	BUTT WELDING	1/2"	3/4"	160	BW	A234-WPB-MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		1"	1"½	XXS	BW	A234-WPB-MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		2"	2"	160	BW	A234-WPB-MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		3"	3"	80	BW	MSS SP-75 WPHY 52-MDS CS03	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		4"	14"	120	BW	MSS SP-75 WPHY 52-MDS CS03	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		16"	24"	pipe thk	BW	MSS SP-75 WPHY 65-MDS CS05	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	1
FLANGES		1/2"	2"	2500# RTJ	BW	ASTM A105-MDS CS01	ASME B16.5	WELDING NECK FLANGE	1
		3"	12"	2500# RTJ	BW	A694-F52-MDS CS03	ASME B16.5	WELDING NECK FLANGE	1
		14"	14"		BW	A694-F52-MDS CS03		HUB CONNECTOR (BW AS PER ASME B16-25)	1-2-3
		16"	24"		BW	A694-F65-MDS CS05		HUB CONNECTOR (BW AS PER ASME B16-25)	1-2-3
		2"	2"	2500# RTJ	BW	ASTM A105-MDS CS01	ASME B16.36	2 ORIFICE WN FLANGE + 1/2"PLUG+JACK SCREW	1
		3"	12"	2500# RTJ	BW	A694-F52-MDS CS03	ASME B16.36	2 ORIFICE WN FLANGE + 1/2"PLUG+JACK SCREW	1
		1/2"	12"	2500# RTJ	-	ASTM A105-MDS CS01	ASME B16.5	BLIND FLANGE	
		14"	24"		-	A694-F52-MDS CS03		BLIND HUB CONNECTOR	2-3
GASKET		1/2"	12"	2500#		SOFT IRON (90 HB max)	ASME B16.5,B16.20	OCTAGONAL RING- JOINT GASKET	
		14"	24"			AISI 4140		SEAL RING FOR HUB CONNECTOR (FOR CLAMP-TYPE DEVICE)	2-3
BOLTING						A193Gr B7+ Zn Bichr. A194Gr 2H+ Zn Bichr.	ASME B16.5 ASME B1.1	STUD BOLT & 2 HEAVY HEX. NUTS DIA≤1"COARSE Series, DIA >1" 8 THREADS series	
							ASME B1.1	SPECIAL BOLTING FOR CLAMP-TYPE DEVICE	3



For each item, the specification defines:

- The material, by reference to an international standard,

SERVICE : DRAIN (BD) HYDROCARBON GAS (P)						GENERAL MATERIAL : CARBON STEEL API 5L Gr. B, X52, X65	RATING : 2500# RTJ	PIPING CLASS : 18A
						Corrosion Allowance = 0		Page : 1/3
Limits T °C: -29 / 38 / 121 / 160; P Barg: 265 / 278 / 278 / 265							CODE: ASME B31-8	
		DIA from	DIA to	Sched./ WT(mm) Rating	End	Material standard		
PIPE		1/2"	3/4"	160	BE	API 5L Gr B-MDS-CS01		
		1"	1"½	XXS	BE	API 5L Gr B-MDS-CS01		
		2"	2"	160	BE	API 5L Gr B-MDS-CS01		
		3"	3"	80	BE	API 5L Gr X52-MDS-CS		
		4"	14"	120	BE	API 5L Gr X52-MDS-CS		
		16"	24"	(*)	BE	API 5L Gr X65-MDS-CS		
FORGED STEEL FITTING	B.W.	1/2"	2"		BW	ASTM A105-MDS CS01		
		3"	14"		BW	A694- F52-MDS CS03		
		16"	24"		BW	A694- F65-MDS CS05		
	BUTT WELDING	1/2"	3/4"	160	BW	A234-WPB-MDS SC01		
		1"	1"½	XXS	BW	A234-WPB-MDS SC01		
		2"	2"	160	BW	A234-WPB-MDS SC01		
		3"	3"	80	BW	MSS SP-75 WPHY 52-MDS CS		
		4"	14"	120	BW	MSS SP-75 WPHY 52-MDS CS		
		16"	24"	pipe thk	BW	MSS SP-75 WPHY 65-MDS CS		

CHEMICAL REQUIREMENTS FOR HEAT ANALYSES (Section 6)

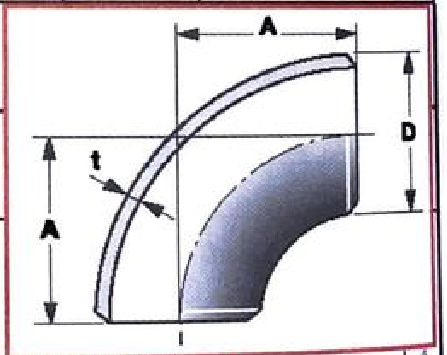
Type of pipe	Grade	Carbon maxi % (1)	Manganese maxi % (1)	Phosphorus maxi %	Sulfur maxi %
seamless					
Non-expanded or cold expanded	A	0.22	0.90	0.030	0.030
	B(6)	0.27	1.15	0.030	0.030
Non-expanded	X42	0.29	1.25	0.030	0.030
	X46(4), X52(4),	0.31	1.35	0.030	0.030
Cold expanded	X42(4), X46(4), X52(4),	0.29(2)	1.25	0.030	0.030
Non-expanded or cold expanded	X56(3,4), X60(3,4)	0.26	1.35	0.030	0.030
	X65, X70, X80	(by agreement)		0.030	0.030

TENSILE REQUIREMENTS (Section 6)

Grade	Yield strength minimum ksi	Yield strength minimum MPa	Ultimate tensile strength minimum ksi	Ultimate tensile strength minimum MPa	Ultimate tensile strength maximum ksi	Ultimate tensile strength maximum MPa	Elongation minimum percent in 2 in. (50.8 mm)
A	30.0	207	48.0	331			See note (1)
B	35.0	241	60.0	413			
X42	42.0	289	60.0	413			
X46	46.0	317	63.0	434			
X52	52.0	358	66.0	455			
X56	56.0	386	71.0	489			
X60	60.0	413	75.0	517			

- the geometry/dimensions, by reference to international dimensional standard, e.g., ASME, for elbows (defining the length, etc.),

SERVICE : DRAIN (BD) HYDROCARBON GAS (P)						GENERAL MATERIAL : CARBON STEEL API 5L Gr. B, X52, X65		RATING : 2500# RTJ	PIPING CLASS : 18A
						Corrosion Allowance = 0			Page : 1/3
Limits T °C: -29 / 38 / 121 / 160; P Barg: 265 / 278 / 278 / 265									
		DIA from	DIA to	Sched./ WT(mm) Rating	End	Material standard	Dimensions standard		
PIPE		1/2"	3/4"	160	BE	API 5L Gr.B-MDS-CS01	ASME B36.10		
		1"	1"½	XXS	BE	API 5L Gr.B-MDS-CS01	ASME B36.10		
		2"	2"	160	BE	API 5L Gr.B-MDS-CS01	ASME B36.10		
		3"	3"	80	BE	API 5L Gr.X52-MDS-CS04	ASME B36.10		
		4"	14"	120	BE	API 5L Gr.X52-MDS-CS04	ASME B36.10		
		16"	24"	(*)	BE	API 5L Gr.X65-MDS-CS06	ASME B36.10	S.A.W. WELDED PIPE (*) 16" thk = 25.4, 18" thk = 28,58 20" thk = 31.75 , 24" thk =38.1	4
FORGED STEEL FITTING	B.W.	1/2"	2"		BW	ASTM A105-MDS CS01	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
		3"	14"		BW	A694- F52-MDS CS03	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
		16"	24"		BW	A694- F65-MDS CS05	MSS SP-97	WELDOLET (BW AS PER ASME B16-25)	1
	BUTT WELDING	1/2"	3/4"	160	BW	A234-WPB-MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		1"	1"½	XXS	BW	A234-WPB MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		2"	2"	160	BW	A234-WPB-MDS SC01	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		3"	3"	80	BW	MSS SP-75 WPHY 52-MDS CS03	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		4"	14"	120	BW	MSS SP-75 WPHY 52-MDS CS03	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	
		16"	24"	pipe thk	BW	MSS SP-75 WPHY 65-MDS CS05	ASME B16.9	45°, 90°ELBOW, TEE, RED. TEE, CAP, REDUCER	1



- the wall thickness (by steps, called schedules, for standardisation reasons), for each diameter, which is calculated from applicable design code (ASME B31.3 for Oil & Gas facilities), pressure, temperature, material properties, corrosion allowance and manufacturing tolerances,

Pipe wall thickness calculation as per ASME B31.3

(ASME B31.3, 304.1.2, eq. (3a), for t < D/6)

$$t = \frac{P * D}{(2SWE + PY)}$$

P Internal pressure
D Pipe outside diameter
S Basic Allowable Stress value for material, at design temperature, as per table Table A-1 of ASME B31.3
W Weld joint strength reduction factor
E Quality factor (1 for seamless, 0.85 for ER welded pipe, etc.)
Y Coefficient from table in ASME B31.3 (from 0.4 to 0.7 depending on material and temperature)

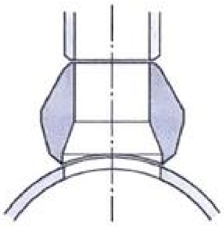
Example: Piping class 1A
Design Pressure: 19 barg, Desgin Temperature: 75°C
Carbon steel, 3mm corrosion allowance

Material API 5L grade B
Seamless pipe (W=1, E=1)
Y = 0.4
S: 20,000 psi (1379 bar)

		Diameter (inch)		
	inch	2	6	10
	mm	60.3	168.3	273.1
t calc	mm	0.4	1.2	1.9
CA	mm	3.0	3.0	3.0
Fab allowance	%	12.5	12.5	12.5
t min		3.9	4.7	5.6
t selected		3.9	4.8	6.4
		sch 40		sch 20

The wall thickness is defined as per the calculated minimum required wall thickness, the corrosion allowance and manufacturing tolerances as well as the selection made for other piping classes, in order to provide another level of standardisation.

The Piping class contains a branch connection table which specifies the type of branched connections to be used depending on the diameters of the main line and the branch (tees, reinforced branch fittings – also called olets such as the weldolet shown here, etc.).



Supply of piping materials take time while these materials are needed at an early stage at Site to start pre-fabrication.

The exact list of piping materials required will not be known until late in the Project, once Engineering is almost completed and piping isometric drawings, which show the exact Bill Of Materials required, have been issued. The Project cannot afford to wait and must order based on preliminary estimates.

These estimates improve as Engineering progresses and purchase orders amendments are made to adjust quantities.

Piping Materials discipline proceeds as follows:

A preliminary list of required materials is estimated from the available drawings, performing what is called a Material Take-Off (MTO). The drawings used at this stage are the first issue of the P&IDs, and associated line list, and the Piping routing drawings (Line diagrams). The **1st MTO** is used to issue inquiries to Piping materials vendors based on realistic quantities, to secure timely availability of materials, obtain unit prices and select vendors.

Vendors are selected and purchase orders are prepared. In the meantime, a second MTO is done, based on the second issue of the P&IDs (IFD), the Piping layout drawings and, for the lines that have been modelled, the 3D model. The purchase orders are placed on the basis of these **2nd MTO** quantities. In order not to order too much, a certain percentage of the quantities estimated are ordered, e.g., 80% only. In such a way, even if quantities decrease by 20% due to design development there will not be any surplus.

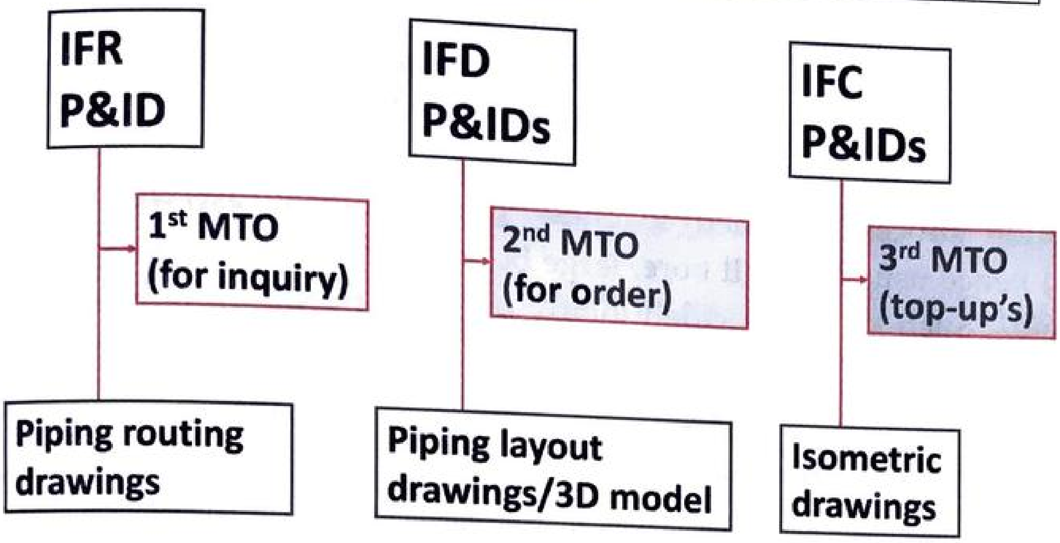
The drawings (P&IDs, Piping layout) available at the stage when the 1st and 2nd MTOs are done only contain the main lines. Small diameter lines, in particular small bore (<2"), are not shown on the drawings hence not part of the MTO. Corresponding materials must therefore be added to the MTO. Quantities are estimated, based on (weight) ratios of small bore to total piping known from previous jobs for each type of material (pipes, flanges, fittings, valves).

Allowances are added to the MTO for what is not yet designed. Uncertain items are identified and excluded. A thorough review of quantities is done for long lead items: large diameter, exotic material lines.

As design develops lines are progressively modelled in the 3D model and isometric drawings, showing the final list of materials required for each line, issued. Balance of materials between what was accounted and ordered for a line (2nd MTO quantities) and the final list of materials appearing on the isometric for that line, the **3rd MTO**, which is extracted from the 3D model, is made. Additional quantities are purchased by amendment to the purchase orders.

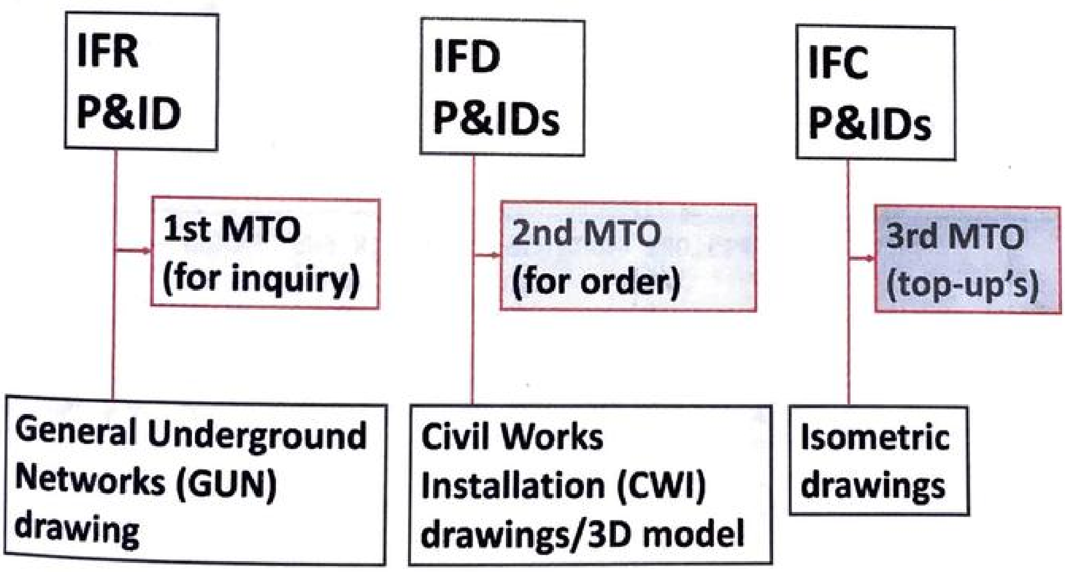
As the design of lines in the model and the issue of isometric drawings take place over several months, several such MTOs and purchases of additional materials are made.

Workprocess for Material Take-Off for Above Ground Piping



Piping MTO shall also include underground piping, which is usually dealt with by Civil rather than Piping discipline. The drawings from which the 3 MTOs are done are different, as shown below:

Workprocess for Material Take-Off for Underground Piping



Codes are assigned to Piping materials, in order to identify them easily rather than to resort to their full designation. The code is independent of the piping class, as the same items, for instance small bore pipes of a given schedule, appear in numerous piping classes.

On large Projects, the quantities of piping materials exceed the minimum of quantities required to purchase them directly from manufacturers, which is the most cost effective. Manufacturers offer only certain types of piping items. Therefore Piping materials are supplied from multiple suppliers and separate **Material Requisitions** must be issued for each one. Typically the split is by types of items (straight pipes, fittings, gate/ball/globe/butterfly/check valves), fabrication process (welded/seamless pipes, forged/cast/welded fittings/valves) hence usually small bore/large bore and materials (CS, LTCS, stainless steel, etc.). Such split is decided jointly by the Piping Materials Engineer and Procurement.

On small projects no such split is required as piping materials are purchased from a stockist, at a premium cost.

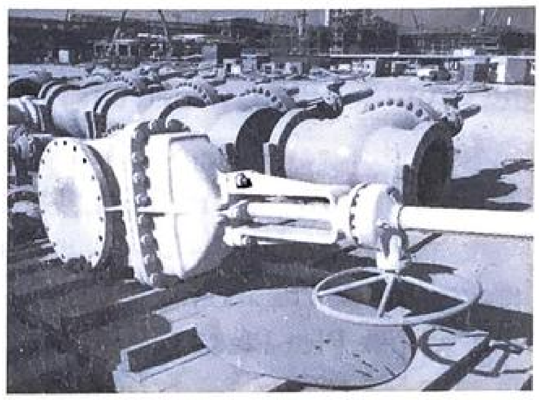
Material requisitions are subject to revisions, which indicate the previously ordered quantity, the new required quantity and the difference. Such accounting is done using the Piping Materials Management software using the piping item codes.

REV	Item	SIGMA CODE CLIENT CODE	large diam.	small diam. /length	QUANTITIES TO BE SUPPLIED New A	Old B	BALANCE TO BE SUPP. A - B
SEAMLESS		PIPE					
		TE04170	API5LGRB -ANSIB36-10 -BW -SCH40 -				
005	34		P 2		1248	1212	36
		TE04900	API5LGRB -ANSIB36-10 -PLAIN END -SCH80 -				
004	37		P 3/4		6	6	0
004	36		P 1		6	6	0
004	42		P 11/2		6	6	0
		TE14795	API5LGRB -ANSIB36-10 -PLAIN END -SCH80 -MDS CS01 -				
005	44		P 1/2		138	0	138
005	25		P 3/4		12	6	6
004	24		P 1		6	6	0
004	43		P 11/2		6	6	0

A brief specification of manual valves is given in the piping class including the reference to the applicable design and fabrication code, the material of the body and trim, type of body/cover assembly, materials of seats and gasket, etc.

DIA		Rating	End	BALL VALVES	
from	to			DESIGNATION	Standard
1/2"	1"1/2	2500#	BW	Full bore with BW Nippples, Trunnion ball, 3-piece body Body:LTC.Steel Trim: 17/4 PH impact tested at -46°C Seats/Seals: PEEK / Viton or equal	API 6D ASME B16-34
2"	20"	2500#	BW	Full bore, welded body with BW pup pieces Trunnion ball Body:LTC.Steel Trim: 17/4 PH impact tested at -46°C Seats / Seals PEEK or PTFCE / PTFE	API 6D ASME B16-34

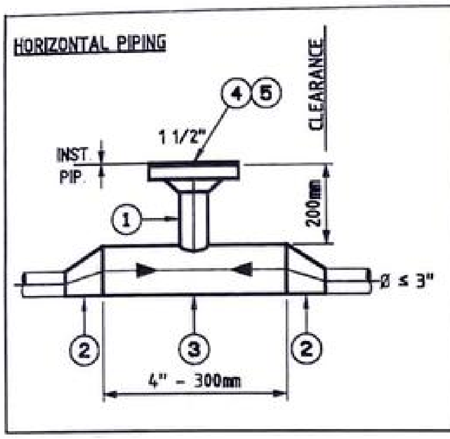
The detailed technical requirements for manual valves, which include the specification of the materials of all valve parts, are indicated in the Valve Data Sheets, issued for each type of valve.



VALVE DATA SHEET for VB-01-2-28A

- Valve type	: **BALL VALVE**	- Piping class	: **18A**
- Rating	: **class 2500 BW**	- Max operating temperat.	: **160°C**
- Size	: **2" to 4" included**	- Mini design temperature	: **- 29°C**
- Service	: **Hydrocarbon Gas**	- Construction codes	: **API 6D - ASME B16.34**
DESIGN (1) (11)		MATERIAL (1)	
Body Construction : (3) Position indicator on actuator,	**3-Piece split body (side entry)** **Fire-safe & anti-static design**	Body : (14) Material requirements :	ASTM A 350 LF2 to M-7-60007 section 3
Ball Type : Port :	**Trunnion mounted** **Reduced bore (one size below)**	Ball : Closure ends : (14)	ASTM A 182 F316 ASTM A 350 LF2
Stem Seal Type : (7)	"O" ring type seal	Stem / Trunnion :	ASTM A 182 F316
Gland Type :	-	Seal rings and O'rings : (other than seat inserts)	Viton AED (4) Secondary seal GRAPHITE (7)
Operation :	By wrench or gear box (13) Position indicator on gear box	Stuffing box :	-
Seat rings : (12)	ASTM A 182 F316 double block and bleed design	Soft Seat insert :	**Peek** (7) (8) (12)
By Pass :	-	Spring :	INCONEL X-750
End Connection : **Butt Welding** to M-7-60007 # 2.7 and # 3.2 (14) Pup Pieces (transition pieces)	(14)	Sealing Face of Disc :	-
End to End Dimension :	API 6 D	Pressure Containing Bolts / Nuts : Zinc plated (electro-deposited) and bichromated or phosphatised	ASTM A320 L7 / A194 Gr.4 or 7
Drain Connection :	Yes	Body / closure Sealing :	As seal ring (7)
Stem :	Shouldered anti-blow out		
DELIVERY REQUIREMENTS			
Test : (Air seat test required)	API 6D and M-7-60007 (section 5 and appendix A and C)	Certification : Technical passport :	M-7-60007 section 3 & page 39 M-7-60007 (suppl.prescriptions)
Marking : (6) MSS SP-25 and Protection :	API 6D and M-7-60007 section 6 refer to M-7-60007 Section 8	External Coating : (15) (or coating according to W-7-60701 for Buried valves listed as SP valve)	2 coats of painting system (16)
Fire Test : API 607 or API spec 6FA or BS 6755 PART II Certificate		Valve location :	**Above ground** (or Buried) (17)

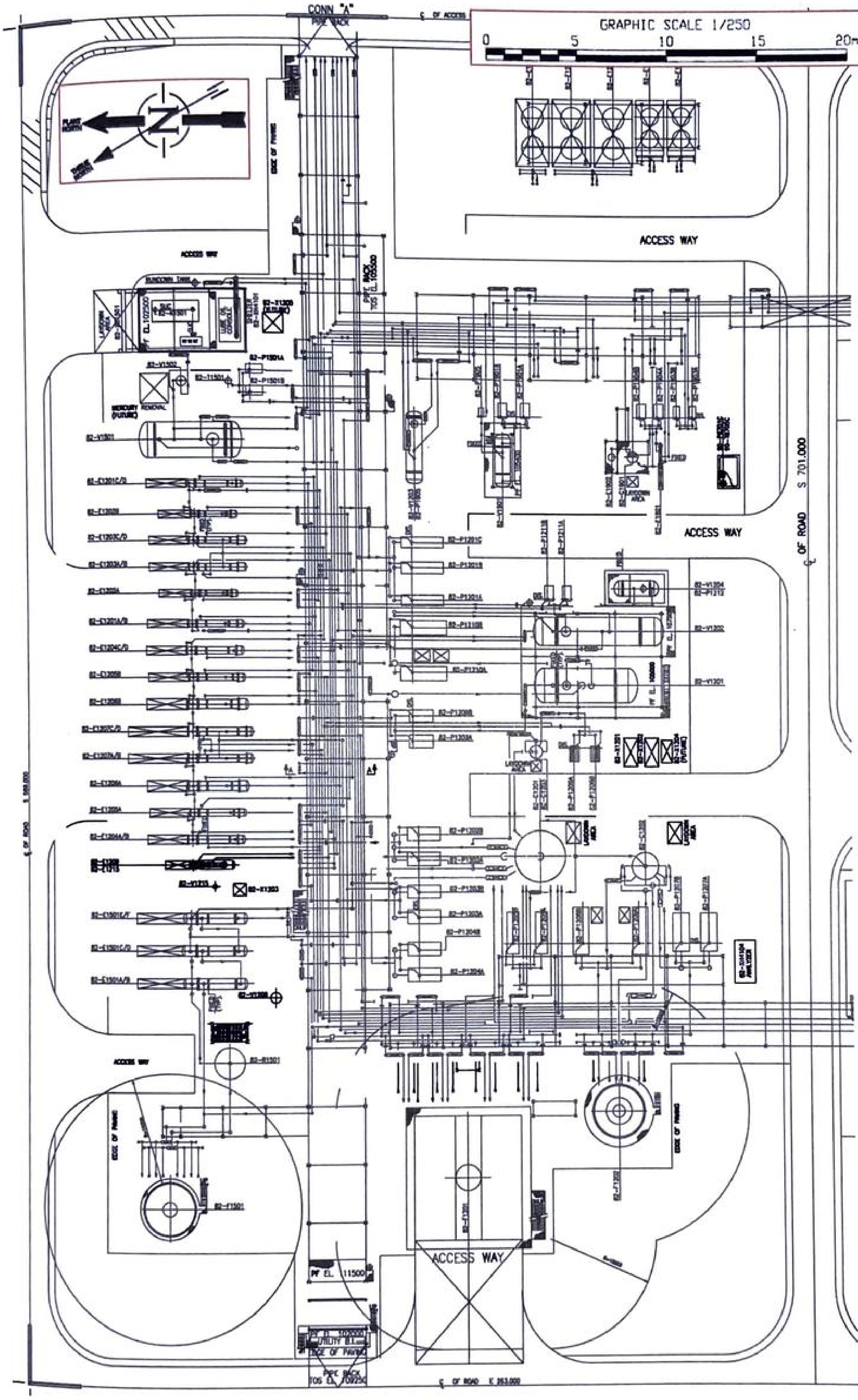
The **Piping details standard** show the arrangement and materials of standard assemblies, including the the piping/instrument interface.



1 LONG WELDING NECK FLANGE	1 1/2"	1	FLW1
2 ECCENTRIC REDUCTION	4" X Ø	2	ERE
3 PIPE	4"	0.3	PIP
4 GASKET	1 1/2"	1	GAS
5 BOLTING	1 1/2"	1 SET	BBJ

The piping design work starts with piping routing studies, done from the Process Flow Diagrams, which shows interconnections between Equipment, and the Unit Plot Plan, which shows Equipment locations.

Line diagrams, also called « line shoot diagrams » or **piping route drawings**, show the route of the lines. They are called line diagrams as they depict each pipe, regardless of its diameter, as a single line. They use the Unit Plot Plan as background. The example of line diagram shown on the next page is that of the unit whose Plot Plan is shown in chapter 5 Plant Layout.

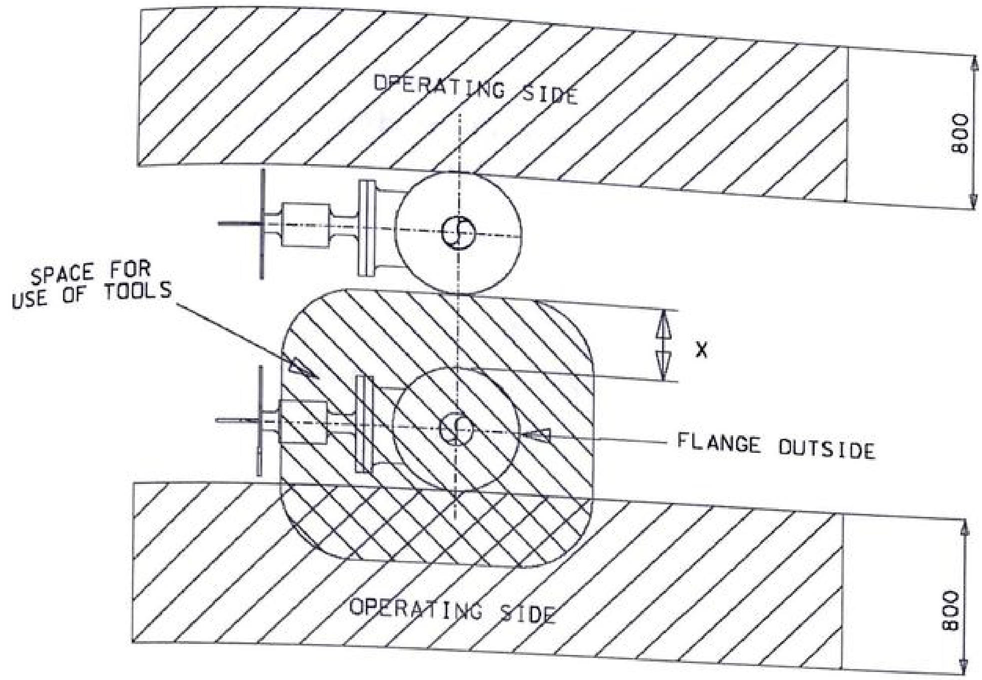

CONN "A"
PIPE RACK
GRAPHIC SCALE 1/250
0
5
10
15
20m
PLANT NORTH
EDGE OF PAVING
ACCESS WAY
ACCESS WAY
PIPE RACK TOS EL. 105500
ACCESS WAY
S 701.000
OF ROAD
ACCESS WAY
PF EL. 111500
PF EL. 102000
UTILITY
EDGE OF PAVING
PIPE RACK TOS EL. 109250
OF ROAD E 263.000

Line diagrams have several purposes: to confirm the Unit Plot Plan, to allow measurement of the lengths of lines for the first MTO, to set the dimensions of pipe-racks and to assign areas to piping designers.

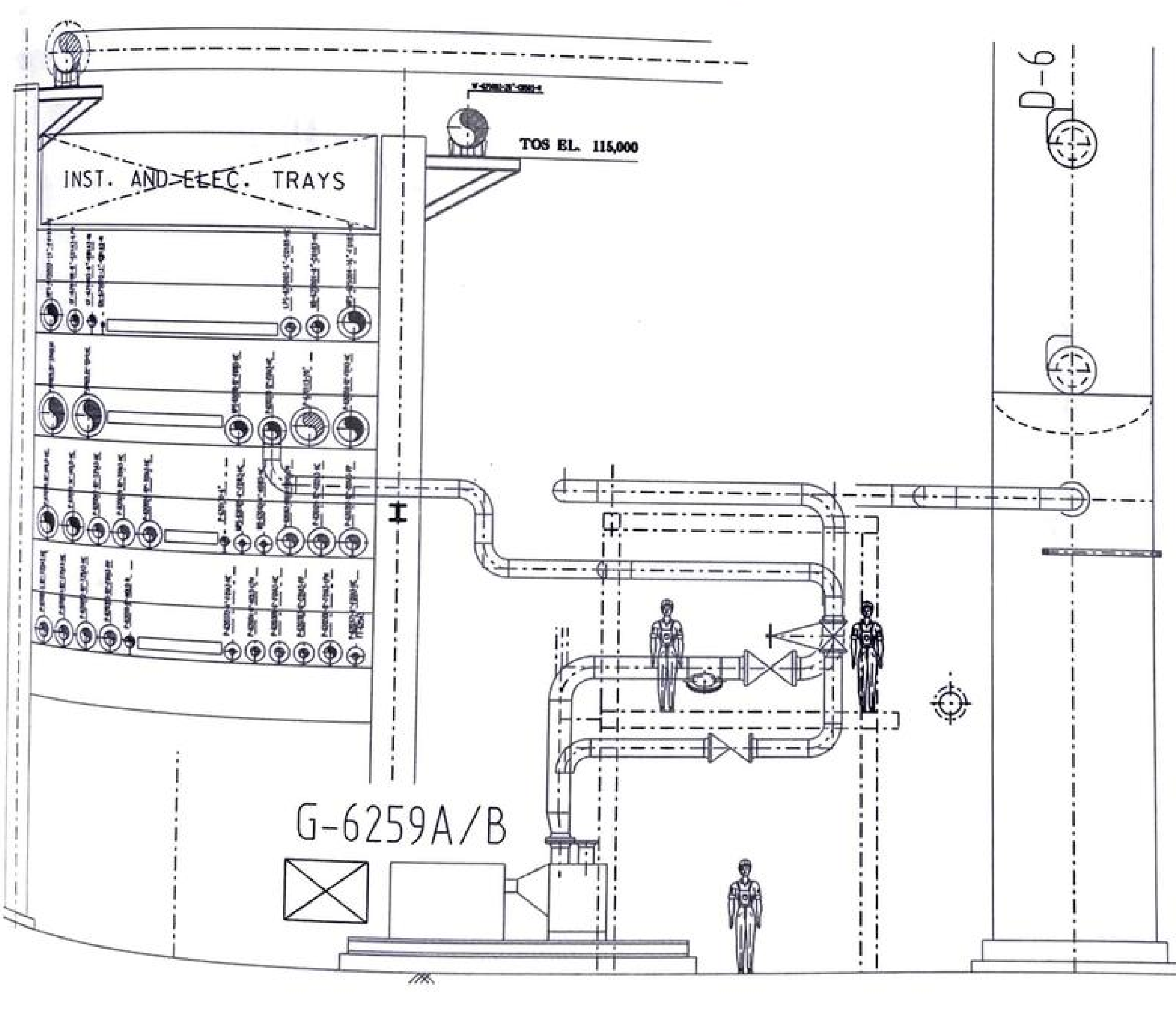
The second stage in the Plant piping design is the **Piping studies**, also called Planning studies, which take into account numerous requirements:

- Process requirements, as shown on P&IDs: sloped line for gravity flow, no pocket, minimum distances, PSVs and BDVs located at high point with slopes on both sides, etc.
- Piping flexibility (provision of directional change or expansion loop in the line to allow its expansion due to temperature),
- Grouping of lines on common support/pipe-rack. Largest pipes are located on the sides of pipe-racks. Pipes exit the pipe-rack by changing level to allow addition of future pipes.

- Operator access to valves and instruments,
- Straight pipe lengths upstream and downstream of flow meters,
- Space for dismantling and handling parts during maintenance: provision of clearance for lifting and lay down area,
- Clearances around control valves, acceptable height of valve hand wheels and other access and ergonomics requirements as defined in the **Human Factors requirements specification**.



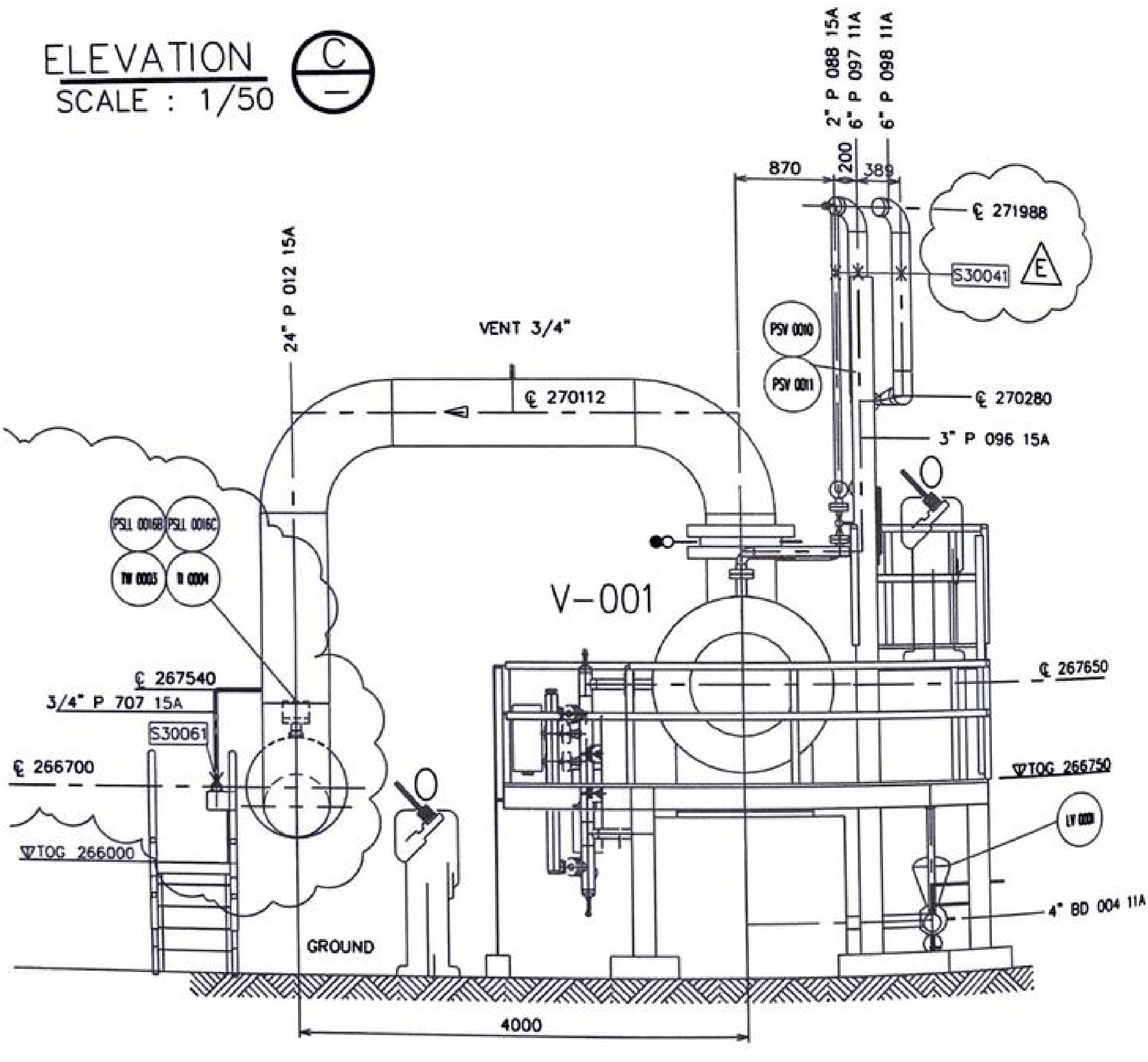
Piping studies result in **Piping Layout Drawings**.

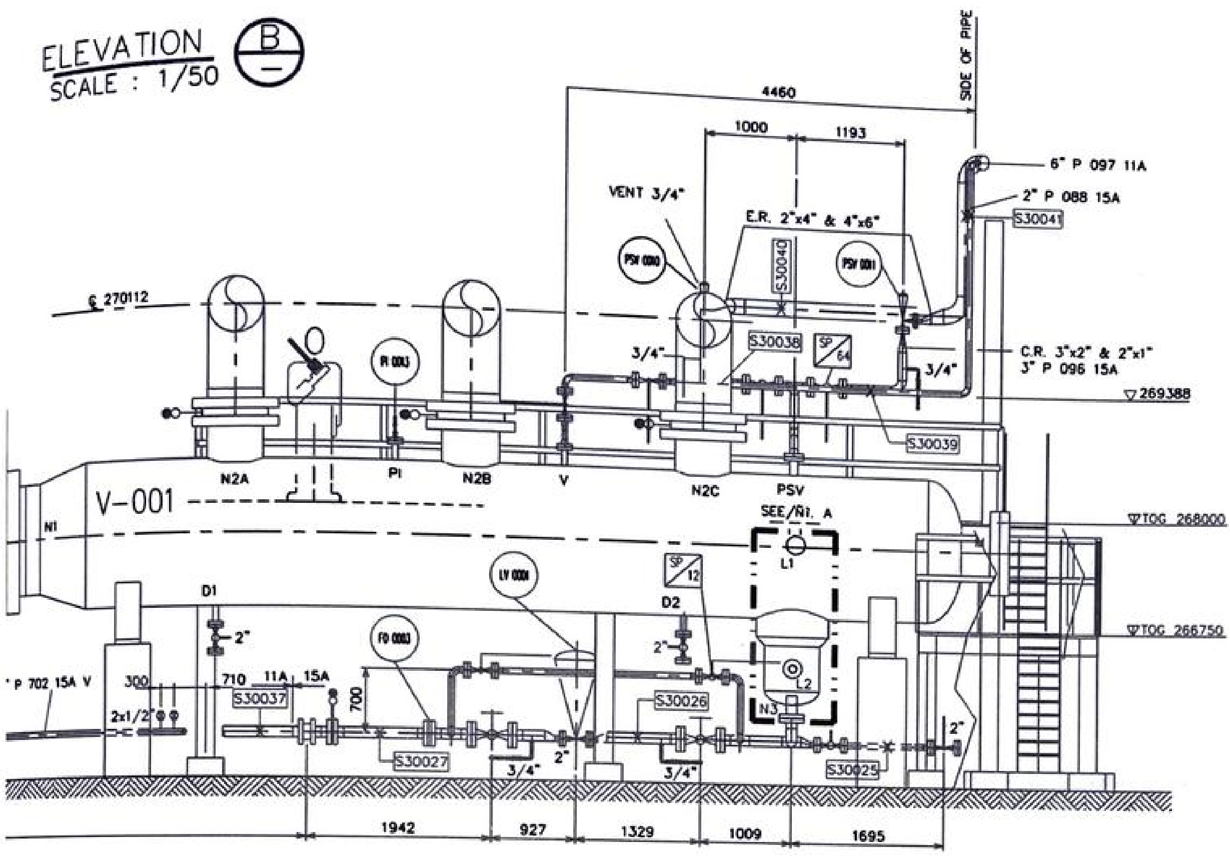


Piping studies set the dimensions of process structures and the width and number of levels of pipe-racks.

Piping issues two types of construction drawings: **General Arrangement Drawings**, used for piping erection, and **Isometric Drawings**, used for piping pre-fabrication.

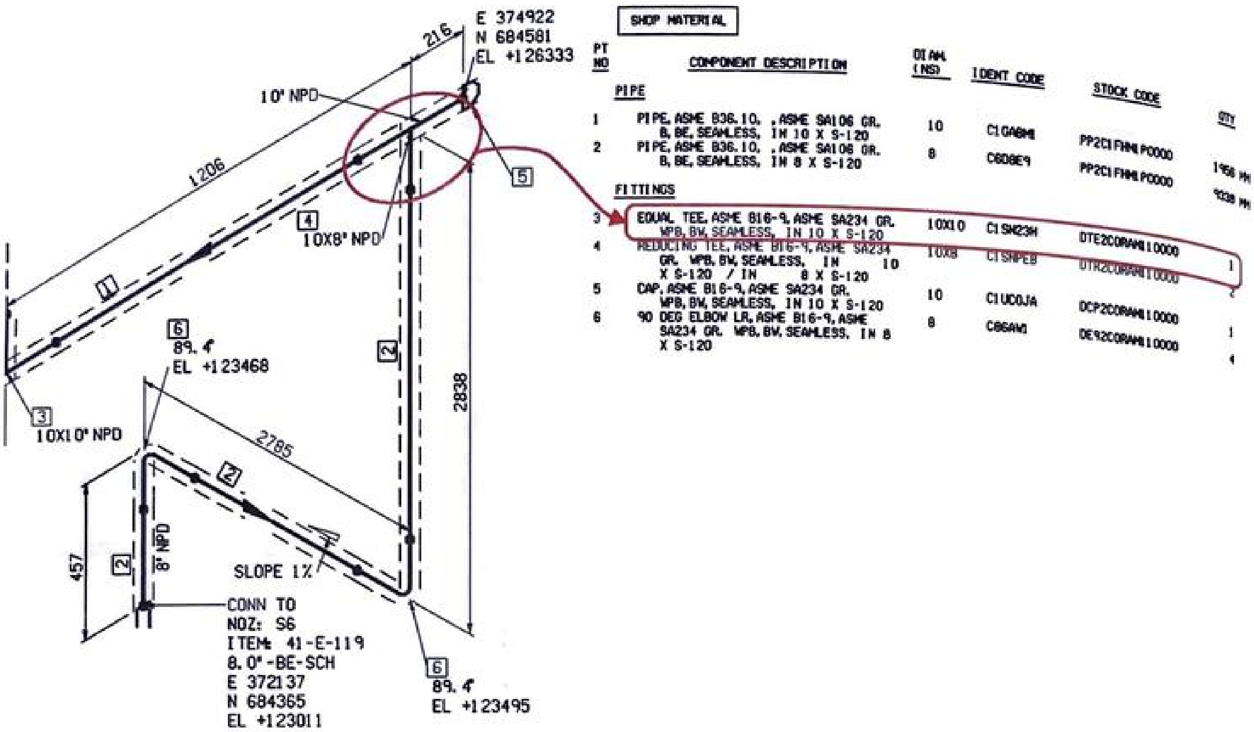
The **Piping General Arrangement drawing** contains all information necessary for erection of piping: all dimensions, elevations, position of valves, etc. It served, in the past, to produce Isometric drawings when done manually. As a CAD tool is now used to produce Isometrics, Piping General Arrangement drawings are no longer systematically produced.





Piping General Arrangement Drawings (GAD) also served to give a view of the complete environment within in area, including all equipment, pipes, valves, structures, etc. They tend to be replaced, nowdays, by snapshots taken from the CAD tool (3D model).

Piping Isometric Drawings show a 3D view of an individual line, with all dimensions defining its geometry, the list and specification of all piping components required to fabricate (straight pipe length, elbows, tees) and erect (valve, gaskets) it, the positions and types of supports, and the inspections and tests to be done during fabrication.



The piping materials short identification codes, which have been used in the material requisitions and have been marked by the suppliers on every item, are indicated on the isometric.

Piping isometric drawings are extracted from the 3D model. Before the extraction, the line route is duly checked in the 3D model and a check list, like the one below, is filled.

Piping isometric check list	
Check compliance with IFC P&ID, including notes (no pocket etc.), spec breaks	☑
Check accessiblity of valve (flange accessiblity for dismantling, handwheel elevation)	☑
Check that all the adjacent lines have no impact on the routing	☑
Check openings in grating and concrete floors (space for sleeve)	☑
Equipment nozzles with removal requirement : spool piece & free space	☑
Check routing and supports compliance with stress calculation note (for critical lines)	☑
Obtain process approval for Process critical lines	☑
Check instrument connection is as per Piping standard	☑
Check upstream & downstream straight lengths are provided for FT	☑
Check the dimensions of Special items	☑
Check that all isometric drawing fields are all filled-in, including NDE, PWHT etc.	☑
Check that Piping insulation type and thickness is as per IFC line list	☑
Check line is not subject to P&ID modification sheet	☑

The piping isometric drawing must indicate all fabrication requirements, including required inspections and tests (surface only or in-depth inspection by means of radiography for instance) and heat treatment of welds.

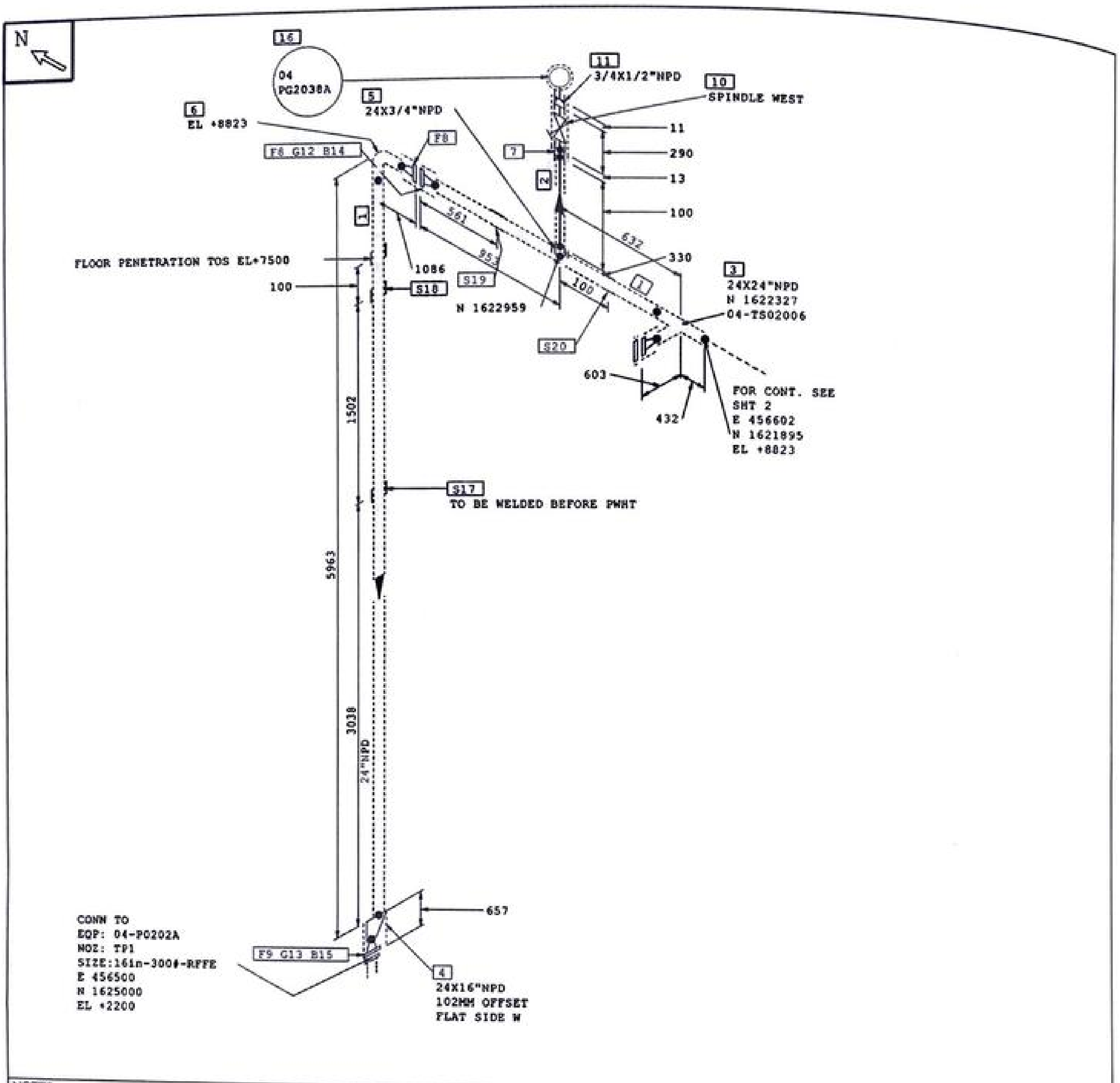
These requirements are specified based on the service, pressure and type of fluid, in the **Piping NDE specification** as per the requirements of the Piping code, usually ANSI B31.3 or, if it exists, the Client specification.

CLASS	RATING FACE GASKET BOLTING	MATERIAL CORROSION ALLOWANCE	DESIGN CONDITIONS P bar	 T °C	SERVICE	Heat Treatment	Fluid Cat.	EXTEND OF NON DESTRUCTIVE EXAMINATION (%) - case of hydrostatic testing Girth Butt welds	 Pipe to pipe branch	 Pressure containing seal, fillet welds	 Socket welds	 Other requirements
A10K	150 RF SP.WND SS316 + GRAFOIL B7 / 2H	Stainless Steel 304/304L CA = 0 mm	19 18	-1 / 38 70,0	UNDERGROUND water		N	20% PT	20% PT		20% PT	
B47A	300 RF SP.WND SS316 + GRAFOIL B7M / 2HM	Carbon Steel CA = 3 mm	Full Rating 52 FV 42	 -1 / 38 220 260	ABOVEGROUND Hydrogen service & Sour service	PWHT	N	100% RT	100% MT	10% MT	100% MT	100% HT

Inspection, testing, Post Weld Heat Treatment requirements, as well as paint system to be applied, are added by Piping to the **Line List** received from Process.

Line Number Fluid Code	 Unit Code	 Seq No.	Line Size	Class	Insulation Code	 Thk.	Paint Code	PWHT	Hardness	NDE Requirement Butt Welds	 Fillet Welds	 Branch Welds	 Attach. Welds	Pressure Test Medium	 Press (Min.) barg	PMI
GN	71	61106	22	3C3AS1	N	NO	1C	YES	YES	A,B	A	A,F	A	H	51,80	0%
GN	71	61106	20	3C3AS1	N	NO	1C	YES	YES	A,B	A	A,F	A	H	51,80	0%
GN	71	61106	12	3C3AS1	N	NO	1C	YES	YES	A,B	A	A,F	A	H	51,80	0%
LNG	71	60001	32	3R0JLL	6	180	7S	NO	NO	A,D,F	A,F	A,E	A,F	P	33,00	100%
LNG	71	60001	22	3R0JLL	6	170	7S	NO	NO	A,D,F	A,F	A,E	A,F	P	33,00	100%
DOW	72	63000	0,75	1P1	N	NO	1C	NO	NO	A,B	A	A,F	A	H	3,00	0%
DOW	72	63001	0,75	1P1	N	NO	1C	NO	NO	A,B	A	A,F	A	H	3,00	0%

Such information is also shown on the **Isometric drawing**.

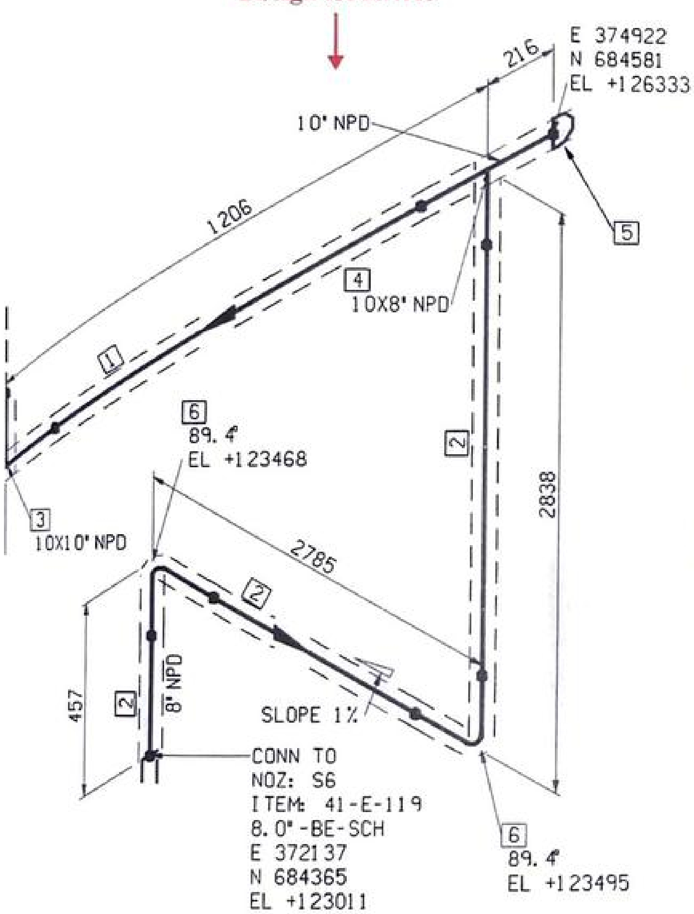


NOTES:
(1) For lines 1.5" and smaller, supporting shall be studied and performed by Subcontractor prior Fabrication. Nevertheless, if already shown, supporting shall be followed by Subcontractor
(2) Could be required for specific conditions (refer to 199-00-00-QA-TS-NA-630032)
(3) Only applicable for butt-weld. For other connections refer to 199-00-00-QA-TS-NA-630032

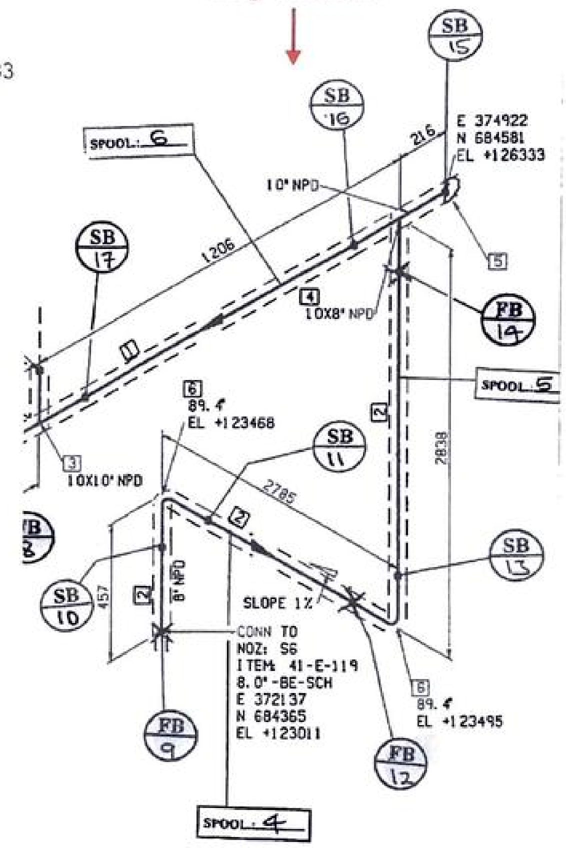
TEST TYPE	HEAT TREATMENT (2)	N.D.E (3)	HARDNESS LIMIT (2)	P.A.M.I	PID NUMBER	LINE LIST	CALCULATION NOTE	INSULATION
Hydrotest	100% PWHT	10% RT	Yes (200 HB)	-	199-04-02-PR-DR-PI-000112	9833N-4200-NN-0022-002	110	1

The Isometric drawing produced by Engineering is not directly used for construction. Indeed, as the line is pre-fabricated in parts, called spools, drawings must be issued showing how the line is divided into spools. **Shop isometric drawings** are issued to this end by the Construction contractor. They are also used to identify welds, each of which will be associated with inspection and test records.

Design isometric

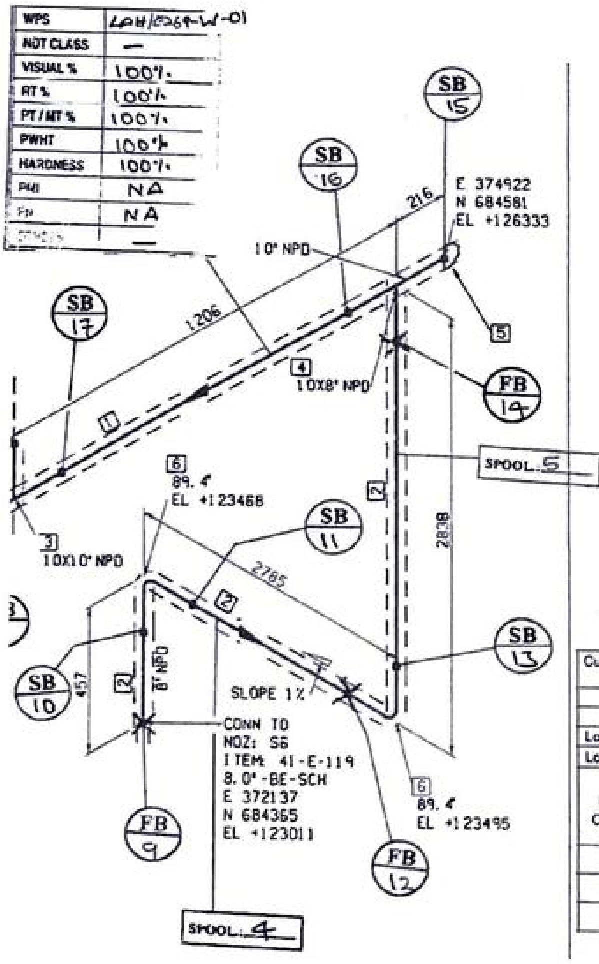


Shop isometric

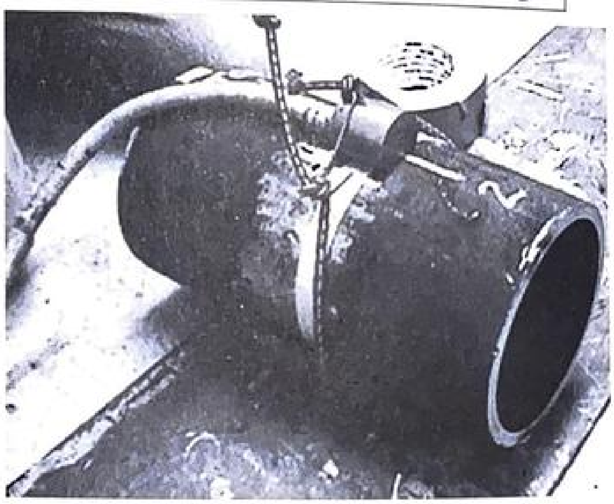


SB = Shop (Butt) Weld, FB = Field (Butt) Weld.

Piping Pre-fabrication: Gas cutting, welding



Piping Inspection and testing

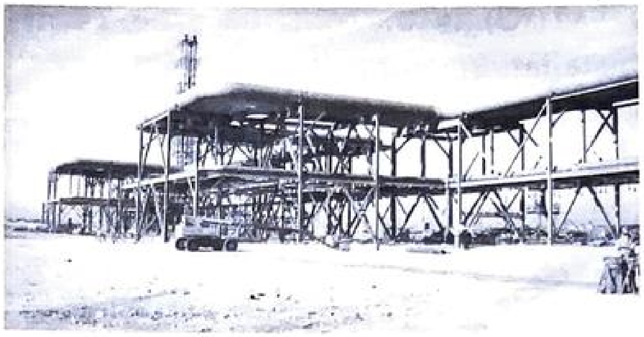


RADIOGRAPHY REPORT

Customer :

Radiographic Technique			Pb Screen Thickness (mm)	Source Isotope
~~SWSI~~	DWSI	~~DWDI~~	Front & Back : 0.125	Source Strength
Location of Penetrameter	~~Source Side~~ / Film Side		Film Density : 2-3	Ug : 0.28
Location of Markers	~~Source Side~~ / Film Side		Sensitivity : 2%	

Ht/treat Condition	Film Location	Crack	Burn Through	Concave Root	Excess Penetration	Lack of Fusion	Lack of Root Pen.	Slag or El Defect	Undercut	Porosity	Surface Concavity	Other	Result
N/A	0 - 12							✓		✓			Acc
	12 - 24											✓	Acc
	24 - 0				✓							✓	Acc



As mentioned above, piping studies take into account the requirements to provide free spans to allow thermal expansion of lines.

Such flexibility is required to prevent exceeding the stress in the line and to limit the forces on equipment nozzles. This is particularly critical at the inlet and outlet of pumps. Excessive forces on pump nozzles could cause the pump to get misaligned with its driver leading to mechanical damage. For all types of equipment the codes provide maximum allowable loads on nozzles.

Once piping studies have been completed, the proposed layout is verified by calculation by the **Piping Stress Analysis** group.

Not all lines are subject to calculations, which take a lot of time. Lines subject to calculations are called critical lines. These are lines with high or low operating temperatures, which are therefore subject to high thermal expansion, and that are not flexible, i.e., which have large diameter and high wall thickness. Lines at the discharge and suction of rotating machinery are also **critical lines.**

The criteria used to define which lines shall be subject to detailed analysis are defined in the **Stress Analysis design criteria specification.** Lines are usually classified in 3 categories:

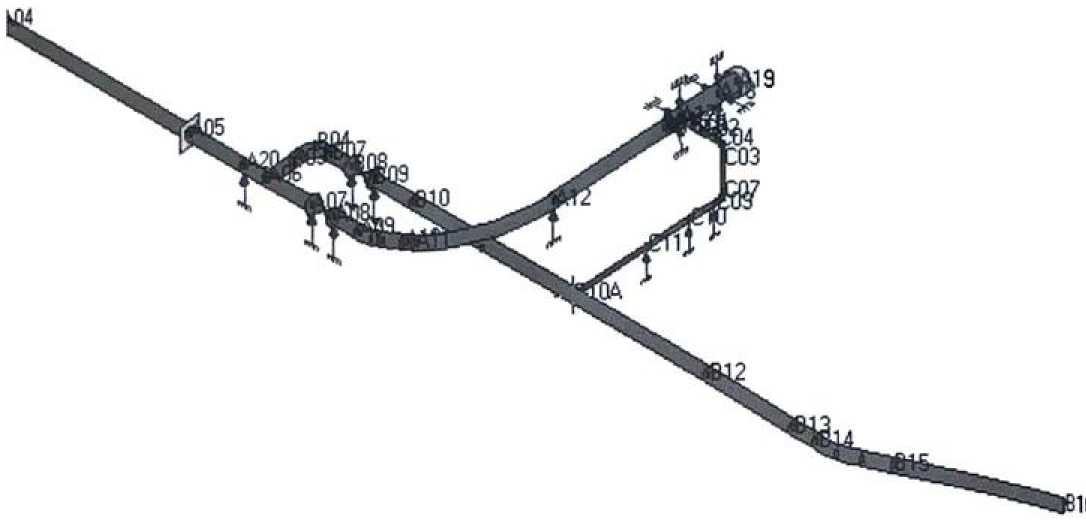
- Level 1: lines not subject to any calculation. The routing and supporting is done directly by the designer based on standard practices.
- Level 2: lines subject to simplified analysis, using simple formulae or chart.
- Level 3: critical lines, subject to detailed analysis

The classification of lines is made according to their materials of construction, temperature change, diameter, thickness and type of connected equipment. The chart below shows the classification for low pressure carbon steel lines connecting non-fragile equipment.

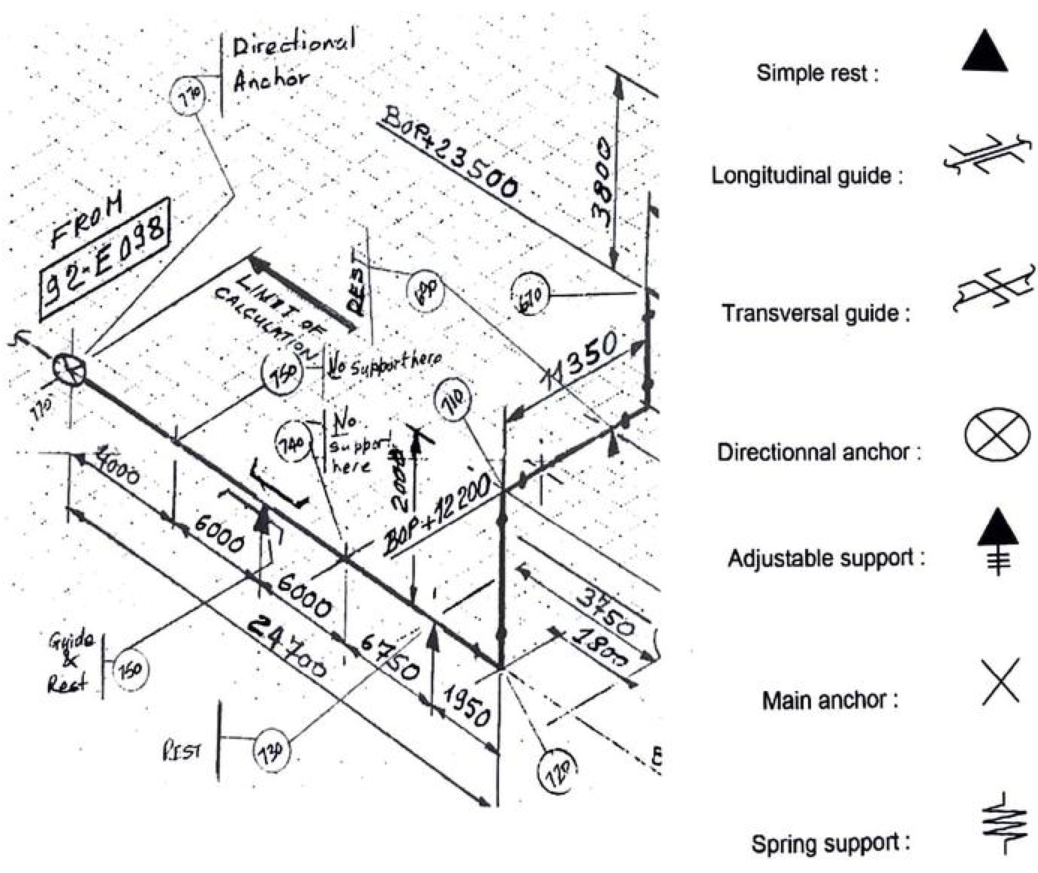
ΔT/Dia	2-4	6-12	14-24	26+
350-400	2	3	3	3
250-350	1	2	3	3
200-250	1	1	3	3
150-200	1	1	2	3
0-150	1	1	1	2

ΔT(°C) is the difference between line maximum operating and the line installation temperature.

The detailed calculation done for critical lines is performed using a finite element calculation software.



The line is modelled, as per the proposed layout and its supports (type, positions), as defined and shown on the stress sketch included in the Stress Calculation Note.



The line mechanical design conditions, in particular its maximum operating temperature and mechanical characteristics (material of construction, wall thickness) are input to the software.

The software calculates the stress at the various points of the line when subject to possible combinations of loads between thermal expansion, internal pressure, weight, wind, seismic, hydrostatic test, on-site or towing acceleration and hull deflection (for Off-Shore) and occasional loads: surge, PSV reaction.

Check is then made that the stress is within the maximum allowable limit for the line material. For lines connecting equipment, check is made that the moments and forces at equipment nozzles is below the allowable limit, such as the ones defined by the codes for pumps. The results are recorded in the **Stress Calculation Note.**

2.6. **RESULTS**

2.6.1. Stresses

a) Maximum operating calculated stress is 336.1 MPa < 448 MPa at node 10940,

b) Maximum primary calculated stress is 125.7 MPa < 310 MPa at node 6440,

c) Maximum secondary calculated stress is 206.7 MPa < 323 MPa at node 10940.

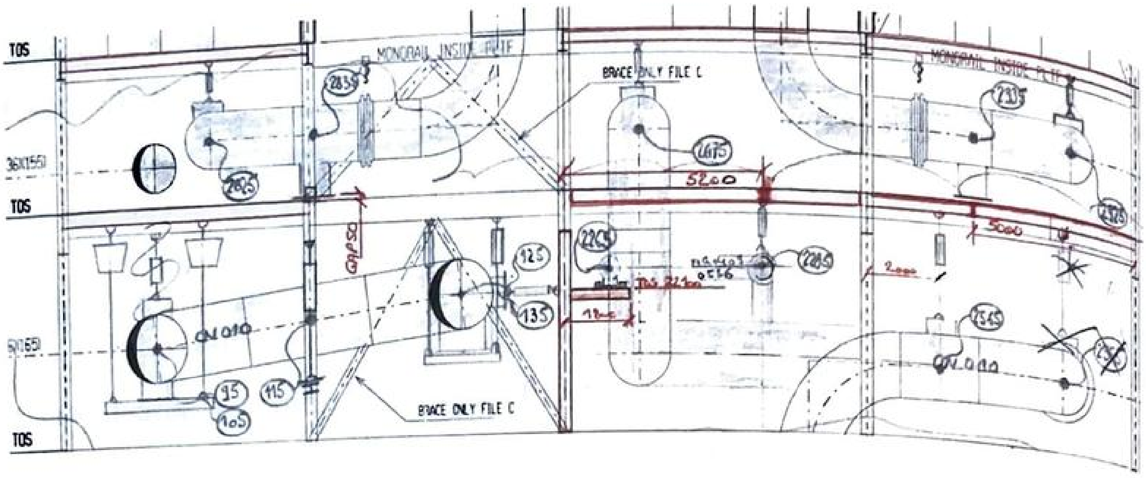
2.6.2. Loads on nozzles

W+D1+T1+P1+F1+F2 DESIGN CONDITIONS

NODE	EQUIPMENT	NOZZLE ITEM	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)
1690	D-002	N3 8" 2500#	2940	-19397	-2174	-8514	-10186	141
1730	D-002	N3 AT THE SHELL	2940	-22578	-2174	-9332	-10186	-1217
550	D-002	N1	-44534	14341	-1885	12587	9766	49525
10590	S-101	N3 16" 2500# AT THE SHELL	-13412	-28622	-19325	49581	-21324	8078
ALLOWABLE LOADS FOR S-101			65526	65526	65526	105151	105151	105151

The software also provides the loads that the line imposes on the supporting structure at the location of its supports. These loads shall be transferred to Civil discipline for input into the design of the supporting structure (process structure, pipe-rack).

This transfer is done by issuing the **Piping Load Study.**



Calculation note	Node :	Case :	Fx (KN):	Fy (KN):	Fz (KN):	Mx (KN):	My (KN):	Mz (KN):
		W (NC)	-5	-86	0	0	0	0
CN010	335	W	-5	-86	0	0	0	0
	SB	Thermal:	16	13	0	0	0	0
		W (Hydro)	0	-196	0	0	0	0
		W (NC)	0	-97	1	0	0	0
CN010	365	W	0	-97	1	0	0	0
	SG	Thermal:	0	1	-24	0	0	0
		W (Hydro)	0	-222	2	0	0	0

The Stress & Support discipline reviews the structural drawings before they are issued for construction to make sure that the structural members required for line supports have been incorporated.

Besides critical lines, as defined above, other lines are subject to stress check:

- Line subject to water hammer, also called surge,

In case of sudden closure of a valve or shutdown of a pump stopping a large liquid flow, a hammer effect can induce forces in the pipework. The resulting constraints in the line and on its supports must be checked.

Lines that could be subject to water hammer are liquid lines with long straight lengths, such as rundown lines. Process performs the dynamic simulation, based on valve closure time or inertia of pump, and provides Piping stress with the pressure/time curves for detailed pipe stress analysis.

- Line subject to slug flow,

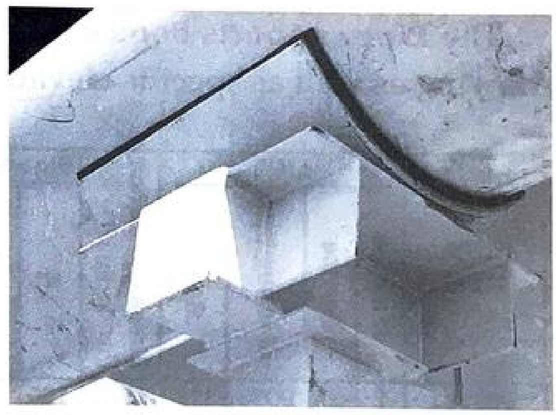
Gas lines in which liquid could accumulate are subject to slug flow. Liquid accumulates in the low points of the line up to the point when it obstructs the gas flow and is then suddenly swept resulting in a pack of liquid, called a slug. When the line changes direction the liquid slug creates forces in the line and its supports.

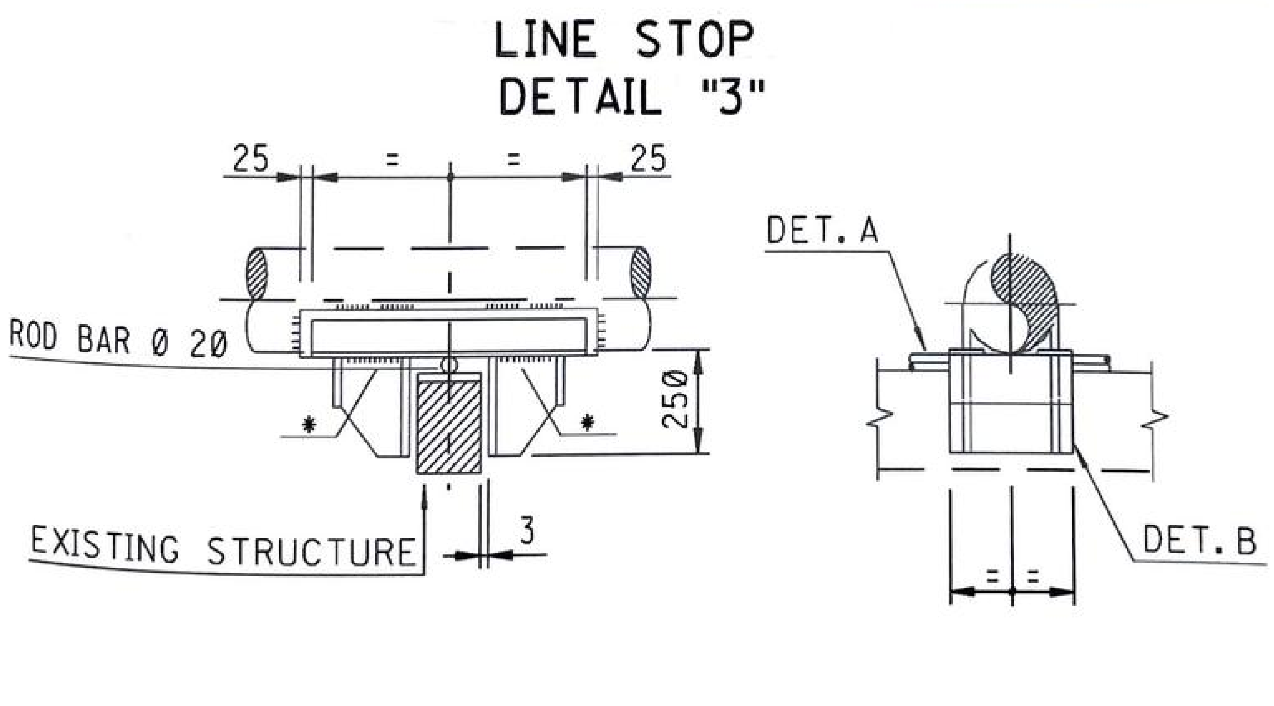
A list of lines subjected to slugging flow is issued by Process to Piping stress. This document gives the fluid velocity, density and forces to be taken into account for each line when the slug occurs.

- Lines subject to 2 phase flow, as indicated on P&IDs, whose supporting is reinforced,
- Lines subject to vibration: an analysis of the vibration mode of the first 20 meters of the lines connecting vibrating equipment is performed. Piping vibration modes are checked against excitation frequency of equipment.
- Lines subject to occasional high flows, such as depressurization lines. The Acoustic Induced Vibration (AIV) can lead to fatigue failure at small bore connections, welded tees, etc. The line thickness might need to be increased to cope with the calculated acoustic power level.

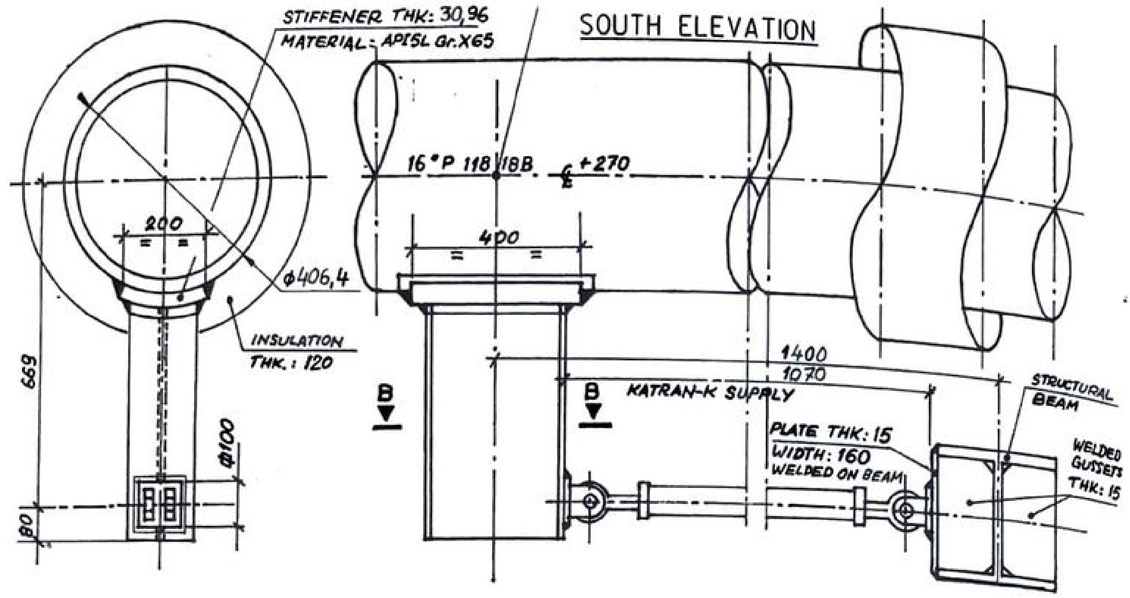
The stress analysis and support studies of Glass Reinforced Polymer (GRP) lines are done by the GRP pipe material vendor as it is a special material whose properties cannot be modelled as simply as steel.

Once the line supports have been defined (location, function), their design must be done and a drawing issued for their fabrication. A standard design is used wherever possible. This allows mass prefabrication as per the Pipe support standard drawings.





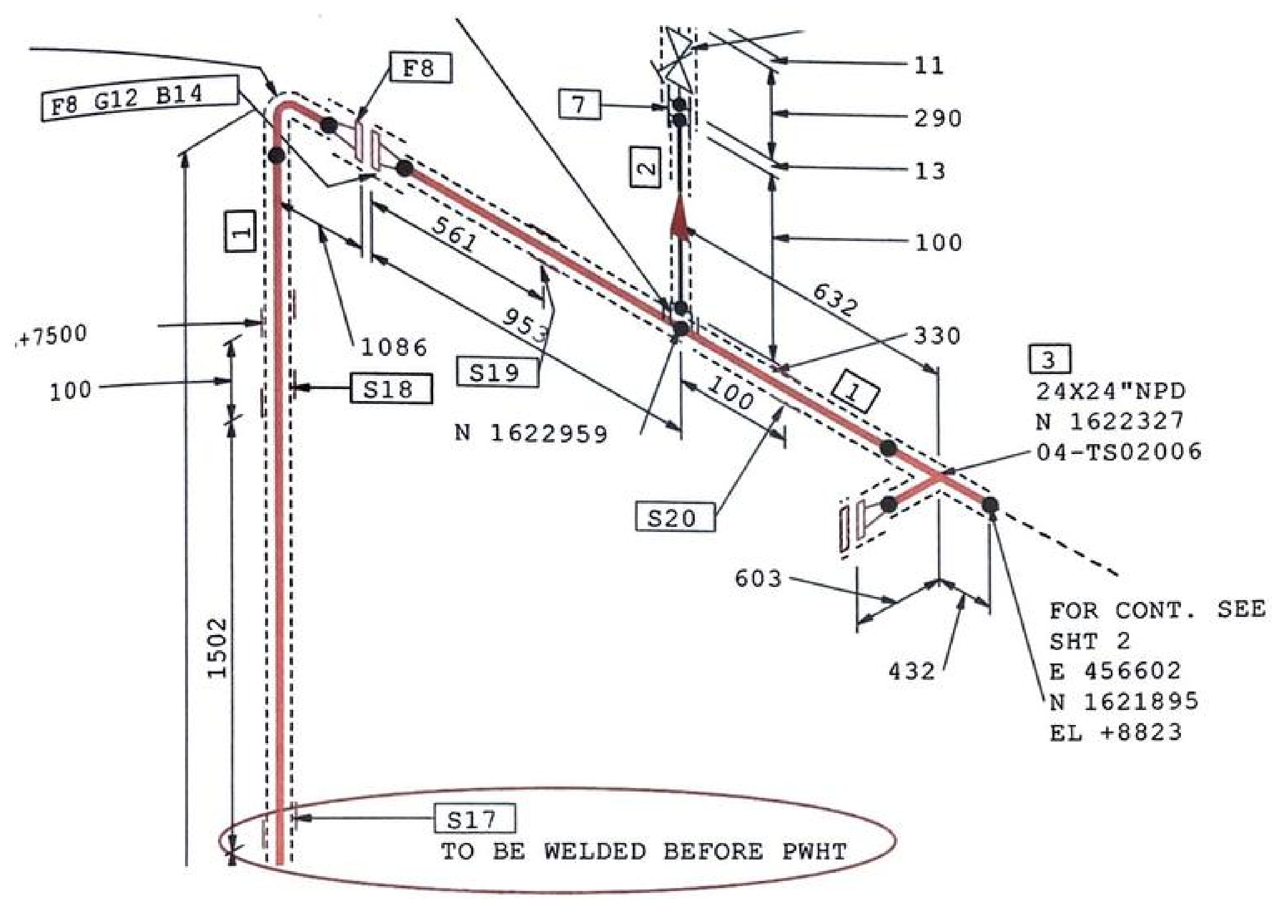
A few pipe supports, called **Special pipe supports**, are non standard, for which individual drawings are issued by the Piping Support group.



The **Pipe supports book** contains the list of all supports, the reference of the drawing as well as specific elevation and dimensional information.

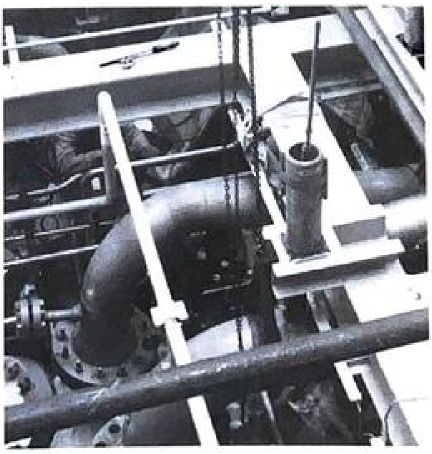
SUPP. ITEM	LINE				Stress calculation note N°	Standard		Remarks
	Ø Inches	Service	Line number	Spec.		N°	TYPE	
S08501	2	UA	005S	11U		160	LE1	gap = 0
S08502	2	UA	004S	11U		160	LE1	gap = 0
S08503	2	UA	003S	11U		160	LE1	gap = 0
S09536	20	P	601	18A	03	/	/	X 174760 Y 144250 EL 242954 see dwg S14536
S09537	20	P	601	18A	03	/	/	X 164060 Y 144250 EL 242954 see dwg S14537
S09538	20	P	601	18A	03	/	/	X 153360 Y 144250 EL 242954 see dwg S14538

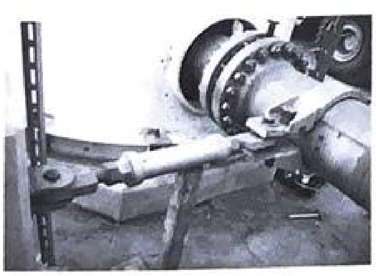
The supports are modelled in the 3D model. They appear on the Piping isometric drawings.



PT NO	COMPONENT DESCRIPTION	DIAM. (NS)	CMDTY CODE	IDENT CODE	QTY
	PIPE SUPPORTS				
17	4002A-6804* -HR01 002 El:5898 180 -WR07 24 E1 200 S-STD CS, including trunnion cut length 16in, sch S-STD, 255.8mm El: 5898 180 -WE01 24 in B 500 S-XS CS El: 5898 180	24		..	1
18	4002A-7733 -CR03 24 200 300 CS El:7400 90.	24		..	1

Lastly, the Stress & Support group is in charge of issuing the Material Requisitions for special supports: spring supports and rigid struts (shown here), sliding plates, expansion joints.

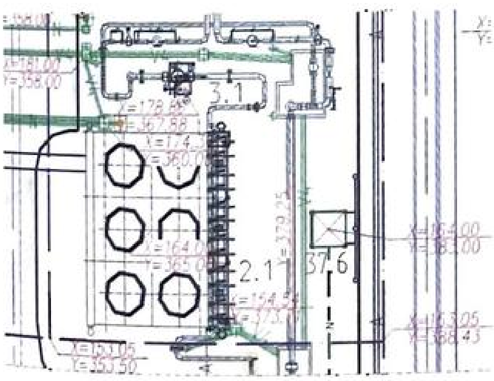




Chapter 10

3D model

Plants, specially Off-Shore platforms, are usually congested due to the limited space available. Several disciplines install their equipment in the same limited space: equipment, pipes, supports, structural steel, cables, etc. This must be coordinated in order to avoid interferences, e.g., pipe and structural steel members installed at the same place, etc.



This coordination used to be done in 2D, by superimposing the various discipline location drawings that were at the time and for that reason done on transparencies, e.g., piping, foundations, underground piping, cable routing plans, all having the same coordinate system, etc.

Superimposing drawings then became a functionality of 2D design softwares such as AutoCAD, which allow the various disciplines to work in independent superimposed layers identified by different colors on the screen, e.g., cable sleeves in green, pipes in black... At any time in its design, the piping engineer can display the civil layout in order to check for civil interference with its own design.

Computer Aided Design systems are now in 3 dimensions, allowing to build a 3D model of the Plant. Models of Plants used to be made using glue and plastic parts. This is now replaced by virtual (digital) 3D models, which are stored on a server and can be accessed by many users at the same time and from different locations.

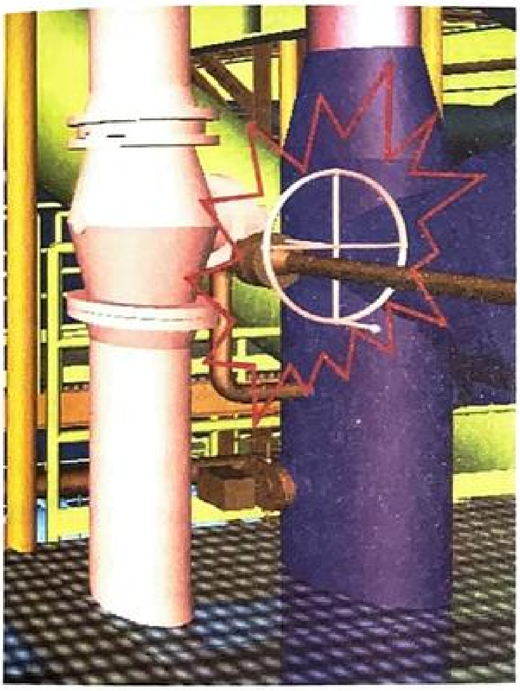
The 3D image of the future Plant is easily understood by everyone. It is used to check and optimize the design and to extract construction drawings and bill of materials.

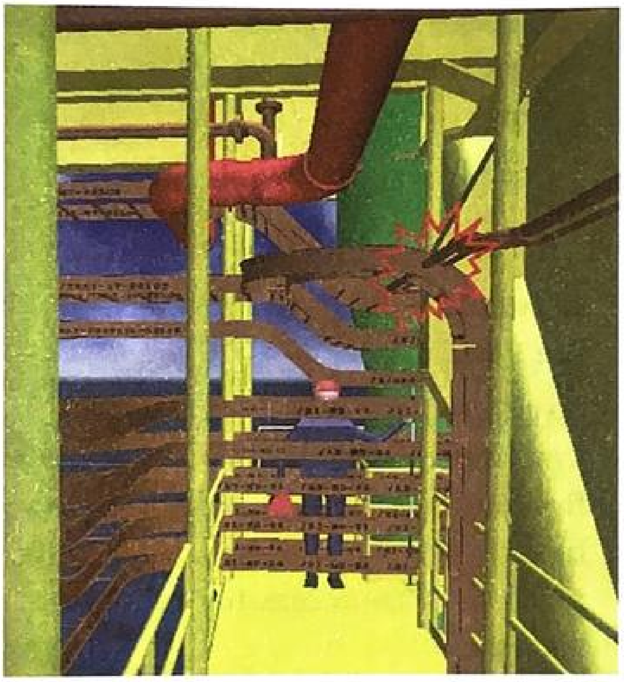
All significant materials are modelled to scale. The model reflects exactly what the Plant will be. All buildings, roads, escape ways, structures, equipment, pipes, pipe supports, insulation, valves, valve operator gear, cable trays, junction boxes, etc. are modelled in details by each engineering discipline.

The use of a 3D model is particularly useful for Off-Shore platforms, where space is limited and its use shall be optimized.

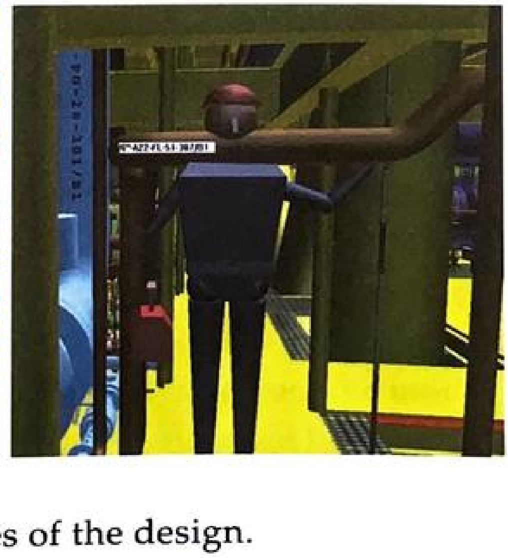
The 3D model is instrumental to check line routing, operator access, location of instruments, fire & gas detectors, fire fighting equipment, utility stations, etc.

Using such a system allows to identify and clear interferences between disciplines in congested areas. Besides manual visual review of possible interferences in the model, the system can perform automatic clash checks, in order to pinpoint the interferences left unnoticed.





Formal model reviews are conducted with the Plant Owner.



These reviews are usually performed at 3 stages of the design.

Model contents, review purpose and aspects to be reviewed are defined for each review to ensure focus. They are typically as follows:

First (30%) model review, also called Plot Plan model review:

- Scope: finalize the Plot Plan.
- Content: Equipment and 30% of piping is modelled, i.e., all lines on PFDs.
- Outcome: after incorporation of COMPANY's comments, the Plot plan is released as the base for the design (IFD).
- Aspects reviewed: Unit location, equipment location, main access and escape routes to facilities, major piping routes indicated on PFDs, arrangement around LLI, location of main manifolds, space around equipment for maintenance, platforms for main operation access.

Second (60%) model review:

- Contents: 60% of the piping is modelled, i.e., all 4 inch and larger lines on the P&IDs.
- Aspects reviewed: location of individual items (valves, instruments, junction boxes, panels), arrangement around equipment, location of fire fighting equipment, confirm space around equipment for maintenance based on vendor requirements, handling equipment (hoist/davit), platforms for access for operation.

Third (90%) model review:

- Contents: 90% of Piping is modelled, i.e., all 2" and larger lines on the P&IDs
- Aspects reviewed: access to all remaining items (flanged joints, etc.), location of remaining items (utility stations, etc.).

Comments are recorded during the reviews with corresponding model snapshot.

Date:	Second Model Review Report and Follow-Up	
Rev: B1		Page 1 Of 47

Comment Tag n°	Unit n°	Check Date	Line / Equipment n°	STATUS
2348	1000/2000/3000	11/02/2011	01-V0804/02-V0804/03-V0804	PENDING

COMMENT DESCRIPTION
Provide access for blind handling
CONTRACTOR'S RESPONSE

After the review the Engineer addresses the comments, provides answer to the Client until close-out.

Each review allows to check and freeze some aspects of the design that can then be used as a base for further development. The first model review, for instance, freezes the Plot Plan.

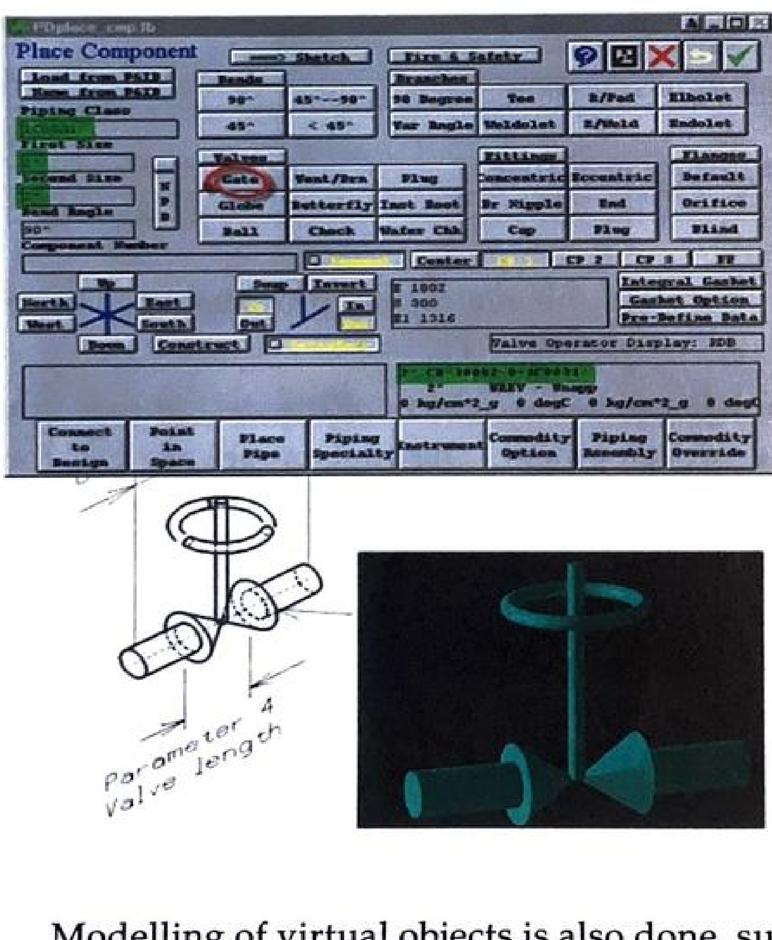
Model reviews demand that disciplines do an early modelling, based on preliminary information, earlier than they would do for their own purpose of extracting their construction drawings.

Ideally all disciplines, e.g., structural steel, piping, etc., not only inputs its design objects (steel structure beams and columns, pipework, valves, etc.) in the model but also performs its design in the model itself, rather than in individual discipline software, and issues directly its construction drawings from the model. This ensures that the latest information is in the model, e.g., if a steel beam depth has recently been changed from 1,000mm to 1,200mm, the pipe router will see it immediatly and be able to locate its pipe at the right elevation so that the latter will not clash with the steel beam.

This has become the norm and today all construction drawings (Plot plan, Piping isometric and GAD, civil area drawings, structure drawings, foundation plans, JB and instruments location drawings) and Bill of Materials (Piping, pipe supports, insulation, etc.) are extracted from the 3D model.

Items modelled include one-off items, such as a pressure vessel, a package, a motorized/control valve, an in-line strainer, and standard items, such as a steel section, a piping elbow, etc. which are part of a catalogue. Using a catalogue allows to define each standard item, complete with detailed dimensions and specification, only once. This information will then appear on all occurrences of this item.

Building catalogues in the model is required prior to modelling. This requires a lot of time. The 3D model set up is nowdays on the critical path of engineering activities.



Modelling of virtual objects is also done, such as volumes reserved for escape ways, travel of dismantled equipment/parts during maintenance, etc.

Modelling of equipment is first done with estimates of equipment dimensions. Indeed, actual dimensions of equipment, which are sized by vendors, are not known initially.

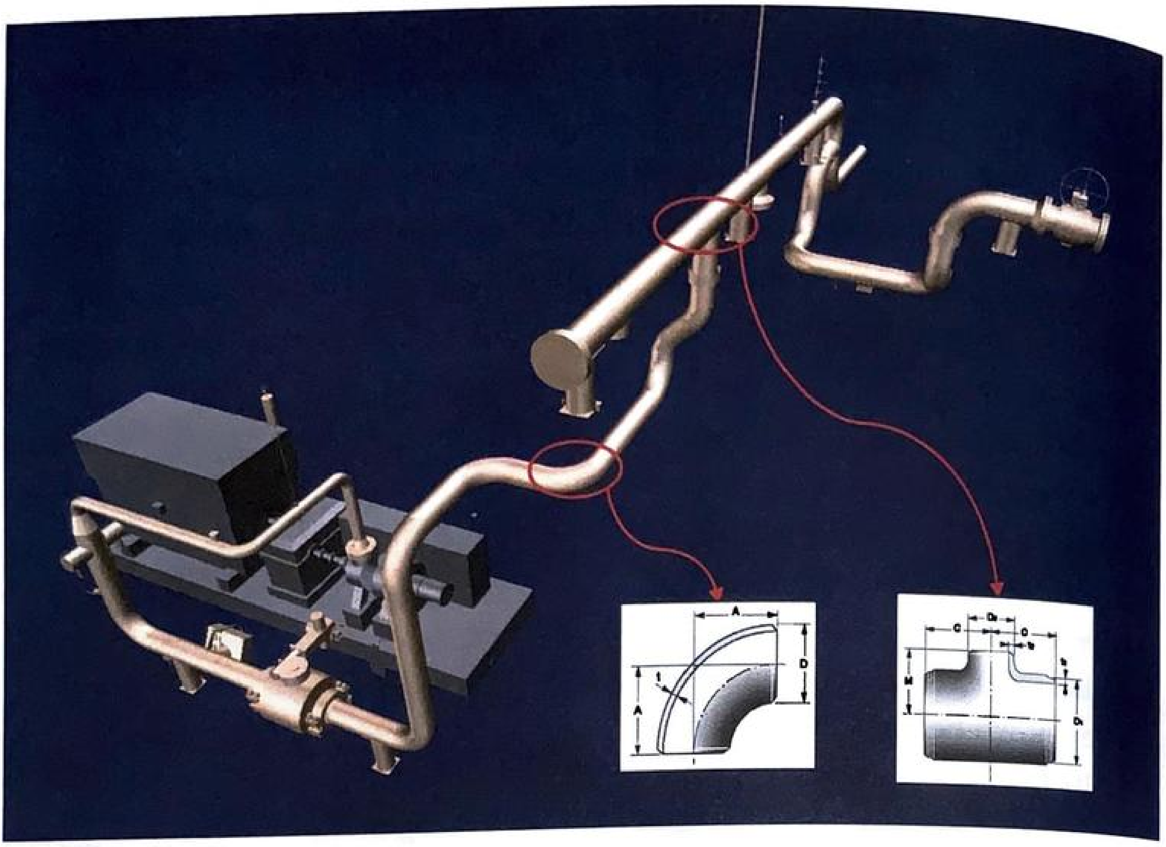
Once vendor information becomes available, the equipment model is up-dated based on vendor drawings: exact dimensions, shapes, nozzle orientation, etc.

A register of items modelled, complete with indication of reference and revision of the vendor drawing, is maintained in each discipline to this end.

Modelling is not only done for large equipment, but also for smaller ones, such as motorized valves, particularly in Off-Shore environment where space is limited. Dimensions of actuators which can be very big, are non standard. Those dimensions will not be known before sizing has been done by the valve vendor.

Once equipment have been modelled and main pipe ways have been defined, lines are modelled in the 3D model.

Lines are modelled using the items from the catalogue for the corresponding piping class. This allows a very fast "just pick and place" modelling, provided one has populated the catalogue with all items before hand.



When extracting the piping Isometric drawing from the 3D model, dimensions and specifications of all items come automatically from the catalogue.

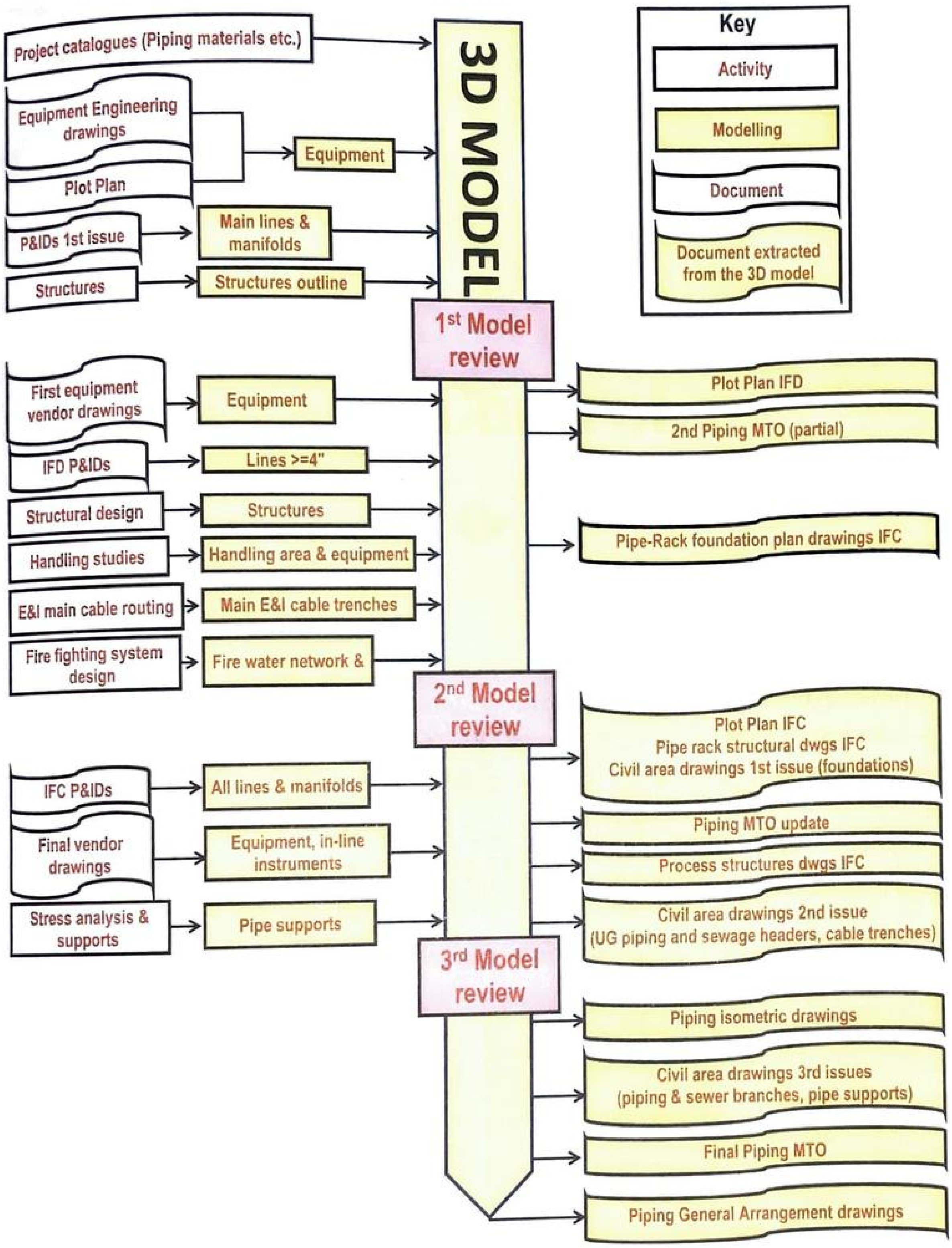
The overall list of materials (straight pipes, ellows, tees, flanges, etc.) is extracted from the model.

Such Material Take Off (MTO) are extracted several times, as design progresses. See chapter 9 for details.

On Off-Shore projects, the model is also used to determine the global module/platform weight and centre of gravity, from the individual components weight and centre of gravity.

The flowchart on the next page shows modelling activities of the various Engineering disciplines and the main documents extracted from the 3D model.

This flowchart shows today's 3D-model centered Engineering development process.


Key
Activity
Modelling
Document
Document extracted from the 3D model
3D MODEL
Project catalogues (Piping materials etc.)
Equipment Engineering drawings
Plot Plan
Equipment
P&IDs 1st issue
Main lines & manifolds
Structures
Structures outline
1st Model review
First equipment vendor drawings
Equipment
IFD P&IDs
Lines >=4"
Structural design
Structures
Handling studies
Handling area & equipment
E&I main cable routing
Main E&I cable trenches
Fire fighting system design
Fire water network &
Plot Plan IFD
2nd Piping MTO (partial)
Pipe-Rack foundation plan drawings IFC
2nd Model review
IFC P&IDs
All lines & manifolds
Final vendor drawings
Equipment, in-line instruments
Stress analysis & supports
Pipe supports
Plot Plan IFC
Pipe rack structural dwgs IFC
Civil area drawings 1st issue (foundations)
Piping MTO update
Process structures dwgs IFC
Civil area drawings 2nd issue (UG piping and sewage headers, cable trenches)
3rd Model review
Piping isometric drawings
Civil area drawings 3rd issues (piping & sewer branches, pipe supports)
Final Piping MTO
Piping General Arrangement drawings

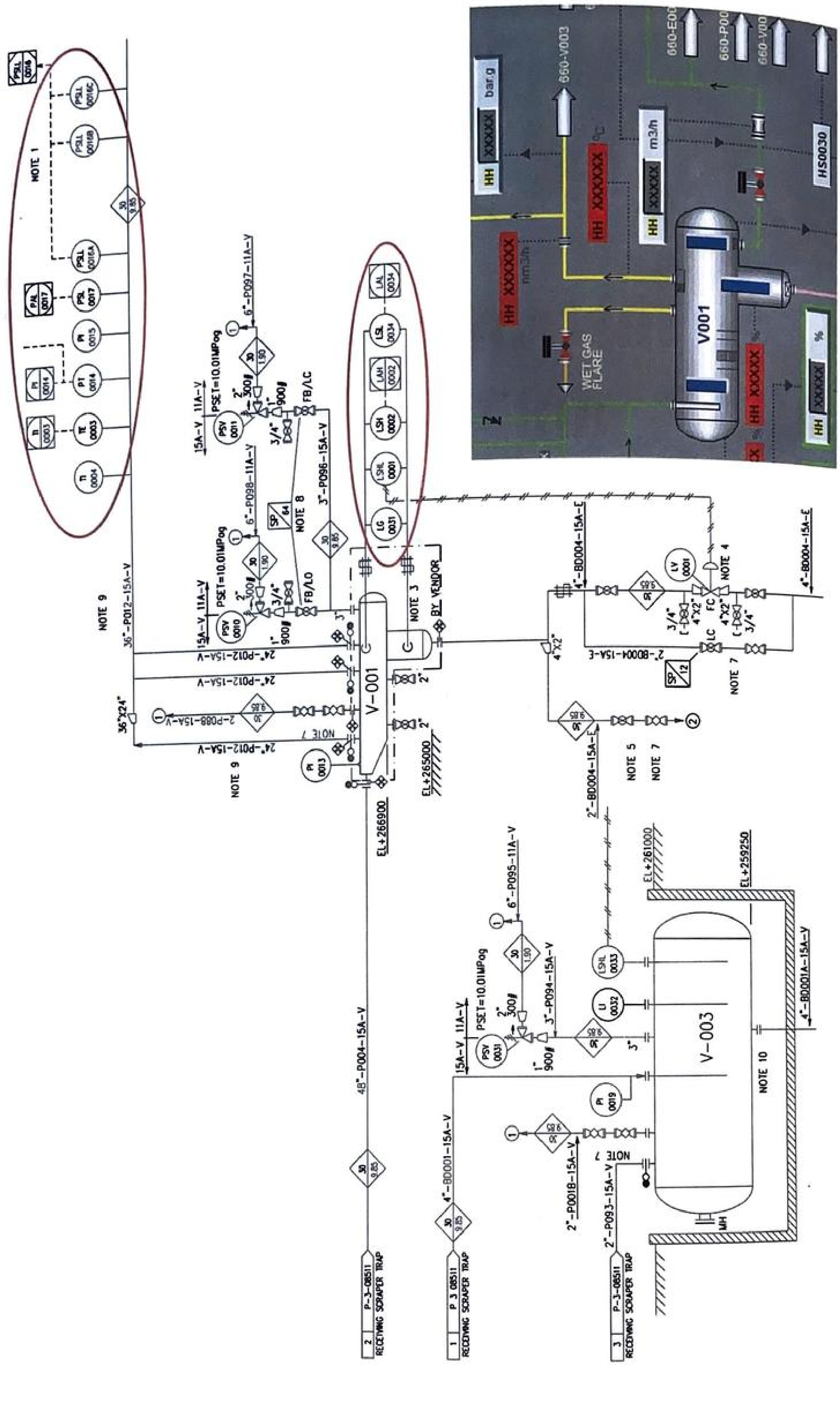
Chapter 11

Instrumentation and Control

Instrumentation and Control (I&C) design starts from the P&IDs, on which all required instruments, controls and automations have been shown by the Process discipline as required for:

- process monitoring,
- process control,
- process safety (alarm, shutdown).

Process not only defines and shows on the P&IDs the required process value to be measured (pressure, temperature, flow) but also the required function (indication, recording, control) and whether the information shall be available locally (like pressure is, for instance, on the gauge shown here), in a local instruments panel located in the field next to the equipment, or remotely in the control room.


660-V003
bar.g
HH
XXXXX
HH XXXXXX
m3/h
HS0030
nm3/h
V001
WET GAS
FLARE
660-E00
660-P00
660-V00
%
NOTE 1
PSLL 0016B
PSLL 0016C
PSLL 0016A
PSL 0017
PAL 0017
PI 0015
PT 0014
PI 0014
TE 0003
TI 0003
TI 0004
36"-P012-15A-V
24"-P012-15A-V
2-P088-15A-V
36"X24"
NOTE 9
NOTE 7
NOTE 3
NOTE 8
BY VENDOR
PSV 0010
PSV 0011
PSET=10.01MPag
15A-V 11A-V
6"-P097-11A-V
6"-P098-11A-V
3"-P096-15A-V
FB/LC
FB/LO
SP 64
SP 12
LG 0031
LSHL 0001
LSH 0002
LAH 0002
LSL 0034
LAL 0034
LV 0001
FC
LC
NOTE 4
4"-BD004-15A-E
2"-BD004-15A-E
NOTE 5
V-001
PI 0013
EL+266900
EL+265000
48"-P004-15A-V
4"-BD001-15A-V
2"-P018-15A-V
2"-P093-15A-V
6"-P095-11A-V
3"-P094-15A-V
PSV 0031
PI 0019
LI 0032
LSHL 0033
V-003
NOTE 10
MH
EL+261000
EL+259250
4"-BD001A-15A-V
P-3-08511
RECEIVING SCRAPER TRAP
P 3 08511

Instrumentation discipline implements the requirements specified by Process:

- specifying and ordering field instruments, and all accessories necessary for their installation, i.e., accessories for instrument process and electrical connections,
- specifying and ordering the process control and safety systems, and developing their detailed functional specifications,
- producing all the drawings required for equipment and instruments installation and wiring.

All Plant instruments are logged in a master register: the instrument index. This data base is progressively filled with all information: service conditions (P,T), instrument type, signal output, material of construction, range, set point, etc.

The instrument data base centralizes all information pertaining to each instrument. Many documents (wiring diagrams, loop diagrams, etc.) and list of materials (hook-up) are produced directly from this unique data base, ensuring their consistency.

Tag Number	Instrument Type	Location	Service	Equipment/ Line	PID N°	I/O Type	Signal	System
AE -0701-1	Analyse measure	MAH	Gas metering station		P-3-08540	AI	4-20 mA	-
AT -0701-1	Analyser transmitter	SBMR	Gas metering station		P-3-08540	AI	SL	GMS
AI -0701-1	Analysis indicator	SBMR	Gas metering station		P-3-08540	-	Soft	GMS
AXA -0703-6	Apparatus failure alarm	SBMR	Gas metering station		P-3-08540	DO	24 Vdc	GMS
ASHH -0703-2	Very High dew point switch	SBMR	Gas metering station		P-3-08540	DO	24 Vdc	ESD
AT -1061	Moisture analyser	Field	Pilot gas system TC-100	S-105	P-3-08555	-		
BE -1201-1	Flame detector	Field	Power turbine TC-100		NUO/10.07/00171	AI	UV	UCS (TC-100)
BL -1201-1	Flame indicator	CMTC-100	Power turbine TC-101		NUO/10.07/00171	-	Soft	UCS (TC-100)
BXA -1201-1	Flame detector fault alarm	CMTC-100	Power turbine TC-102		NUO/10.07/00171	-	Soft	UCS (TC-100)
FT -0013	Flow transmitter	Field	Fuel gas for turbocompressors	8"-FG001-15A-V	P-3-08541	AI	4-20 mA	PCS
FO -1003	Restriction orifice	Field	TC-100 Emergency vent	4"-P107-28A-V	P-3-08514	-	-	-
FE -1005	Orifice plate	Field	TC-100 Suction	20"-P101-18A-B	P-3-08516	-	-	-
FT -1005	Flow transmitter	Field	TC-100 Suction	20"-P101-18A-B	P-3-08516	AI	4-20 mA	PCS

A data sheet is produced for each instrument, specifying the range, material of construction, etc. in order to purchase it, as well as for reference for its maintenance at Site.

Tag No 84 FV -6703A			Instrument Type	Air Actuated CV (Globe) E/P positioner
PID No RG6-D-84-1225-340			Valve Type	Control Globe
Service SM TO 84FL061			Valve Service	
			Quantity Tags	1
Manufacturer Name		53	Manufacturer	Model 667-4
Model No ET	Ser No 17982719	54	Type of Actuator	spring & diaphra Size 70
Air Failure Action FC		55	Material	
Max Shut Off Pressure 19	bar	56	Case	Yoke Stem
Leakage Class IV (standard)		57	Mechanical Design Pressure	4.1 barg
Material Corrosion Requirement		58	Actuator Force Design Pressure	
		59	Required Air Supply Pressure	4.5 barg
Line		60	Stroke Speed	within 10 seconds
Line No 84SM-60020-8"-3S1-1		61	Travel Indicator	Yes
Line Size 8 in	Schedule 30	62	Orientation	vertical up

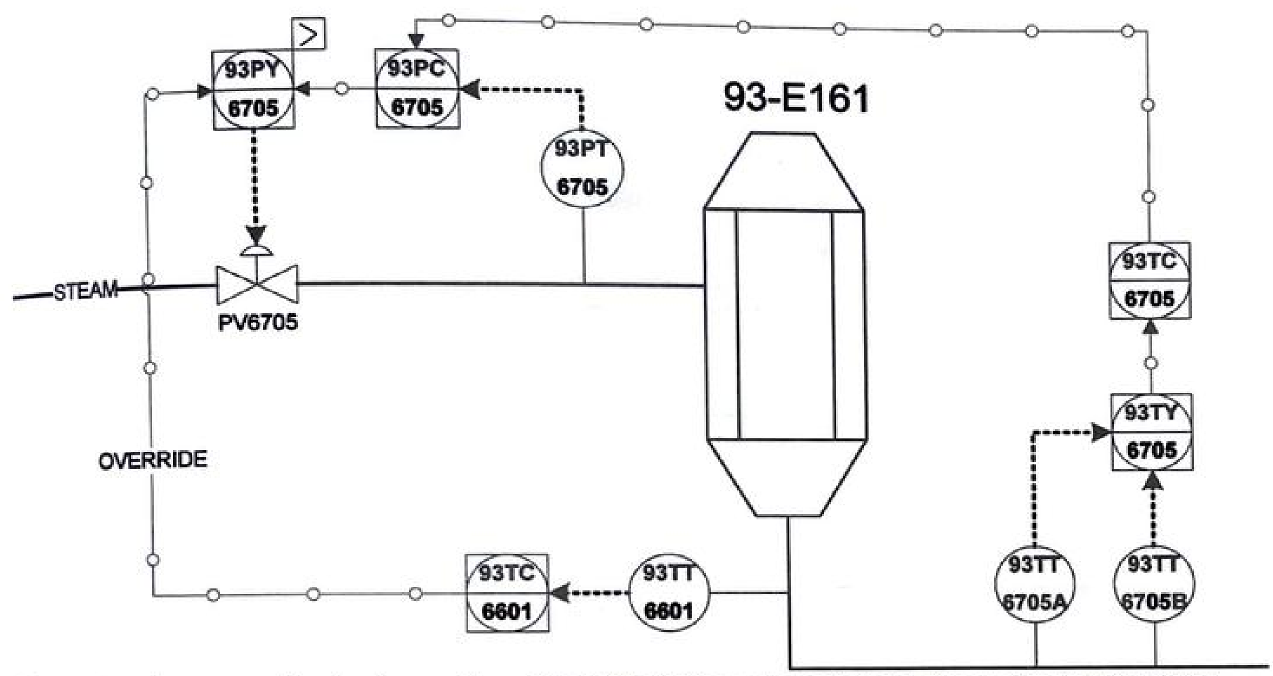
Tag No 84 FV -6703A	Instrument Type Air Actuated CV (Globe) E/P positioner
PID No RG6-D-84-1225-340	Valve Type Control Globe
Service SM TO 84FL061	Valve Service
Line No 84SM-60020-8"-3S1-1	

Process Condition	Unit	Max
Process Case		120
Case Description		Maximum flow
Phase		
Fluid Name		
Flow Rate	t/h	15
Upstream Pressure	bar-g	11.6
Downstream Pressure	bar-g	6.3
Temperature	°C	217
Density @ Condition	kg/m³	6.463
Molecular Weight		18.02
Viscosity	cP	0.0165
Specific Heat Ratio		1.402
Compressibility Factor		
Superheat Temperature	BtuIT/lb°F	
Critical Pressure	bar-a	
Vapour Pressure	bar-a	
Flash Ratio	%	
FL(Liquid Pressure recovery factor)		
Xt(Pressure drop ratio factor)		
Calculated CV		125
Required CV		129
Travel of Valve	%	95
Predict SPL	dBA	84.8
Allowable SPL	dBA	85
Max Shut Off Pressure		19
Design Pressure		18 /
Design Temperature		270 /

Monitoring and control of the process is performed by the **Process Control System (PCS)**, also called the **Distributed Control System (DCS)** due to the fact that its hardware is located in several Instrumentation Technical Rooms (ITR) located in different buildings throughout the Plant.

Control requirements, e.g., temperature in such vessel shall be controlled by varying flow of cooling medium using such control valve, are defined by Process, shown on the P&IDs and described in the Operating & Control philosophy.

Specific and complex controls are described to the control system supplier in Control Narratives which are prepared on the basis of Complex loops descriptions issued by Process.

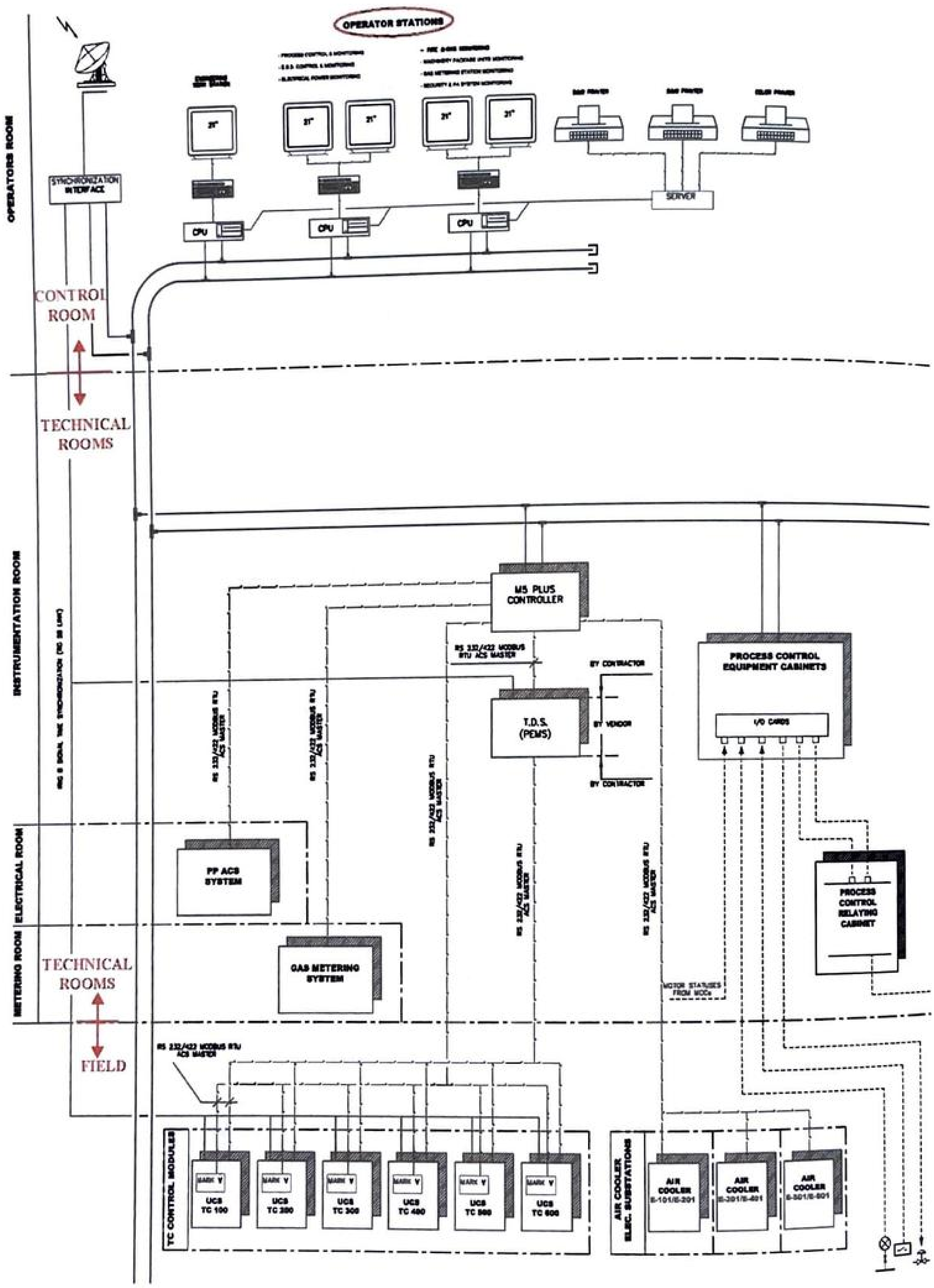


Temperature is measured by two transmitters 93TT6705A/B.Operator selects the transmitter by 93HS6705 and a ramp is performed during switchover. When one transmitter is in bad value, controller used the value from the healthy one.

Controller 93PC6705 acts on valve 93PV6705. If temperature measured by 93TT6601 (93-E161 outlet) is very low (output of 93TC6601 will increase), 93PC6705 will be overridden by 93TC6601. This in order to prevent low temperature at 93-E161 outlet (93TT6705A/B are close to GF distribution utility area). Set point of controller 93TC6601 will be lower than set point of controller 93TC6705.

The specification of the process control system entails gathering all the requirements in the System specification, and producing a number of other documents describing the system capacity, geographical spread and functionnalities.

The System Architecture drawing shows the various pieces of hardware of the system, their location, and the interfaces with other systems, including the electrical control system and the equipment control systems supplied by vendors.



Marshalling and system cabinets are located in instrumentation buildings/ rooms spread throughout the Plant. Indeed, they must be located close to the field instruments, to reduce cable lengths. Operator interface units (consoles) are centrally located in the control room.

The I/O count, which is done from the P&IDs, determines the required capacity of the system.

1) DISCRETE INPUT /OUTPUT LIST

POS.	DESCRIPTION	DI	DO	AI	AO	RTD
1	FIELD INSTRUM.	300	20	150	20	40
2	VALVES	280	60	-	-	-

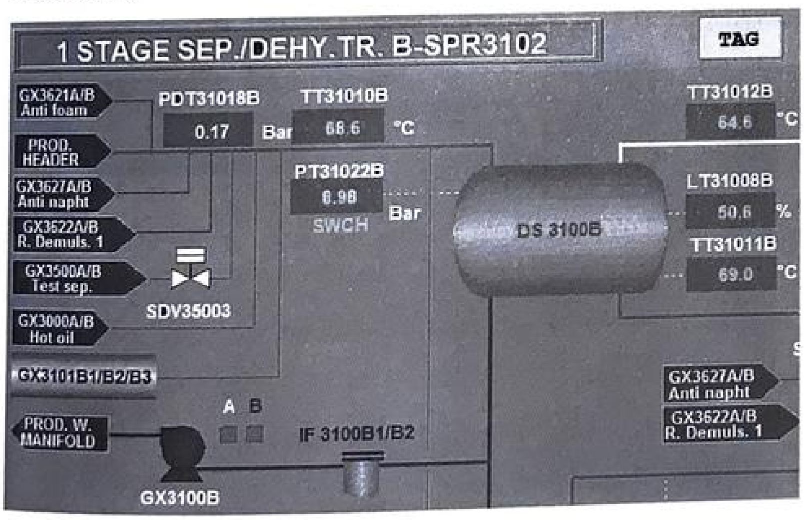
In addition a +10 % spare Input /output shall be considered and additionally +20% space for future requirements.

I/O COUNT

2) SERIAL INPUT /OUTPUT LIST

POS.	DESCRIPTION	DI	DO	AI	AO
1	TC-100	200	-	50	-
2	TC-200	200	-	50	-
3	TC-300	200	-	50	-
4	TC-400	200	-	50	-
5	TC-500	200	-	50	-
6	TC-600	200	-	50	-
7	FIRE & GAS	1200	-	-	-
8	GAS METERING	60	20	60	10
9	POWER SUPPLY	100	-	30	-

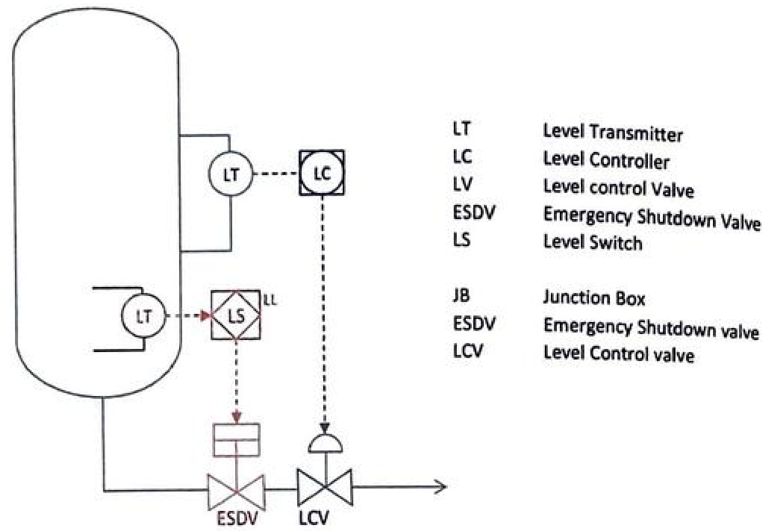
The system engineer specifies the Mimic displays to the control system vendor, i.e., the content of the views that will be displayed on the operator consoles.



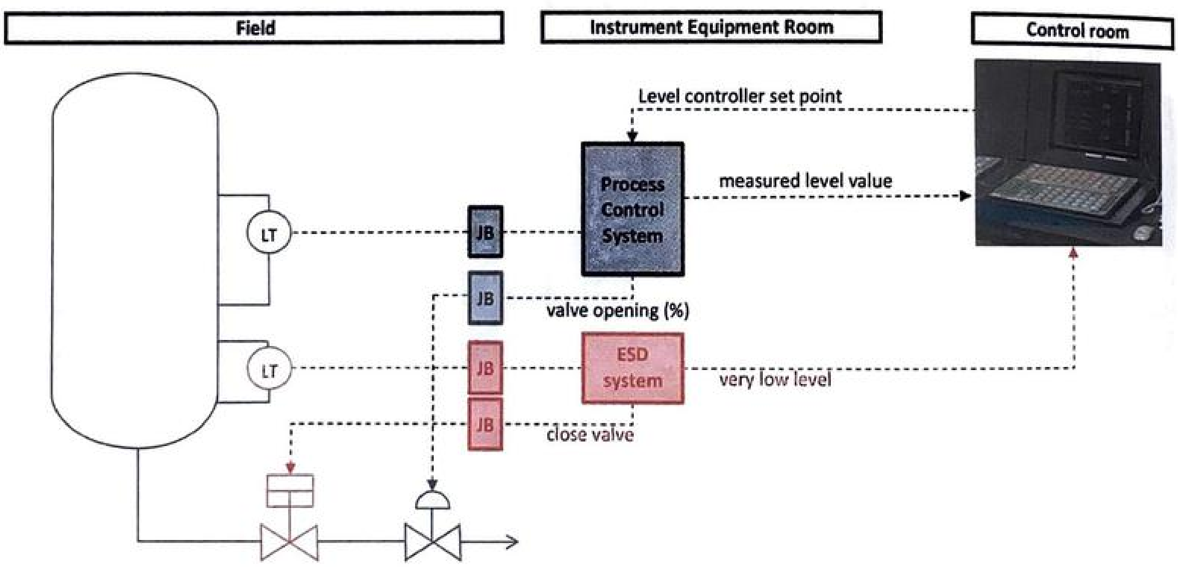
Such displays are the Plant Operator's interface with the control system. Their adequacy is critical. They are reviewed with the Client's operations staff.

Process and emergency shutdown is performed by the **Emergency ShutDown (ESD)** system, also called the Safety Instrumented System (SIS). The ESD system uses separate sensors, controllers and final elements than the Process Control System. This ensures redundancy and independence.

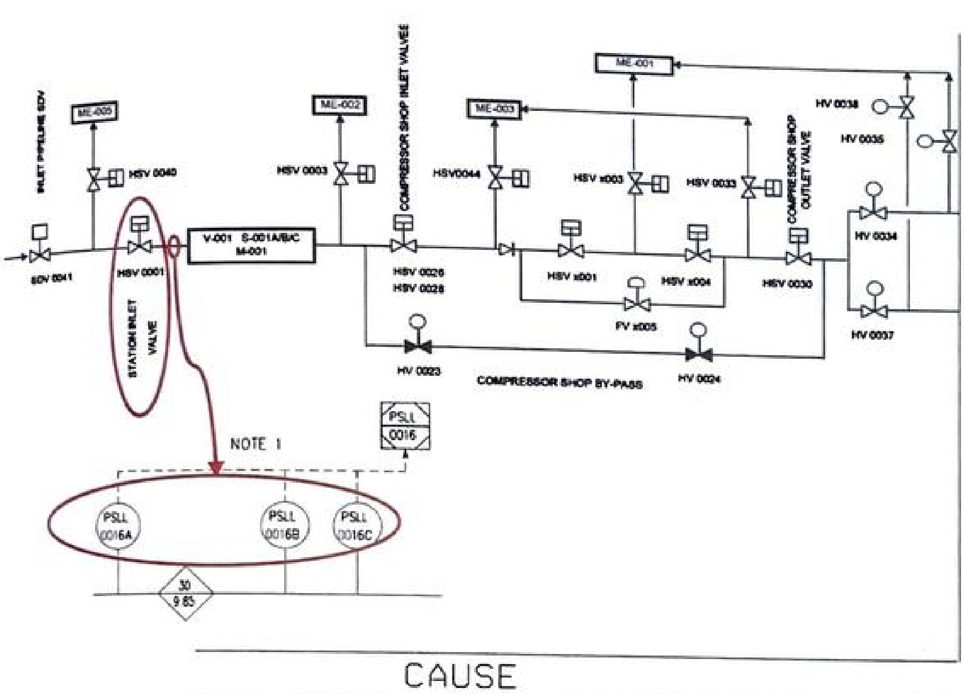
Depiction on the P&ID



Corresponding hardware



The ESD system initiates process equipment shutdown and closure of isolation valves in an emergency. The shutdown logic is implemented in the ESD system as defined by Process on the ESD Cause & Effects diagrams.



			ACTION	CLOSE	CLOSE	CLOSE		CLOSE	OPEN		CLOSE
			DESCRIPTION	PIPELINE SHUTDOWN INLET VALVE	PIPELINE SHUTDOWN OUTLET VALVE	PIPELINE SHUTDOWN OUTLET VALVE		CS ESD INLET VALVE (NOTE 7)	INLET FACILITIES VENT VALVE (NOTE 3)		SUCTION HEADER ESD INLET VALVE
			TAG. No.	SDV-41	SDV-42	SDV-43		HSV-1	HSV-3		HSV-26
INSTRUMENT TAG No.	DESCRIPTION	VOTING	SL No.	1	2	3	4	5	6	7	8
LSHH-22	HIGH HIGH LEVEL IN FILTER SEPARATORS		23					X			X
LSHH-26	HIGH HIGH LEVEL IN FILTER SEPARATORS		24					X			X
			25								
PSLL-16A/B/C	LOW LOW SUCTION GAS PRESSURE	YES	26					X			X
PSL-17	LOW SUCTION GAS PRESSURE		27								

A **SIL (Safety Integrity Level Review)** is carried out to define and check the level of reliability of all Safety Instrumented Functions (SIF), i.e., safety interlocks, appearing on the P&IDs.

It is done in two steps:

- The review of the criticality of the Safety Instrumented Functions and the assignment, to the ones identified as critical, of a required reliability level,
- The check that the Safety Instrumented Functions, to which reliability levels have been specified in step 1, indeed meet these reliability levels.

In step 1, the consequence of the failure of each SIF is evaluated: impact on personnel (Safety), economical loss and environmental. The assessment delivers a severity rating, e.g., category 1 in case of fatalities on the public, category 2 in case of serious injury on public, category 3 if impact on Plant personnel only, etc.

The likelihood of the event requiring the SIF to operate is then evaluated. For a SIF acting as a safeguard of a process controller, for instance, a likelihood of once every 10 years will be assumed.

This is indeed the common failure rate of Process Control loops.

The product of the SIF failure severity and likelihood of the event is the risk level. A matrix defines the tolerable risk area (minor consequence, low likelihood) where no action is required, and the area were the risk is not tolerable.

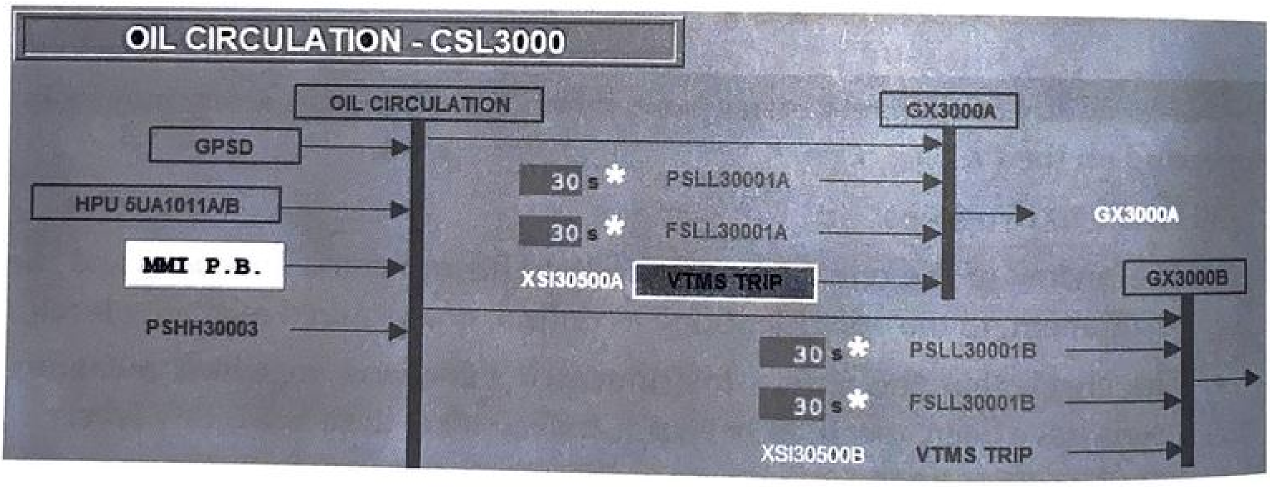
A level of reliability, called Safety Integrity Level (SIL), is assigned to the SIFs that fall in the non-tolerable risk area.

Once the required SIL level for each SIF is determined, comes the second step of the SIL Study. It consists of calculating the actual reliability achieved by each SIF. Such calculation takes into account the hardware used (component failure rates), architecture (redundancy, voting), test intervals, etc.

In case the calculated achieved reliability is below the target set in step 1, improvements are required, such as increase of testing interval, change of SIF component types and addition of components for redundancy.

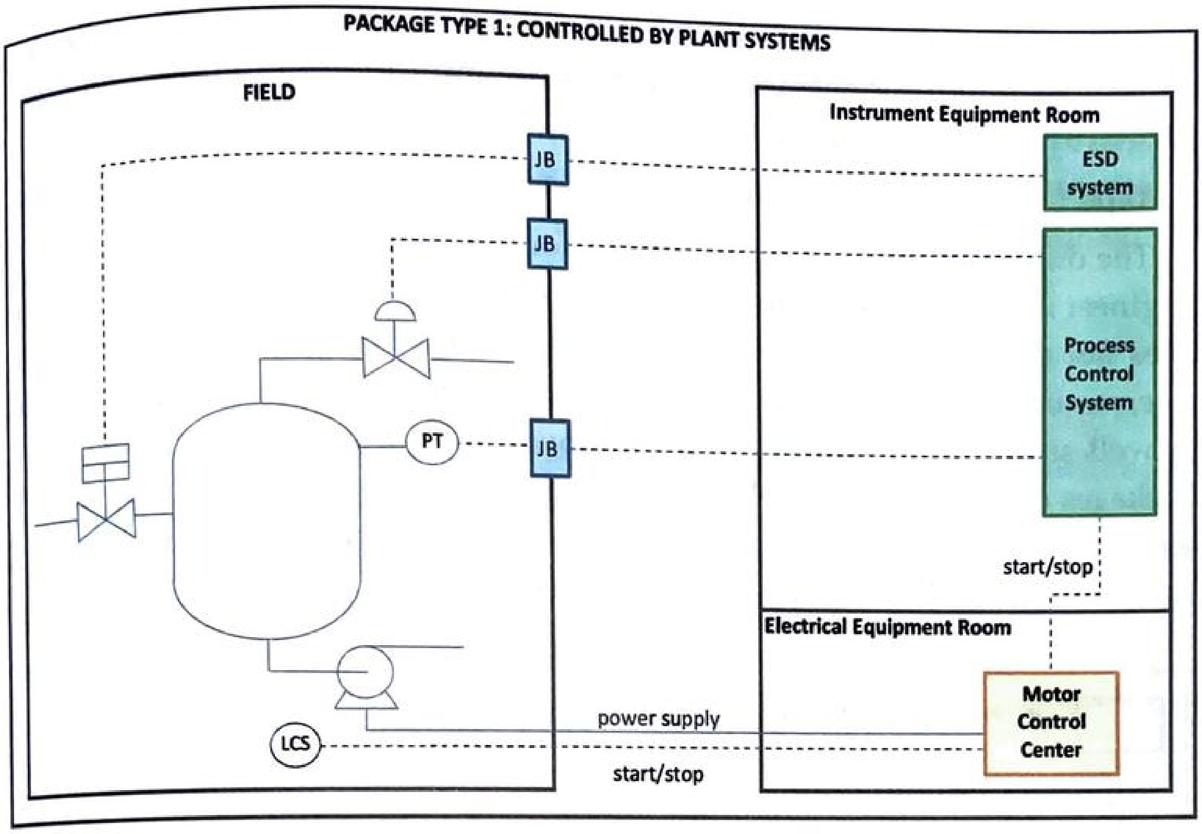
In the example shown above, three low pressure sensors had to be provided to secure the closure of the isolation valve upon detection of a major leak/line rupture.

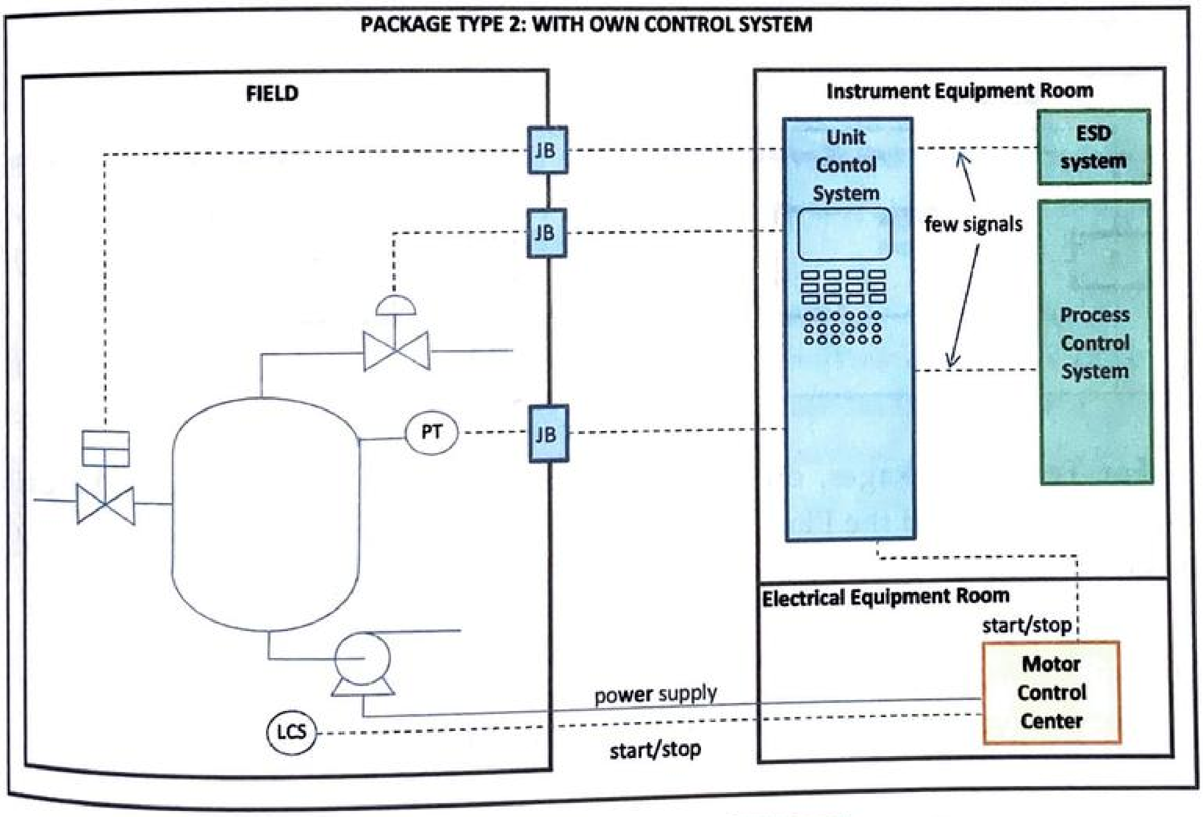
The ESD system vendor programs the automation logic in the system. The system displays the status of activation of emergency levels and implementation of actions to the operator.



The Plant Process Control and Emergency ShutDown systems are usually supplied by the same vendor who supplies what is then called the ICSS (Integrated Control and Safety System).

Equipment with complex controls, such as turbo-machinery, come with their own instrumentation and control system, called Unit Control System (UCS). Packages come with their instrumentation and may, or may not, come with their control system.



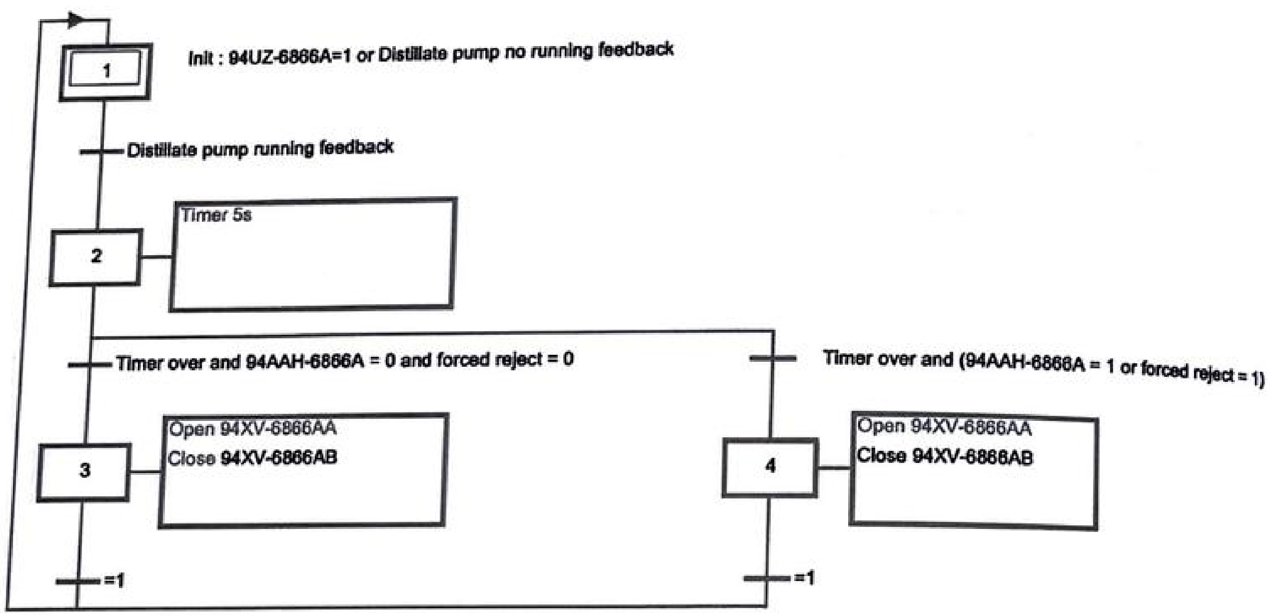


LCS Local Control Station
PT Pressure Transmitter
JB Junction Box
ESD Emergency ShutDown
Marshalling cabinet

The automation, control and shutdown functions of Type 1 Packages are implemented in the Plant ICSS while they are implemented in the Unit Control System by the Vendor for Type 2.

Type 1 and 2 differ in a number of ways for the Engineer and the Plant Owner.

The difference between Types 1 and 2 for the Engineer is that, for Type 1, the Engineer implements the automation requirements in the Plant Systems which it does not do for Type 2. In order to be able to do this, the Engineer needs to receive numerous documents from the Vendor: P&IDs, Cause & Effects diagrams as well as control, sequences and shutdown logic descriptions and diagrams. Packages often include complicated start-up sequences, such as burner light-off sequence for a fired equipment, etc. Diagrams such as the one shown below must be received from Vendor describing such sequences.



For Type 2 Packages, only a few signals are exchanged between the Unit Control System and the Plant systems. The document that the Engineer needs to receive from the Vendor is limited to the table of exchanged signals.

The responsibility of the correct implementation of the Package automation and shutdown functions lies with the Engineer for Type 1 Packages and with Vendor for Type 2. The Unit Control System of a Type 2 package is tested by the Vendor at its premises.

This is why Equipment with complex controls, such as turbines, are always supplied with their UCS for liability reasons.

The drawback of type 2 packages, for the Plant Owner, is that they bring various models and makes of hardware and software to the Plant, increasing the maintenance costs (spare parts, update of software releases, training of personnel). Hence the Plant Owner prefers type 1 packages. An alternative is also to restrict the variety of make/model of Unit control systems for type 2 packages.

The main milestones for the supply of the ICSS (manufacturing and configuration) are the **hardware freeze** and the **software freeze**.

The **hardware freeze** is the point at the control system cabinets are defined so that the supplier can start their fabrication. The terminals of the marshalling cabinets (rear side) are identical to that of the Junction Boxes located in the field. Therefore the system supplier needs to receive from the Engineer the allocation of instruments to JBs to launch the fabrication of the marshalling cabinets.

The allocation of instruments to JB requires the finalized (IFC) P&IDs, incorporating HAZOP/SIL actions, the IFC Plot Plan as well as the Hazardous area classification drawings. The Hazardous area drawings are indeed used to optimize the location of JBs. The same information is required from Type 1 package suppliers.

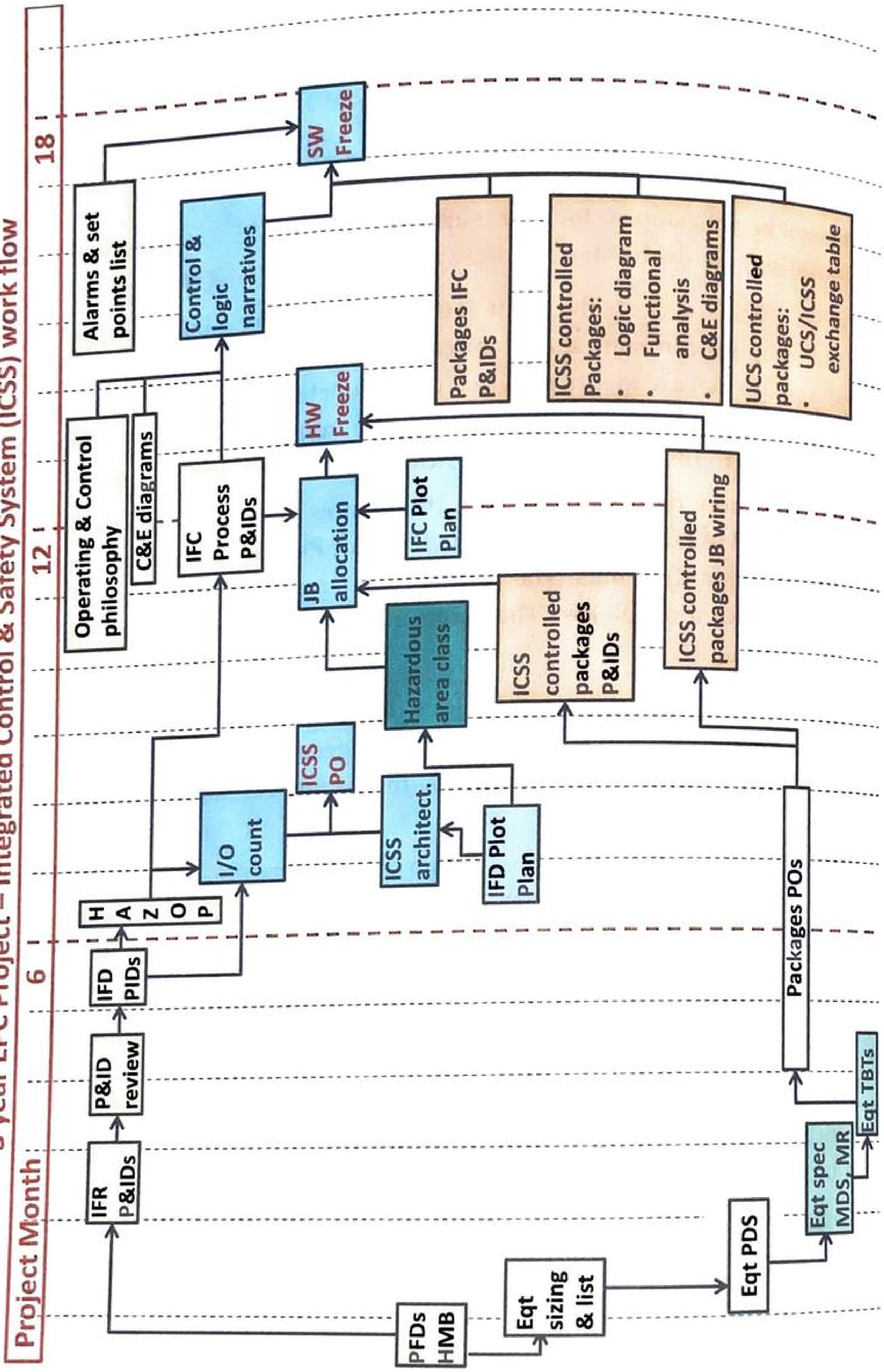
The **software freeze** requires, besides the IFC P&IDs, the Control narrative and the Safeguarding narrative and C&E diagrams. The same information is required Type 1 packages, as well as the sequences logic description and diagrams.

Obtaining the above documents from Type 1 Vendors, and finalizing such documents, is critical for the timely hardware and software freeze. Obtaining finalized P&IDs is often not possible at the date of the hardware freeze which may be done with Approved with Comments P&IDs instead. Delay in finalizing the package control, sequence and shutdown description and logic can delay the Factory Acceptance Test (FAT) of the system.

The main milestones related to the ICSS (Integrated Control and Safety System) procurement, fabrication and programming are shown on the next page for a large size 3 year EPC Project.

The following abbreviations are used: SW: Software, HW: Hardware, PO: Purchase Order.

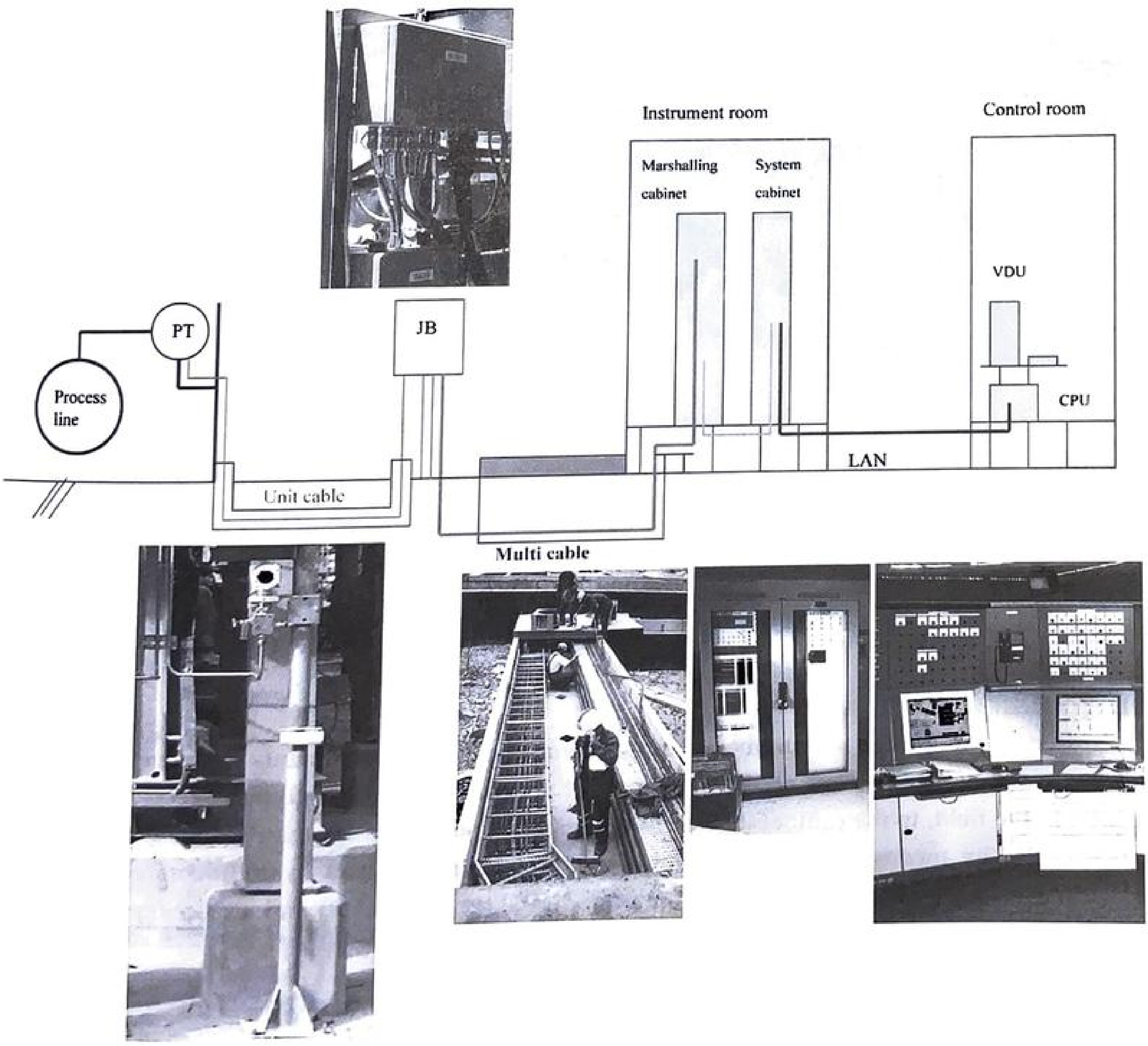
3 year EPC Project – Integrated Control & Safety System (ICSS) work flow



Besides the Plant Process Control system, Emergency shutdown system, Packages and Machinery Unit Control Systems, stand-alone systems are usually found for:

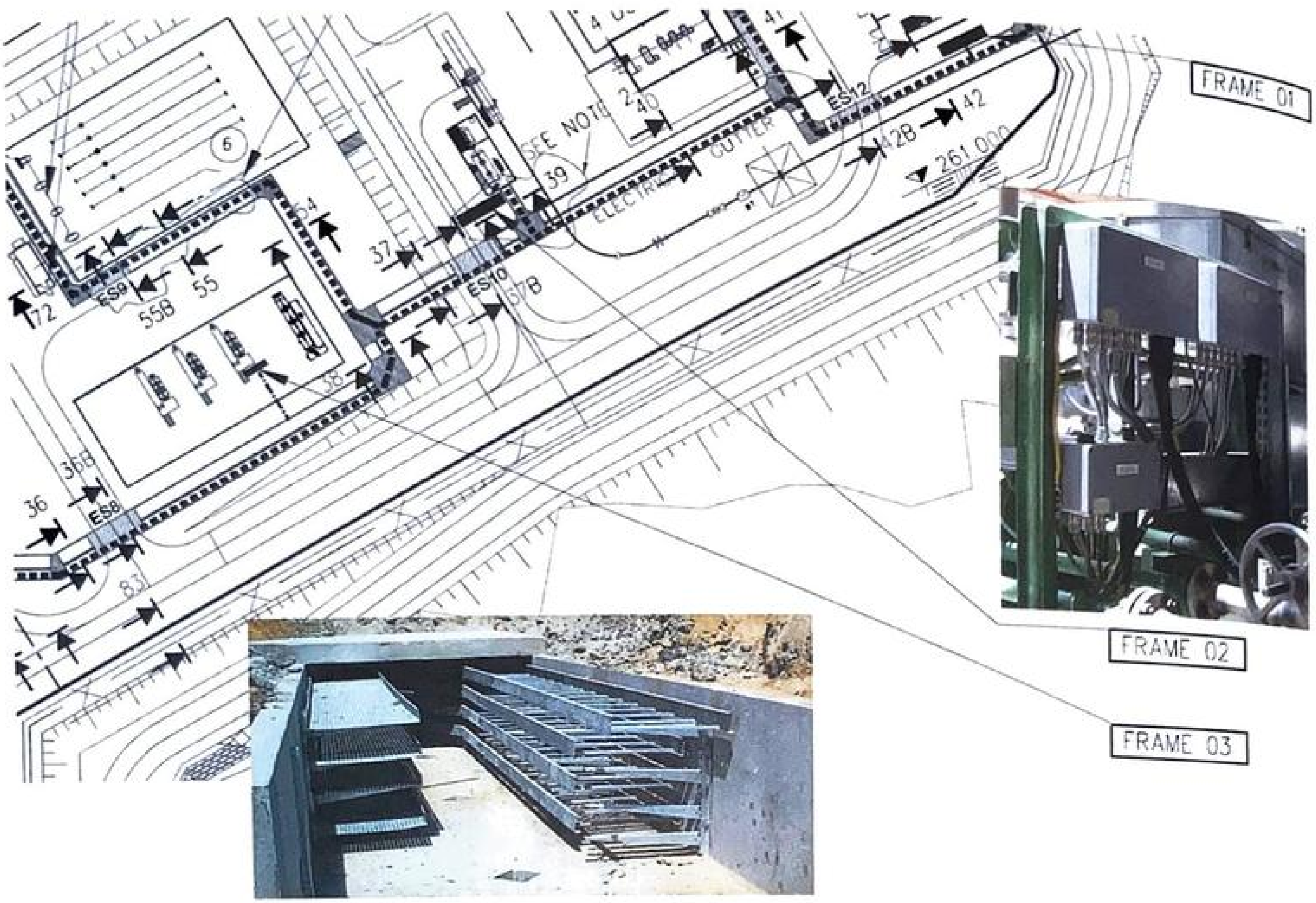
- Machinery Monitoring System (MMS) for rotating machinery vibration & temperature monitoring
- Burner Management System (BMS)
- Compressor Anti-Surge System
- Motorized valves
- Analyzers Data Acquisition system
- Fiscal Metering Systems for Custody transfer and allocation
- Storage tank data acquisition (gauging) system
- Continuous Emissions Monitoring System (CEMS)

Instrumentation equipment and materials, from the field sensor to the control room, are shown on the synoptic below.



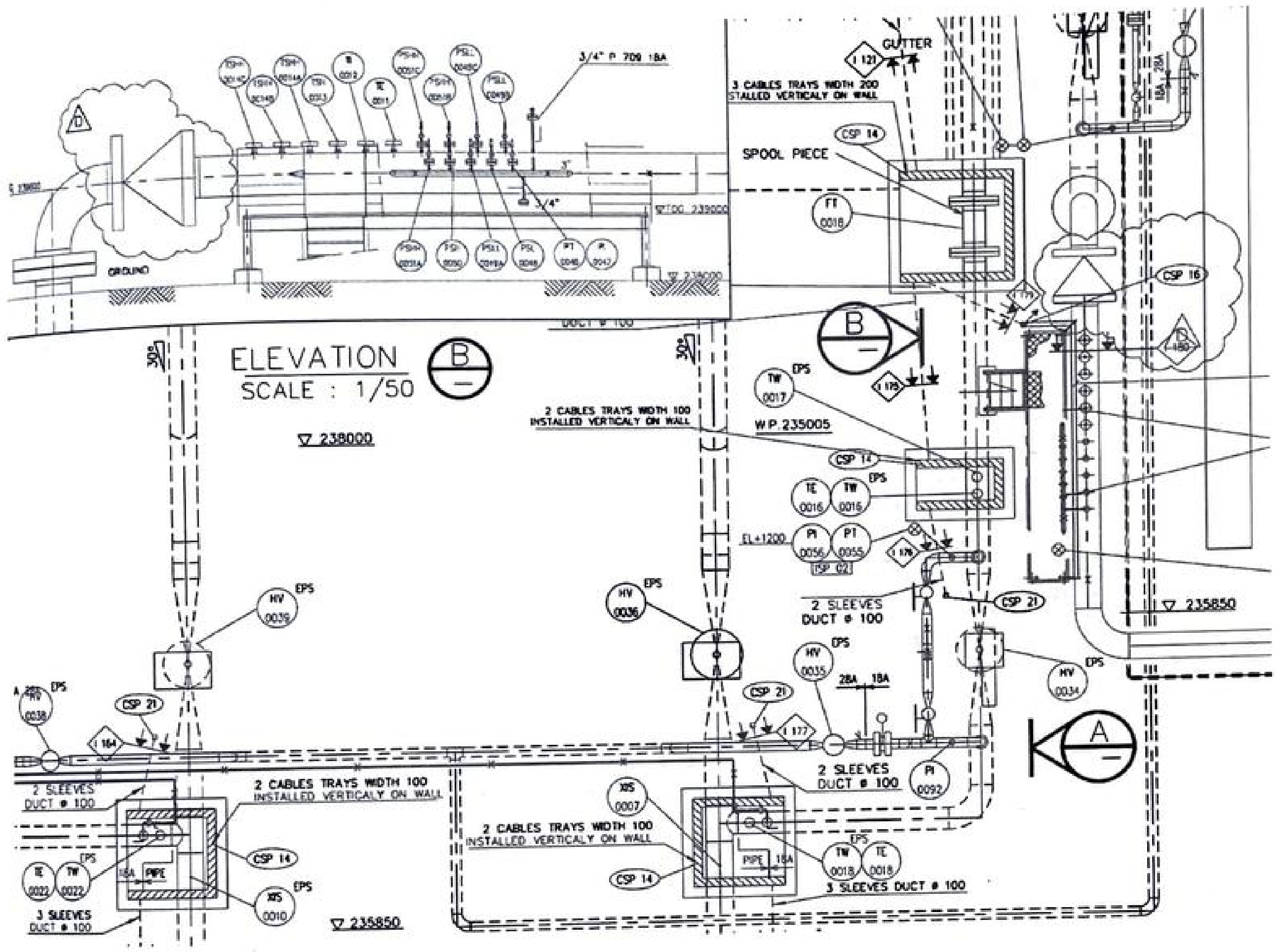
Instrumentation produces all drawings required for installation of these equipment and materials at Site, which include:

- The Main Cable Routing and Junction Box Location drawings, which show the location of the junction boxes[1] and main cable routes.

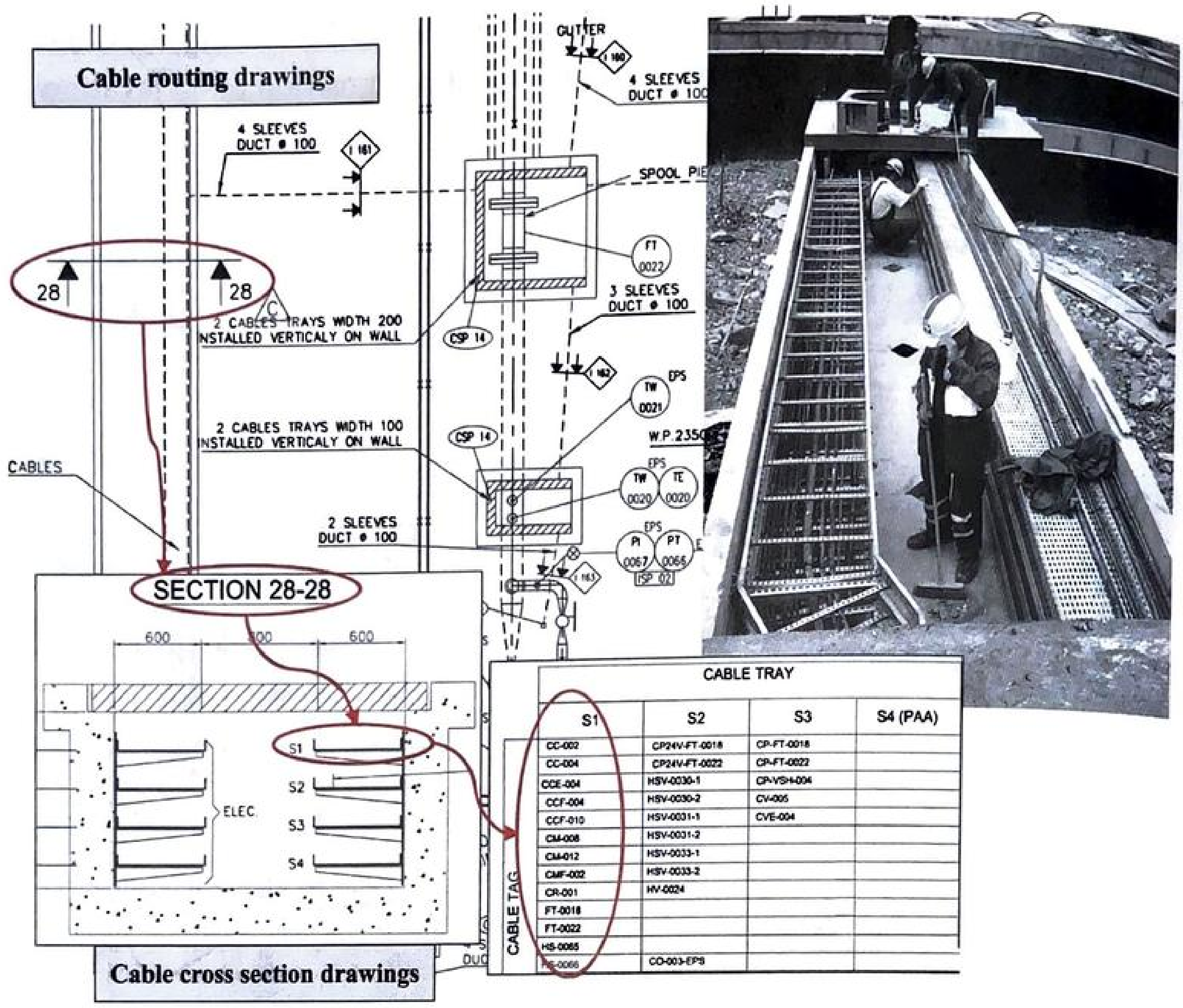


1. In order to reduce the number of cables connecting field instruments to cabinets in technical rooms, multi-core cables are used. They connect several instruments (typically 7/12/19), located nearby in the field, to the cabinet located in the instrumentation room. Instruments are connected to multi cables by means of junction boxes. Grouping of instruments in multi-core cables is done according to the nature of their signal (analog, digital, voltage level) and service/system (process monitoring, emergency shutdown).

- **Instrument location drawings**, which are derived from Piping General Arrangement drawings and show the location, position and elevation of fields instruments.



- **Cable routing drawings** showing in which cable trench/duct the cables shall be installed and **Cross section drawings** showing on which cable tray each cable shall be installed, in compliance with segregation rules, e.g., control cables and power supply cables on different trays,



- Instrument cable schedule, showing the list of cables to install, cable type, length, origin, destination and route,

CABLES TAG	CABLES TYPE	SUPPLY BY (1)	FROM	LOCATION FRAME or OTHER	TO	LOCATION FRAME or OTHER	LENGTH m	ROUTING CROSS SECTIONS
CC-004	A-T-1-19-P-2-0	CONTRACTOR	JC-004	PIG D-002	CA-052	INSTRUM. ROOM	370	I121-I119-I161-28-11B-11-9-44-4-2-1-96
CC-005	A-T-1-12-P-2-0	CONTRACTOR	JC-005	FILTER-SEPARATOR	CA-052	INSTRUM. ROOM	440	I127-35B-36-36A-71-35-35B-65-34-3-1-96
CC-006	A-T-1-12-P-2-0	CONTRACTOR	JC-006	FILTER-SEPARATOR	CA-052	INSTRUM. ROOM	440	I127-35B-36-36A-71-35-35B-65-34-3-1-96
CC-007	A-T-1-7-P-2-0	CONTRACTOR	JC-007	STATION INLET VALVES	CA-052	INSTRUM. ROOM	370	I193-I190-36A-71-35-35B-65-34-3-1-96
CC-008	A-T-1-7-P-2-0	CONTRACTOR	JC-008	DIESEL GENERATOR	CA-052	INSTRUM. ROOM	120	I350-30-70B-70
CC-009	A-T-1-7-P-2-0	CONTRACTOR	JC-009	FIRE WATER	CF-004	FIRE BUILDING	100	I185-I183-I182-I181
CC-101-1	A-T-1-19-P-2-0	CONTRACTOR	JC-101	AERO E-101	UA-101	S/S ELECTRICAL 27-1	160	I207-I205-I204-I202-I200-24-62-27
CC-101-2	A-T-1-7-P-2-0	CONTRACTOR	JC-101	AERO E-101	UA-101	S/S ELECTRICAL 27-2	160	I207-I205-I204-I202-I200-24-62-27

The Cable Material Take-Off sums up the length of all cables, by type, showing the overall quantities to purchase.

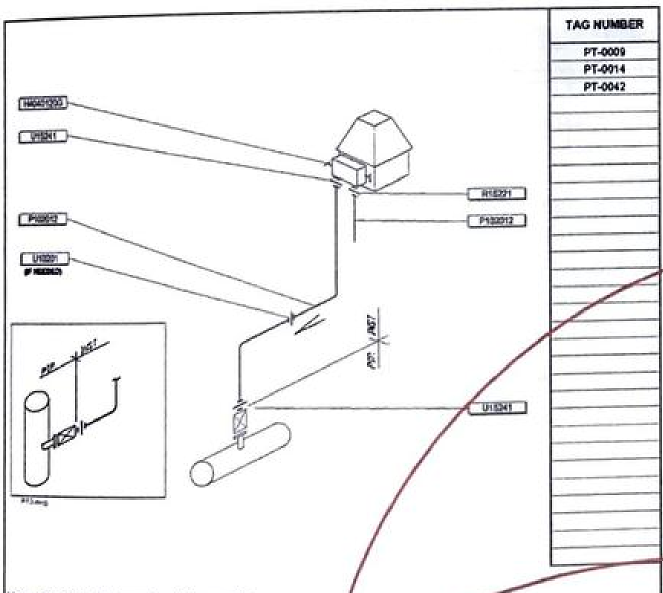
CABLES TAG	CABLES TYPE	FROM	LOCATION FRAME or OTHER	TO	LOCATION FRAME or OTHER	LENGTH m	ROUTING CROSS SECTIONS
CCE-001	A-S-1-12-P-2-0	JCE-001	FILTER-SEPARATOR	CE-051	INSTRUM. ROOM	440	I127-36B-36-36A-71-35-35B-65-34-3-1-00
AE-701	A-T-1-7-P-2-0 (1)	AE-701	ANALYSER HOUSE	MA-721	METERING ROOM	530	55B-55-54-[illegible]B-36-36A-71-35-35B-65-34-3-1-00
AE-702	A-T-1-7-P-2-0 (1)	AE-702	ANALYSER HOUSE	MA-722	METERING ROOM	530	55B-55-54-35-36B-36-[illegible]A-71-35-35B-65-34-3-1-00
AE-705	A-T-1-7-P-2-0 (1)	AE-705	ANALYSER HOUSE	MA-722	METERING ROOM	530	55B-55-54-35-36B-36-36A-7[illegible]-35-35B-65-34-3-1-00
CCE-004	A-S-1-12-P-2-0	JCE-004	PIG D-002	CE-051	INSTRUM. ROOM	370	I121-I119-I181-29-11B-11-[illegible]-4-2-1-00
ASH-703-2	U-S-1-1-P-2-0	PA-722	METERING ROOM	CE-051	INSTRUM. ROOM	20	
ASHH-1081	A-T-1-1-P-2-0	ASH-1061	PILOT GAS DRYER S-105	CA-052	INSTRUM. ROOM	240	I214-I213-I212-65-34-[illegible]
ASHH-2081	A-T-1-1-P-2-0	ASH-2061					
ASHH-3081	A-T-1-1-P-2-0	ASH-3061					
CC-002	A-T-1-7-P-2-0	JC-002					
CC-003	A-T-1-12-P-2-0	JC-003					
CC-004	A-T-1-19-P-2-0	JC-004					
CC-005	A-T-1-12-P-2-0	JC-005					
CC-006	A-T-1-12-P-2-0	JC-006					

CODE	DESIGNATION	RAW QUANTITIES (m)	CONTINGENCIES	QUANTITIES TO BE PURCHASED
A-S-1-12-P-2-0	Armoured - Fire resistant - Overall screen - 12 - pairs - 1.5mm² - Non IS	1 656	10%	1900m
A-S-1-1-P-2-0	Armoured - Fire resistant - Overall screen - 1 - pair - 1.5mm² - Non IS	9 150	20%	11000m
A-T-1-12-P-2-0	Armoured - Flame retardant - Overall screen - 12 - pairs - 1.5mm² - Non IS	8 280	10%	9200m
A-T-1-1-P-2-0	Armoured - Flame retardant - Overall screen - 1 - pair - 1.5mm² - Non IS	5 655	20%	6800m
U-S-1-1-P-2-0	Unarmoured - Fire resistant - Overall screen - 1 - pair - 1.5mm² - Non IS	3 725	20%	4500m
U-S-1-1-P-3-0	Unarmoured - Fire resistant - Overall screen - 1 - pair - 2.5mm² - Non IS	460	20%	600m

Cable Material Take-Off

- Instrument Hook-up drawings, which show mounting and connection of instrument to process lines and corresponding list of required material (tubing, manifold, connectors, etc.),

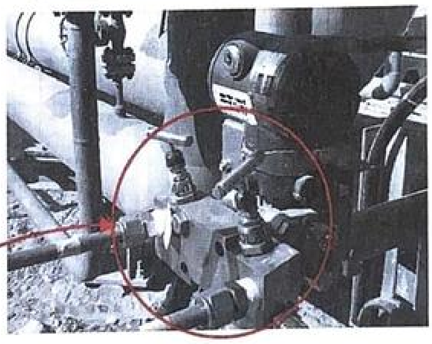
PRESSURE - GAS SERVICE
PIPING CLASS : 15 A



Note : Block manifold supply with transmitter (H4020120G)

ITEM	QTY	DESIGNATION	SIZE	RATING	CONNECT.	MATERIAL
U15241	2	Male connector	12 mm x 1/2"		OD x NPT M	AISI 316 SS
U10201	1	Union	12 mm		OD	AISI 316 SS
R15221	1	Reducer	12 mm x 1/4"		OD x NPT M	AISI 316 SS
P102012	4m	Tubing	12 mm OD x 1 mm			AISI 316 SS
H4040120G	0	Block manifold 2 valves (Gas)/D	1/2" (Proc.) / 1/4" (Drain)	6000 psi	NPT F	AISI 316 SS

Instrument Hook-up drawings



& material take-off

ITEM	QUANTITY	DESIGNATION
1	195	Gauge adapter – ½" x ½"
2	37	Block manifold 2 valves (Gas) – ½"
3	23	Block manifold 5 valves (Gas) –½"
4	0	Ball valve ½" – 12mm
5	300m	Tubing – 12mm OD x 1mm
6	200	Reducer – 12mm x ¼"
7	50	Union tee – 12 x 12 x 12mm
8	50	Female connector – 12mm x ½"
9	350	Male connector – 12mm x ½"

The **Bulk Material Take-Off** indicates the quantity of junction boxes, cable trays, small installation accessories (cable glands, cable markers, etc.), hook-up material, etc. to be purchased.

DESIGNATION	MATERIAL	RAW QUANTITIES	CONTIN GENCIES	QUANTITIES TO BE PURCHASED
CABLE TRAYS (Return flange) (d: 50mm / w: 100mm) - Note 1	HOT-DIP GALVANIZED	956m	10%	1100m
CABLE TRAYS (Return flange). (d: 50mm / w: 200mm) - Note 1	HOT-DIP GALVANIZED	419m	10%	500m
CABLE TRAYS (Return flange) (d: 50mm / w: 400mm) - Note 3	HOT-DIP GALVANIZED	690m	10%	800m
CABLE TRAYS (Return flange). (d. 75mm / w: 600mm) - Note 1	HOT-DIP GALVANIZED	8000m	10%	8800m
COVERS FOR CABLE TRAYS (w: 100mm)	HOT-DIP GALVANIZED	700m	10%	770m
COVERS FOR CABLE TRAYS (w: 200mm)	HOT-DIP GALVANIZED	419m	10%	470m
COVERS FOR CABLE TRAYS. (w. 400mm) - Without junction boxes frames	HOT-DIP GALVANIZED	660m	10%	750m
COVERS FOR CABLE TRAYS (w: 600mm)	HOT-DIP GALVANIZED	2100m	10%	2400m
HORIZONTAL TEES (Return flange) (d: 75mm / w: 3x600mm)	HOT-DIP GALVANIZED	65	10%	75
90° HORIZONTAL BEND (Return flange). (d: 75mm / w: 600mm)	HOT-DIP GALVANIZED	67	10%	75
COVERS FOR TEES (w: 3x600mm)	HOT-DIP GALVANIZED	17	10%	20
COVER FOR 90° HORIZONTAL BEND. (w: 600mm)	HOT-DIP GALVANIZED	17	10%	20

For junction boxes, the MTO specifies the number of terminals, the number and diameter of cables (for cable entries in the JB), the size of the cores (for sizing of terminals, etc.). An **arrangement drawing**, such as the one shown here, may be attached to the junction boxes requisition to provide more detailed or specific requirements.

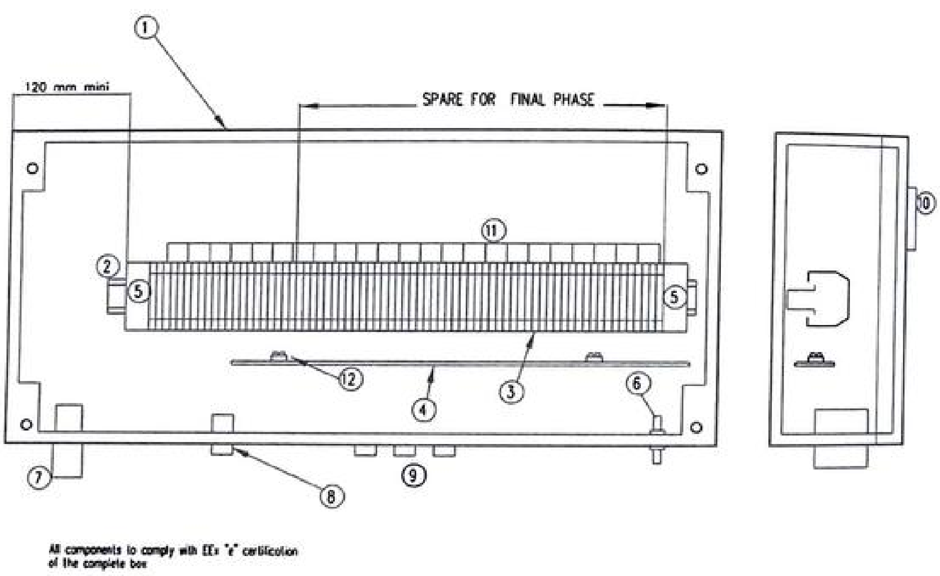
Junction box arrangement drawing

TYPICAL 1

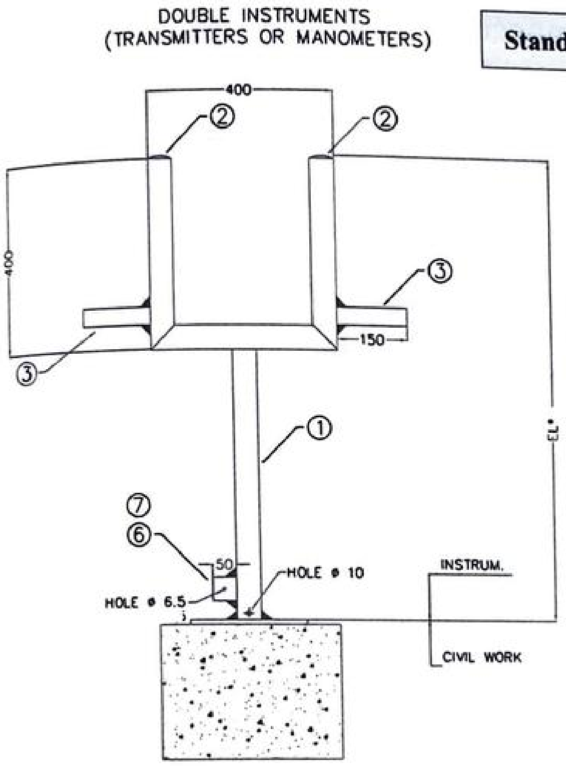
EEx e FIELD JUNCTION BOX
FOR ANALOGIC SIGNALS - TYPICAL1

MATERIAL TO BE SUPPLIED BY VENDOR

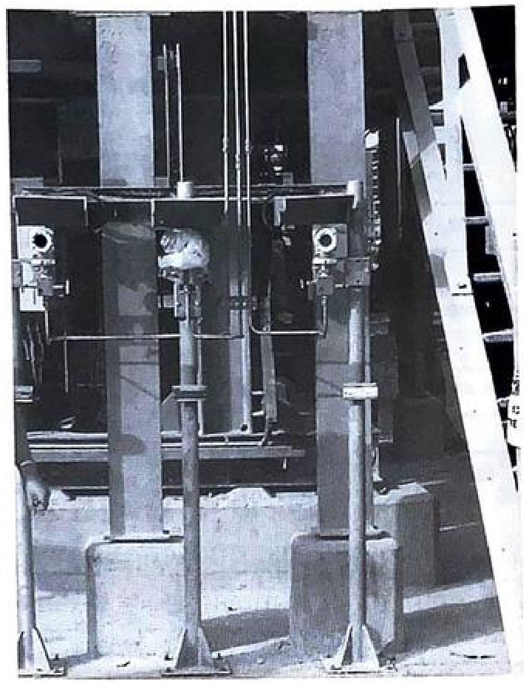
ITEM	QTY	DESCRIPTION
1	1	JUNCTION BOX EEx e x 13 (mm) FLAME RETARDANT GRP (GLASS FIBER REINFORCED POLYESTHER) IP 55 INCLUDING GASKET, BOLTS
2	1	DIN STEEL GALVANISED AND CHROMATED RAIL
3	*	TERMINAL BLOCKS EEe 2 SIDES TO SCREW WIDTH = 6 mm SECTION WIRING = 1 to 1.5 mm² PROVIDED WITH TAGGING SYSTEM COLOR OF TERMINALS = GREY COLOR OF TERMINALS = BLUE FOR "IS"
4	1	CONNECTING BAR FOR CABLE ARMOUR EARTHING
5	2	END BLOCKS
6	1	EXTERNAL MAIN EARTH CONNECTION BOLT
7	*	CABLE GLAND PVC FOR MULTICORE CABLE
8	*	CABLE GLAND PVC FOR SINGLE CABLES
9	*	PVC PLUGS
10	1	NAME PLATE OF JUNCTION BOX
11	1	CROSS CONNECTING FOR SCREENS
12	*	CLAMPING SCREW + PRESSURE CLAMP



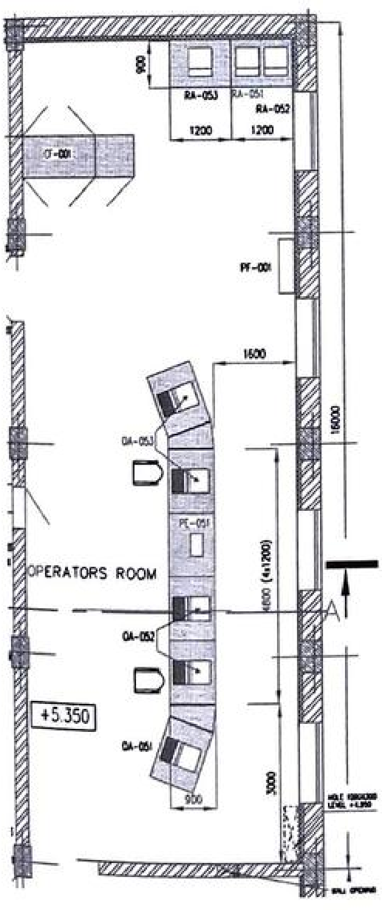
- **Standard installation drawings**, such as instrument, junction box and cable tray support drawings, earthing drawings, etc., which show typical arrangements,



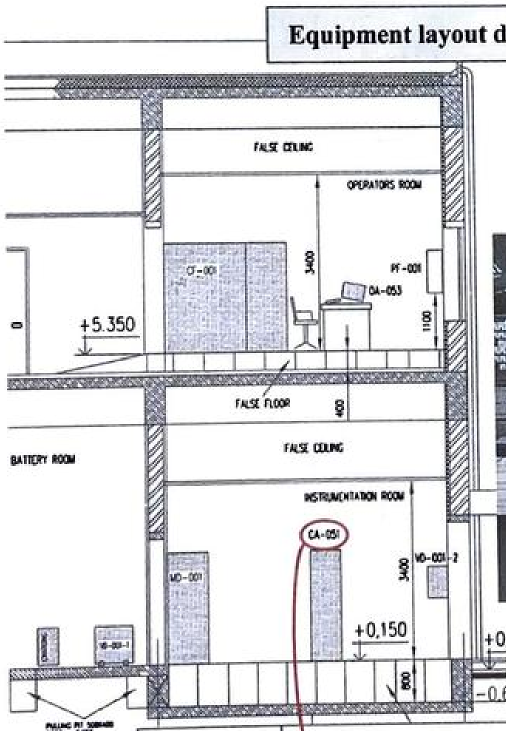
Standard installation drawings

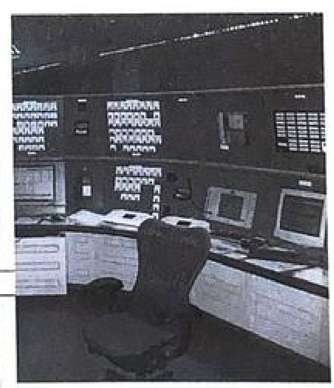


- Equipment Layout drawings, showing arrangement of cabinets inside instrumentation technical/control rooms,



Equipment layout drawing

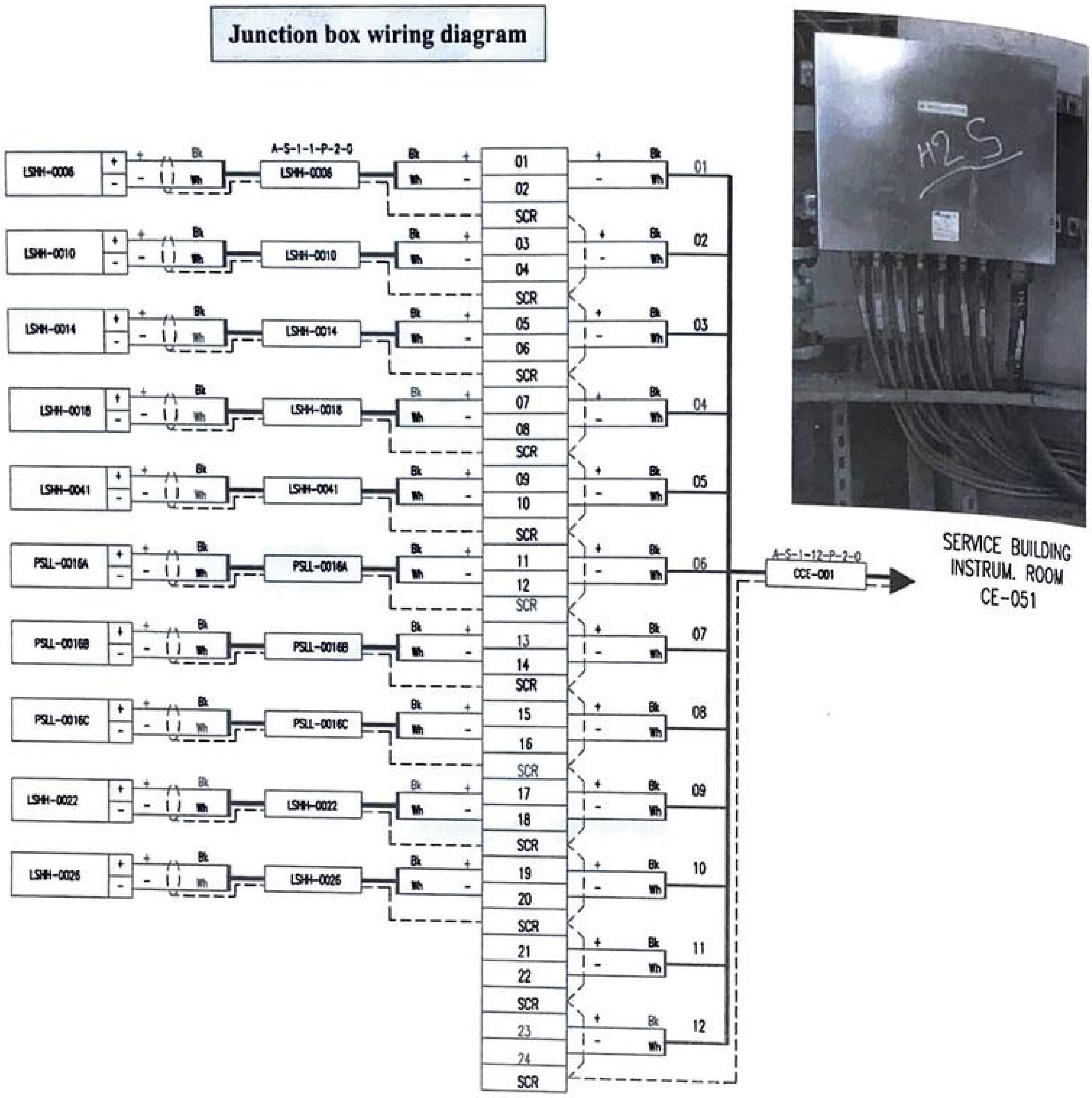




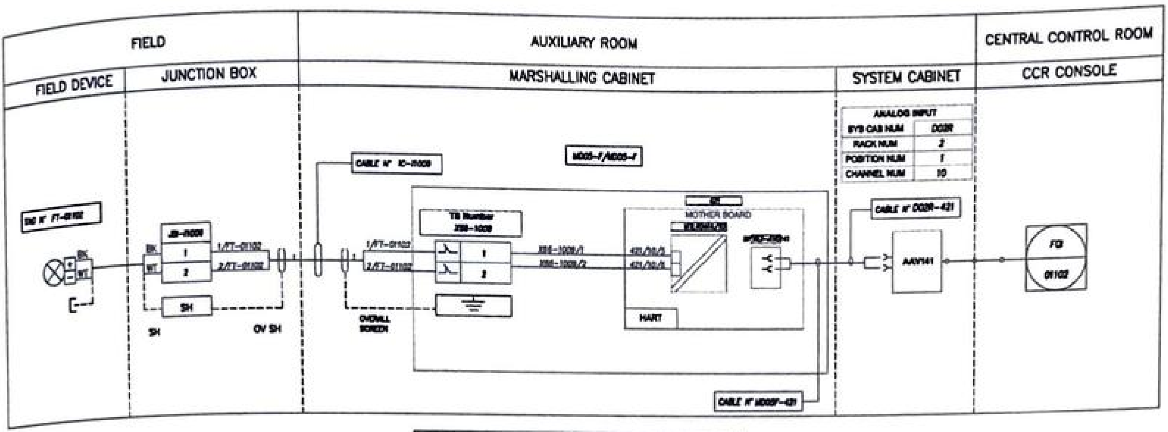
TAG EQUIPMENT	DESIGNATION	OVERALL DIMENSION mm (HxWxD)
CA-051	SYSTEM CABINET DUAL ACCESS	2100x1200x800
CA-052	SYSTEM CABINET DUAL ACCESS	2100x1200x800
CA-053	SYSTEM CABINET DUAL ACCESS	2100x1200x800

- Wiring diagrams show cable connections at terminals of junction boxes and marshalling cabinets,

Junction box wiring diagram



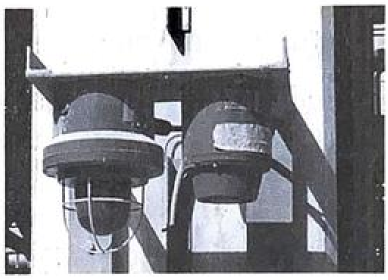
- Loop Diagrams, also called troubleshooting diagrams, show the complete wiring of each instrument. They are used during the testing of the instrument (from the field to the display on screen) during commissioning and for maintenance,



Instrument loop diagram

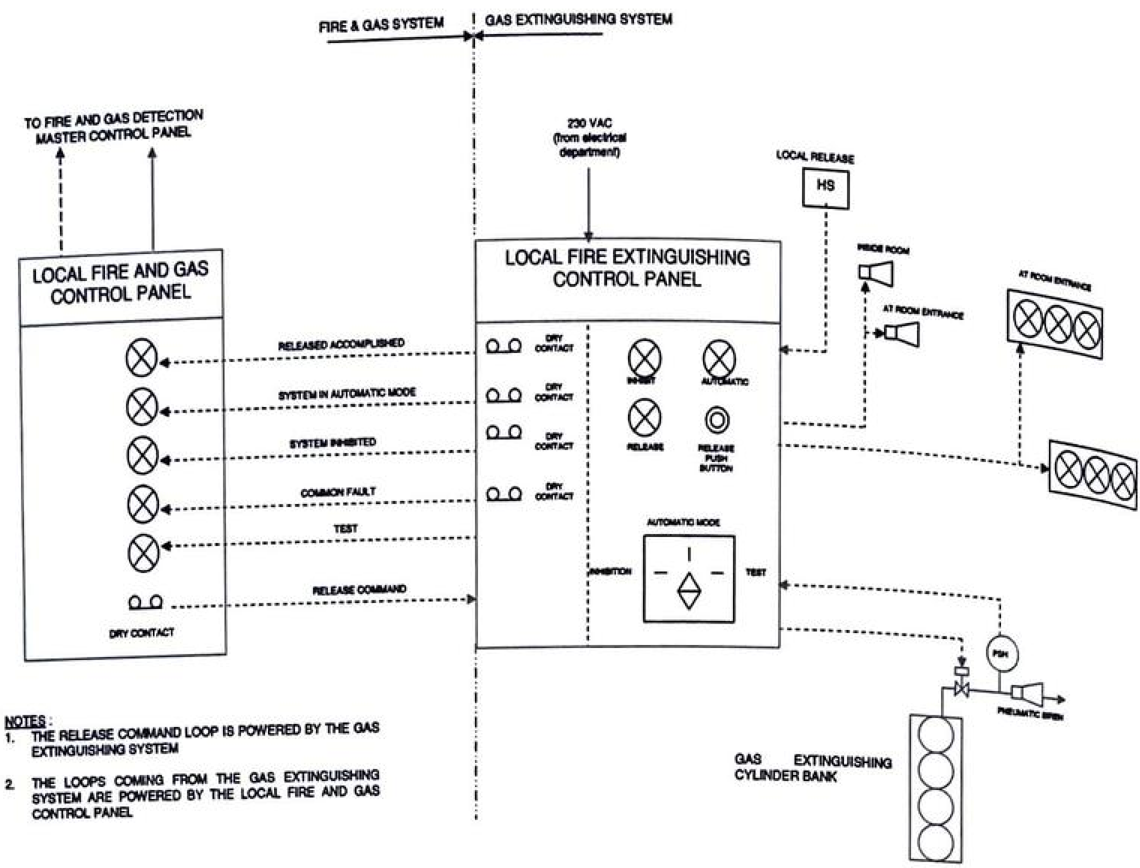
The lists of tagged items, such as the instrument index, cable schedule, etc. are used for the inspections and tests, prior the hand-over to the client, as part of Mechanical Completion activities. The type of inspection required depends on the type of item: calibration for instruments, insulation test for cables, etc. Each inspection is recorded against the item inspected.

A computer software "the mechanical completion system" is used to record the requirements and status of the inspection and testing of the thousands of individual tagged items.



Similarly to the Process control system, Instrumentation discipline implements a Fire and Gas detection and alarm system. This is a Safety system, similar system to the ESD system. The functional requirements are given by Safety (see corresponding section). Instrument discipline specifies and procures the materials (detectors, sounders, etc.), the system, and produces all drawings for Site installation.

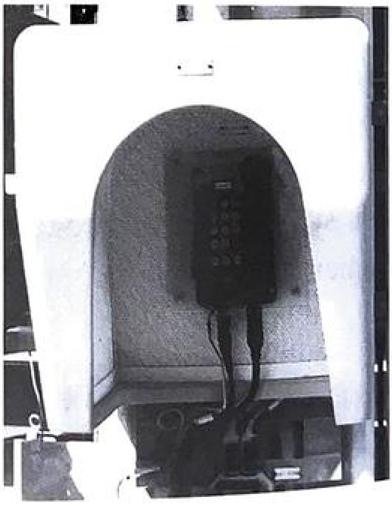
The system is purchased based on the required capacity (I/O count). It is also specified to interface with the stand-alone Fire & Gas detection and Fire fighting systems of the main equipment packages, with the Plant ESD system and with the Fire Fighting systems of buildings (see Interface diagram on the next page). The system vendor programs the logic shown on the F&G matrix (see Safety section) in the system.



The same deliverables are produced for the Fire and Gas system as for the Process Control System: instrument list, location drawings, cable schedule, bill of materials, wiring and troubleshooting diagrams, etc.

Telecommunication systems fall in the scope of the Instrumentation engineer, such as the Public address system (for paging personnel or sounding general alarm using loudspeakers, etc.), the Plant internal telephone system (PABX), the computer network (LAN), the access control system, CCTV, etc.

An Off-Shore facility requires telecommunication with land, supply boats, tankers, etc. This will involve a variety of systems, which will be designed by the Telecommunication engineer, such as radio frequency (UHF, VHF), microwave, satellite, entertainment system (TV) in living quarters, etc.



Chapter 12

Electrical

Electrical Engineering designs the Electrical power generation and distribution. Its work starts with the inventory of all consumers in the Electrical Consumers List, which include Process Equipment, shown in the Process Equipment list, along with hidden consumers such as packages and machinery auxiliaries, e.g., lube oil heater and pumps, HVAC, lighting and small power of buildings, heat tracing, motorized valves, etc.

Consumers are grouped by voltage levels. Process consumers use Low Voltage (LV), typically 400 V, except above a defined maximum power, typically 200kW, above which they are fed Medium Voltage (MV), typically 6.6 kV.

For each consumer, the following information is indicated in the consumers list:

- Service: continuous/intermittent/spare
- Category: normal/essential/vital

Essential consumers are consumers to which power supply cannot be stopped without affecting the Plant production as well as consumers that shall remain powered upon Plant shutdown to ensure integrity or safety, e.g., process cooling medium pumps/machinery lube oil pumps, fire water pumps. They are identified by Electrical in co-ordination with Process, Equipment and Safety disciplines.

Back-up power from diesel generators, also called emergency or essential generators, is supplied to essential consumers. This does not, however, ensure uninterrupted power supply as the diesel generators take 15-30s to start-up and take the load upon trip of the main power generators.

Consumers that need uninterrupted power supply are classified as "vital" and provided back-up power from an Uninterrupted Power Supply (UPS) system.

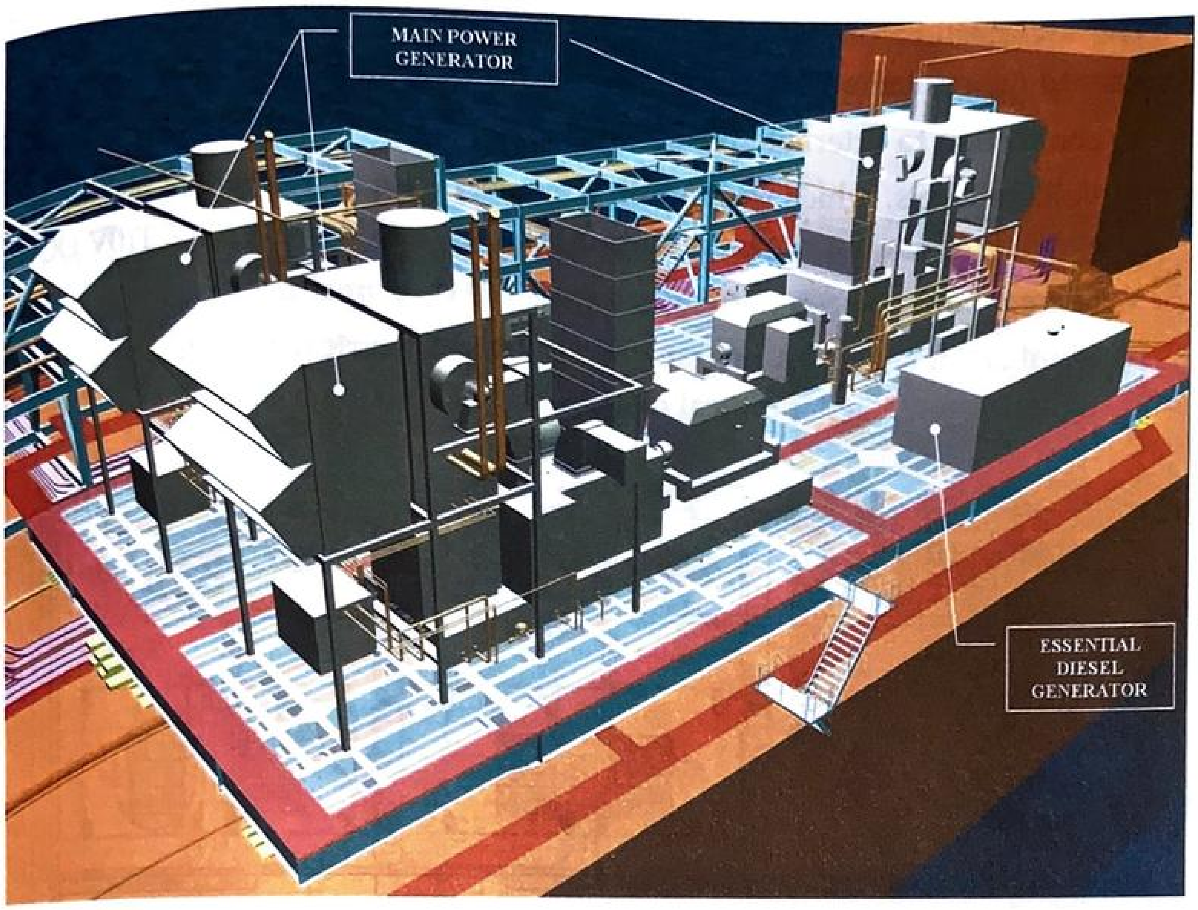
Electrical consumers list and Power balance 400 V AC 50 Hz										
Pos.	Consumer	Vital	Essential	Normal	ABSORBED LOAD (=A)	RATED POWER	EFFICIENCY (=B)	CONSUMED LOAD (=A/B)		
								Continuous	Intermittent	Spare
					kW	kW	%	kW	kW	kW
E-1	Electric Heater			X	407	490	95	428		
P-1A	Reflux pump			X	25	30	91	28		
P-1B	Reflux pump			X	25	30	91			28
MOV-1	MOV valve			X	1,5	2	75		2	
MOV-2	MOV valve			X	1,5	2	75		2	
	Building lighting and small power			X	20				20	
P-2A	Fire water jockey pump A		X		8	10	80	10		
P-2B	Fire water jockey pump B		X		8	10	80			10
WS-1	Welding Socket 415V, 30A			X	18		90			20
	Emergency lighting		X		2,6		97	3		
	Control & Safety systems	X			10			10		
Peak load (100 % Continuous + 30 % Intermittent + 10 % Spare)								492		

<u>Note:</u> values in red are estimated

In the initial consumers list, the consumption of consumers is estimated. The efficiency of pumps and compressors, for instance, is estimated and applied to the hydraulic power calculated by Process. This validity (estimated/final) is indicated.

The Electrical consumers list yields the Plant Electrical Power demand by applying the coincidence factor (continuous/intermittent/spare) to the absorbed loads of the various consumers. The most demanding but realistic power demand cases are considered to identify the maximum load condition. This is done by Electrical in close co-ordination with Process who knows which are the operating cases.

The number and size of power generators are defined to ensure continuous power supply, by means of spare capacity, and maintenance requirement. A typical arrangement includes 4 generators, each having a capacity of 50% of the Plant total power demand. 3 generators run at 2/3 of their capacity in normal conditions while the 4th can be taken out for maintenance. Should one generator trip, the remaining 2 generators ramp up to full capacity, preventing any shortage of power.



Unlike the main power generators, which run on fuel gas fed from the Process, diesel generators have their own stand alone fuel reserve in order to be independent from the Plant operation.

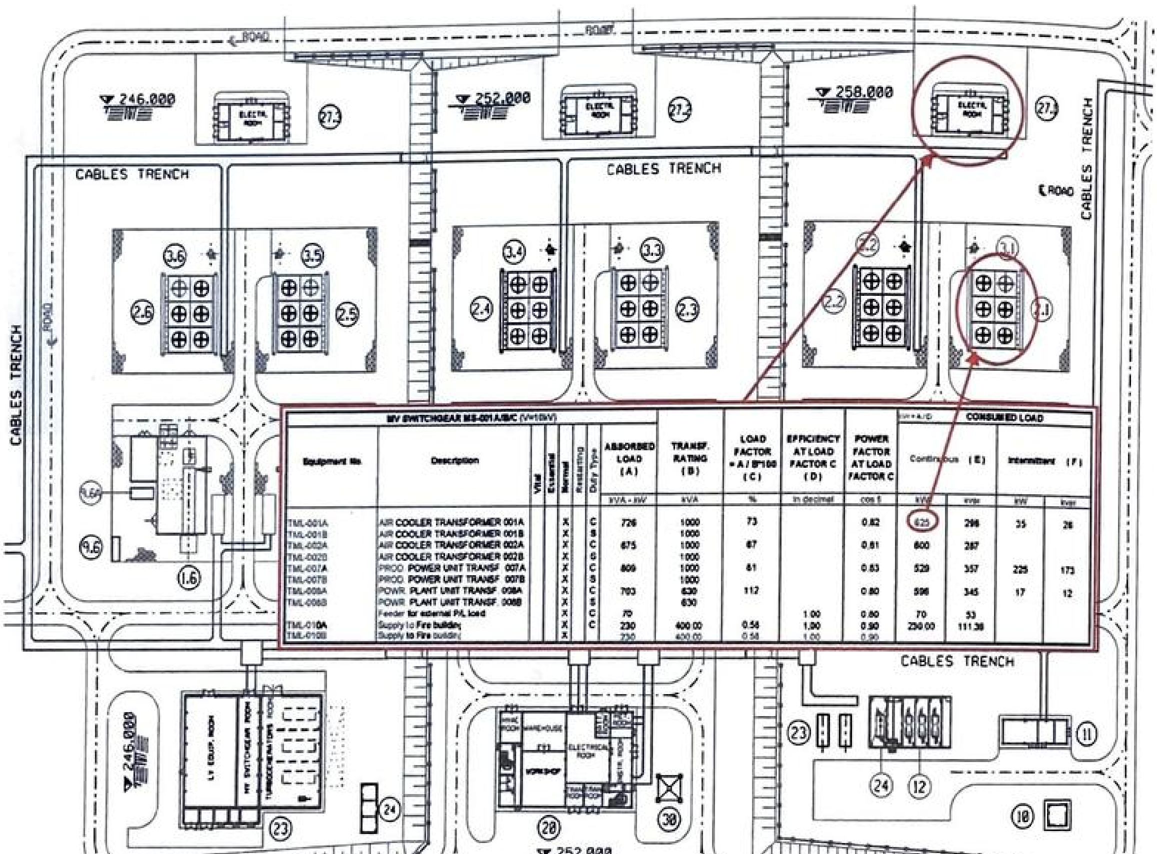
They are sized to supply power to all essential consumers and to re-start the main power generators.

The requisitions for the main power generators and the diesel generators are prepared by the Mechanical Engineer. They include the data sheet for the Electrical part (alternator) prepared by the Electrical Engineer and the data sheet for the driver prepared by the Mechanical Engineer.

The Uninterrupted Power Supply (UPS) system and its battery banks are sized to supply power to all vital consumers for the required number of hours.

The architecture of the electrical distribution system is determined by a number of factors including:

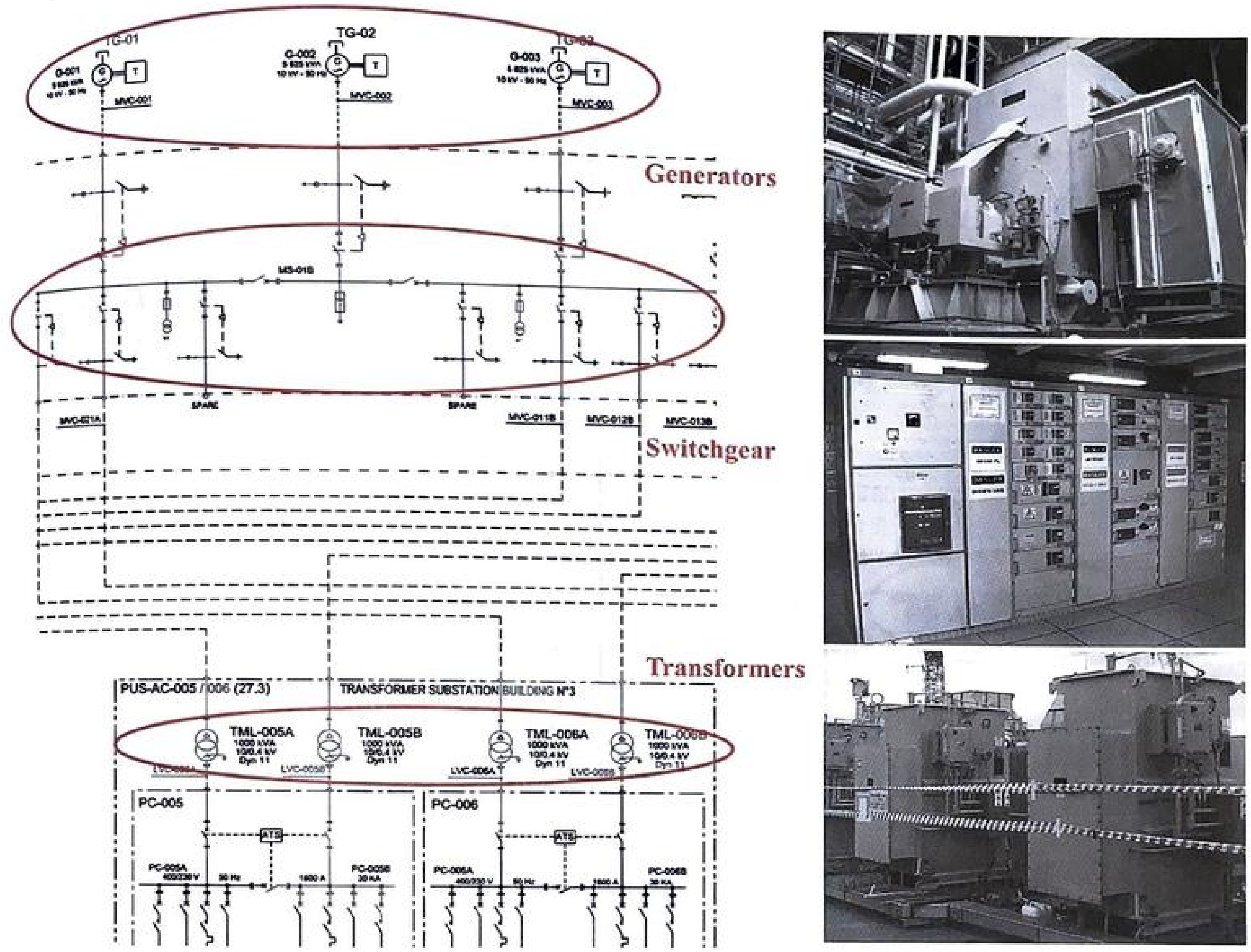
- connection to external grid (On-Shore),
- voltage levels, which depend on consumers, e.g., large motor require MV instead of LV for ordinary motors, e.g., 11kV, 6.6kV, 400V, 230V, 110V DC,
- segregation between normal and essential consumers,
- number and location of transformers and Electrical sub-stations, which depend on the geographical distribution of consumers[1].



Equipment No.	Description	Vital	Essential	Normal	Restarting	Duty Type	ABSORBED LOAD (A) kVA - kW	TRANSF. RATING (B) kVA	LOAD FACTOR = A / B*100 (C) %	EFFICIENCY AT LOAD FACTOR C (D) in decimal	POWER FACTOR AT LOAD FACTOR C cos	CONSUMED LOAD Continuous (E) kW	Continuous (E) kvar	Intermittent (F) kW	Intermittent (F) kvar
TML-001A	AIR COOLER TRANSFORMER 001A			X		C	726	1000	73		0.82	625	298	35	26
TML-001B	AIR COOLER TRANSFORMER 001B			X		S		1000							
TML-002A	AIR COOLER TRANSFORMER 002A			X		C	675	1000	67		0.81	600	287		
TML-002B	AIR COOLER TRANSFORMER 002B			X		S		1000							
TML-007A	PROD. POWER UNIT TRANSF. 007A			X		C	809	1000	81		0.83	529	357	225	173
TML-007B	PROD. POWER UNIT TRANSF. 007B			X		S		1000							
TML-008A	POWR. PLANT UNIT TRANSF. 008A			X		C	703	630	112		0.80	596	345	17	12
TML-008B	POWR. PLANT UNIT TRANSF. 008B			X		S		630							
	Feeder for external P/L load			X		C	70			1.00	0.80	70	53		
TML-010A	Supply to Fire building			X		C	230	400.00	0.58	1.00	0.90	230.00	111.38		
TML-010B	Supply to Fire building			X			230	400.00	0.58	1.00	0.90				

1. Sub-stations shall be as close as possible to main consumers to reduce cable length and section: on the plot Plant shown here the power Plant is item 23. Power supply to the gas-coolers (items 2.1-6), which are large low voltage consumers, is not done directly from the power Plant but through sub-stations 27.1 to 3 equipped with high/low voltage power transformers. In such a way, high voltage cables are provided between the power Plant and the sub-stations, which reduces the cable section, whereas low voltage cables, with large section, are required only on the short distance between the sub-stations and the consumers.

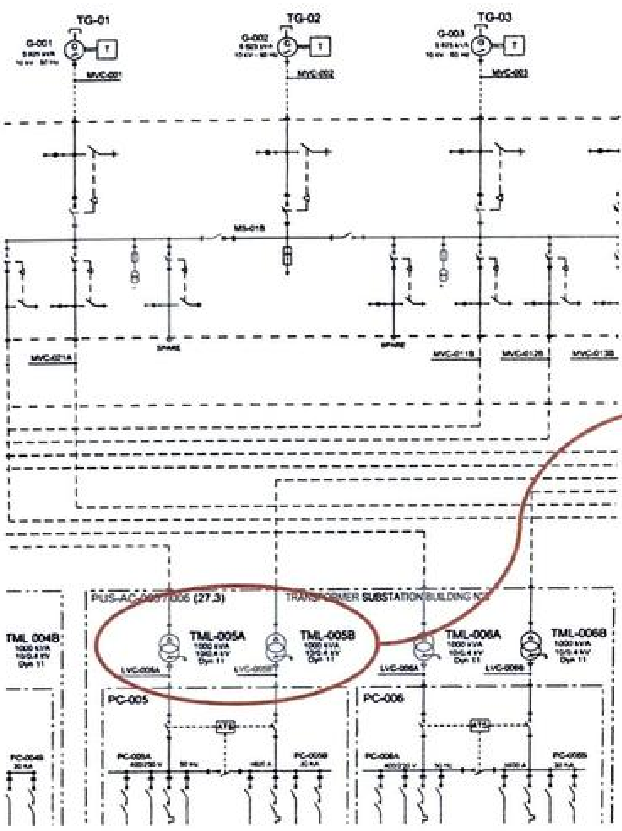
The overall power generation and distribution system is depicted on the General One Line Diagram, which shows generators, switchboards of various voltage levels, transformers and main consumers.

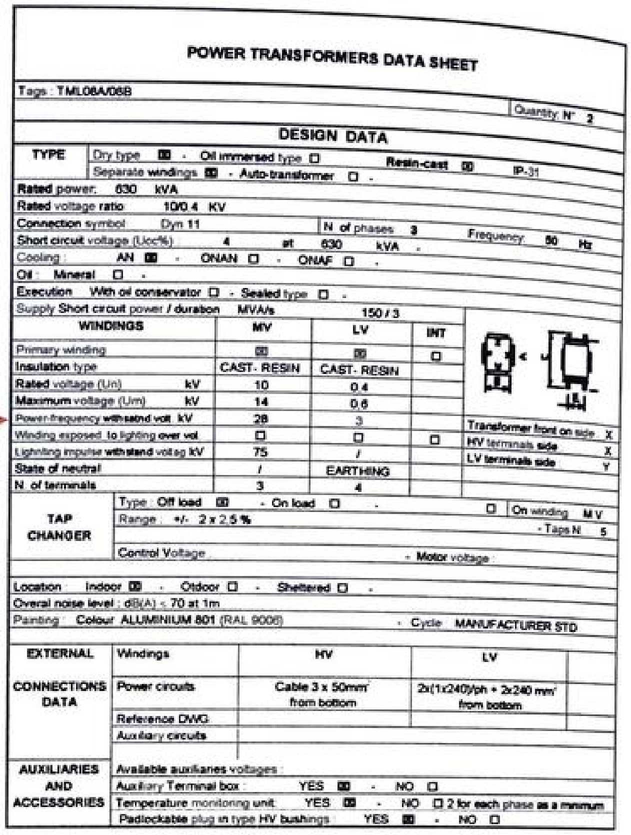


The distribution architecture determines the allocation of consumers to distribution switchboards.

The distribution network is modelled in Electrical software to perform the Load Flow Analysis which calculates the value of current and voltage for each equipment and cable. This allows sizing of Electrical equipment (switchboards, transformers).

A **data sheet** and a **specification**, usually a general specification per type of equipment, form the requisition for purchase.





POWER TRANSFORMERS DATA SHEET

Tags : TML08A/08B

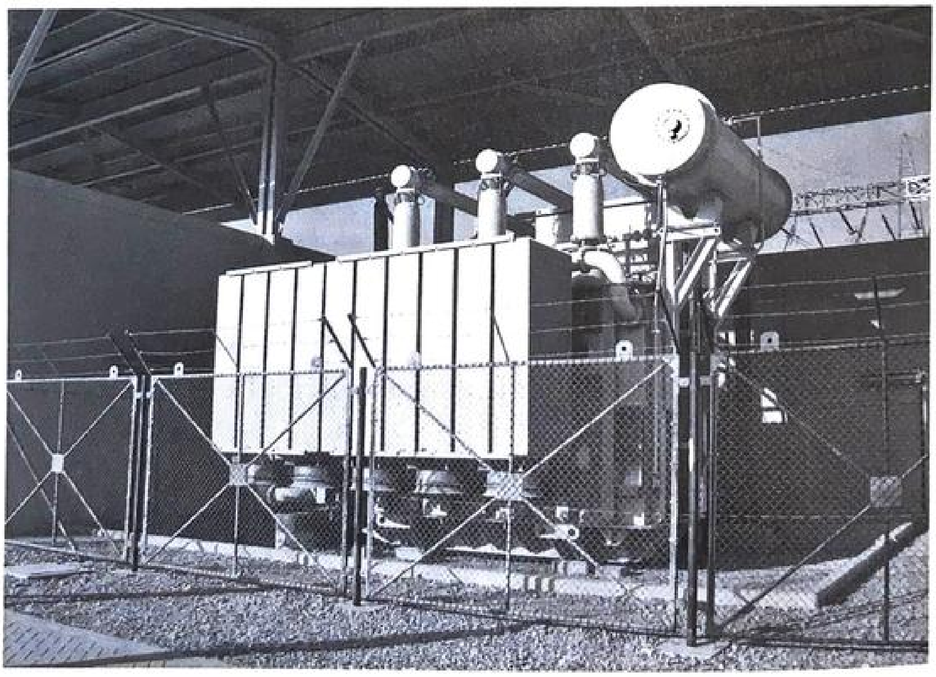
Quantity N° 2

DESIGN DATA

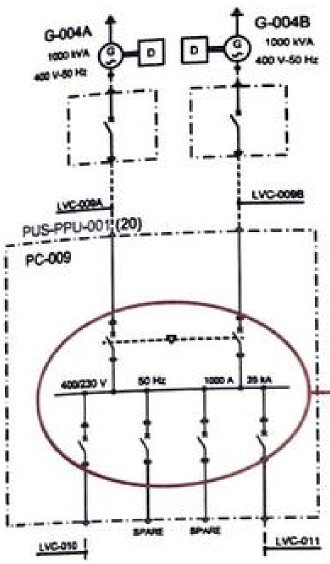
TYPE	Dry type ☒ - Oil immersed type ☐ Resin-cast ☒ IP-31			
	Separate windings ☒ - Auto-transformer ☐ -			
Rated power: 630 kVA				
Rated voltage ratio 10/0.4 KV				
Connection symbol Dyn 11	N of phases 3			Frequency 50 Hz
Short circuit voltage (Ucc%) 4 at 630 kVA -				
Cooling : AN ☒ - ONAN ☐ - ONAF ☐ -				
Oil : Mineral ☐ -				
Execution With oil conservator ☐ - Sealed type ☐ -				
Supply Short circuit power / duration MVA/s	150 / 3			
WINDINGS	MV	LV	INT	
Primary winding	☒	☒	☐	
Insulation type	CAST- RESIN	CAST- RESIN		
Rated voltage (Un) kV	10	0.4		
Maximum voltage (Um) kV	14	0.6		
Power-frequency withsatnd volt kV	28	3		Transformer front on side X
Winding exposed to lighting over vol	☐	☐	☐	HV terminals side X
Lightning impulse withstand voltag kV	75	/		LV terminals side Y
State of neutral	/	EARTHING		
N. of terminals	3	4		

TAP CHANGER	Type : Off load ☒ - On load ☐ -	☐	On winding M V
	Range : +/- 2 x 2.5 %		- Taps N 5
	Control Voltage	- Motor voltage :	
Location Indoor ☒ - Otdoor ☐ - Sheltered ☐ -			
Overal noise level : dB(A) < 70 at 1m			
Painting : Colour ALUMINIUM 801 (RAL 9006)		- Cycle MANUFACTURER STD	

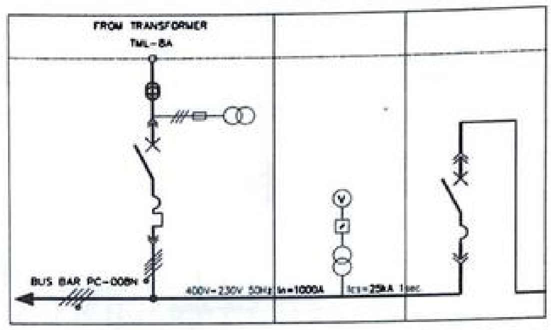
EXTERNAL CONNECTIONS DATA	Windings	HV	LV
	Power circuits	Cable 3 x 50mm² from bottom	2x(1x240)/ph + 2x240 mm² from bottom
	Reference DWG		
	Auxiliary circuits		
AUXILIARIES AND ACCESSORIES	Available auxiliaries voltages :		
	Auxiliary Terminal box : YES ☒ - NO ☐		
	Temperature monitoring unit YES ☒ - NO ☐ 2 for each phase as a minimum		
	Padlockable plug in type HV bushings : YES ☒ - NO ☐		



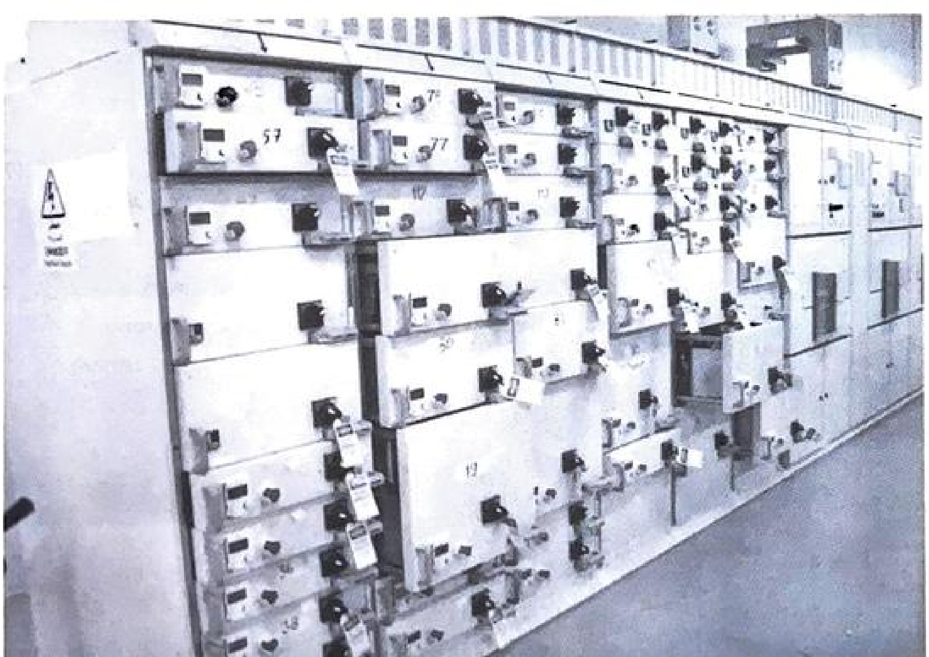
Single Line Diagrams are produced for electrical switchboards, specifying to the vendor the content of the switchboard (incomers/outgoers), capacity, protections, control and monitoring devices.



Switchboard Single Line Diagram

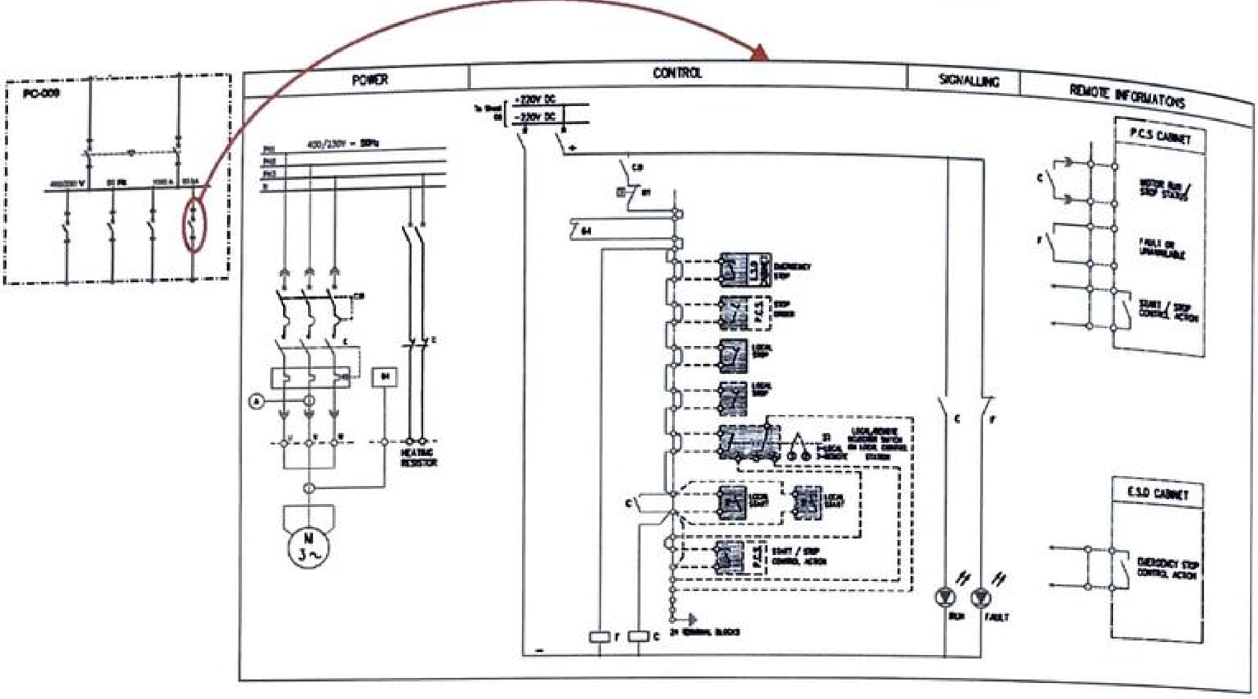


	CUBICLE DESIGNATION	INCOMER 0008N	BUS BAR VOLTAGE TRANSFORMER	BUS TIE
CHARACTERISTICS – INCOMERS	CUBICLE TAG NUMBER	0008N	VT 008N	BT008
	CIRCUIT BREAKER RATED CURRENT			
	FUSE RATING			
	VOLTAGE AND / OR CURRENT TRANSFORMER RATIO	3CT 1000A/1A 20VA Cl. 0.5 Fs5 /1A 20VA Cl. 0.5 Fs5 3VT $\frac{400V}{\sqrt{3}}/\frac{110V}{\sqrt{3}}$ 30VA Cl. 0.5	3VT $\frac{400V}{\sqrt{3}}/\frac{110V}{\sqrt{3}}$ 30VA Cl. 0.5	
	PROTECTIVE RELAYS	86 LOCKOUT RELAY 27 UNDER VOLTAGE RELAY 25 SYNCHRO CHECK DEVICE 51 AC TIME OVERCURRENT RELAY 49 THERMAL RELAY	27 UNDER VOLTAGE RELAY	86 LOCKOUT RELAY 25 SYNCHRO CHECK DEVICE 51 AC TIME OVERCURRENT RELAY
	METERING	-1 AMMETER WITH SELECTOR SWITCH -1 VOLTMETER WITH SELECTOR SWITCH -1 WATTMETER -1 POWER FACTOR METER	-1 VOLTMETER WITH SELECTOR SWITCH	
	TERMINAL TAG NUMBER			
	SUPPLY RATED POWER / RATED CURRENT	630 kVA		
	SUPPLY SHORT CIRCUIT POWER			
	CABLES – POWER CROSS SECTION AND TYPE	4X2x(1x240 mm2) Cu		
	CABLES – CONTROL CROSS SECTION AND TYPE			
REF. DWGS	TYPICAL DIAGRAM NUMBER	E-3-42005	E-3-42005	E-3-42005
	SHEET	10-11-07-08	06	13-14



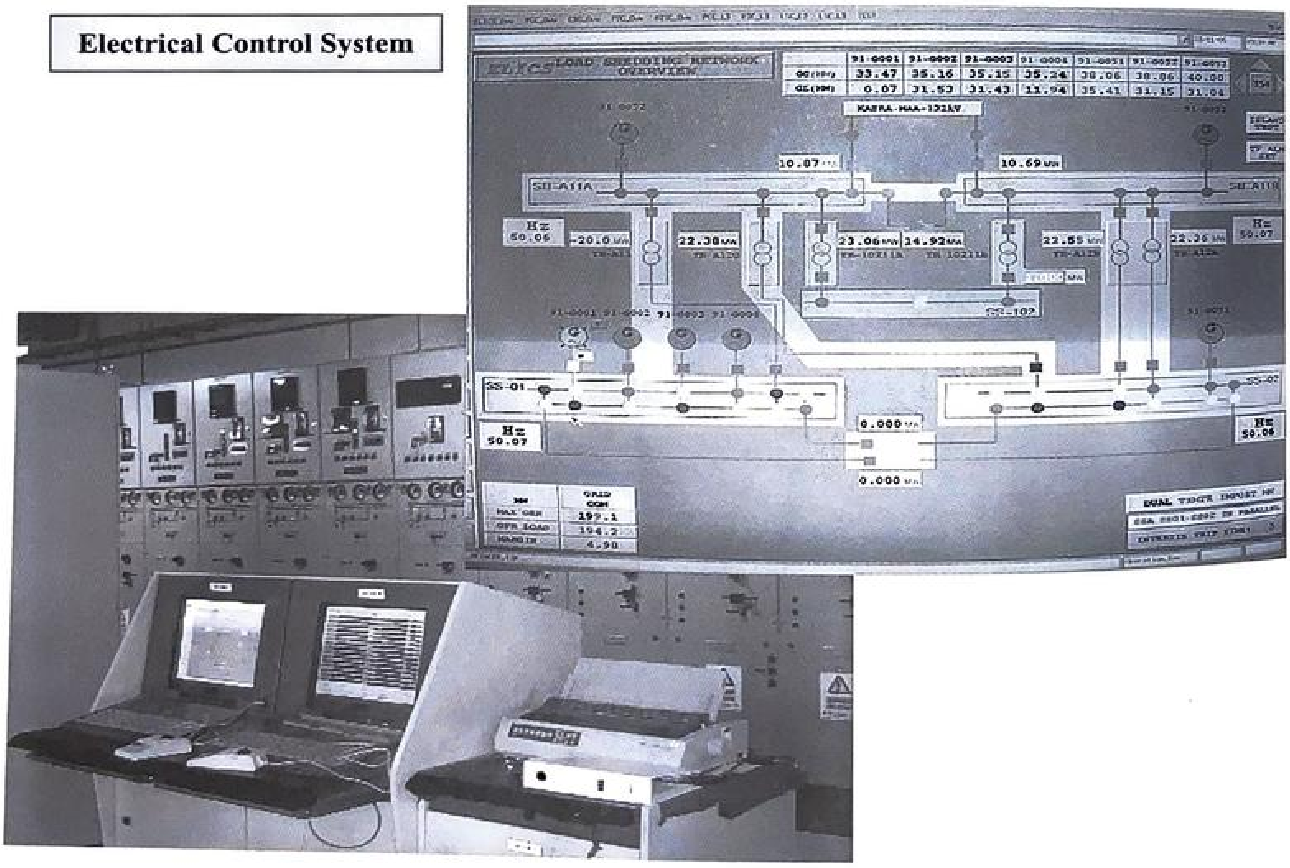
The power connection, the control, indication and remote monitoring features of switchgear cubicles are specified, for each type, e.g., motor outgoer, on the **Switchgear Typical Diagrams**.

Switchgear Typical Diagram



The electrical power distribution is monitored and controlled by an automated system: the **Electrical Control System**, also called the **Power Distribution Control System (PDCS)**, or **ELectrical Integrated Control System (ELICS)**.

Electrical Control System

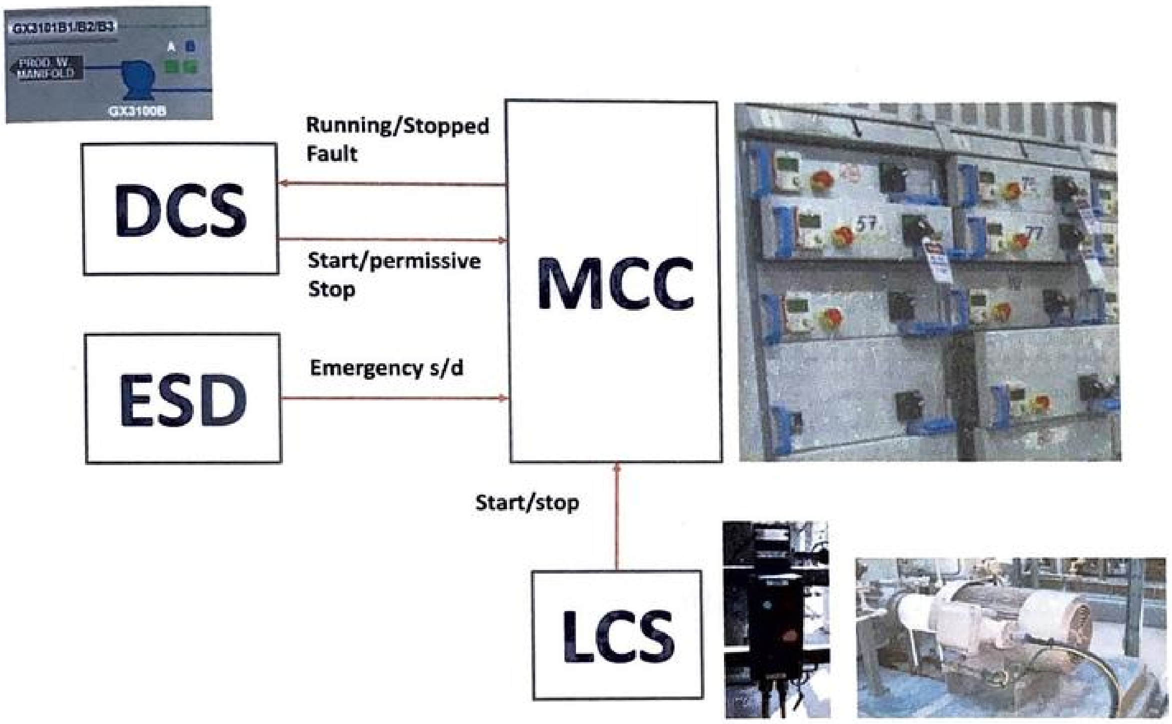


The electrical control system allows monitoring (status of protections, voltage/amperage/power values) at various points of the electrical system and control (start/stop of motor, etc.).

It also performs the key function of load shedding, interrupting power supply to non-essential consumers upon loss of power from the main generators, in order to reserve the limited power available, supplied by the emergency generators, to essential consumers. Load shedding function is also required at emergency generators start-up as the generators cannot take immediately 100% the load. Loads steps are implemented with associated time schedule.

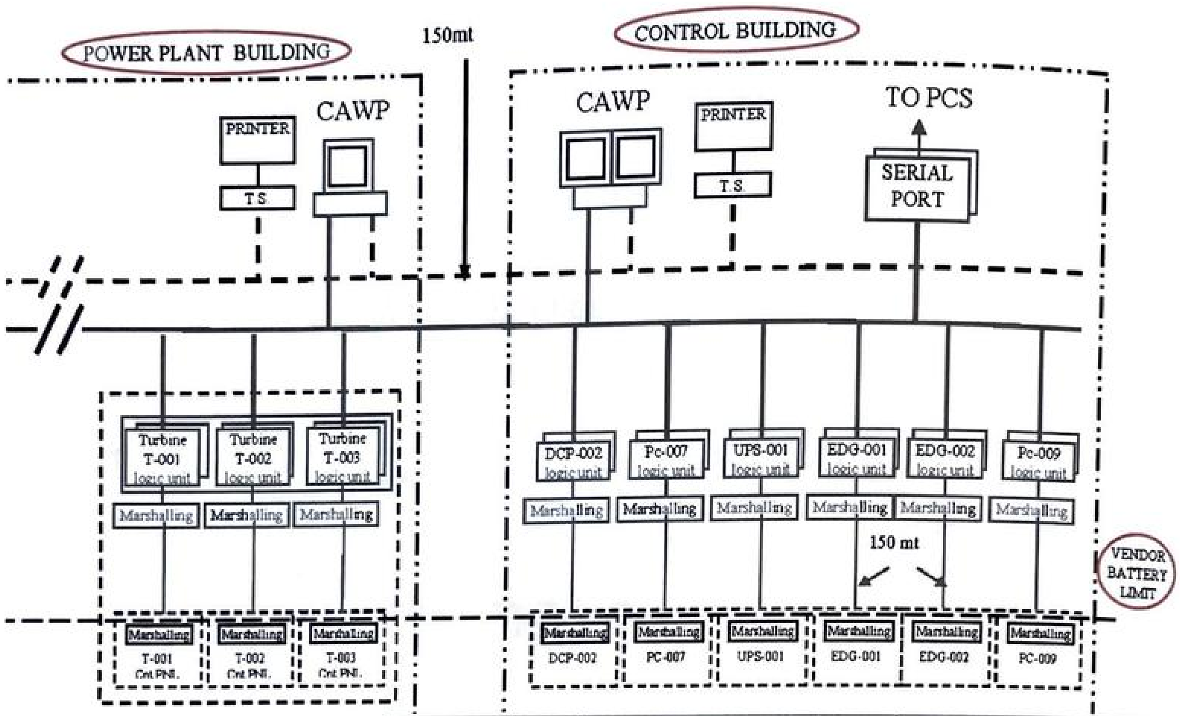
The electrical control system is interfaced with the Process Control System for the start-up/shut-down of Equipment. The typical interface for a pump is shown below.

Electrical/Instrumentation interface for a pump



The Electrical control system is also interfaced to the vendor supplied control system of the power generators, as shown on its architecture drawing below.

A specification is produced to define the functionalities and capacity of the electrical control system: architecture and geographical distribution of equipment (allowing the vendor to identify the number and location of equipment its system will connect to, such as electrical switchboards, generator control equipment, etc.).

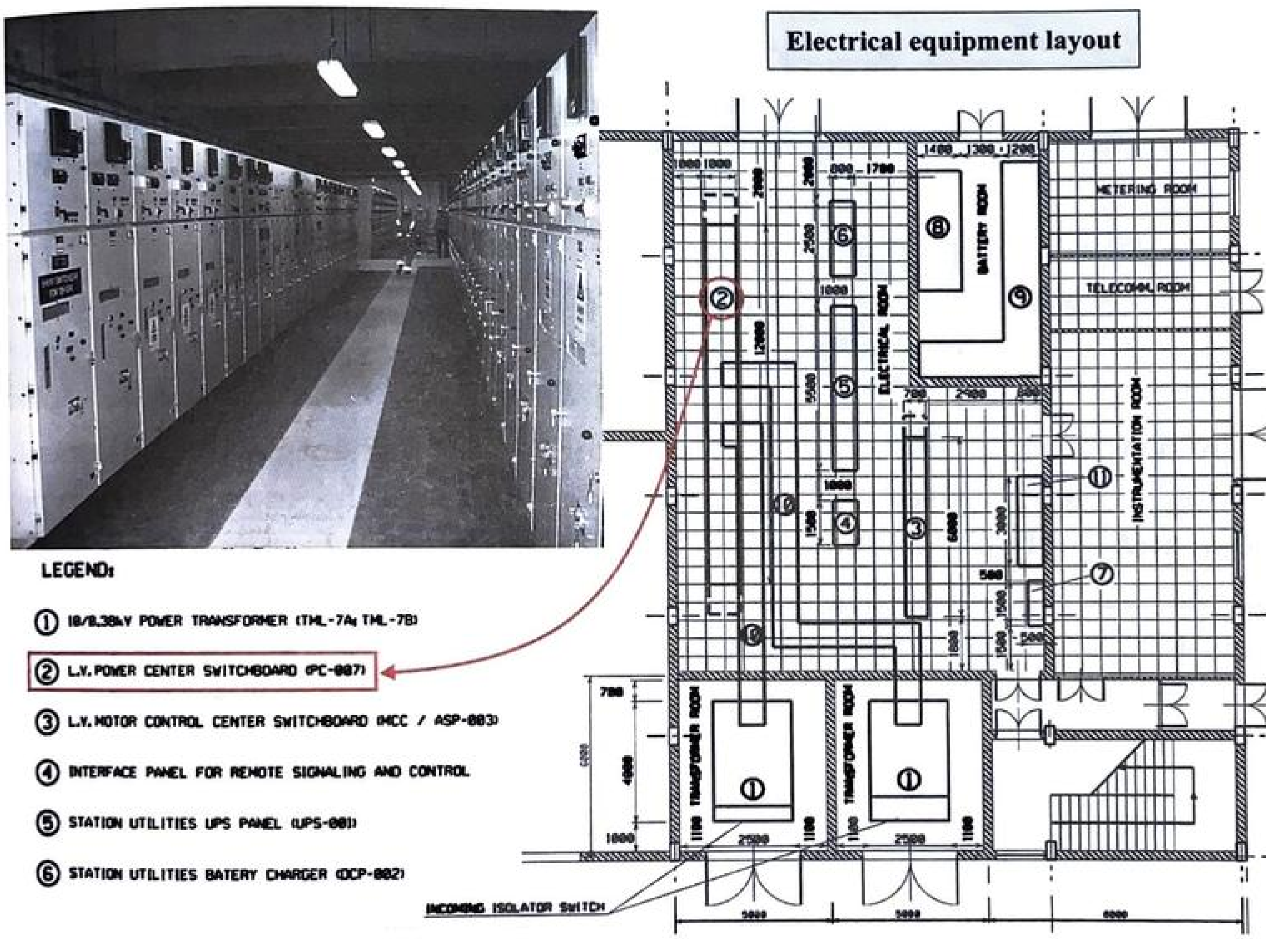


Electrical Control System Architecture drawing

I/O	Power Plant Building									Control Building						
	MS-001	T-001	T-002	T-003	TG-001	TG-002	TG-003	PC-008	DCP-001	EDG-001	EDG-002	PC-007	PC-009	UPS-001	DCP-002	Serial Link to PCS
DI hardwired	348	33	33	33	5	5	5	23	5	10	10	23	23	5	5	
DO hardwired										4	4	6	6	10	10	
AI hardwired	64	9	9	9	10	10	10	6	5	15	15	6	6	5	5	
DI via serial link	348	33	33	33	5	5	5	23		10	10	23	23	5	5	600

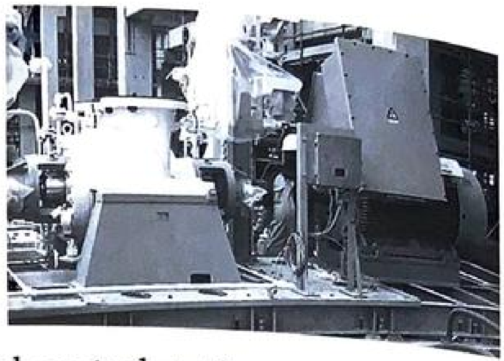
As discussed above, data from equipment vendors is not available initially, including power consumption which is estimated at first. When actual power consumption is known from vendor, the capacity of all electrical generation and distribution equipment is checked (main power generators, emergency generator, switchboards, transformers, cables, etc.).

Once the electrical equipment (switchboards, etc.) is purchased, its actual dimensions will be known. This allows the electrical engineer to define the equipment arrangement inside sub-stations, including provision for spare, which is shown on the Electrical equipment layout drawing.



Electrical discipline also contributes to the specification of the mechanical equipment by preparing the electrical data sheets for the motors that are the drivers of these equipment, e.g., pumps, gas-coolers, etc. Such data sheet specifies in particular the type of explosion protection required for the equipment.

Electrical field equipment located in an area where an explosive atmosphere can be present shall have a special design so that they cannot be a source of ignition.



Such special design, called explosion (Ex) protection of the equipment, is specified by the Safety engineer, according to the type of explosive atmosphere, its probability, ignition energy and temperature.

The Electrical engineer implements the Ex requirement for the various type of equipment (electric motor, electrical socket, local control stations, etc.).

The size (cross section) of electrical cables is selected so that the cable is able to withstand the short circuit current (until the upstream breaker opens) and to limit the elevation of temperature.

In practice, the cable size is determined:

- By the carried current for Medium Voltage (MV) cables: the code gives maximum current for each cable size
- By the allowable voltage drop, typically 3% in normal operation and 15% for motor start-up, for Low Voltage (LV) cables

Fire resistant cables are selected for power supply to Plant Safety equipment. Armored cables are used outdoor and non-armored cables indoor. The type, section and length of cables are shown on the cable schedule.

Cable N°	Coming from	Going to	Voltage (V)	Type	N° of Cores	Cross section (sqmm)	Length (m)
MVC-010A	MS-001A	TML-010A	10 000	2	3	50	720
MVC-010C	MS-001C	TML-010C	10 000	2	3	50	720
MVC-011A	MS-001A	TML-001A	10 000	2	3	50	520
MVC-011B	MS-001C	TML-001B	10 000	2	3	50	520
MVC-012A	MS-001A	TML-002A	10 000	2	3	50	520
LVC-001A .Ph.1-1	TML-001A	PC-001A	400	2	1	240	25
LVC-001A .Ph.1-2	TML-001A	PC-001A	400	2	1	240	25
LVC-001A .Ph.1-3	TML-001A	PC-001A	400	2	1	240	25

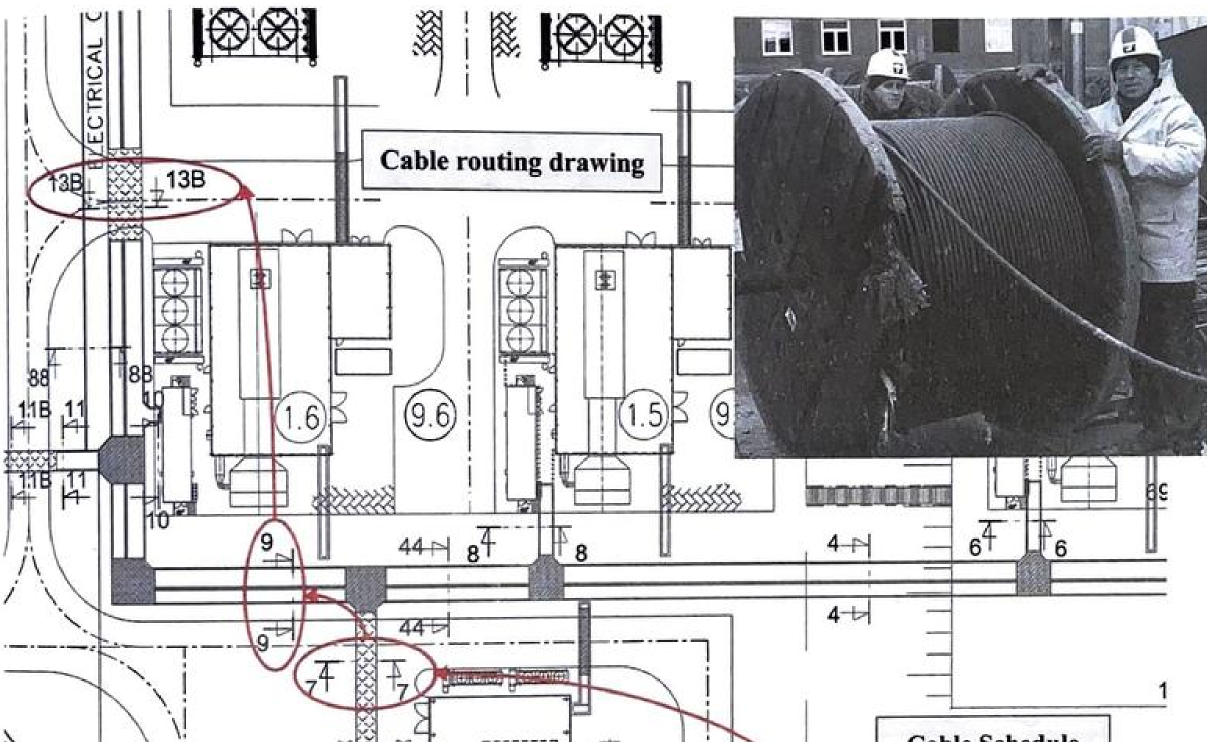
Besides the electrical power distribution network, Electrical discipline also designs:

- the lighting system (as per illumination level requirements in each area),
- the earthing system,
- the lightning protection system,

- the underground piping cathodic protection (see Material & Corrosion section),
- the heat tracing system of some process lines used to, e.g., avoid freezing of liquids or condensation of gas.

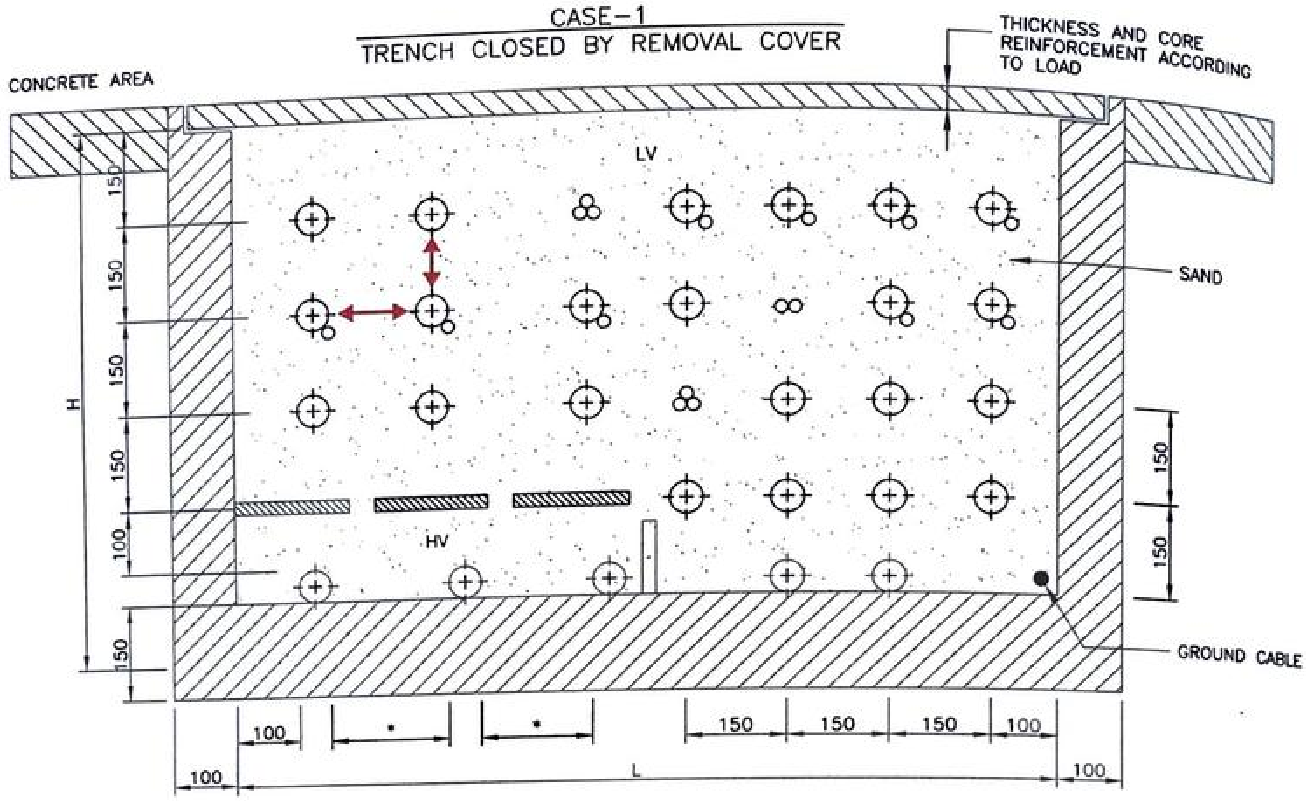
Electrical installation studies result in the production of all drawings required to install and connect the electrical equipment at Site:

- Electrical **cable routing drawings** and cross section drawings,

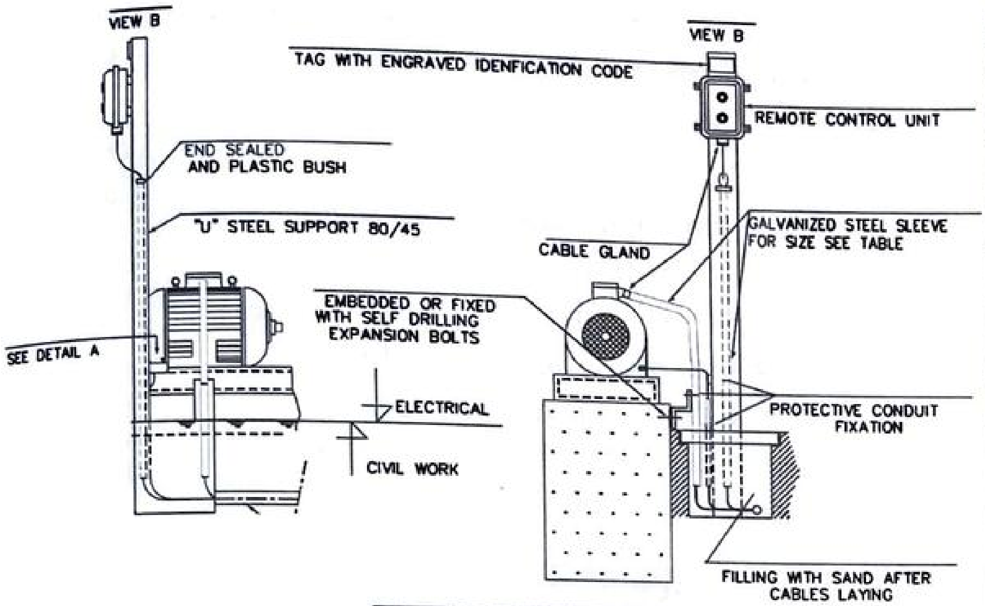


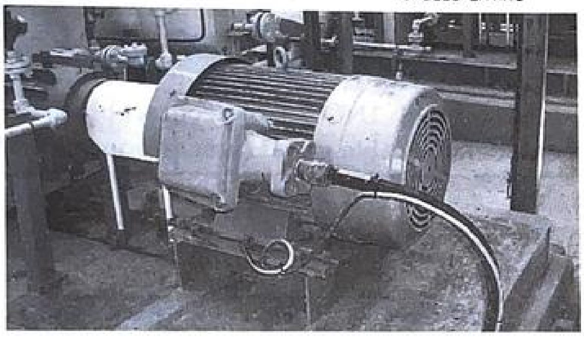
Cable N°	Coming from	Going to	Voltage (V)	Type (sheet 3)	N° of Cores	Cross section (sqmm)	Length (m)	cable routing
MVC-010A	MS-001A	TML-010A	10 000	2	3	50	720	-7-9-13B-[illegible]-60-18-61-23-62-74-36A-36-36B-37-37B-40-41-E32.2-E32.3-E32.1-
MVC-010C	MS-001C	TML-010C	10 000	2	3	50	720	-7-9-13B-13-60-18-61-23-62-74-36A-36-36B-37-37B-40-41-E32.2-E32.3-E32.1-
MVC-011A	MS-001A	TML-001A	10 000	2	3	50	520	-7-9-13B-13B-13-60-18-61-23-62-27-
MVC-011B	MS-001C	TML-001B	10 000	2	3	50	520	-7-9-13B-13B-13-60-18-61-23-62-27-
MVC-012A	MS-001A	TML-002A	10 000	2	3	50	520	-7-9-13B-13-60-18-61-23-62-27-
MVC-012B	MS-001C	TML-002B	10 000	2	3	50	520	-7-9-13B-13-60-18-61-23-62-27-
MVC-013A	MS-001A	TML-003A	10 000	2	3	50	430	-7-9-13B-13-60-18-61-22-

- Unlike instrument cables, electrical cables are not installed next to each other but at a minimum distance to allow heat dissipation.



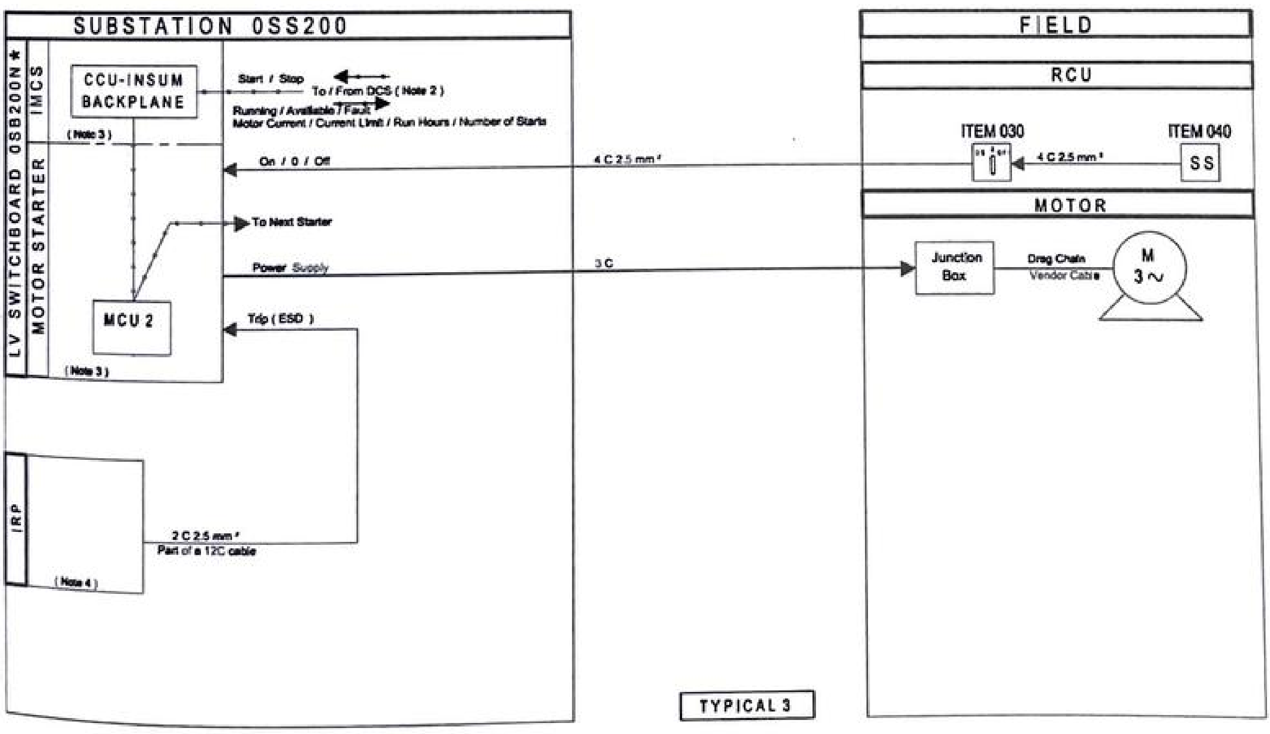
- Electrical cable schedule (showing the list of cables, the type, such as fire resistant, section size, number of cores, length of each cable),
- Typical installation drawings, for power, lighting, earthing, heat tracing, etc.,





Typical installation drawings

- Block diagrams show typical (repetitive) connections,

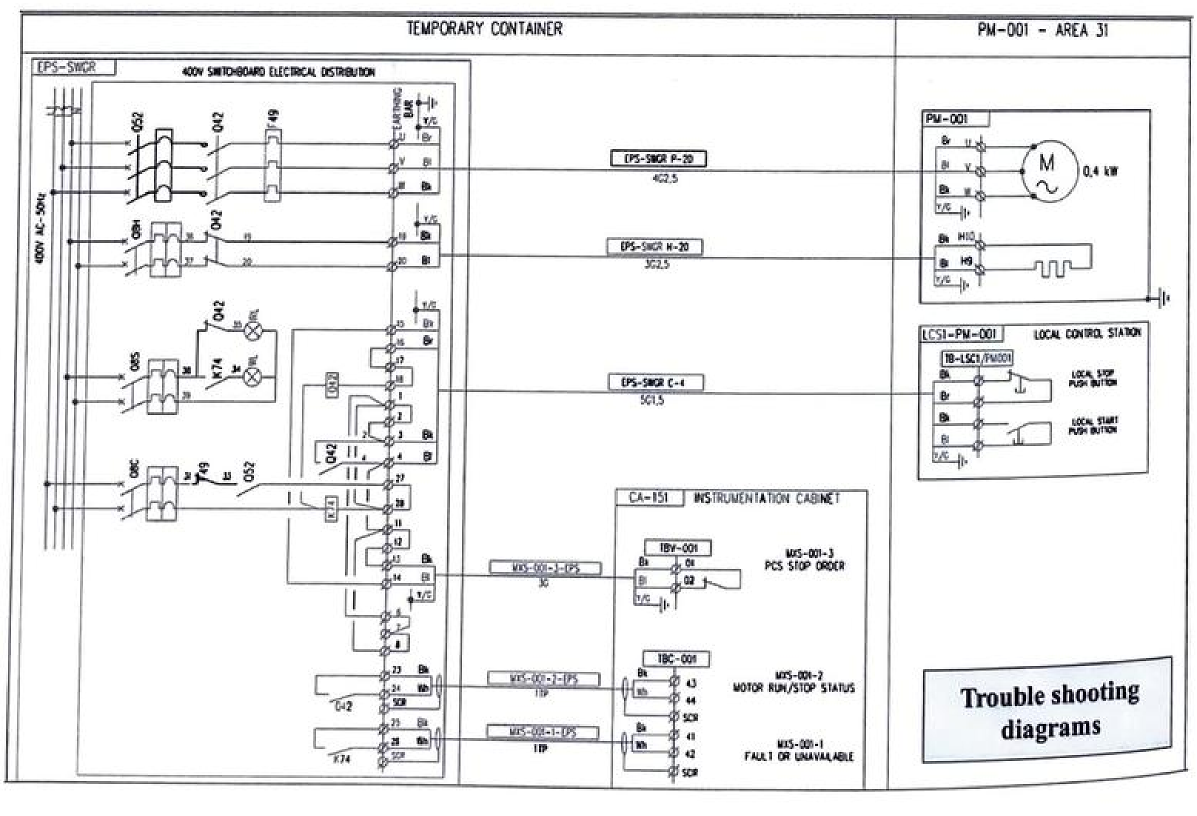


- **Electrical equipment location drawings**, showing location of all electrical consumers: motor local control stations, field sockets, lighting fixtures and junction boxes, etc.,

Alongside installation drawings the **Electrical bulk material take-off** is prepared in order to purchase cables, cable ladders, motor local control stations, junction boxes, cable glands and all other small installation materials.

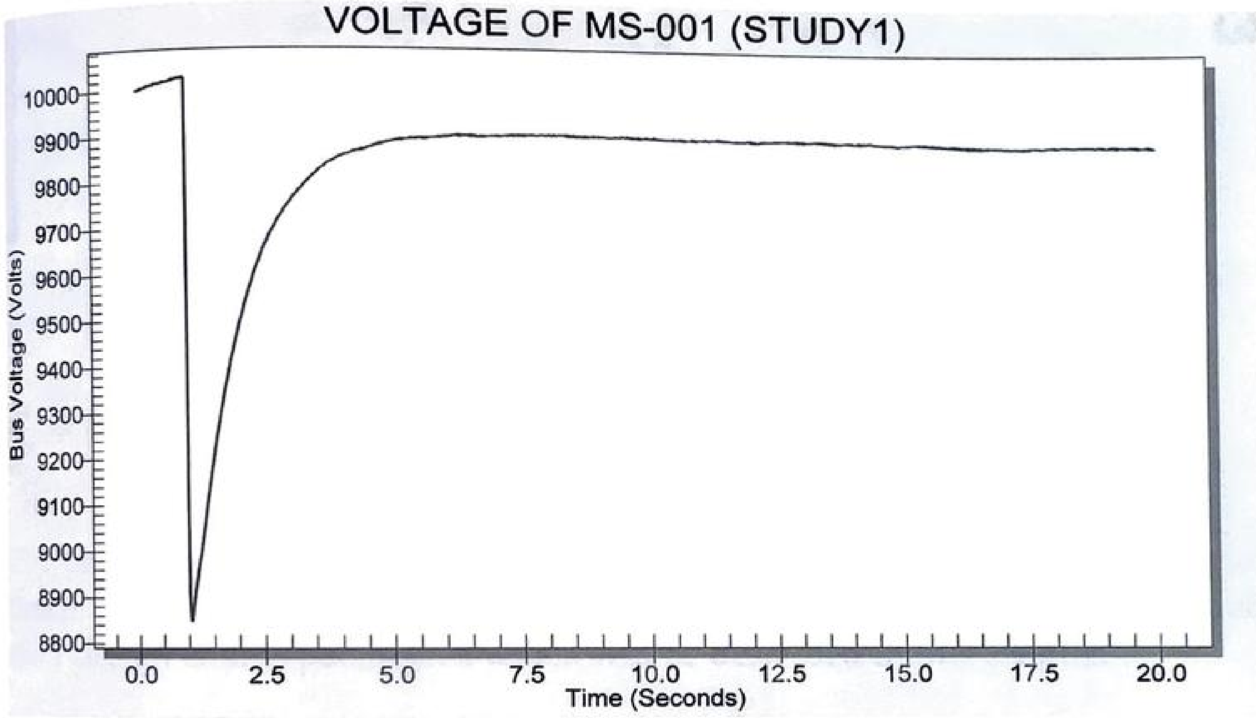
ITEM	DESCRIPTION	QTY
1	local control station enclosure with: - 1 "START" push button with 1NO + 1 NC contact block - 1 "STOP" push button with 1NO + 1 NC contact block - 1 cable entry and metallic cable gland (non armoured cable 5 G1,5)	27
2	Welding socket 63 A – 400V – 3Ph + E – IP44 with: - connection to 35mm2 terminal - 1 cable gland for non armoured cable (4G35)	18

Lastly, Electrical discipline produces the **Trouble Shooting Diagrams**, which show the wiring of each consumer and will also be used for the Plant maintenance.



The electrical generation and distribution system is modelled using computer software to perform calculations and run simulations.

Simulations include, for instance, that of the loss of one of the main power generators. The resulting transient conditions, before the stand-by generator has taken over, are checked to ensure that, for instance, process pumps will not have stopped.

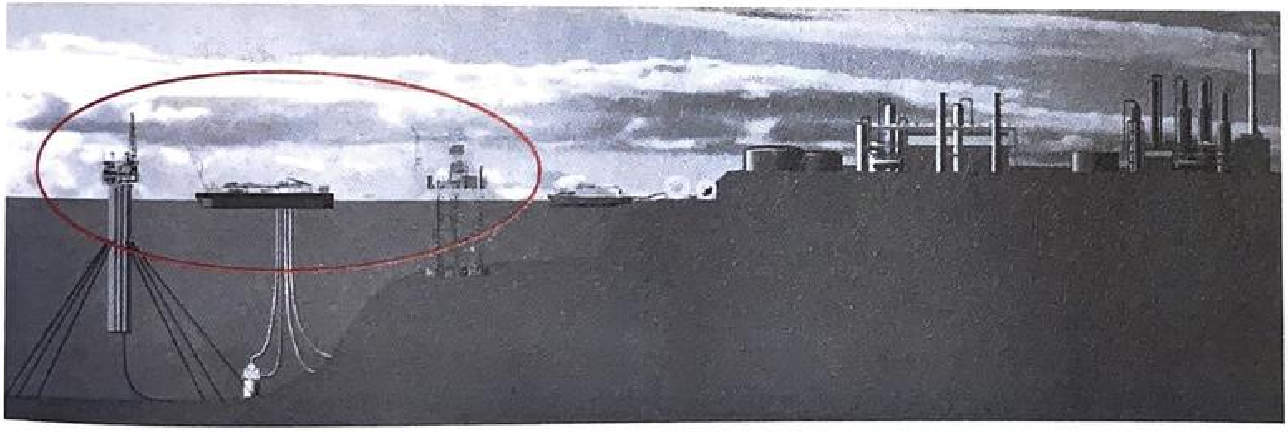


Final Electrical calculations are performed once all consumers and electrical equipment characteristics are known, all cables are sized, etc. The calculations determine the right setting of electrical protections. This right setting ensures selectivity. Selectivity means that, in case there is a short circuit on a motor, the protection of that motor only will open, no higher level protection will open, leaving the other consumers unaffected. The results are collected in the Electrical Relay Schedule, which is used at Site during commissioning to set the protections.

Chapter 13

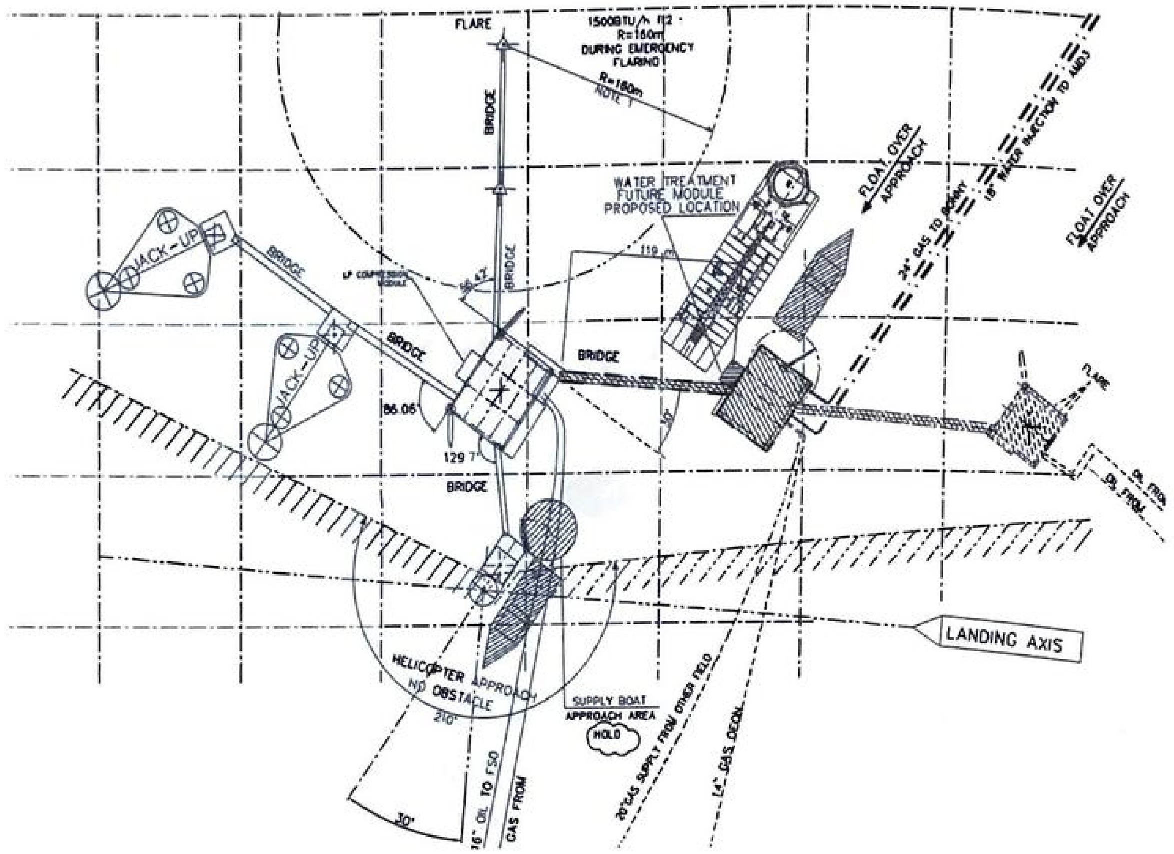
Off-Shore

The Engineering work described in the previous chapters applies to any type of Process facility. Many Oil & Gas production facilities are located Off-Shore and their design entail specificities which will be described in this chapter.



The type of facility will, first of all, depend on the water depth and sea conditions. Fixed structures will be installed in shallow water and floating ones in deep seas.

The **Overall Field Layout** shows the various field structures: wellhead platforms, production facilities, living quarters, flare, flowlines, export/off-loading lines, etc.



Considerations coming into the field architecture entail location of living quarters, with evacuation area and life boats furthest away from the high hazards, location of the flare upwind of all facilities to prevent ignition of gas cloud resulting from a leak, etc.

Provision is made for access of rigs to wellhead platforms for work-over. Access ways and counter-current landing areas are provided for supply boats. This will include boats supplying consumables, such as catering, fuel, water, production chemicals, etc. as well as boats ferrying equipment parts sent out for repair, spare parts, etc. The landing area of the later will be coordinated with the position of the cranes on the facilities themselves.

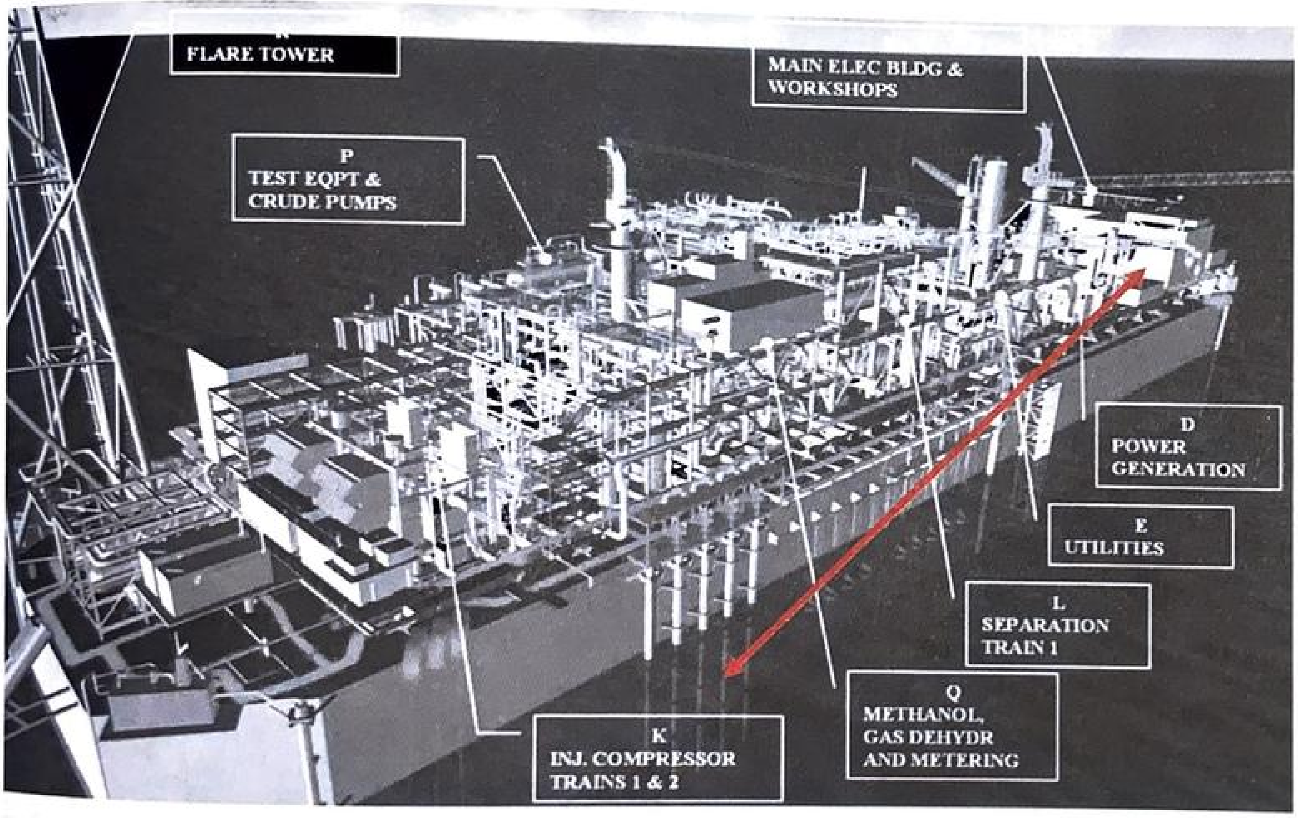
Finally, provision for future field developments, such as addition of risers, gas injection facilities, etc., will be made in the layout.

The design of off-shore facilities depends, to a large extent, on the way they will be built, transported and installed.

For the case of a shallow water field with fixed support (jacket) platforms, the split of the overall facilities into individual structures derives from the maximum platform weight/size that can be lifted by the installation crane.

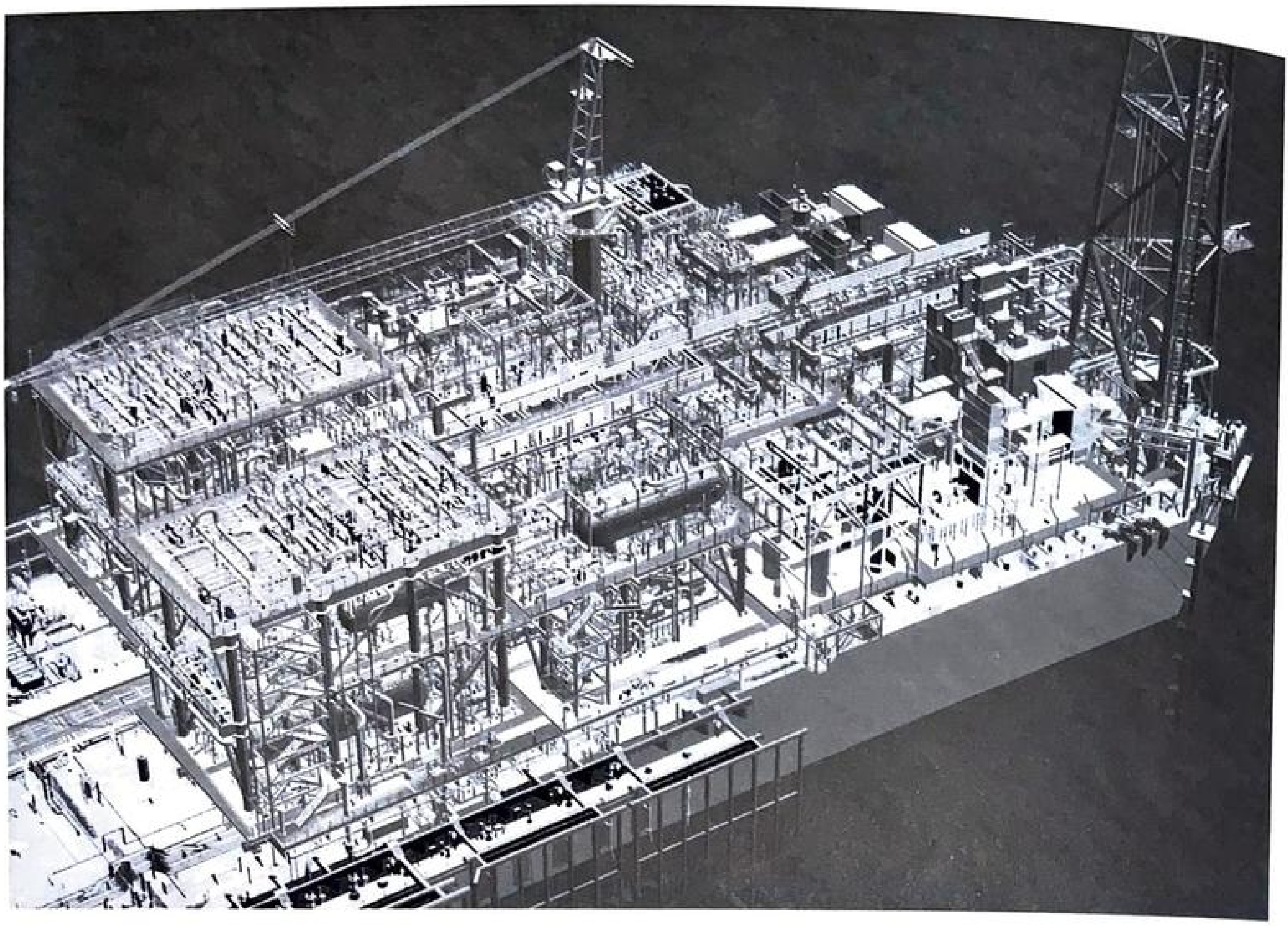
The topsides of a FPSO (Floating Production Storage and Offloading) vessel are split into several modules in order to allow their fabrication on the shipyard quay prior to their integration on the FPSO's hull. A larger capacity barge allows increasing the size and weight of modules, reducing their number and the integration work.

Process units are located as far as possible from living quarters, which is achieved by locating utility units in between. The highest risk process unit, gas compression, is located the furthest away from the living quarters.

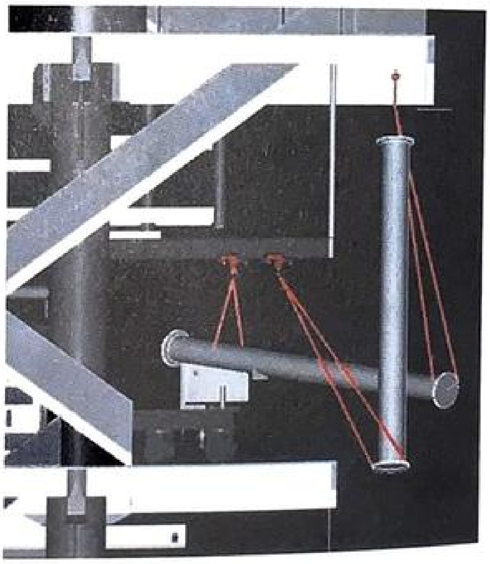


For what regards the layout of equipment inside units, the main difference between Off-Shore and On-Shore facilities is that the fixed minimum separation distances that are applied On-Shore, e.g., 30 feet between two compressors, cannot be applied Off-Shore due to the limited space available. The distances between equipment are the mimimum required for access and maintenance.

Contrary to land facilities where the equipment is horizontally spread with easy access, the equipment of Off-Shore facility is stacked and access is limited.



Handling Studies are performed for the maintenance of each piece of equipment.

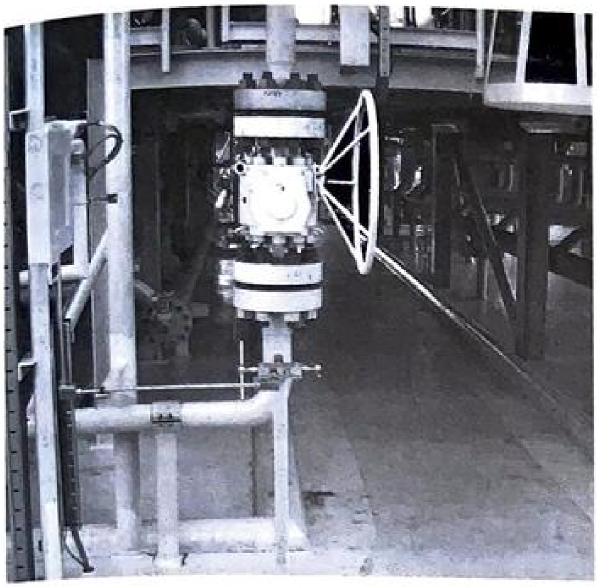


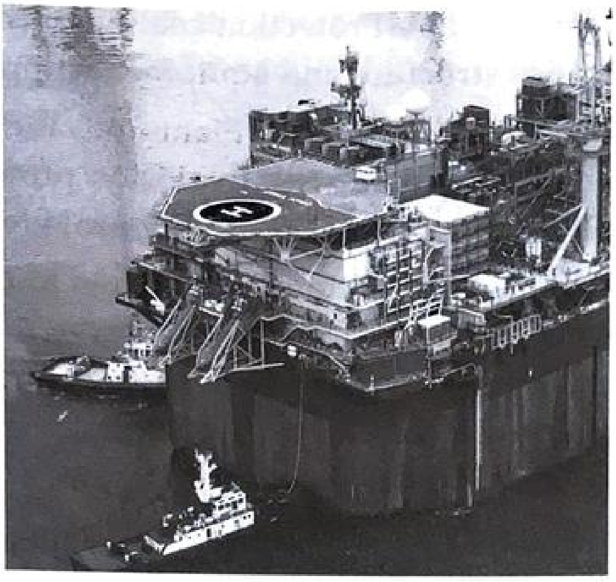
Equipment subject to frequent maintenance, such as heat exchangers, are located at a location easily accessible by the crane, e.g., on the upper deck.

Monorails are provided, along with free space overhead of equipment, for hoisting and moving the parts, up to the nearby trolley/ crane pick-up area.

Other specific factors come into play in equipment layout, such as location of main equipment on the primary structure members and their method (lift/slotting) and timing of installation.

Escape ways are provided throughout the facilities, up to life boats for personnel evacuation.





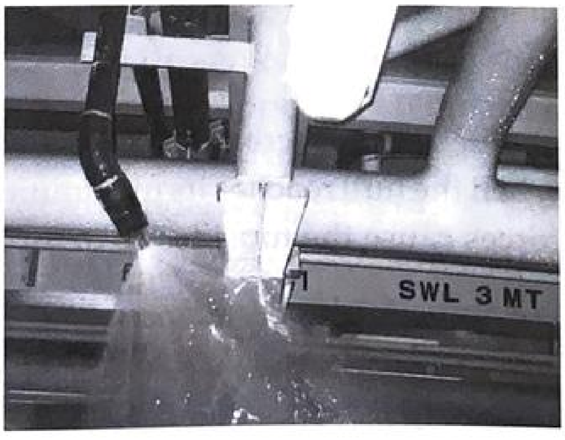
Escape ways must be free from obstruction. Their volume is modelled in the 3D model to reserve the space.

One may wonder how escalation of fire/explosion is avoided, on Off-Shore facilities, as separation distances between equipment cannot be provided as for On-Shore facilities. A more refined approach is applied.

For what concerns explosion, a Quantitative Risk Assessment is performed, as described in chapter 6: the most likely explosion scenarii are identified and the blast pressures calculated. Critical equipment and their supports are designed to resist such blast pressures. Blast studies might also result into the provision of a blast wall.

The blast calculations entail modelling the facility. Such model does not only extend to equipment, structure but also the level of confinement of the environment, including that created by the pipe-work, cable trays, etc. Indeed, the latter determines whether a gas cloud resulting from a leak would safely disperse or could accumulate and reach the explosive limit. Reducing congestion is an important safety aspect of Off-Shore facilities.

As equipment cannot be spaced to reduce fire radiation as they are at an On-Shore Plant, most equipment – compared to only a few On-Shore – are provided with fixed water spray (deluge).



Passive Fire Protection coating of the steel structure is widely applied to the primary structure and equipment support.

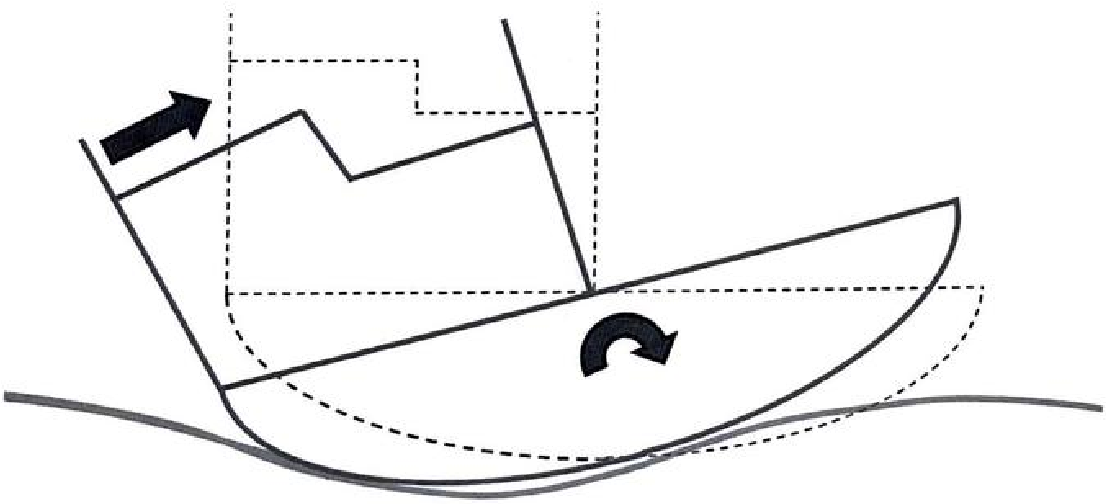
Whereas in On-Shore Plants only the electrical equipment located in hazardous area are provided with Explosion protection enclosure, all electrical equipment of Off-Shore Plants are usually provided such protection.

A special attention is also given to the location and protection vital facilities, such as shutdown valves that serve to isolate the platform from the connected pipelines. In an emergency, such as a major leak on the facilities leading to a fire, it is essential to isolate the latter from the connected pipelines to prevent fuelling the fire with the inventory contained in those pipelines.

A specificity of Off-Shore facilities is that their submerged parts are subject to action from the sea.

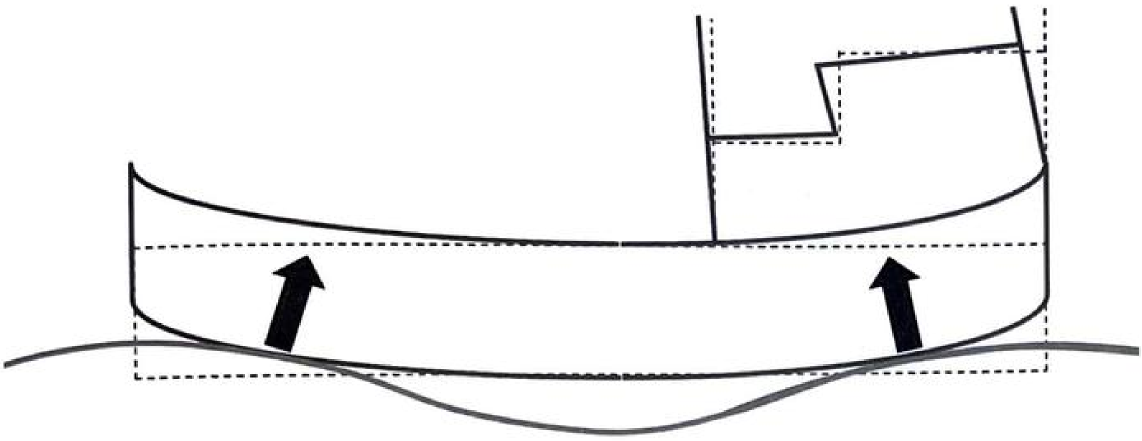
The sea causes the submerged part (hull) to both move and deform. The extent of the motion and deformation obviously depends on the sea state. Such motion and deformation of the hull transfer to the topsides and result in constraints to be taken into account in their design.

The hull of a FPSO, for instance, is subject to motion from the sea (waves, swell) that causes it to oscillate. The sketch below illustrates such motion (roll) around one of the hull axis.

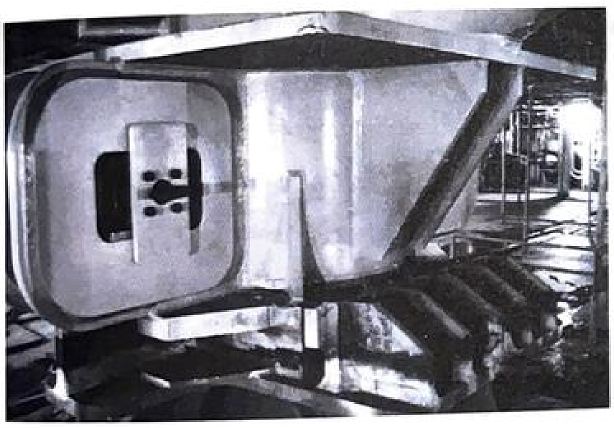


Such motion creates acceleration forces on the topsides, which are maximum when the hull reaches its maximum inclination and starts to roll back. Acceleration forces cause the topsides to deform under its inertia.

As the sea forms an uneven support to the hull, the latter will be subject to deformation. The hull will also deforms as a result of cargo loading/off-loading.



Such deformation transfer to the topsides. The transfer is minimized by providing sliding rather than fixed topsides supports on the hull.



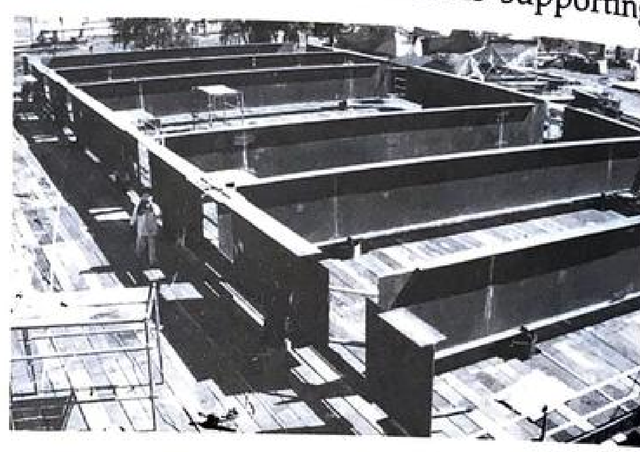
Such sliding supports (shown on the left), called bearing pads, allow vertical displacements, both up and down, unlike fixed supports (shown on the right). Down motion is allowed by compression of the pad, made of elastomer.

Motion and deformation of the hull lead to relative displacements between equipment located on deck. Such relative displacements are not acceptable for long shaft rotating equipment whose driver, gear box and driven equipment must remain strictly aligned. The driver, gear box and driven equipment of such equipment are therefore mounted on a common baseplate supported on the deck at 3 locations only. Use of a 3 point type support ensures that the assembly remains in a plane regardless of the deflection of the underlying structure.

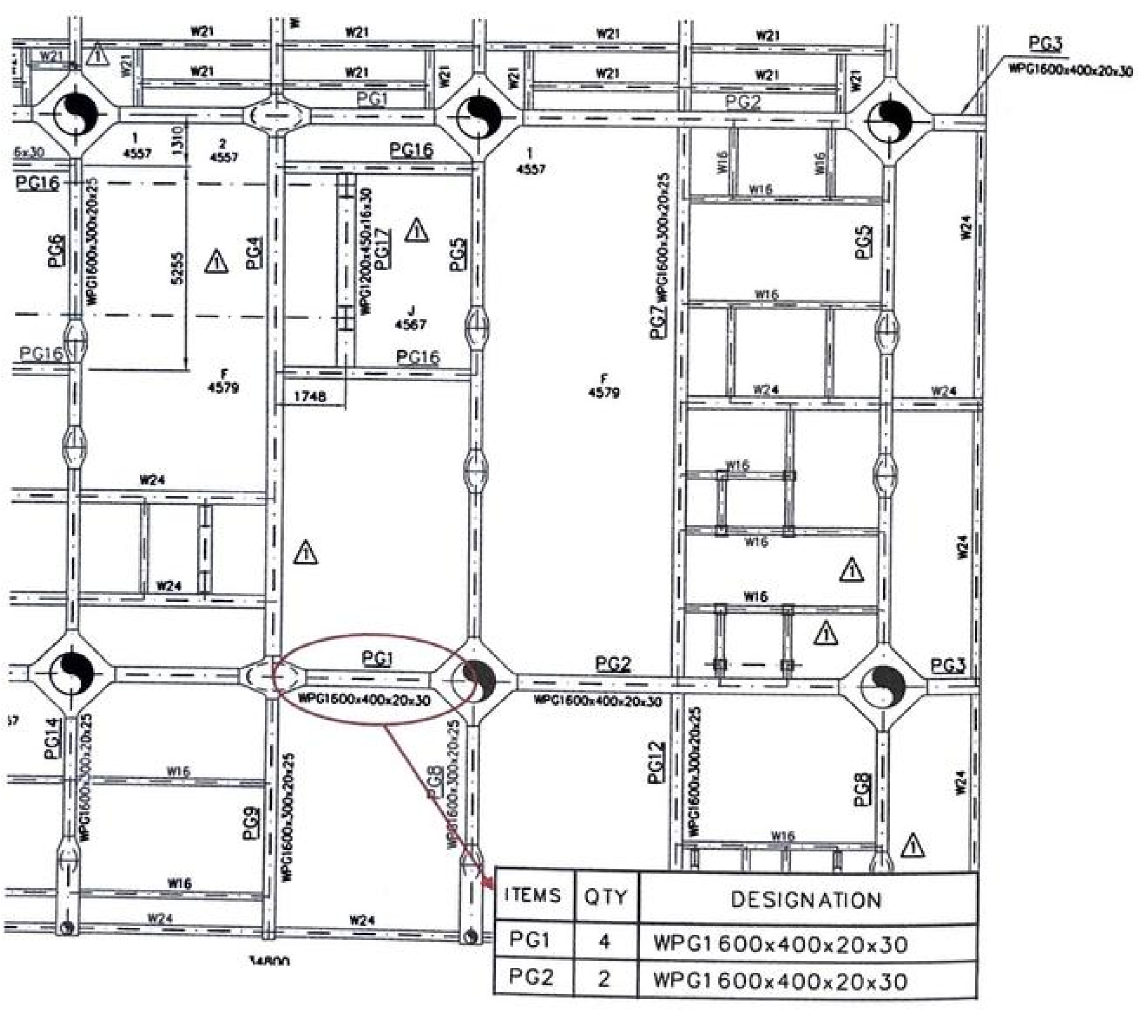
The motions and accelerations to which Equipment is subject are determined in Naval Engineering's Hydrodynamic Analysis as a function of the Equipment position and elevation.

Thickness of some slender equipment, such as columns, may need to be increased to sustain the forces induced by the acceleration (inertia forces induced by the motion of the top of the column).

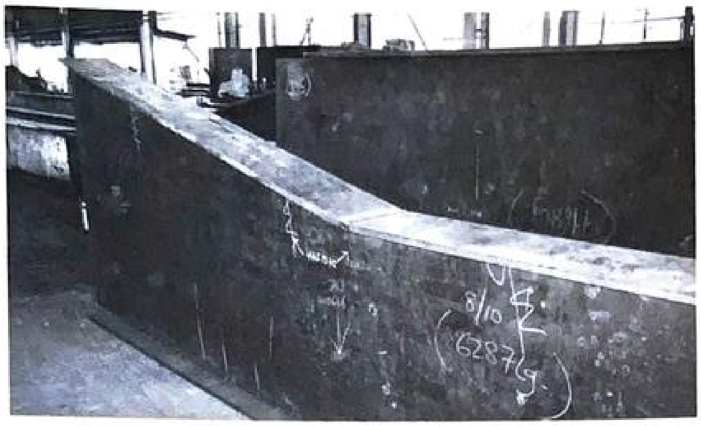
The steel structure of Off-Shore topsides is made of the **primary structure**, which comprises the main girders making the different deck frames, the connections between the various decks (legs), the **secondary structure**, made of beams supporting equipment, and **tertiary structure**, made of deck beams supporting plating/grating, handrails, operating stages, staircases, etc.



Layout studies giving dimensions, number and elevations of deck levels, primary equipment location and weights allow the Structure discipline to perform its design and calculations and issue the **Primary Steel Structure drawings**.

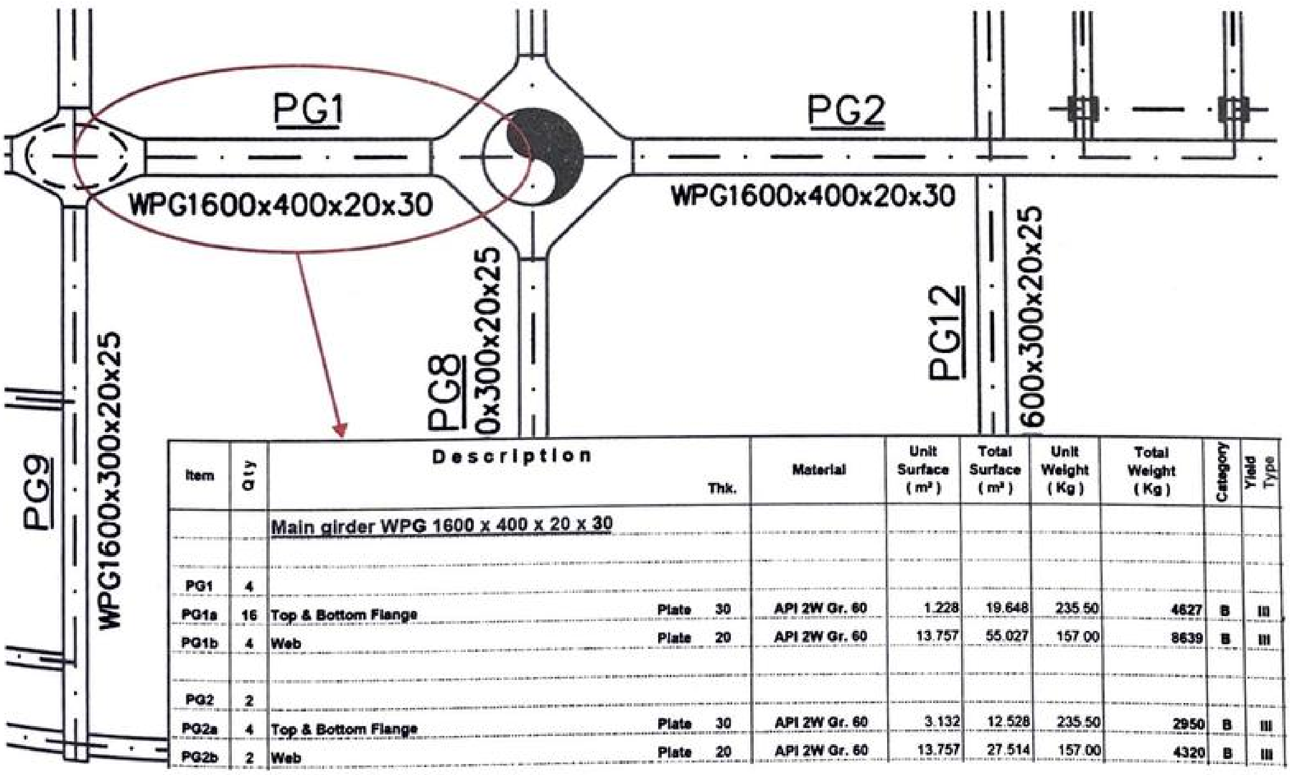


Primary steel structure is purchased as steel plates which are welded/rolled into welded plate girders/tubulars at the shipyard. Special steel is used, of high strength and through thickness properties, that requires special tests and can only come from a few duly qualified mills.



Yield Type	Specified Minimum Yield Strength (Mpa)	Toughness Classes		
		0 No test	1 Test @ LAST	2 Test @ 30°C below LAST
I	240/248	20 J	20 J	20 J
II	344	N/A	35 J	35 J
III	412	N/A	45 J	45 J

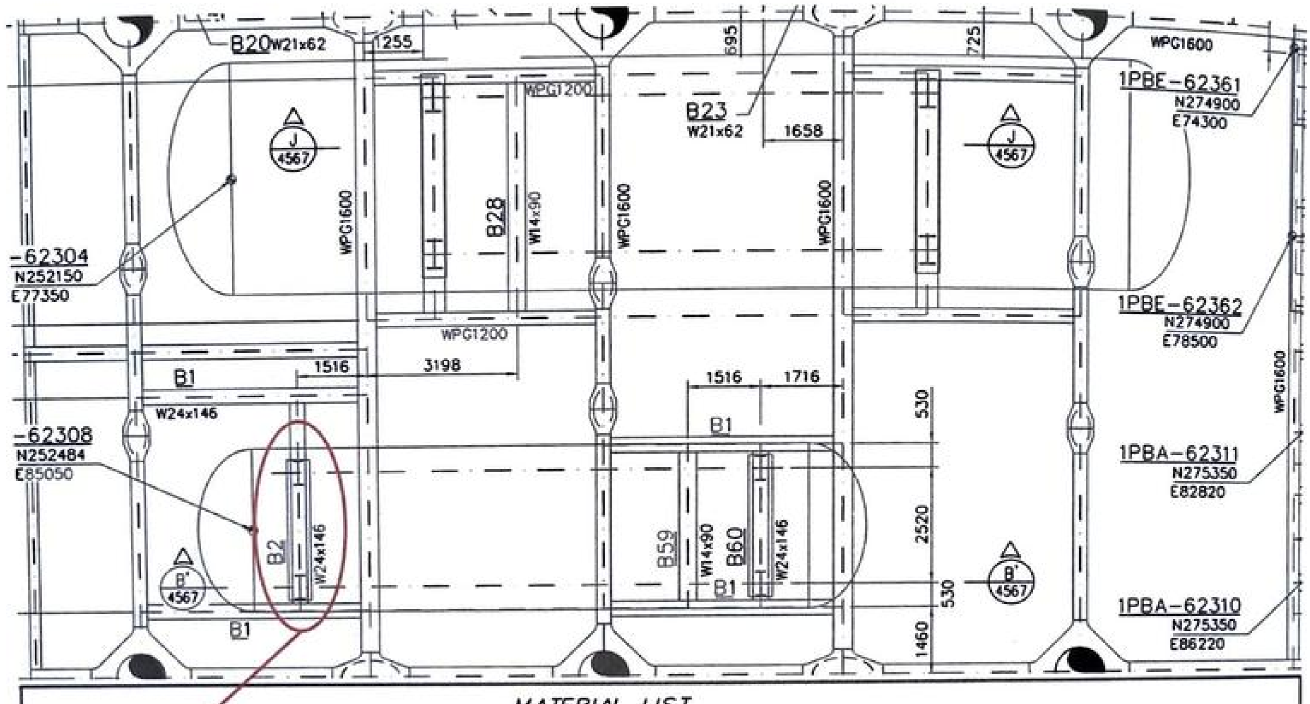
For this reason the plates must be purchased early hence their Specification and Material Take-Off are issued at an early stage of the Project.



Item	Qty	Description		Thk.	Material	Unit Surface (m²)	Total Surface (m²)	Unit Weight (Kg)	Total Weight (Kg)	Category	Yield Type
		Main girder WPG 1600 x 400 x 20 x 30									
PG1	4										
PG1a	16	Top & Bottom Flange	Plate	30	API 2W Gr. 60	1.228	19.648	235.50	4627	B	III
PG1b	4	Web	Plate	20	API 2W Gr. 60	13.757	55.027	157.00	8639	B	III
PG2	2										
PG2a	4	Top & Bottom Flange	Plate	30	API 2W Gr. 60	3.132	12.528	235.50	2950	B	III
PG2b	2	Web	Plate	20	API 2W Gr. 60	13.757	27.514	157.00	4320	B	III

Several calculations are done for Off-Shore structures: In-place analysis, lifting analysis, towing analysis, blast and fatigue. The stresses in the structure are checked for the extreme sea conditions (100 year wave, current, wind). Plated decks that could be subject to a blast are designed for the corresponding dynamic pressure. The connections of the steel structure members could be vulnerable to the repetitive action of the sea waves (fatigue). This is checked both during transport, where stresses can be higher, and during the facility design life at its installation Site.

Secondary structure drawings show the beams supporting the main equipment, and the associated bill of materials. These beams are standard and have a much shorter lead time than primary steel.



MATERIAL LIST									
ITEMS	QTY	DESIGNATION	MATERIAL	L.A.V. UNIT	L.A.V. TOTAL	WEIGHT UNIT	WEIGHT TOTAL	CAT	TYP
B1	4	W24x146	ASTM A131DH/EH36	4.980	19.920	217	4323	B	II
B2	1	W24x146	ASTM A131DH/EH36	4.734	4.734	217	1027	B	II
B60	1	W24x146	ASTM A131DH/EH36	3.564	3.564	217	773	B	II

As motion and deformation of the hull leads to differential displacements between equipment, it induces stress (expansion, compression) on the pipework that connects them.

Flexibility is provided, in On-Shore Plants piping routing, to allow thermal expansion. In Off-Shore facilities, the flexibility of piping is also required to cope with differential displacements.

Let's consider for instance a line connecting a pump on the hull deck to a vessel on the topsides.

The line is fixed at both ends: the nozzles of the pump and vessel. Ordinary stress calculations, such as the ones that would be done for an On-Shore Plant, would check that the line is not subject to excessive stress when it thermally expands while reaching its service temperature. Another factor must be considered for Off-Shore facilities. Indeed, under the action of the sea, the pump attached to the hull deck and the vessel on the topsides will move relatively to each other. The same situation is found for a line connecting equipment located on different topsides modules.

Off-shore piping flexibility calculations also take into account the relative horizontal and vertical displacements of the line supports. They will result in requirements to provide flexibility to the line, by means of directional changes, purposely made loops, etc. As usual, thick and large diameter lines are the most affected, as they are the less flexible.

On an Off-Shore project, the weight & centre of gravity of the various structures shall be monitored continuously to ensure the feasibility of their installation.

A Lifting Study is produced, based on the equipment and bulk weight, the latter being obtained from the Material Take-Off in each discipline. The lifting study serves to validate the lifting feasibility by the selected crane.

If the load exceeds the hook capacity, a weight management is required, which would consist of removing some of the equipment from the module prior to the lift, or even to split the module.

The equipment summary is used to prepare the **Weight Report**. The objective of the weight report is to anticipate and manage the weight & centre of gravity of the various modules in order to ensure at any time, the feasibility and the integrity of the project.

Detail for module X				Center of Gravity		
		Reported weight (te)		East	North	Elevation
Riser protec. / Acc. ladders	Boarding access ladders	1098	171	100,0	222,6	86,0
	Riser Protector		915			
	Cathodic protection		12			
Mooring Equipment		493	493	97,0	242,1	101,1
Instrumentation & electrical Equipment	Instrumentation equipment	99	13	100	100	87,5
	Electrical Equipment		49			
	Electrical cable integration		32			
	Electrical cable tray / support		5			
Riser inst. winch support and Casings	Paint on riser / caisson	501	14			
	Fire water caisson		66	100	100	83,75
	SW lift caisson		43	66,4	215	83,75
	Suction Hoses		126			
	Riser instalation winch support		252	136,1	NA	102,4
	Total	2190		95,5	249,3	87,9

(*) Gross Estimation of the centre of gravity

Specific **design codes** are applied to Off-Shore facilities which result in the provision of extra safety devices, including isolation valves, and requirements, such as that to be able to depressurize the facilities in less than 20 minutes, etc. Being installed at sea, they are subject to class certification, like a ship, by a third party. The class certification body thoroughly checks the design, in particular Safety, escape and evacuation, etc.

Lastly, Off-shore facilities give much more room to the Engineer to propose different concepts than On-Shore facilities. This allows differentiation between Engineering firms and is one of the reasons why design competitions are often organized between them by Clients.

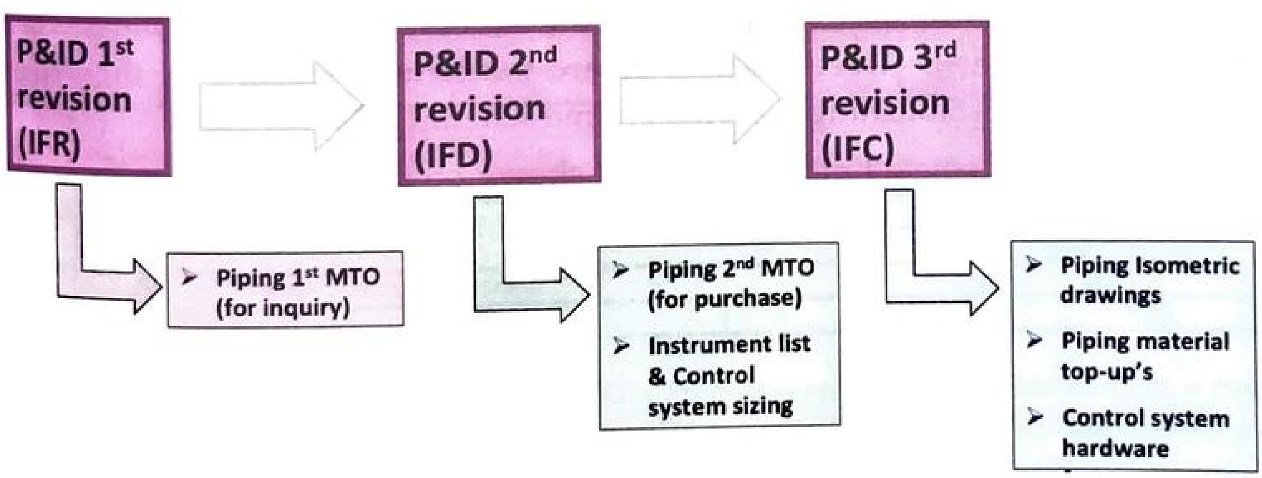
Chapter 14

The overall work process

The work of Engineering disciplines is highly inter-related. The input data of one discipline is very frequently the output data of another.

Piping and Instrumentation and Control (I&C) disciplines, for instance, work from the P&IDs issued by Process.

The usual P&IDs revisions are shown below.

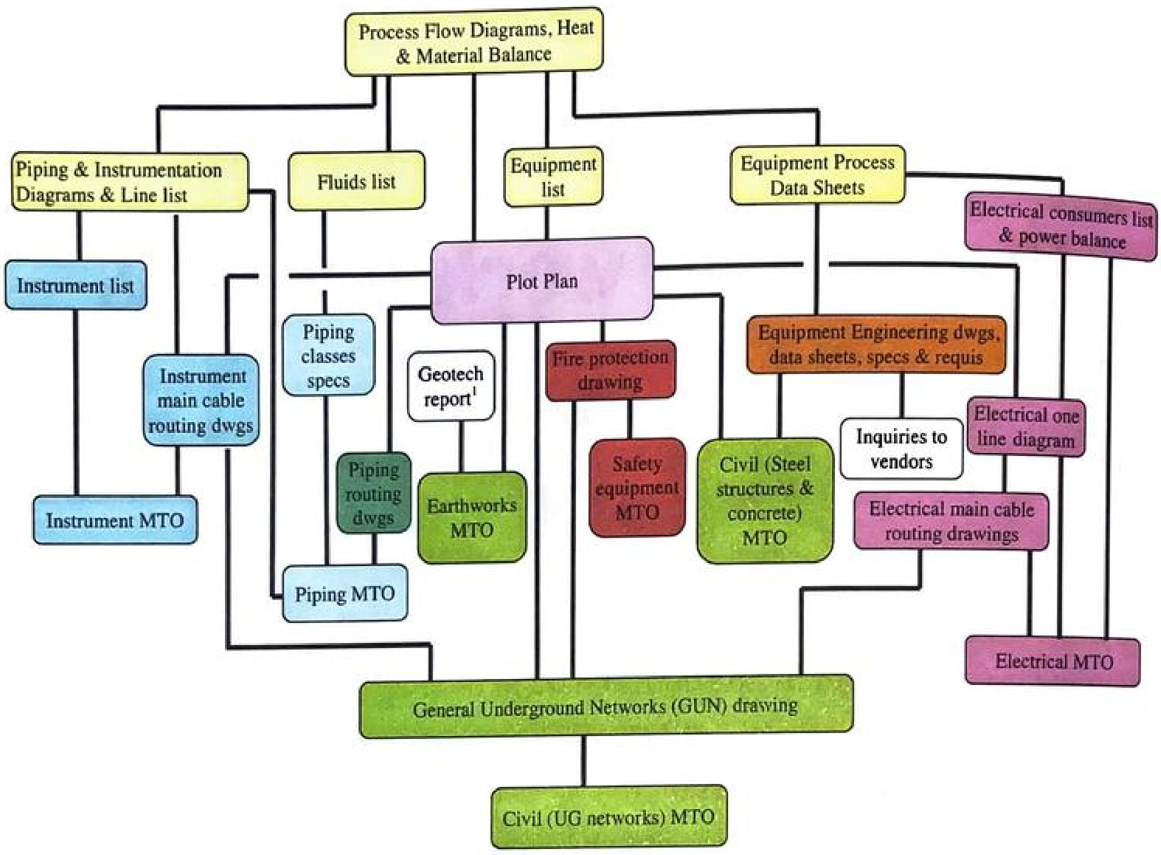


The same can be said of the Plot Plan, which serves to virtually all disciplines (Safety, Civil, Piping, Electrical) to develop their design.

The inter-relations between Engineering tasks/documents can be depicted, for a **FEED**, as shown below.

The different colours correspond to different engineering disciplines.

FEED Engineering work sequence

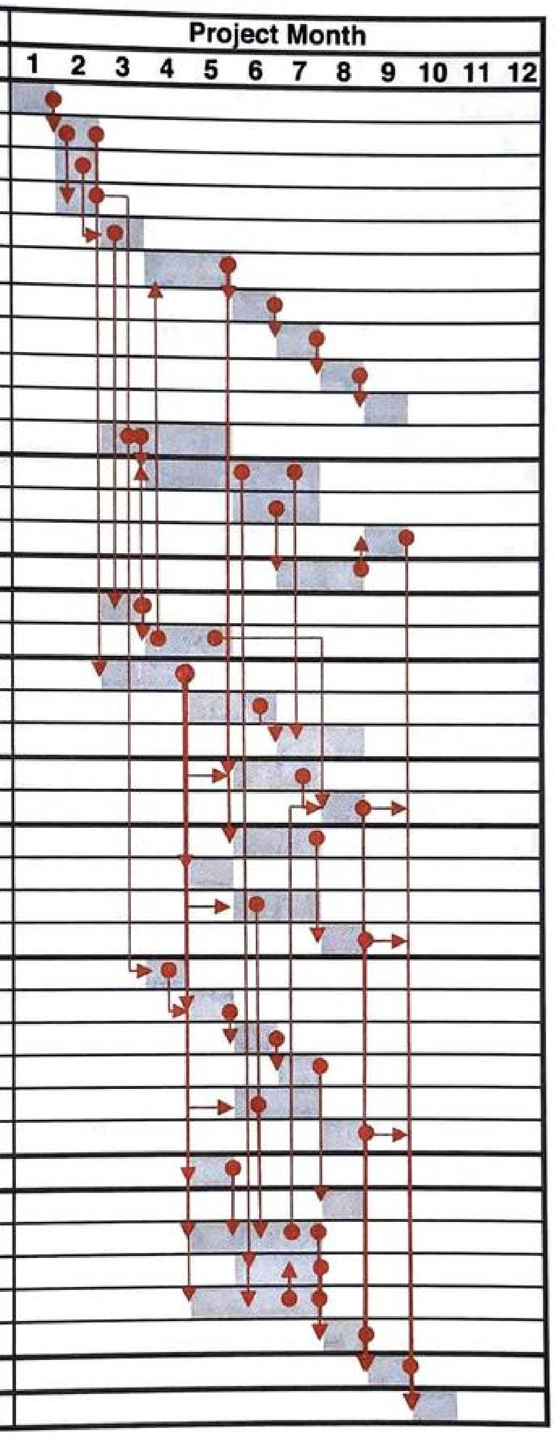


The input data of many disciplines are output data of other disciplines. These inter-dependencies between disciplines are taken into account by the Project scheduler when establishing the Project time schedule.

The resulting typical FEED schedule is shown on the next page.

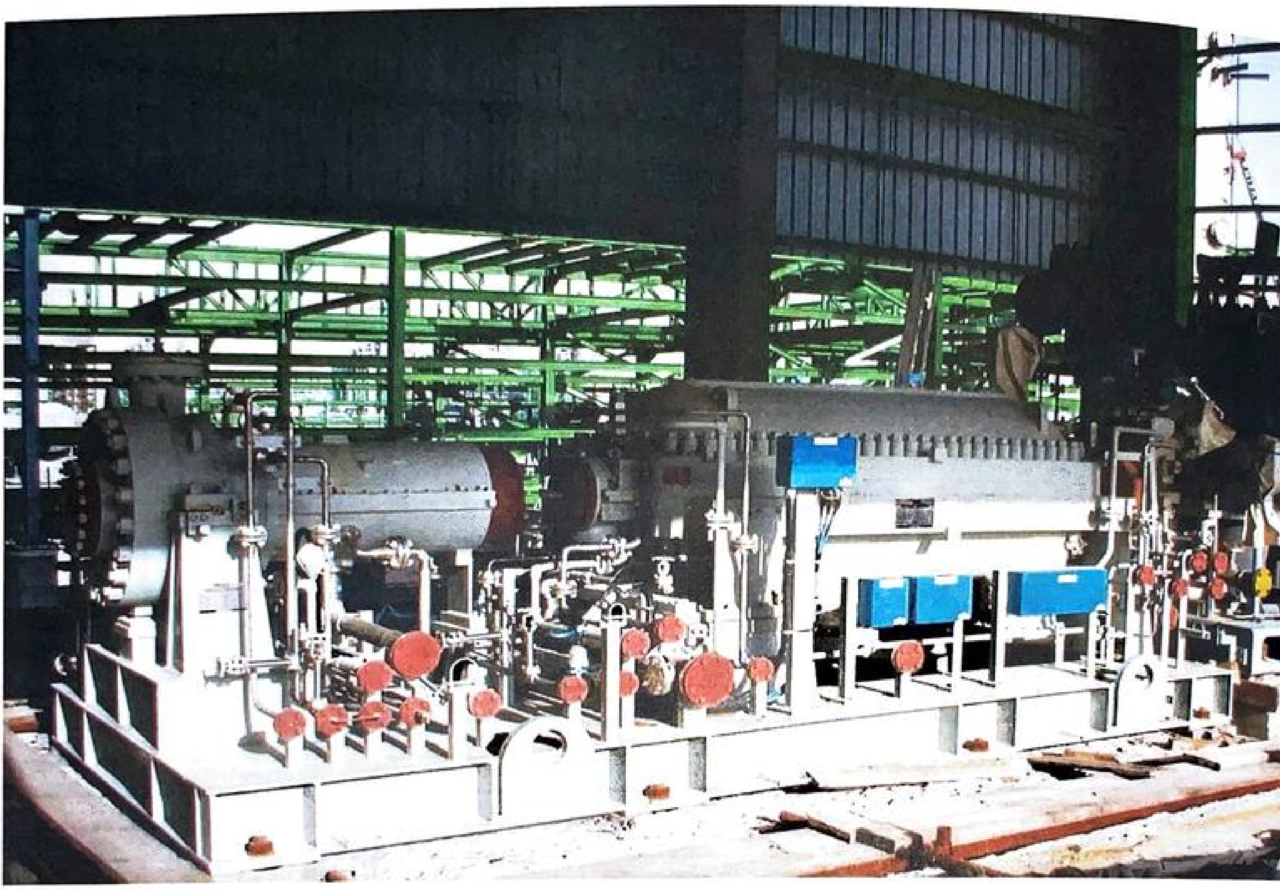
FEED Engineering schedule

Disc.	Activity
Gen	Contract Effective Date
PR	Process simulations
	PFD
	H&MB
	Equipment list
	Fluids list
	P&IDs preparation and 1st issue (IFR)
	P&ID review with COMPANY
	P&IDs 2nd issue (IFH)
	HAZOP review
	P&IDs IFD
	Process equipment sizing & data sheets
EQT	Equipment Mechanical design, dwgs, data sheets
	Equipment Material Requisitions
	Equipment Technical Bid Tabulations
PRT	Inquiries to Equipment Vendors
PM	Material selection report
	Piping classes summary & specifications
PL	Plot plan - 1st issue (IFR)
	HAZID + Plot Plan review with COMPANY
	Plot Plan IFD
PI	Piping routing
	Piping MTO
I&C	Instrument list
	System architecture drawing
	Main cable routing drawings
	MTO
EL	Load list
	Single line diagram
	Equipment sizing
	Sub-station arangement drawings
	Main cable routing drawings
	MTO
HSE	Fire Protection drawing
CIV	Building architectural drawings
	General Underground Networks drawing
	Foundation guide drawings
	Pipe-racks and Steel structures outline drawings
	Civil MTO
SUB	Inquiries to Construction contractors
COST	Cost estimate



PR = Process, EQT = Equipment/Mechanical, PRT = Procurement, PM = Piping Material, PL = Plant Layout, PI = Piping Installation, I&C = Instrumentation & Control, EL = Electrical, HSE = Safety & Environment, CIV = Civil, SUB = Sub-Contracting Dept, COST = Cost estimate Dept

At Detail Engineering stage comes another interface: that with Equipment vendors. Engineering is indeed the integrator of Equipment in the Plant.

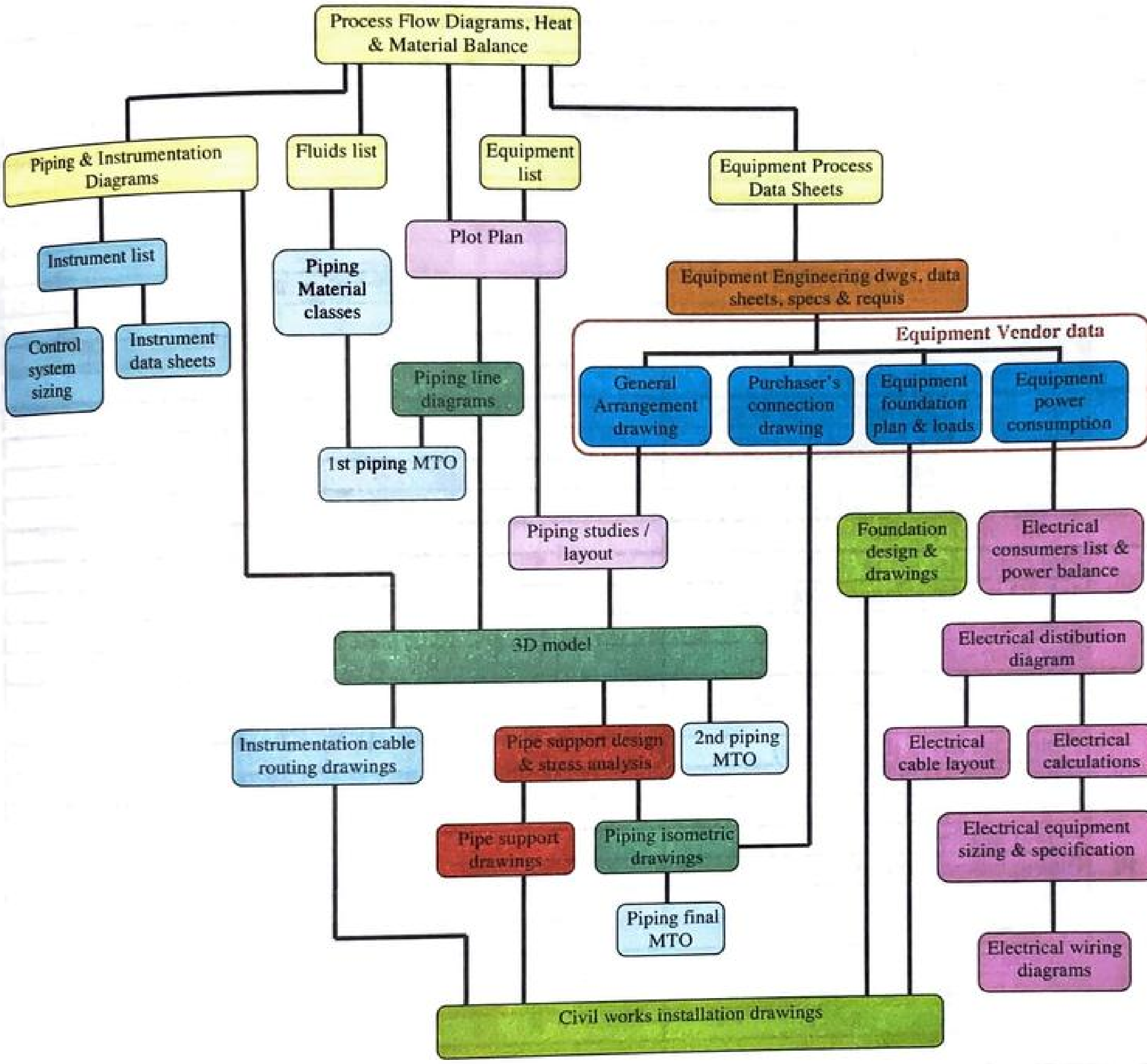


Plant layout design, for instance, is done on the basis of the size of Equipment obtained from suppliers. Such size will only be known once the equipment is ordered and the vendor has completed its design and submitted the Equipment General Arrangement Drawing.

The other disciplines (Electrical, Piping, Civil/Structural, Instrumentation & Control) also depend on information from Equipment vendors to develop their design.

The work sequence of Detail Engineering therefore includes information from Equipment vendors, as shown on the next page in the red frame.

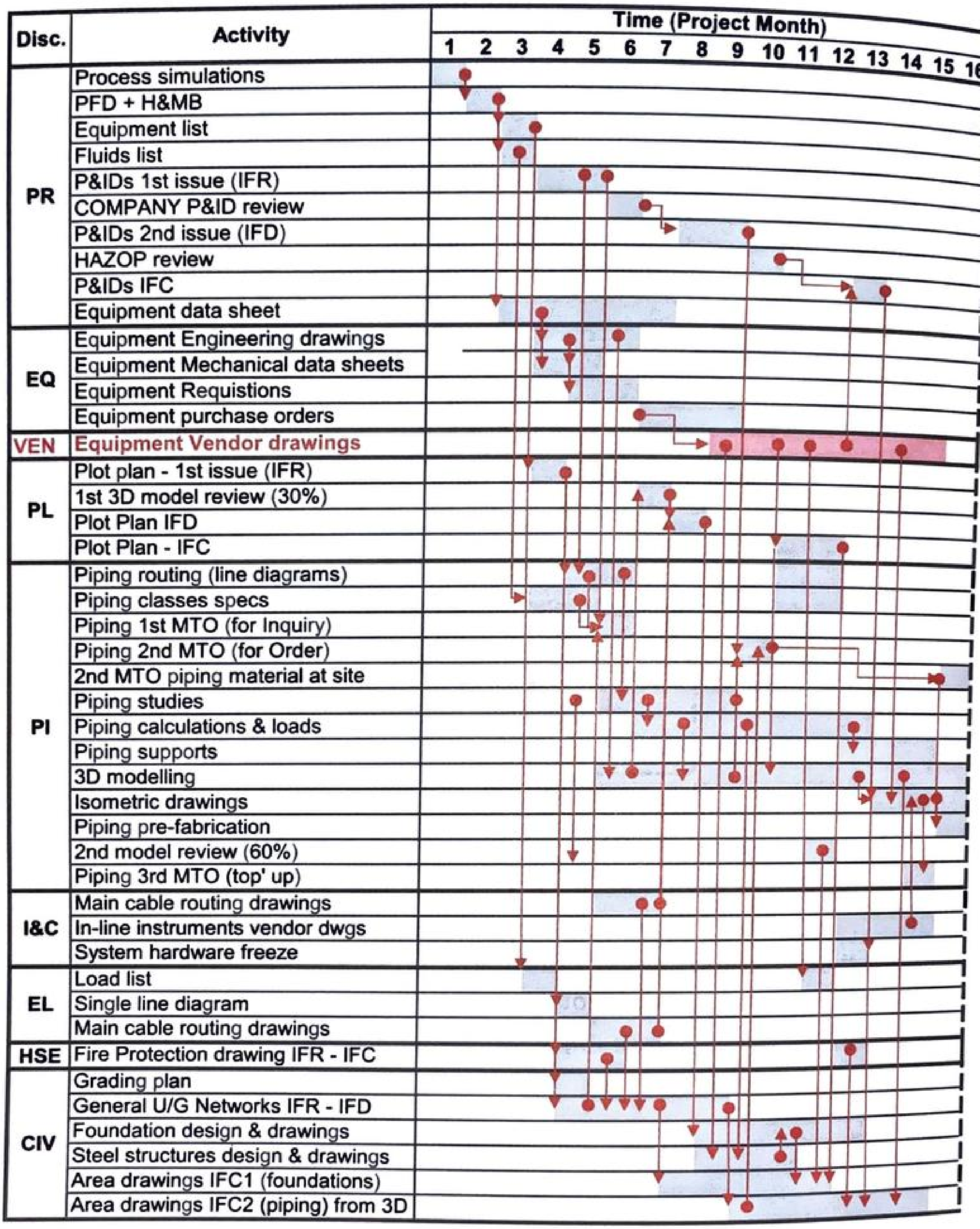
Detail Engineering work sequence



The dependencies between the Engineering tasks, along with the required time of deliveries of Engineering documents to Procurement and Construction (see chapter 16) are taken into account to establish the Engineering Time Schedule.

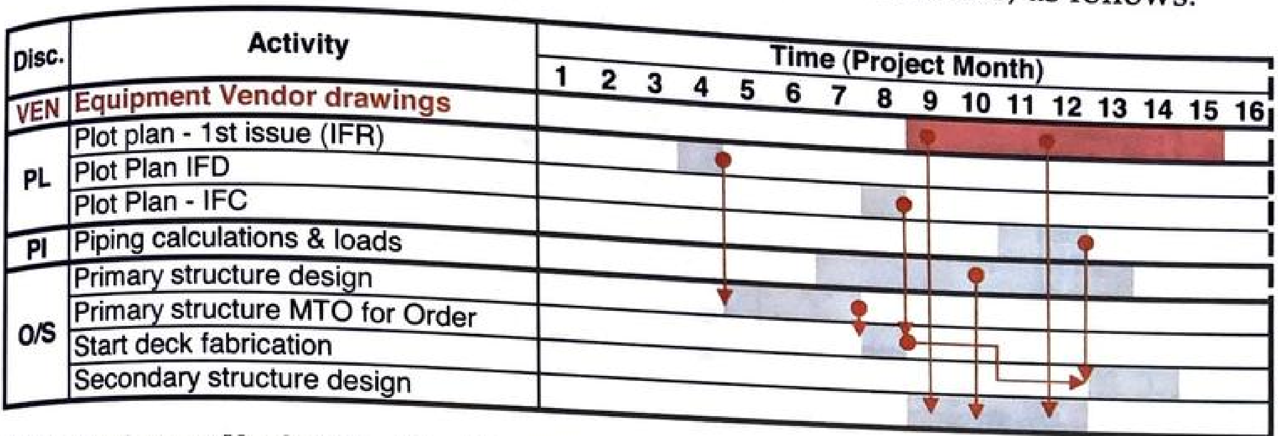
The resulting typical Detail Engineering time schedule for a 3 year EPC job is shown on the next page.

Typical **Detail Engineering schedule** for a 3 year EPC Project



PR = Process, EQ = Equipment, PL = Plant Layout, PI = Piping, I&C = Instrum. & Control, EL = ELectrcial, HSE = Safety & Env., CIV = Civil, VEN = Equipment Vendor

For Off-shore jobs, Civil is replaced by Off-shore structure, as follows:



VEN = Equipment Vendor, PL = Plant Layout, PI = Piping, O/S = Off-Shore Structure

The overall synoptic view on the next page shows the key On-Shore EPC Engineering development steps and the deliverables at interfaces between disciplines, in particular:

P&IDs	IFR, IFD, IFC
Piping MTOs	1st MTO (IFI), 2nd MTO (IFP), MTO up-dates
Plot Plan	IFR, IFD, IFC
Model Review	1st (30%), 2nd (60%), 3rd (90%)

The disciplines are shown in different colors.

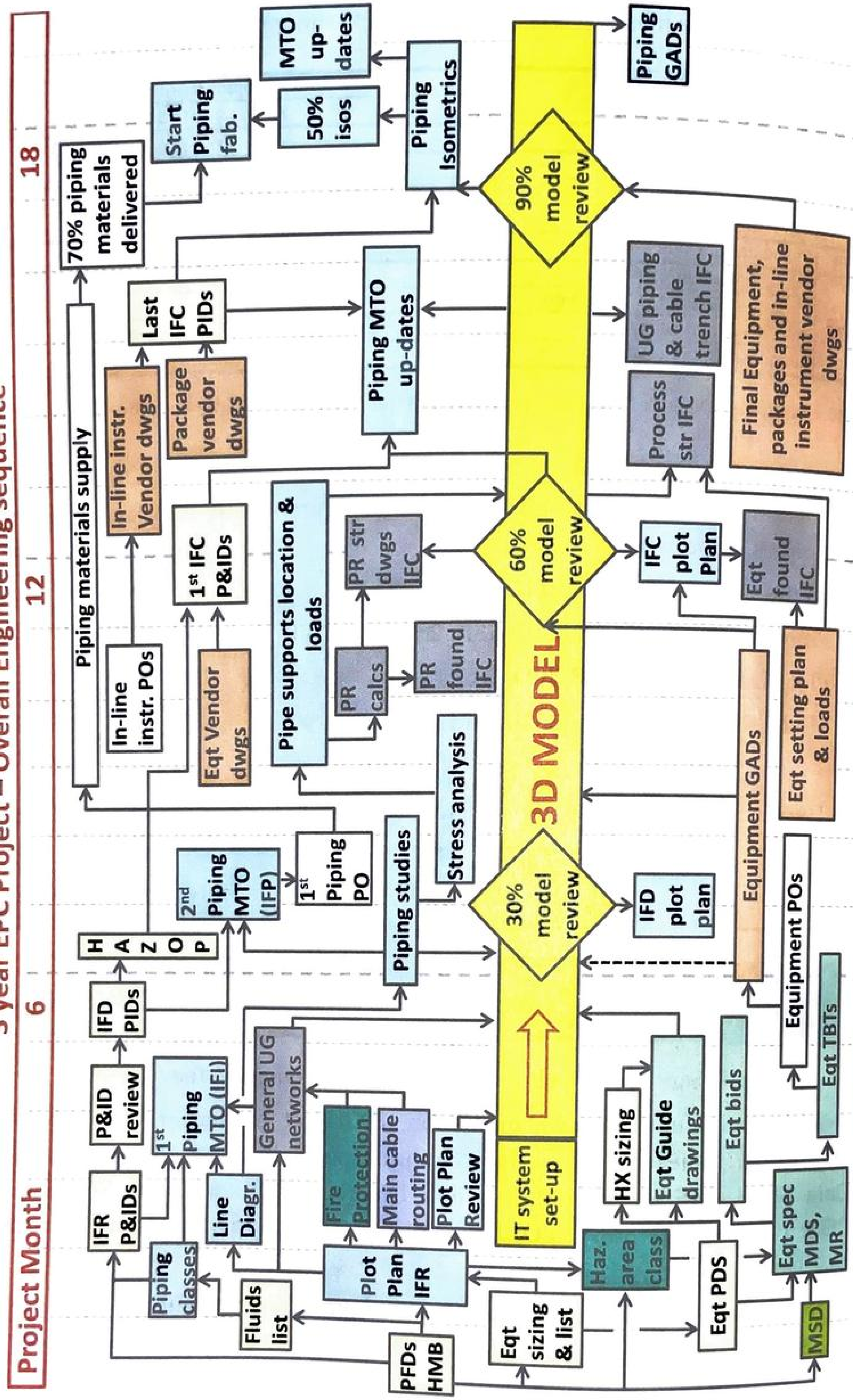
Process | Equipment/ Mechanical | Plant Layout / Piping | E&I

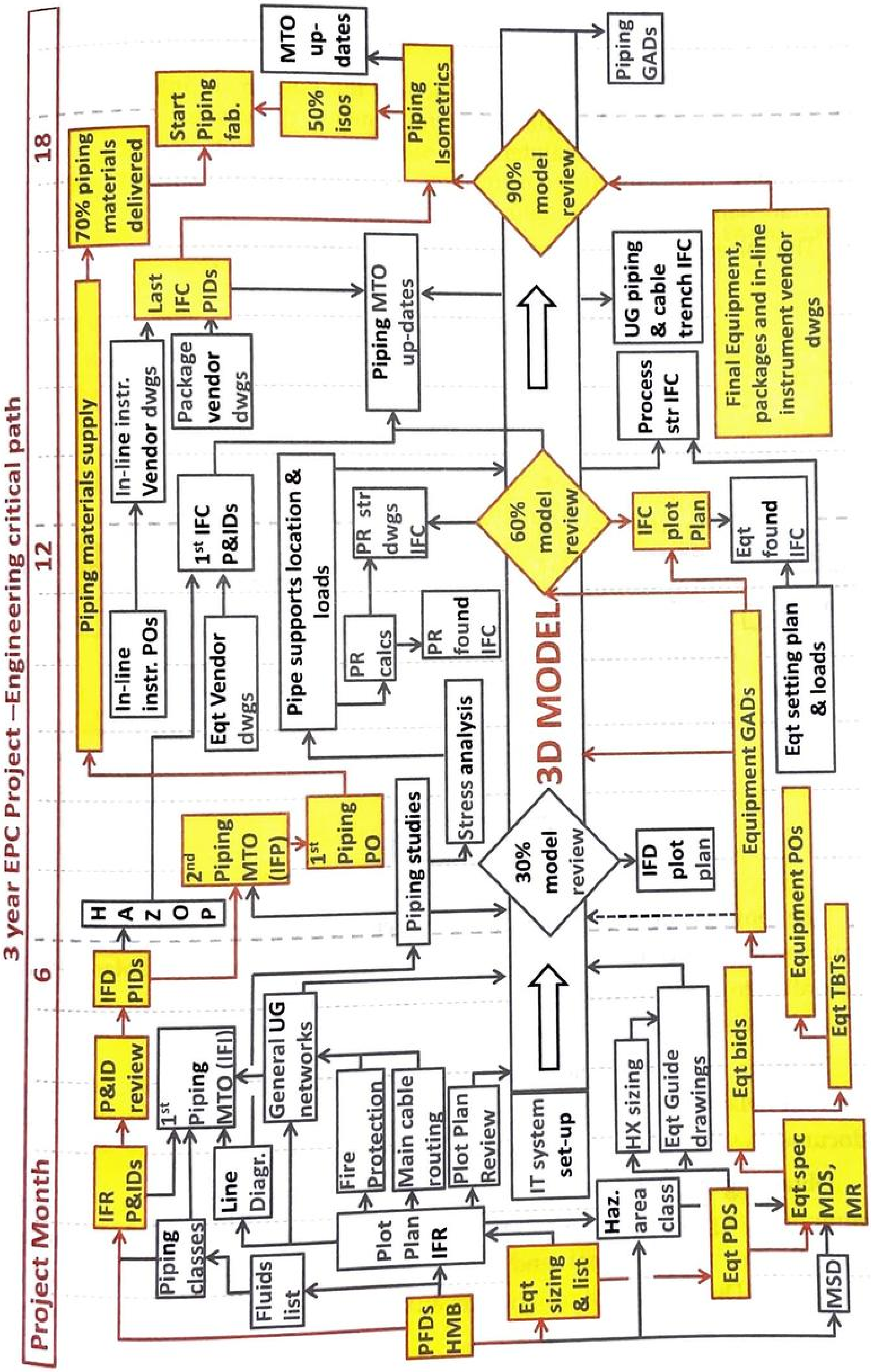
Safety | Materials & Corrosion | Civil | Vendors | Procurement

The usual Engineering abbreviations are used alongside the following:

Eqt: Equipment, **Found**: Foundation, **HX**: Heat Exchanger, **IFI**: Issue For Inquiry, **IFP**: Issue for Purchase, **isos**: Piping isometric drawings, **MDS**: Mechanical Data Sheet, **MSD**: Material Selection Diagrams, **MR**: Material Requisition, **PDS**: Process Data Sheet, **PO**: Purchase Order, **PR**: Pipe-Rack, **Str**: Structure, **UG**: Underground.

The usual Engineering schedule critical path (Equipment and Piping) is highlighted on the page that follows.

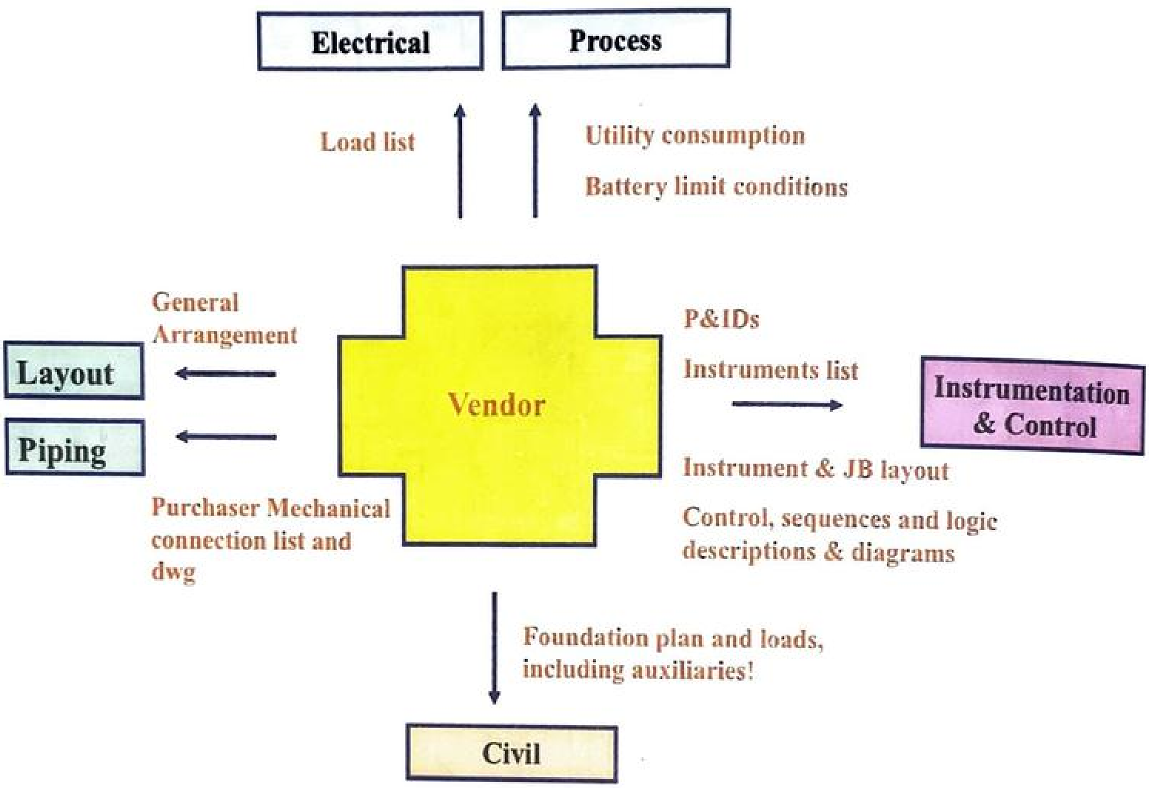

3 year EPC Project – Overall Engineering sequence
Project Month
6
12
18
PFDs HMB
Fluids list
Piping classes
IFR P&IDs
P&ID review
IFD PIDs
HAZOP
1st Piping MTO (IFI)
Line Diagr.
General UG networks
Plot Plan IFR
Fire Protection
Main cable routing
Plot Plan Review
IT system set-up
Eqt sizing & list
Haz. area class
HX sizing
Eqt Guide drawings
Eqt PDS
MSD
Eqt spec MDS, MR
Eqt bids
Eqt TBTs
Equipment POs
Equipment GADs
30% model review
IFD plot plan
Piping studies
Stress analysis
2nd Piping MTO (IFP)
1st Piping PO
Piping materials supply
In-line instr. POs
Eqt Vendor dwgs
1st IFC P&IDs
In-line instr. Vendor dwgs
Pipe supports location & loads
PR calcs
PR found IFC
PR str dwgs IFC
3D MODEL
60% model review
IFC plot Plan
Eqt found IFC
Eqt setting plan & loads
Package vendor dwgs
Last IFC PIDs
Piping MTO up-dates
Process str IFC
UG piping & cable trench IFC
Final Equipment, packages and in-line instrument vendor dwgs
70% piping materials delivered
Start Piping fab.
50% isos
Piping Isometrics
MTO up-dates
90% model review
Piping GADs


3 year EPC Project –Engineering critical path
Project Month
6
12
18
PFDs HMB
IFR P&IDs
P&ID review
IFD PIDs
HAZOP
Piping classes
Fluids list
1st Piping MTO (IFI)
Line Diagr.
General UG networks
Plot Plan IFR
Fire Protection
Main cable routing
Plot Plan Review
IT system set-up
Eqt sizing & list
Haz. area class
HX sizing
Eqt Guide drawings
Eqt PDS
Eqt spec MDS, MR
MSD
Eqt bids
Eqt TBTs
Equipment POs
2nd Piping MTO (IFP)
1st Piping PO
Piping studies
Stress analysis
30% model review
IFD plot plan
Equipment GADs
Piping materials supply
In-line instr. POs
Eqt Vendor dwgs
Pipe supports location & loads
PR calcs
PR found IFC
3D MODEL
Eqt setting plan & loads
In-line instr. Vendor dwgs
1st IFC P&IDs
PR str dwgs IFC
60% model review
IFC plot Plan
Eqt found IFC
Package vendor dwgs
Last IFC PIDs
Piping MTO up-dates
Process str IFC
UG piping & cable trench IFC
Final Equipment, packages and in-line instrument vendor dwgs
70% piping materials delivered
Start Piping fab.
50% isos
Piping Isometrics
90% model review
MTO up-dates
Piping GADs

Information from Equipment/package vendors is essential to Detail Engineering development.

This information is that which relates to the Equipment interfaces with the Plant: Equipment and auxiliaries arrangement, dimensions and free space required for access and maintenance, support/foundation, connecting process and utility lines, utility consumption, electrical loads list, instrumentation interfaces and automation requirements.

The corresponding vendor documents are identified below.



The above vendor documents, which are critical for Engineering development, must be identified, their contents defined and their submission dates specified according to the Engineering schedule. Please refer to the Equipment/Mechanical discipline chapter for details on how to do so.

In order to ensure timely submission of these documents by vendors, to prevent delay of Engineering development, payments must be conditionned to documents submission and penalties applied in case of delays.

Obtaining all needed vendor information is most difficult for packaged equipment, e.g., compressors. Indeed, the vendor usually designs/manufactures only the main equipment and sub-supplies secondary equipment such as auxiliaries. Due to this, information on auxiliaries is available at a late stage only.

It must also be integrated by the package vendor into the overall package drawings, such as the package General Arrangement and foundation drawings

Exchange of information is not only one way, from Vendors to Engineering, but from Engineering to Vendors as well, as shown below for a column.

Interface data provided by Engineering to the Vendor
Nozzle elevation, orientation, loads
Elevation & position of manholes, height of skirt/support
Platform supports (location and load)
Pipe supports (location and load)
Elevation of instrument level connections
Internals support, positions and loads
Earthing lug / lightning lug
Passive Fire Protection
Insulation clips
Handling (davit)

Interface data provided by Vendor to Engineering
Exact dimensions for 3D model
Nozzle exact position
Weight, lifting points
Loads on foundation
Location of temporary supports (for transport)

Such exchange of information is done through the review of Vendor documents by the Engineer, which involves multiple disciplines.

Chapter 15

BASIC, FEED and Detail Design

The respective levels of design development of Basic Engineering and Front End Engineering Design (FEED) mainly derive from the respective accuracy of the cost estimate of the facility required at each stage:

- ± 30-40% (AACE class 4) at BASIC stage
- ±15-20% (AACE class 2) at FEED stage.

A facility's cost is made of cost of goods (supply), cost of works (installation) and cost of services (Engineering, Project Management).

Goods include the main Equipment, i.e., the Equipment listed in the Process Equipment list, and bulk (piping, structural steel, concrete, cables, etc.).

At Basic Engineering stage the facility's cost is estimated using parametric models:

- The main Equipment cost is estimated in-house on the basis of the Equipment characteristics (type, duty, dimensions, materials of construction) shown on the Equipment list. The estimate is done using purchased price of similar Equipment on past projects as well as cost ratios, e.g., USD/kg for pressure vessels, USD/m^2 for heat exchanger, USD/kW for pumps, etc. No inquiries to Equipment vendors are done at this stage.

- Bulk quantities are estimated using ratios observed on similar past projects/units. Such ratios include equipment/pipe weight ratio, typically 45% for a Refinery Unit, equipment/foundation concrete weight ratios, etc.
- Costs of works, i.e., installation, are estimated using ratios of manhours per quantity of work, e.g., hours/tons for Equipment/pipes/steel structures, and estimated labour cost.
- Cost of services is estimated using ratios, typically hours/Equipment.

At FEED stage, the higher accuracy of the facility's cost estimate requires:

- Issue of inquiries to Equipment vendors, to get up-to-date market prices. In order to get precise quotations, additional information to that of the Process Data Sheet issued at BASIC stage is required. Such information is indicated on the Mechanical Data Sheet and Material Requisition.
- Detailed estimates of bulk quantities. Design drawings must be prepared in order to perform Material-Take-Off's from these drawings.
- The technical definition of all items whose cost is significant, e.g., electrical equipment, expensive instruments (ON/OFF, control valves, analyzers, etc.),

Additionally to the requirements of the cost estimate, an Owner aiming to contract the Enginering and Construction of a Plant under a Lump Sum Turn-Key (LSTK) contract requires precise definition of the scope of work and the quality level. The LSTK contract must include a number of specifications and standards, in all disciplines, related to the design, equipment, materials and workmanship. These documents are developed during FEED.

Documents for permitting shall also be carried out at this stage, including Environment Impact Assessment (see chapter 6 Safety & Environment).

The table on the following pages show at which stage each Engineering document is issued. Documents issued at a given stage are of course revised/ up-dated at subesquent stages.

Discipline	Deliverable/activity	BASIC	FEED	DETAIL
General	Basic Engineering Design Data		✓	
	Procurement Plan with identification of LLI		✓	
	Project Time schedule	preliminary	update	final
	Project Equipment list		With dimensions & weights	
Safety & Environment	HAZOP report		✓	✓
	HAZOP close-out report (see note)		✓	✓
	HAZID		✓	
	HAZID close-out report		✓	
	Quantitative Risk Assessment (QRA)		for permitting and blast design	✓
	Hazardous area classification drawings		IFD	✓
	Fire water demand calculation		prelimnary	final
	Fire & Gas detection layout			✓
	Fire Water pumps and network P&IDs		IFD	IFC
	Fire water network layout drawing		IFD	IFC
	Safety concept & philosophies		✓	
	Environment requirements specification		✓	
	Environment impact Assessment (EIA)		for permitting	✓
Process	Process Design basis	✓		
	Process Design criteria	✓		
	Process Flow Diagrams (PFDs)	✓	✓	✓
	Heat & Material Balances (HMB)	✓	✓	✓
	Process Equipment list	Sized except HX	Sized	✓
	P&IDs	Process	Process + Utility	Process + Utility + Packages
	P&ID review	✓	✓	✓
	Process description		✓	
	Operating manual			✓
	Equipment Process Data Sheets	Process Equipment only	Process + Utility Equipment, flare, drain, etc.	
	Instrument Process Data Sheets		Control & on/off valves, analysers, flowmeters	all
	Packaged units duty specifications	Main	all	
	Emergency shutdown philosophy		✓	
	Causes & Effects diagrams		✓	
	Heat exchangers thermal design & data sheets		✓	
	Utility consumption	preliminary	update	final
	Flare relief load	preliminary	update	final
Equipment/ Mechanical	Equipment specifications		✓	
	Equipment Mechanical Data Sheet		✓	
	Material requisition for inquiry		For main equipment	For all
	Technical Bid Tabulation		For main equipment	For all
	Material requisition for purchase		For LLI	For all
	Vendor drawings			✓
Plant Layout	Unit Plot Plan	typical	IFD	IFC
	3D modelling		Equipment + main process lines only	✓
Piping Installation	Piping routing drawings		✓	
	Piping studies and Layout drawings			✓
	Piping General Arrangement drawings			✓
	Isometric drawings			✓
Piping/Material	General specification for piping materials		✓	
	Piping classes summary		✓	
	Piping Material Classes Specifications		✓	
	Material selection diagrams	✓		
	Special piping items specification			✓
	Standard drawings		design	installation
	Piping MTO		from P&ID and Plot Plan	from Piping layout studies/3D model

IFD: Issued For Design/IFC: Issued For Construction/LLI: Long Lead Item/HX: Heat Exchanger

Note: The revision of the P&IDs incorporating the HAZOP actions is not always requested. However it is in important that HAZOP actions are answered, in the close-out report, and that outstanding ones are included in punch list

Discipline	Deliverable/activity	BASIC	FEED	DETAIL
Piping/Stress	Design specification (piping stress design basis)		✓	
	Piping stress calculations		Simplified calculation of critical lines with impact on Equipment layout	✓
	Piping support drawings and list			✓
Instrumentation & Control	Instrumentation & automation design specification		✓	
	Systems specifications		✓	
	Instrument data sheets		ON/OFF valves, control valves, flowmeters, analysers	all
	Instrument specification for packaged units		✓	
	System architectural drawing		✓	
	Systems I/O sizing		✓	
	Instrument list		✓	
	Material requisitions for Systems		For inquiry	For purchase
	Material Take-Off			✓
	Cable schedule			✓
	Loop diagrams			✓
	Standard drawings		✓	
	Control and technical rooms Equipment Arrangement drawings		Prelimnary (size of building only)	✓
	Cable routing drawings		Main routings and JB locations only	Main and secondary routing
Civil	Soil investigation specification		✓	for additional soil investigations
	Review soil investigation report		preliminary report	final report
	Earthworks drawings		✓	
	Underground networks drawings		General (1:200 scale)	Area (1:50 scale)
	Civil & Structural design basis & criteria		✓	
	Specifications for civil works		Main	all
	Guide /outline drawings		if needed to perform MTO	
	Design drawings			✓
	Equipment foundation drawings		Typical	✓
	Calculations & calculation notes			✓
	Drainage network calculation		✓	
	Concrete/steel standard drawings		design	construction
	Buildings architectural drawings		✓	
	Material take-off		preliminary	up-date
Electrical	Electrical design criteria		✓	
	Single Line Diagram		General	Switchgear's
	Electrical consumers list & power balance		preliminary	final
	Equipment general specification		✓	
	Electrical specification for packaged units		✓	
	Equipment data sheet		HV, MV switchgear only	all
	Material requisitions for Electrical Equipment		For inquiry	For purchase
	Standard drawings		design	installation
	Specification for bulk			✓
	MTO		preliminary (for cables only)	all
	Cable schedule		preliminary	final
	Substation Equipment arrangement drawings		prelimnary (for sizing of sub-station only)	
	Cable routing drawings		Main routings only	all routings
	Calculations		Load summary	all
Painting, Coating, Insulation	Specification		✓	
	Standard drawings			✓
Cost estimate	+/-30-40% cost estimate	✓		
	+/-15-20% cost estimate		✓	

LV: Low Voltage/MV: Medium Voltage/HV: High Voltage

A number of outstanding design work remains at the completion of a FEED. Each discipline of the FEED contractor must prepare the list of such activities, the punch list, in the form of a narrative to be included in the Engineering part of the EPC contract scope of work.

Chapter 16

The Project Time Schedule

Set-up and Up-date of the Project Schedule

The Project schedule is established starting from the required Plant completion date, working backwards, adding the duration of the various activities and their sequence, to work out the required start/completion date of each one.

Let's take piping activities as an example. Let's assume that the completion of piping construction is due on month 36 of the Project. Piping activities include Engineering, Procurement and Construction.

Piping construction includes the following sequential activities: pre-fabrication, erection, and completion (testing, cleaning and re-instatement).

Piping completion activities are estimated to take 6 months. They start, for each piping system, once erection is completed. Piping erection is estimated to take, based on historical data on previous jobs with similar quantity of pipe-work, 12 months. Piping erection starts 3 months after the start of pre-fabrication, once enough spools have been fabricated.

Pre-fabrication starts once materials (and drawings) have been delivered to Site.

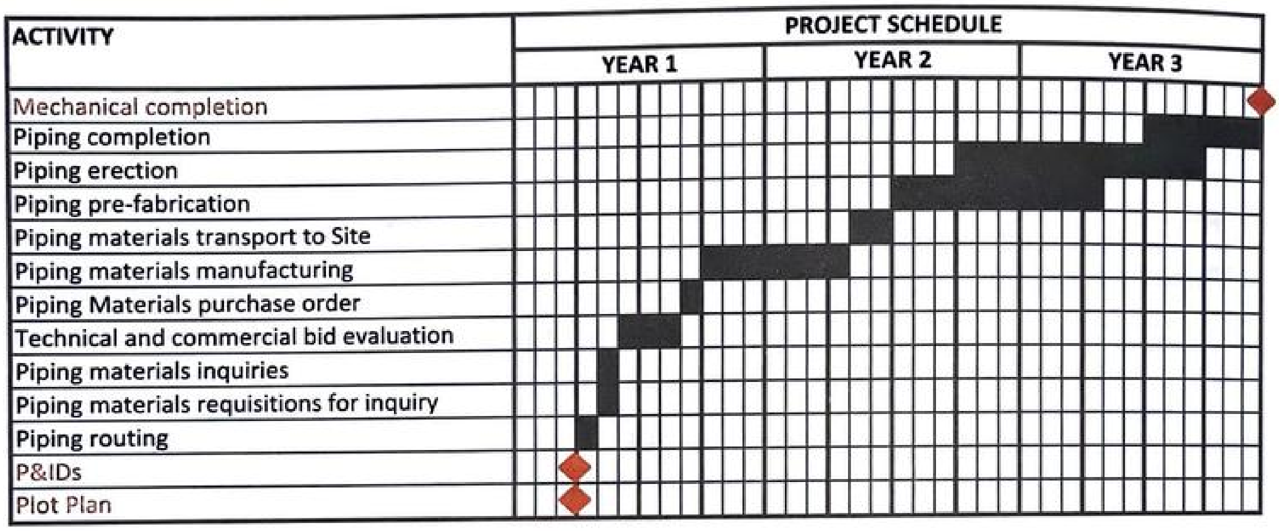
Manufacturing of all types of piping materials takes 7 months. Their transport to site takes 2 months.

Materials manufacturing starts after purchase orders are placed. Purchasing activities include issue of inquiries to suppliers, bid preparation by suppliers, technical and commercial bid analysis and negotiations with suppliers. The whole cycle takes 4 months on large projects.

The cycle starts with the issue of inquiries to suppliers which requires the production of the material requisitions, which include specifications and bill of materials.

Bills of materials are produced, by Piping discipline, from the Piping & Instrumentation Diagrams, received from Process, and from Piping routing drawings, developed on the basis of the Equipment Layout (Plot Plan), issued by Plant Layout discipline.

Working backwards in such a way, one sets the required issue dates of Piping & Instrumentation Diagrams and Plot Plan on Project Month 3, as shown below.

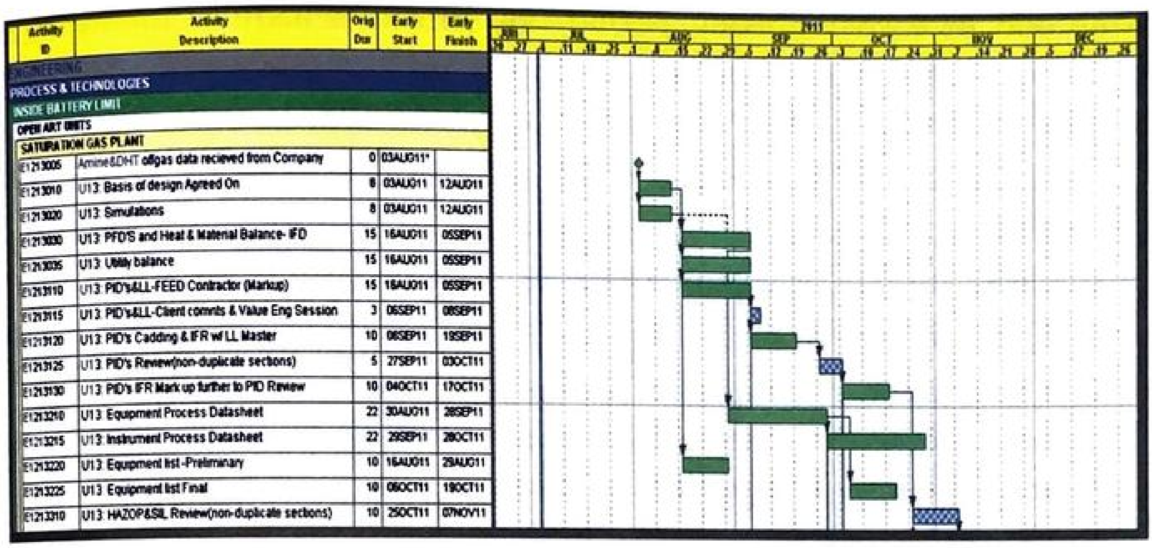


The project schedule is established in such a way, taking into account the sequence of construction works at Site, the lead time of Equipment and materials and the Engineering work sequence described in chapter 14.

The main objective of the Project time schedule is to co-ordinate, time wise, the interfaces between the different Project functions. It shall therefore focuses on interfaces, e.g., Engineering deliveries to Procurement, to Construction, etc.

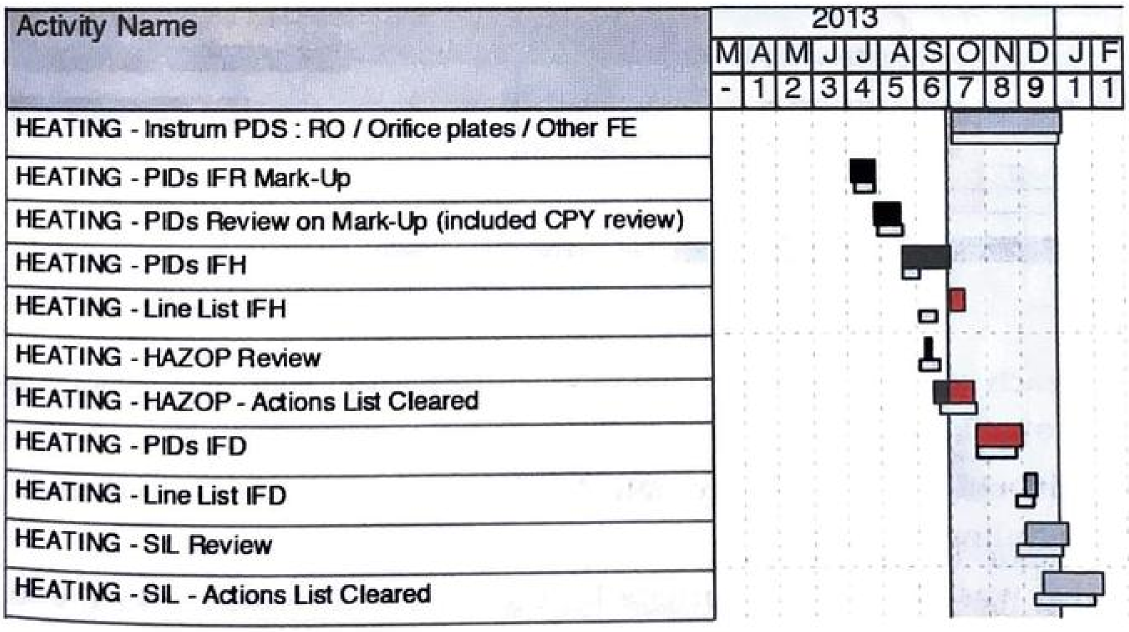
The Project schedule is produced using a scheduling software in which the list, durations and sequence of activities, by means of predecessor/successor links, are entered. From this data the scheduling software calculates the start and finish dates of all activities.

The project schedule is usually displayed in the form of a Gantt chart, showing a time bar for each activity. The links between the activities that have been entered in the software to reflect the sequence can also be displayed.



The scheduling software calculates the float of each activity and allows to identify activity with zero float, i.e., that would delay the completion date if delayed. Such activities, which are called critical activities, are displayed in red.

The look ahead schedule, such as the one shown below, shows the activities to be carried out in the coming period.



In the example above, the critical activities in the next 3 months are: Line list IFH, HAZOP Actions list cleared and PIDs IFD. Two time bars are shown for each activity: a thin one, which corresponds to the initial plan, and a thick one, which corresponds to the current, up-dated plan.

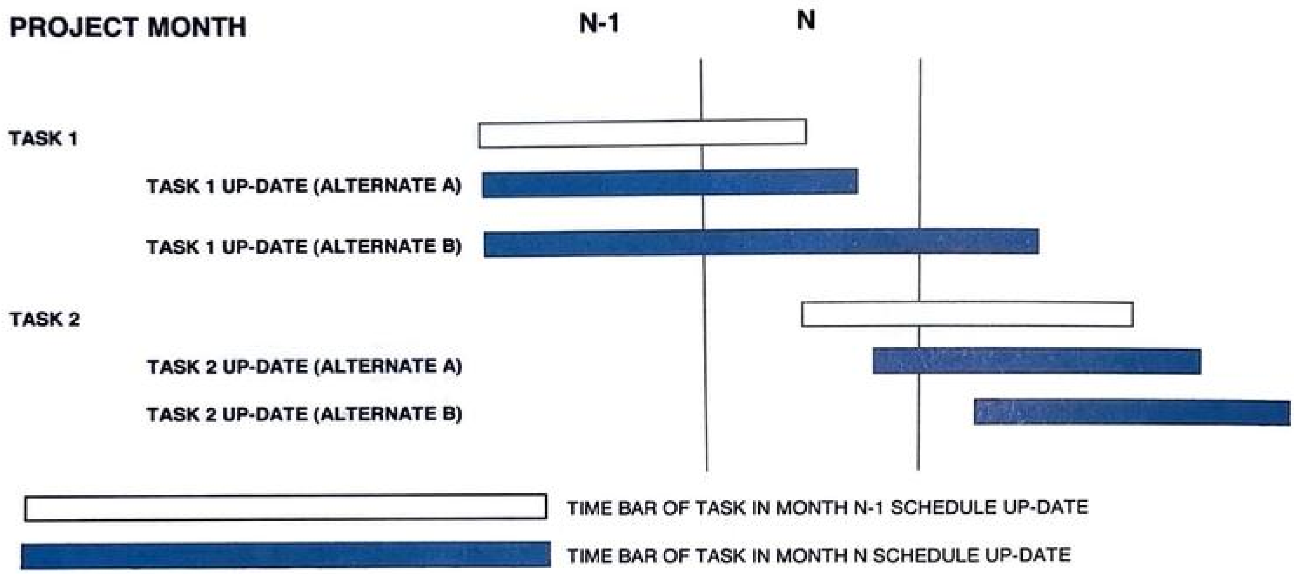
The Project schedule is indeed dynamic. The initial schedule must be adjusted, as the project progresses, to reflect actual progress, unexpected events and better project definition. Such schedule up-date is carried out by the Project scheduler.

At the end of each reporting period, the Project scheduler identifies, from Project reports/data or by asking the concerned discipline, the status of the activities that should have been started or completed in the reported period.

- for each activity that was due to be completed in the reported period, such as task 1 shown below,

  ◊ if it was actually completed (alternate A), the finish date is recorded in the scheduling software.

  ◊ if it has not been completed (alternate B), the Project scheduler asks the forecast completion date to the concerned discipline and up-dates it, by adjusting the activity duration, in the scheduling software,



- for each activity that was due to start in the reported period, such as task 2 shown above,

  ◊ if it actually started (alternate A), the actual start date is recorded in the scheduling software,

  ◊ if it wasn't started (alternate B), the Project scheduler asks the forecast start date to the concerned discipline and enters the same, by means of a new start constraint, in the scheduling software, Once this is done for all activities, the scheduling software is run to calculate the new dates of all activities linked to the ones whose status has been up-dated.

This up-date also allows to check if the Project completion date is affected, in which case mitigation measures are taken, such as doing some activities in parallel, increasing resources to reduce duration, etc.

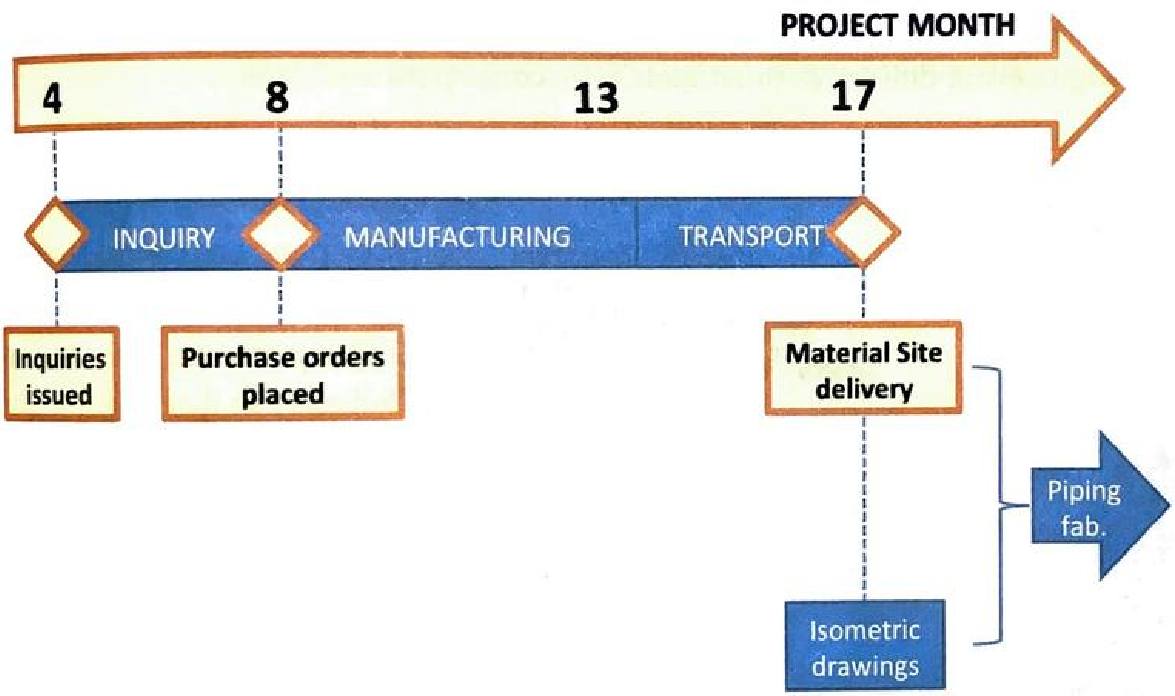
Concurrent E, P and C execution

The parallel rather than sequential execution of Engineering, Procurement and Construction activities to reduce the duration of an EPC job sets particular requirements for Engineering to support the project execution, as explained below:

➤ **Materials procurement**

Materials, such as pipes, flanges, cables, etc. need to be ordered much before the construction drawings, showing their exact quantities, are available.

Materials are indeed needed, at Site, at the same time as drawings but their manufacturing and transport take time.



Engineering must therefore anticipate the procurement of materials and produce the list of the materials to be purchased much earlier than the time by which these materials will be shown and can be counted on drawings.

As design progresses, the balance is made between the quantities shown on the drawings and the quantities already purchased.

For piping materials, the strategy employed by Engineering is:

- Gain time by issuing inquiries to get unit prices, without committing on quantities, at first. Commit on first purchased quantities only some months later, once offers have been clarified and vendors selected,
- Order initially only 70% of the estimated quantities in order to prime fabrication while avoiding surplus that could be caused by design development,
- Identify and exclude uncertain items,
- Identify and focus on the definition of the most expensive and longest lead items, e.g., large diameter and exotic pipes

Please refer to the Piping section (Chapter 9) for additional details.

The same constraint is found for steel structure materials, particularly Off-Shore where special steel grades are purchased from mills. Engineering must perform a Material Take-Off and issue Material Requisitions for structural steel materials much before drawings are finalized and issued for Construction.

➤ **Construction sequence**

Engineering deliveries must match the construction sequence.

The installation of the equipment shown here, for instance, prevents completion of one side of the platform.

The equipment has to be installed early so that construction works of the affected side of the platform, which will in any case start later than works in other parts, do not delay the completion of the overall platform.

Requisition of this equipment, fabrication of its supporting structure and issue of engineering drawings will have to be prioritized. The same applies to any equipment whose installation requires some space to remain free, such as heavy equipment whose lift require a crane at close proximity and with a large footprint.

A dedicated meeting, the constructability review meeting, is held to align the Engineering schedule with the Construction sequence. It takes place at the early stage of the Project. Construction explains to Engineering the installation and construction sequence so that Engineering aligns its deliveries to the construction needs.

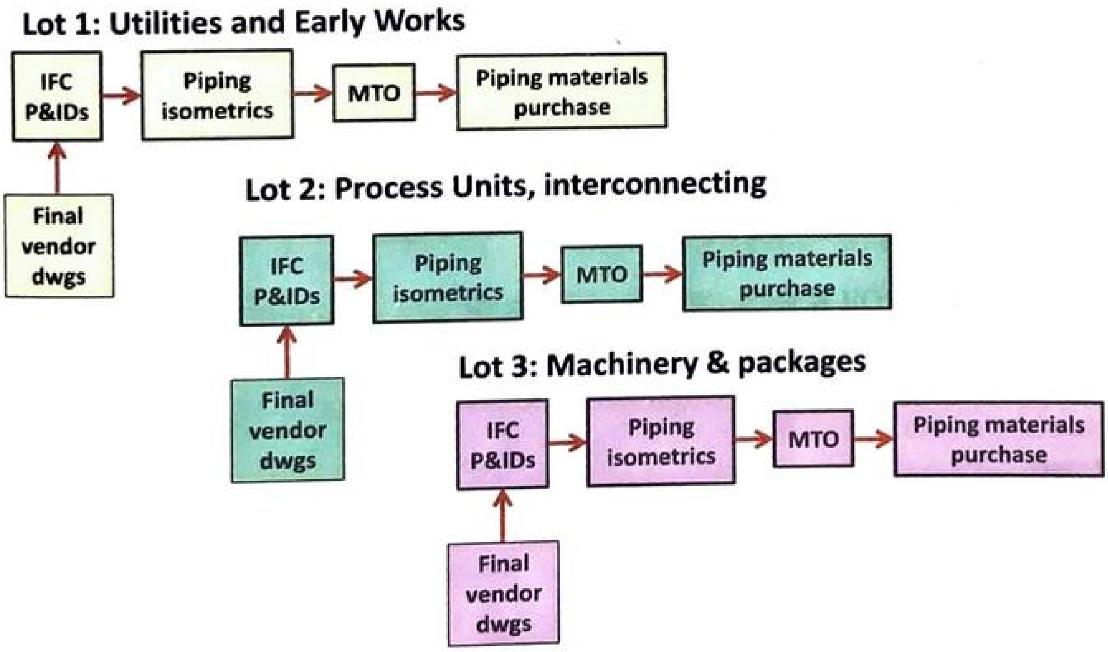
The Constructability review covers the following items:

- Critical path of the Construction schedule, consistency with the availability of the engineering deliverables
- Construction sequence/schedule and minimum requirements for construction activities to start, e.g., availability of piling, foundations, underground isometric drawings.
- Construction activities with heavy interferences on others, e.g., heavy lifts, fireproofing, underground networks, paving
- Prefabrication (manholes, trenches)

➤ Plant commissioning sequence

For the initial Plant start-up, the Plant systems are not all started at the same time. Plant utilities are started first, as they are required for the commissioning of the other units. Engineering priorities are aligned with such start-up sequence.

Engineering could be delivered in lots, utilities being given priority.



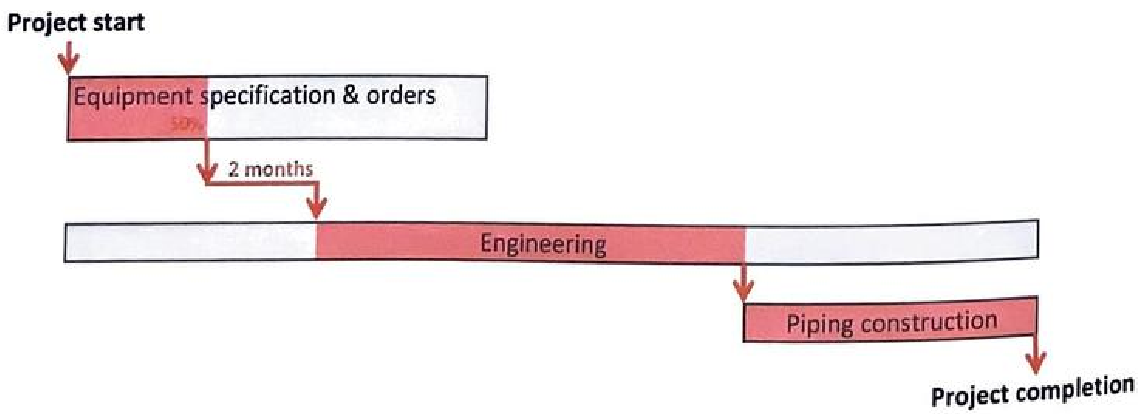
The Critical path of Oil & Gas Projects

Even though each Project seems to be unique, it is stunning to find out that they all have the same critical path: Piping.

Piping connects the Plant Equipment designed by Equipment vendors. Equipment nozzles to which the Plant piping connects are defined and positioned by vendors. It is therefore not surprising to find that Equipment are also on the critical path of Oil & gas Projects, whose duration is dictated by the following law:

Project Critical Path Law

"The duration of an Oil & Gas EPC Project is driven by piping. Piping construction starts once Engineering is almost completed. Engineering effectively starts 2 months after 50% of the Equipment have been purchased."



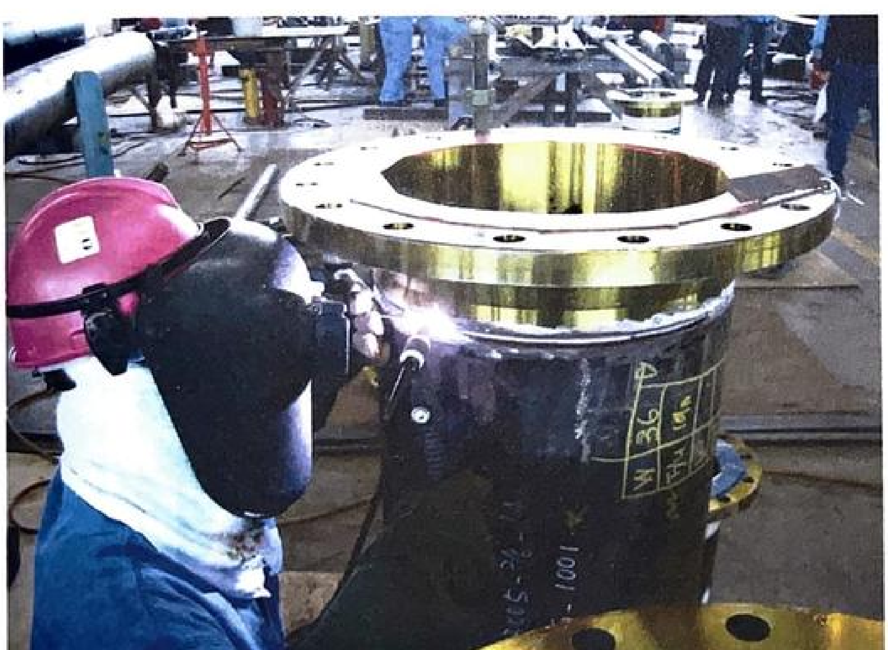
This law is easily understood when considering the numerous and time consuming activities related to the piping. Piping is, first of all, designed rather late. Piping design indeed only starts once the Process design is completed and the Plant Layout (equipment location) is set.

Plant and Piping layout cannot proceed without information from Equipment vendors: General Arrangement Drawings (GADs) showing Equipment dimensions, as well as number, type and positions of process and utility connections.

GADs start to be received from vendors no sooner than a couple of months after orders have been placed. It takes a much longer time to get them finalized.

Certified final vendor drawings showing the exact positions of Equipment nozzles are required prior to issue piping drawings for construction.

Piping construction follows, which entails numerous time consuming activities: spooling, pre-fabrication, erection, fit-up, welding, post-weld heat treatment, non-destructive examination, supports, test, painting, reinstatement, insulation, cleaning.



Welding alone takes a lot of time : it takes a welder one day to do a circumferential weld on a 20" pipe of average thickness at Site (field weld) and there are many welds: at every flange, elbow, tee, between pipe straight runs that come in single (6 meters) or double (12 meters) length.

The supply of piping materials and Equipment erection shall also be considered as part of the schedule critical path created by piping.

Piping materials are very numerous. They vary in type (straight length, fittings), material (carbon, stainless steels etc.), diameter, thickness.

On large projects, these materials cannot be found in traders stocks, which would anyway be cost prohibitive, and must be purchased from manufacturers.

Manufacturing takes time, typically 6-8 months depending on the type of items, to which shall be added transport, typically 2 months

Every piping isometric drawing includes materials of several types. It can only be fabricated once all the materials shown on the drawing have been delivered.

Obtaining sufficient matches between drawings issued and materials received requires a large quantity of materials received and isometric drawings issued.

Experience shows that, for pre-fabrication to start, the following is needed:

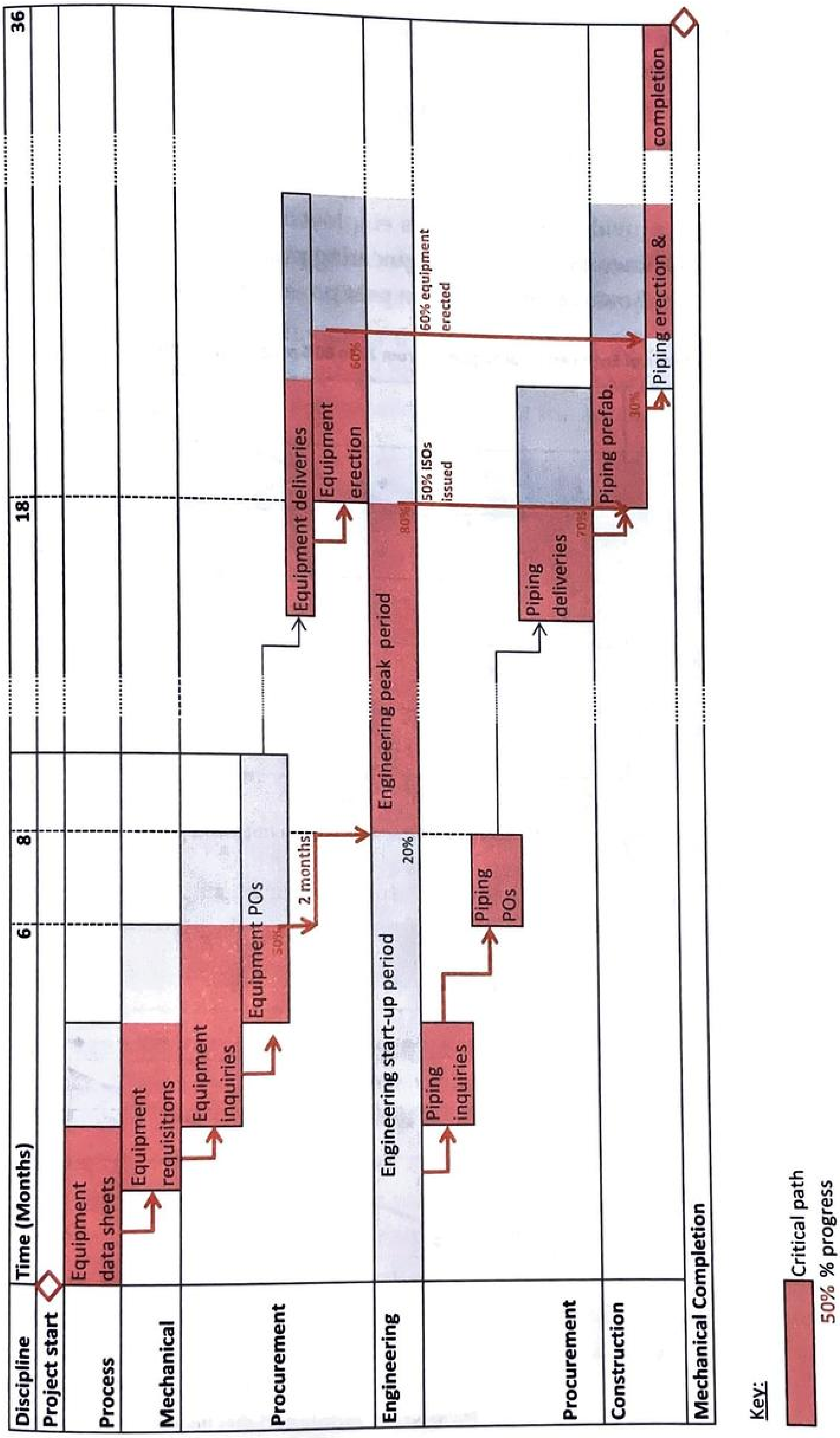
- 50% of the total number of isometrics have been issued,
- 70% of the total quantity of piping materials (all types, grades, etc.) have been delivered at Site,

When the above conditions are reached, 35% of the total number of piping isometrics only have matching materials available hence can be fabricated.

Once piping spools have been fabricated, they need Equipment to be installed to be erected. Experience shows that piping erection is effectively enabled with good productivity once 60% of the equipment nozzles are available.

The complete schedule critical path is shown on the next page.

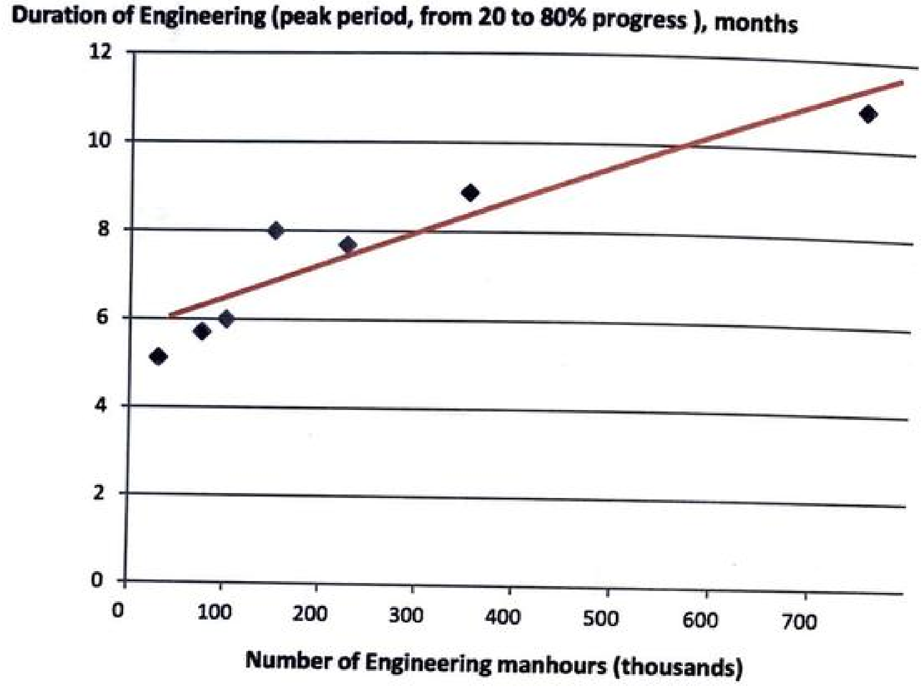
The most likely critical path of an Oil & Gas Project



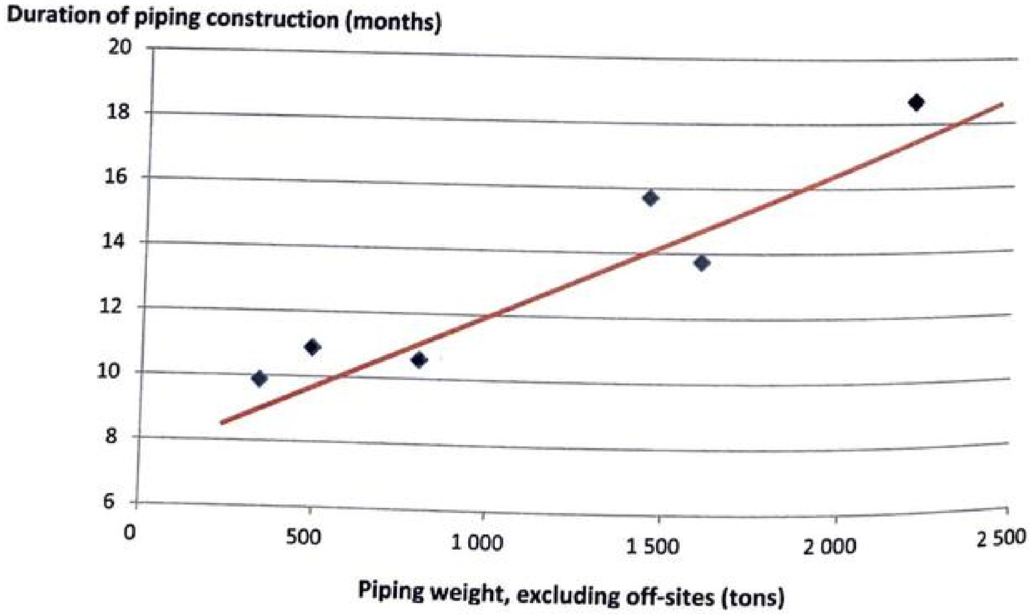
The importance of placing Equipment purchase orders early cannot be over-emphasized. The date Equipment is ordered directly determines the project duration.

Indeed, the duration of Engineering and Construction is almost fixed and determined by the volume of work.

One would think that the duration of Engineering activities would be the same on any project, provided that resources employed are adjusted to the scale of the Project. This is known to be wrong. Engineering productivity falls when the Project size increases as shown on the data from past projects recorded on the chart below.



The same is experienced for the duration of Piping construction, which strongly correlates to the quantity of piping on any job.

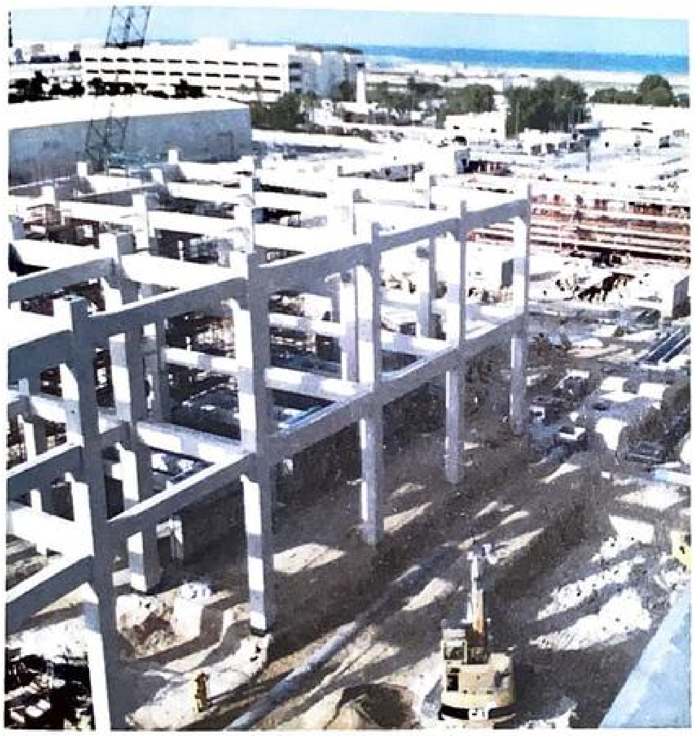


The above observations can be explained by the fact that an increased number of people involved is less easy to co-ordinate. It also results in additional interfaces, delay in communication and lower productivity.

The main conclusion from the facts exposed above is that the only means to influence the duration of an EPC Project is the early placement of the purchase orders for Equipment.

The most likely critical path of all project described above shall not hide underlying activities that, if miss-managed, could impact the project schedule.

A common issue is the installation of the Underground networks. For piping erection to proceed, cranes must indeed be able to access the area which requires that all underground networks are installed and that the area is backfilled.



The underground networks are however designed late in the Engineering work sequence. Drains, for instance, are usually the last system Process discipline intends to design, not realizing that it will be the first one to be installed at Site!

Even though Underground networks are designed by Civil, design input is need from many disciplines: Safety (fire water network), Process (drains), Piping (underground services), Electrical and Instrumentation (cable trenches/ducts).

The Project scheduler must inform these disciplines of the required date of their input data. The Project scheduler must also set the dates at which Material

Requisitions for underground piping are required to be issued and clearly identify the same in the Project schedule

Other delays could come from steel structures (process structures, pipe-racks), which take time to manufacture, typically 6 months, and transport to the job Site. Their design must be completed early even though the input to their design, in particular piping loads, are defined late, once piping layout is completed and stress analysis done.

Other underlying activities that could impact piping construction include spooling activities, pipe supports, for which mass fabrication shall be considered, Equipment and packages final vendor drawings, in-line instrumentation dimensional drawings.

Chapter 17

Engineering Management

Defining the technical baseline

The first task of the Engineering Manager is to establish and clarify the Project technical basis. He/she dispatches the Contract technical exhibits to the various disciplines and prepares the **Engineering Design Data** as described in Chapter 2.

Each discipline performs a review of its scope of work and identifies any missing information. A Kick-Off Meeting is held prior to the start of Engineering activities to clarify the technical basis and to collect the initial data necessary for the Engineering work to proceed. The latter includes symbols to be used for PFDs and P&IDs, numbering system and range to be used for documents, equipment, lines, document revision naming/cycle, Client specifications and 3D model catalogs, etc.

Any new information/change to the technical baseline shall be treated using the procedures described in chapter 19 Methods:

- Missing technical information shall be requested from the Client and recorded by means of an **Engineering Query**.
- Technical information shall be exchanged with 3rd parties by means of an **Interface Agreement** system.
- Client's requests that constitute changes to the Contract technical requirements shall be processed as per the change clause of the Contract.

Definition of the scope of work of each discipline

Based on the scope of work identified in the Contract Exhibits, each discipline produces its list of documents. These lists are consolidated into the Master Document Register.

Discipline	Description
Process	UTILITIES - DESIGN BASIS
Process	OPERATING PHILOSOPHY
Process	EFFLUENT LIST
Process	UNIT 12 - CONDENSATE FRACTIONATION - DESIGN BASIS
Process	UNIT 12 - CF - SAFEGUARDING NARRATIVE/CAUSE AND EFFECT CHART
Process	UNIT 12 - CF - COMPLEX CONTROL LOOP DESCRIPTION
Process	UNIT 12 - CONDENSATE FRACTIONATION - MSDS
Pressure vessels	MECHANICAL DATA SHEET - U12 - COLUMN
Pressure vessels	MECHANICAL DATA SHEET - U12 - DRUM

The Engineering Manager shall clarify the split of Engineering work. Engineering activities are indeed usually performed by several parties including local Engineering sub-contractors and construction contractors.

Some detailed installation drawings are commonly left to the construction contractor. It is common, for instance, that small bore lines, secondary cable trays etc., are left to the construction contractor to route and purchase.

This must defined in the Project Engineering Plan, which contains a split of responsibility matrix between the Engineer and other parties.

RESPONSIBILITY MATRIX						
ACTIVITY	STUDY / EXPERTISE ACTIVITY	ENGINEERING / PROCURT / SUPPLY				
		STUDIES ENGINEER	REQUISITIONS ENGINEER	STUDIES SHIPYARD	MTO's SHIPYARD	SUPPLY SHIPYARD
PIPING						
	Plot Plan and Equipment general lay out	X				
UTILITIES PIPING	Utilities upstream of modules			X	X	X
	Utilities Headers inside modules lay out	X			X	X
	Utilities Headers Prelim. Weight report	X				
2" and above	Utilities Headers inside modules drwgs	X				
below 2"	Utilities smaller lines inside modules lay out			X	X	X
	Utilities MTO's inside modules			X	X	X
	Weight report	R		X		
PIPING CLASS	900# Piping Class Specification	X				
	900# Valves, Relief Valves Specifications	X				
	All other Piping Class Specifications	R		X		

Among the items for which split of work must be defined between the EPC Engineer and its construction sub-contractor is the responsibility for spooling, for procurement of bulk materials which, if left to the construction sub-contractor, requires the MTOs to be issued by the EPC Engineer.

Engineering companies from high cost countries commonly split the work with their affiliates or sub-contractors located in lower cost countries. The usual split of the work is shown below:

Discipline	Home office (%)	Satellite office (%)
Process	100	-
Safety	100	-
Equipment/Mechanical	75	25
Electrical	50	50
Instrumentation & Control	50	50
Civil	30	70
Piping	30	70

Document revision cycle and Client reviews

It is important to agree with the Client the document review cycle. Engineering documents are issued to the Client for review (IFR) before being issued for design (IFD), for Purchase (IFP) or Construction (IFC).

Clients may require an additional step, such as Issue For Approval (IFA), after the incorporation of comments received on IFR issue.

Ensuring Engineering timely deliveries

The main responsibility of the Engineering Manager is to make sure that Engineering deliverables are issued on-time to support the project execution schedule. In other words the Engineering Manager's responsibility is to ensure that engineering progresses as planned.

Due to its importance, a whole chapter of this book, chapter 18, is dedicated to Engineering progress control.

As Engineering development and completion is dependent on availability of Vendor drawings, the Engineering manager shall make sure that provisions for their timely submission and completion by Vendors are included in the Equipment MRs, as detailed in chapter 4, and in Purchase Orders.

The Engineering manager shall regularly check the status of submission of the critical vendor drawings, which is extracted from the EDMS (see chapter 20), and make sure that outstanding submissions of critical documents are duly expedited up certified "as manufactured" drawings.

This concerns Equipment vendor drawings as well as in-line instrumentation drawings. Indeed the dimensions of In-line instruments (control valves, pressure safety relief valves) are not standard. These dimensions are required to produce the piping isometric drawings.

In order to prevent schedule delays, the Engineering Manager shall track and expedite what constitutes the main risks to Engineering activities.

- IT tools set-up: see chapter 20 Tools
- Missing information from the Client, i.e., outstanding Engineering Queries
- Technical information at interface with 3rd party
- Receipt and review of critical vendor documents, using status from the EDMS (see chapter 20 Tools),
- Studies that could impact the design, such as RAM[1],
- Approval of documents by the Client
- Approval of deviation requests by the Client
- Incorporation of design changes

1 Calculations of Plant availability, called RAM (Reliability Availability Maintainability) studies, are made based on statistical mean time between failure and between repair of equipment and instrumentation. They can result in recommendation to add equipment and instruments to provide redundancy and improve the Plant availability.

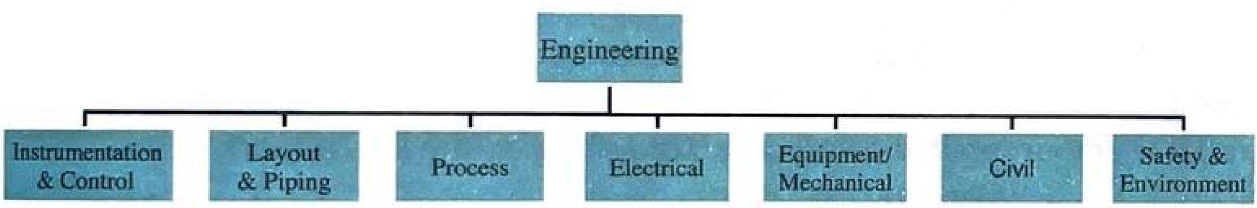
- Incorporation of design review action items: HAZOP, SIL, 3D Model reviews etc. Tracking list such as the one shown below for HAZOP must be maintained.

HAZOP ACTIONS TRACKING LIST

HAZOP Action n°	Action Description	ACTION ON (allocation according to HAZOP report)	CTR Response			CPY Response			Action Status			
			Response sent?	ref.	Date	Return received?	ref.	Date	Response agreed by CPY?	Action closed/ Implemented	Actual Implementation Date	Reference of Documentation providing evidence of Implementation
			Y/N			Y/N			Y/N	Y/N		
1	Verify type and location of tie-in for instrument air	Process										
2	Verify there will be no adverse effects to BOG Compressor suction drum due to proximity to existing flare	Process										
3	Check opening of SDV in various scenarios (for example in case one SDV already opened for assist gas)	Process										
4	Verify PRVs on 09-V9303 are adequate for resized PV	Process										

Coordination of the Engineering disciplines

Engineering work is split among disciplines. The usual split among disciplines is shown below:

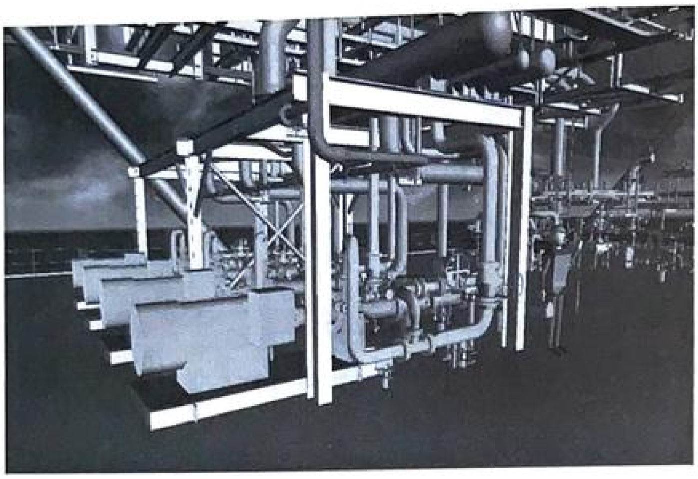


The role of the engineering manager is to make sure a clear basis for the Engineering work (scope of work, technical requirements) is established, to co-ordinate the work of the various disciplines and to ensure on-time deliveries of Engineering documents to Procurement and Construction.

In order to be pro-active and anticipate issues before they occur, the Engineering Manager organizes a weekly co-ordination meeting with all the Engineering disciplines. The main purpose of the meeting is to identify the data awaited by one discipline from the other.

Monitoring and communicating bulk quantities

This is required, in the various disciplines, for cost forecast and, most importantly, for mobilization of the adequate construction resources.



Construction planning and resources mobilization are based on the quantities and types of works.

They take place at an early stage when the design is not yet fully developed and only estimated Bill Of Quantities (BOQ) are available.

As the design develops, quantities change. The steel structure shown here, for instance, will not be identified until late in the design.

Such changes could be significant in certain trades and require mobilizing more manpower and equipment.

It is therefore essential that Engineering regularly issues to Construction BOQ up-dates in all trades for Construction to adjust its mobilisation.

This is even more critical as EPC Contractors sub-contract construction works under Unit Rates contracts. The construction sub-contractor is paid a fixed amount, called indirect cost, usually around 40% of the contract value, plus a variable amount, called direct cost, depending on the actual work done.

This direct cost is calculated by applying a fixed unit rate, shown in the sub-contract price schedule, to the final installed quantities.

STEEL STRUCTURES PRICE SCHEDULE

Designation of price schedule items	Unit	Quantity	Unit price	Total price
MAIN STRUCTURE	kg	312 400	4,89	1 527 291
SECONDARY STRUCTURE, HANDRAIL AND LADDER (excluding safety bar, grating & plate tread)	kg	475 884	8,22	3 909 557
SHELTER	kg	498 960	4,55	2 270 778

In the example above, for each kg of main steel structure erected, the sub-contractor will get paid 4,89 *regardless* of the resources actually employed.

In this type of contracts the sub-contractor takes the risk on its productivity: if it has mobilized too much manpower/equipment and some is idle the sub-contractor will not be compensated.

The construction sub-contractor has little control over the risk of idle resources as it does not know the precise quantities nor the schedule of receipt of drawings and materials from the EPC contractor. It is therefore essential that the EPC Contractor regularly communicates to its sub-contractors an up-date of overall bill of quantities.

CONSTRUCTION BILL OF QUANTIES (BOQ) FOLLOW-UP		
Commodity	**Initial**	**Current forecast**
Concrete (m3)	12300	15800
Steel (tons)	7000	15000
Piping (tons)	8000	12500
Elec cables (km)	450	520

The EPC Contractor must also regularly communicate to the construction sub-contractor the up-dated dates of delivery of equipment, materials and drawings.

The table below was used for this purpose for structural steel: it shows the up-dated list of steel structures, their weight (information coming from Engineering) as well as up-to-date delivery forecast (information coming from the steel structure manufacturer).

Structure Identity	Latest weight (MT)	Fabrication	Galvanizing	Inspection.	Delivered to Site Status				Foreact delivery completion date
		comp.%	comp.%	comp.%	Frames Wt. (MT)	comp.%	Bolts + Misc Qty.	comp.%	
80-PR-03E	24.12	100	91	91	21.97	91	26-Nov-07	100	25-Dec-07
80-PR-07E	22.32	100.0	59	31	7.00	31	partially del. 26-11-07	99	07-Jan-08
92-STG-063	13.88	100					26-Nov-07	100	27-Jan-08
95-STG-61	22.07	100	100	100	22.06	100	07-Oct-07	100	
94-STG-91	5.42	100.0					26-Nov-07	100	27-Jan-08
80-PR-04E	32.01	100	100	99.5	31.86	99.5	26-Nov-07	100	20-Dec-07
667-PR-61	231.16	100	100	100	231.16	100	20-Jun-07	100	
660-XS-63	244.65	100	100	100	244.65	100	20-Jul-07	100	
660-XS-66 & 67	146.393	100	100	100	146.393	100	28-Oct-07	99.7	20-Dec-07
94-STG-125	0.78	100.0							30-Jan-08
94-STG-135	3.45	100.0							15-Feb-08

Chapter 18

Engineering control

"Control" usually refers to both cost and schedule control. For Engineering activities, it is sufficient to control the schedule, as timely deliveries also ensures cost control as resources can be demobilized early!

Engineering progress measurement

Engineering progress is commonly measured based on the actual results achieved and is called, for this reason, the "**physical progress**".

Engineering results are documents issued and, for Detail Engineering, progress of the 3D model.

As the exact number of documents, e.g., number of P&IDs, is not known initially, the progress is measured at the level of groups of documents, called "deliverables", rather than at the level of individual documents.

Each deliverable is assigned a weight, which corresponds to the number of manhours required for its preparation. As Engineering documents are not issued once but go through different stages, e.g., IFR/IFD/IFC, the percentage of the manhours required for the preparation of each stage is identified.

The required issue dates are set as per the Project Schedule.

Deliverable	Weight (hours)	Stage	Stage progress (%)	Planned date
UNIT 13 PROCESS FLOW DIAGRAMS	120	START	5	08/09/2018
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFR	75	22/09/2018
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFD	100	13/10/2018
UNIT 13 P&IDs	450	START	5	25/09/2018
UNIT 13 P&IDs	450	IFR	25	24/11/2018
UNIT 13 P&IDs	450	IFD	60	13/02/2019
UNIT 13 P&IDs	450	IFC	100	27/08/2019

The planned progress is calculated at any given date. On 25/09/2018, for instance, the plan is to have the PFDs issued IFR and the P&IDs started. This means a planned progress of 120*75/100 + 450*5/100 = 20%.

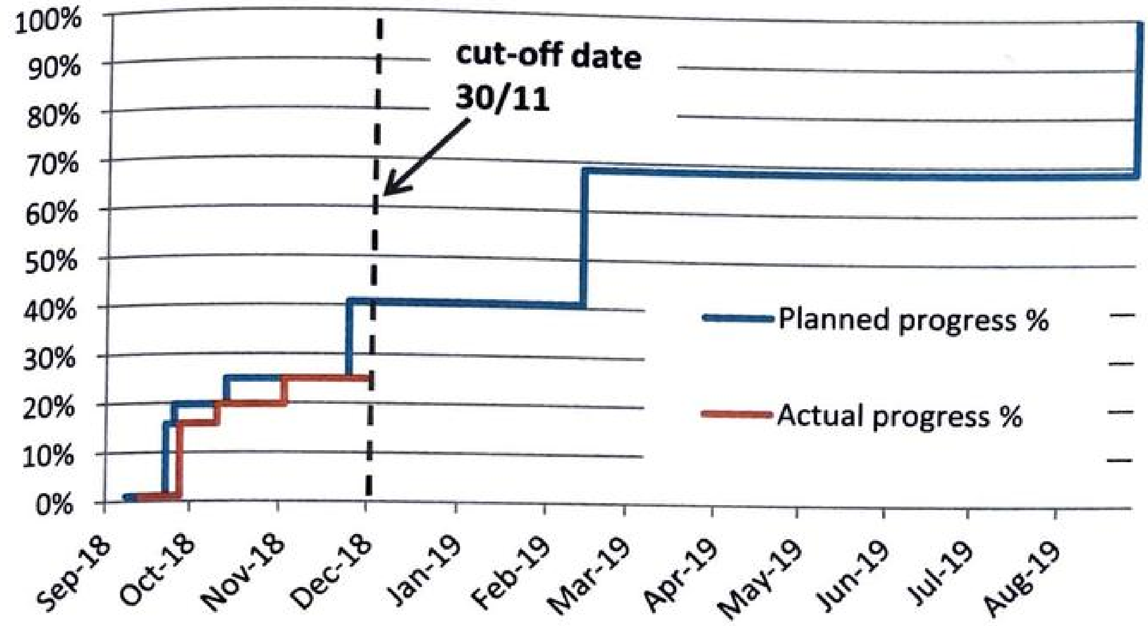
Deliverable	Weight (hours)	Stage	Stage progress (%)	Date	Planned cumulative progress %
UNIT 13 PROCESS FLOW DIAGRAMS	120	START	5	08/09/2018	1%
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFR	75	22/09/2018	16%
UNIT 13 P&IDs	450	START	5	25/09/2018	20%
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFD	100	13/10/2018	25%
UNIT 13 P&IDs	450	IFR	25	24/11/2018	41%
UNIT 13 P&IDs	450	IFD	60	13/02/2019	68%
UNIT 13 P&IDs	450	IFC	100	27/08/2019	100%

At the end of each reporting period, the actual Engineering progress is calculated on the basis of deliverables issued. Let's assume that the deliverables issue status as of 30/11/2018 is as shown below:

Deliverable	Weight (hours)	Stage	Stage progress (%)	Planned date	Actual date
UNIT 13 PROCESS FLOW DIAGRAMS	120	START	5	08/09/2018	13/09/2018
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFR	75	22/09/2018	27/09/2018
UNIT 13 PROCESS FLOW DIAGRAMS	120	IFD	100	13/10/2018	02/11/2018
UNIT 13 P&IDs	450	START	5	25/09/2018	10/10/2018
UNIT 13 P&IDs	450	IFR	25	24/11/2018	
UNIT 13 P&IDs	450	IFD	60	13/02/2019	
UNIT 13 P&IDs	450	IFC	100	27/08/2019	

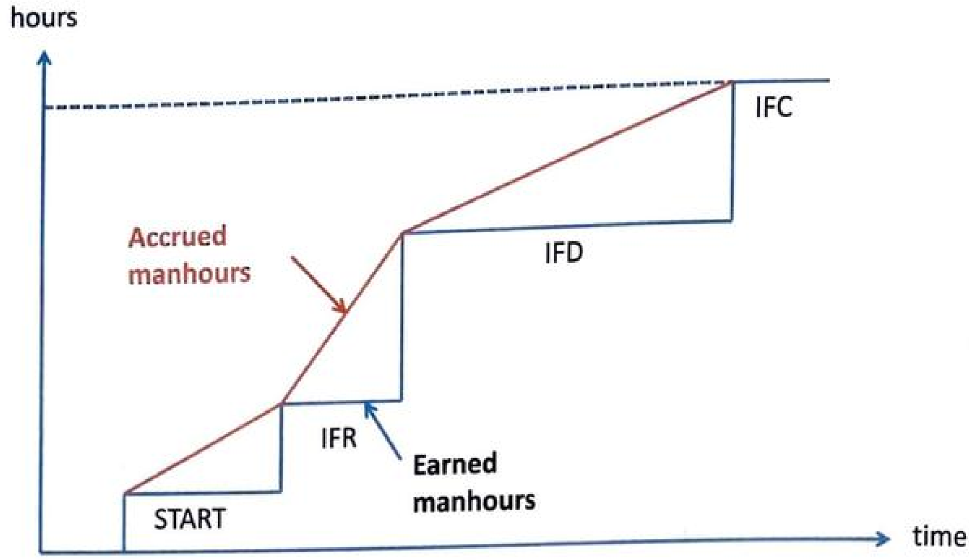
The actual progress as of 30/11/2018 would be (120 + 450*0,05)/570*100 = 25% vs planned progress of 41%. Such calculations are heavy and done in a dedicated Engineering progress monitoring tool as described in chapter 20.

The actual and planned progress curves are drawn and compared.

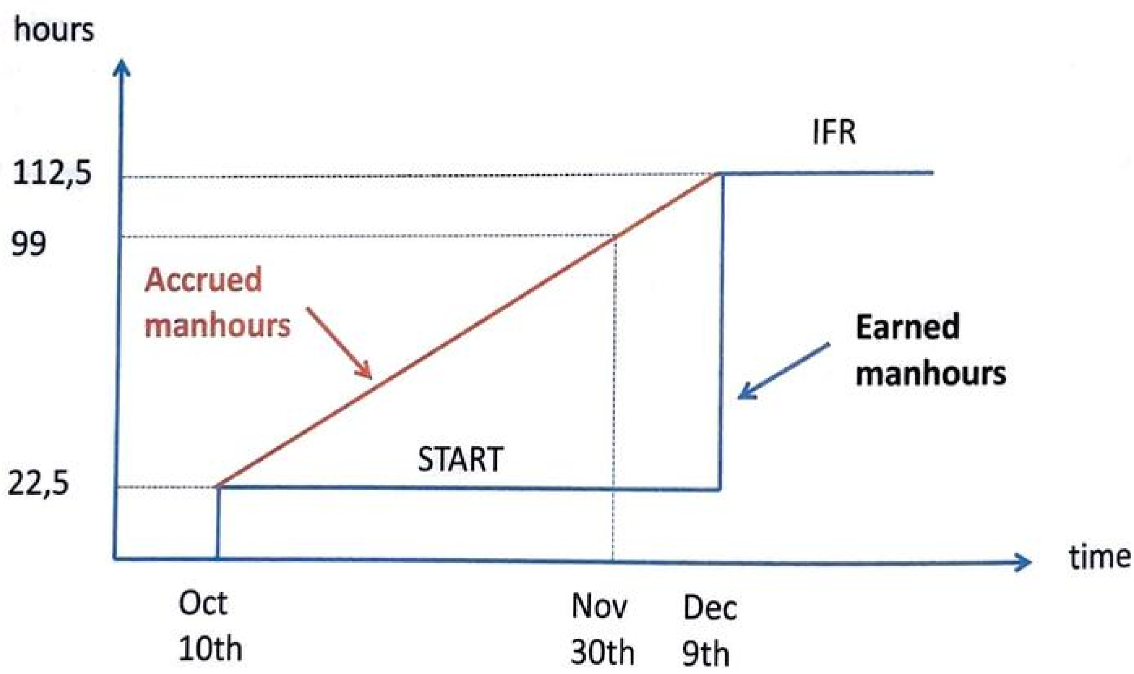


The above measure of progress does not give any information on Engineering productivity. To obtain the latter, one must compare the progress achieved and the resources used, i.e., hours spent. However, as the progress is only recognized once the work is done, i.e., the deliverable is issued, it is always lagging behind the manhours spent. In the example above, the progress as of 30/11/2018 is 25%. It would be inappropriate to compare the amount of spent manhours as of 30/11/2018 with the earned manhours (0,25*570 = 143).

Indeed some hours have been spent, for the preparation of the IFR P&IDs, but have not yet been recognized in the progress. Therefore the spent manhours must be compared to the *accrued* manhours and not the *earned* manhours.



The accrued hours for the work on the P&IDs, as of 30/11/2018, are 99 as depicted below.



To assess the Engineering productivity up to 30/11/2018, the spent manhours must be compared with the 219 *accrued* hours (120 for the PFDs + 99 for the P&IDs) and not with the 143 *earned* manhours.

Detail Engineering progress measurement must take into account the progress of the 3D model which is nowadays central to Engineering development. The progress in each discipline is assessed on the basis of:

- Number of items modelled and state of modelling: as per preliminary / final vendor drawings
- Readiness for 30% / 60% / 90% Model review, including clash check
- Incorporation of 30% / 60% / 90 Model review comments

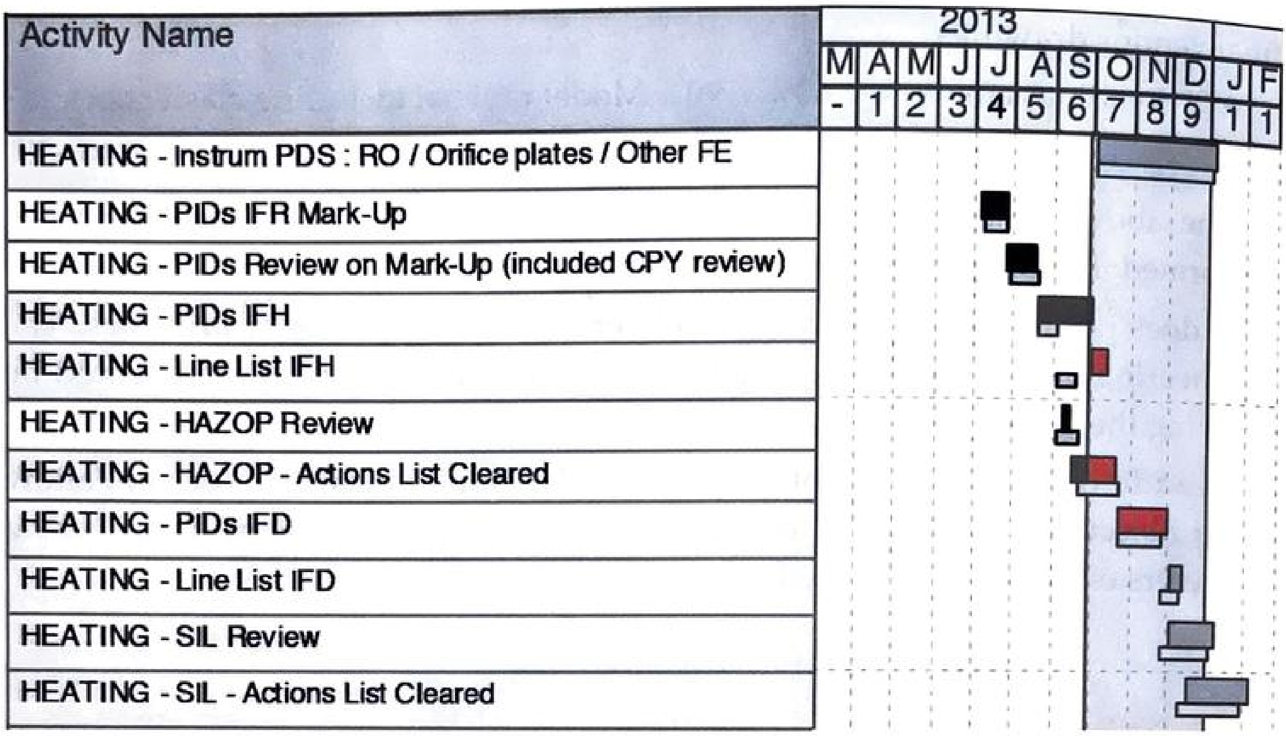
The above measure of progress reflects the volume of Engineering work performed. It is widely used for invoicing Engineering activities for this reason.

It does not tell if Engineering is delivering as per the project priorities. The Engineering actual progress could be above planned but Engineering could be delaying the Project as it did not issue some documents on the critical path.

In addition, this measure of progress is a lagging indicator. It does not allow to set objectives. Alternative leading controls are used to ensure Engineering deliverers on time, as described below.

Look ahead schedule

The look ahead schedule allows to identify which activities shall be carried out in the coming period and which ones are critical.



In the example above, the critical activities in the next 3 months are: Line list IFH, HAZOP Actions list cleared and PIDs IFD.

The look ahead schedule is an essential pro-active tool to set the objectives for the coming period. At the end of such period a check is made to review if such objectives have been met.

Monitoring Milestones

Defining Engineering progress Milestones, with target dates, allows focusing everyone's attention on the Engineering deliverables that on the Project critical path of the Project schedule.

The most critical Engineering Milestones for an EPC Project are the following:

- o P&ID 1st issue
- o Long Lead Items (LLI) Material Requisitions for Purchase
- o Material Requisitions for other Equipment
- o HAZOP
- o 1st model review
- o 1st Piping Material Requisitions for Purchase
- o Primary steel MTO (Off-Shore job only)
- o Primary steel drawings IFC (Off-Shore job only)
- o Control valves, PSVs Material Requisitions for Purchase
- o IFC Plot Plan
- o IFC P&IDs

At the early stage of the Project the prime focus shall be on:

- Early specification of Equipment, finalisation of requisitions including clarifications with vendors and issue of Requisitions for order,
- Early issue of Material requisitions for Piping materials,

The tables below help follow the Engineering progress at that early stage:

EQUIPMENT MATERIAL REQUISITION PROGRESS STATUS			
Discipline	Total number of Material Requisition (MRs)	MRs issued for Inquiry	MRs issued for Purchase
Rotating Equipment	6	4	2
Static Equipment	10	5	3
Fired Equipment	3	2	1
Packages	4	2	1

PIPING BULK MATERIAL REQUISITION PROGRESS STATUS		
Total number of MRs (see note)	MRs issued for Inquiry	MRs issued for Purchase
30	20	9

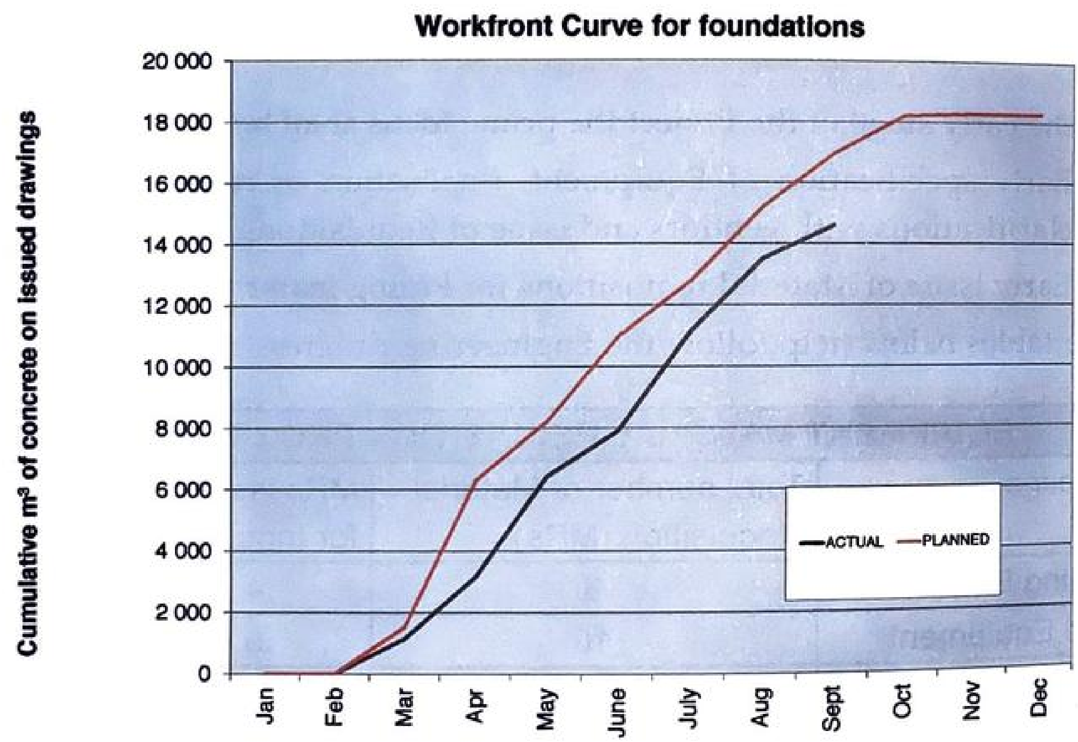
Note: There are numerous MRs as piping materials are purchased to many different suppliers depending on item types, materials of construction, etc.

Monitoring construction workfront

Controlling the progress of issue of construction drawings on large project is not easy. Indeed, there is a large number of individual drawings. In addition, not all drawings represent the same amount of work at Site: the drawing of a small foundation and that of a large and complicated one open significantly different work fronts at Site.

What is important is that Engineering provides enough Workfront to Site, i.e., enough quantity of work to fully employ manpower and equipment at Site. This is best monitored by means of Workfront Curves.

For foundations, such curve is obtained by reporting the cumulative number of cubic meters of concrete on foundation drawings issued to date versus plan. The plan derives from the construction schedule for foundations.



Cumulative m³ on issued foundation drawings	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
PLANNED	0	0	1 529	6 303	8 213	10 990	12 781	15 196	16 954	18 213	18 276	18 276
ACTUAL	0	0	1 143	3 147	6 420	7 903	11 132	13 512	14 592			

Ensuring that the actual stays above planned ensures that Engineering supports construction. Similar workfront curves are drawn for the other commodities, including steel structures (cumulative tons), piping (cumulative tons or dia.inch).

Methods

The design is performed in accordance with published standards, Client's specifications as well as criteria and rules defined by the Engineer.

It is essential that the bases of design are defined and approved by the Client out prior to the start of design activities.

There are 2 types of bases of design: the Design Data and the Design Criteria. The Design Data are collected by the Engineering Manager in the Basic Engineering Design Data (see chapter 2).

Each discipline defines its design criteria in a Design Specification, also called Specification for Design, Design Basis or Design Philosophy.

These design specifications are called the Process Design Criteria, the Safety Concept, the Plant Layout Guidelines, the Health and Environmental Requirements, the Instrumentation and Control System Design Basis, the Piping Stress Analysis Criteria, the Electrical system design specification, etc.

The Process Design Criteria impacts the Plant design most. It sets the sizing rules for Equipment and lines, including their mechanical design (design pressure and temperature) and overdesign.

The Civil design criteria specifies the code, loads and load combinations considered in the design for foundations and structures.

The Piping design basis specifies the amount of free space provided on pipe-racks for future lines, etc.

Engineering companies develop internal **Design Guidelines**, which capture their know-how in every discipline.

Oil & Gas facilities processes, units, equipment and materials are always the same from one job to the other. It is very useful to retrieve documents from previous jobs. To enable easy retrieval of all documents pertaining to a certain type of commodity, a code is assigned to each one and is included in the number of all documents pertaining to this commodity. This also applies to vendor documents. In this way, all documents from a previous job pertaining to, say, thermowells, can be quickly retrieved.

Standards are developed and up-dated based on lessons learnt. They are used to capitalize experience. Material Requisition standards, for instance, gather the precise definition of the scope of supply and scope of work to be assigned to the Vendor, based on experience on former jobs. When ordering similar equipment, one shall start from the Material Requisition standard for this particular Equipment type. One shall not start from the Material Requisition used on the last job, as it could include requirements specific to that job that are not applicable to the job at hand.

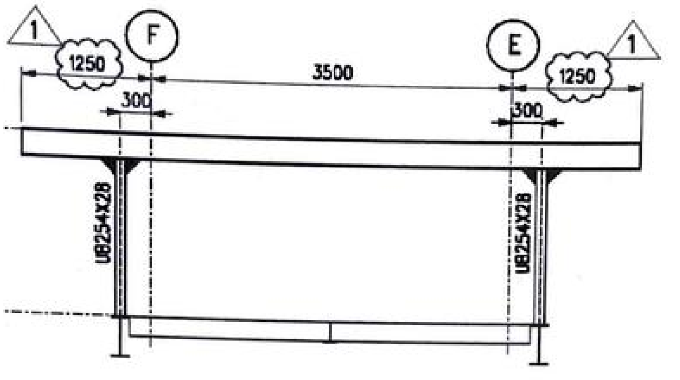
Check lists, such as the isometric drawing check list shown in chapter 9, capitalize the experience from one job to the next. Should an issue of vibration of small piping connections be encountered on a job, for instance, check that a bracing is provided on small bore connections will be added to the piping isometric check list.

Internal procedures of Engineering Companies define:

➢ Who is doing what: split of responsibilities between disciplines for specifying and ordering the various types of materials, e.g., who is in charge of underground piping, handling equipment, cathodic protection, etc.,

➢ What information is to be supplied by each discipline to the others and in what form, e.g., Piping Load Study as per typical shown in chapter 9 for transfer of piping loads on pipe-racks and process structures to Civil,

Document revision is an important necessity of Engineering work. Engineering work is indeed iterative: documents are developed progressively with increasing amount of details and firming-up of the information they contain. However, many Engineering disciplines need input data from other disciplines to work and they need such input data before the containing document is finalized. It is therefore necessary to issue intermediate versions of documents in order to freeze such input data at certain stages.



P&IDs and Plot Plans, for instance, are used as input data by many disciplines. An intermediate revision of the P&IDs, the "IFD" (Issued For Design) revision, is issued by Process to enable Piping and Instrumentation to proceed with their work.

To enable quick identification of the changed data in document revisions, revised parts are highlighted with marks (red text for documents, clouds for drawings).

Treatment of Client comments on Engineering documents

Engineering documents are submitted to the Client's review. The Client review may result in Rejection, Approval with comments or Approval. It is important to properly address the Client's comments.

A good practice is to answer these comments using a Comments Response Sheet, which is issued with the next document revision.

No	PAGE	REFERENCE	COMPANY COMMENT	CONTRACTOR REPLY / CONFIRMATION
1	15 OF 35	PARA 2.7	All CS U-Tubes shall be stress-relieved, prior to bundle assembly, for the following services: 1. Caustic above 50C (125F) 2. Amine	Noted, CS U-tubes bends will be stress relieved after bending (refer to notes on mechanical drawings).

On Lump Sum contracts, for which the Engineer is paid a fixed amount for a fixed scope, Client comments shall be screened to make sure that they relate to the compliance with the technical requirements of the Contract and nothing else. Client comments that constitute additional requirements to that of the Contract shall be identified and answered as described in the section "management of design changes" that follows. This is critical in order to safeguard the project execution against cost and schedule impacts of extra contractual requests.

The Quality of engineering is ensured using a number of processes covering the requirements of the Quality standards (ISO 9001 and 10006).

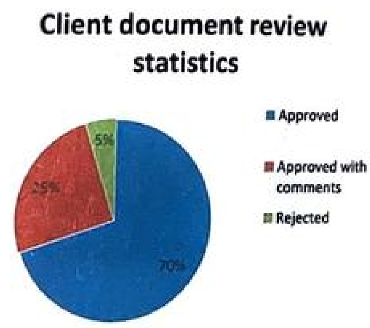
Documents issued are checked by the issuing discipline. Documents concerning several disciplines are subject to an Inter-Disciplinary check which can be formal (document circulation) or informal (review is made during a meeting).

Besides the above technical check, documents are approved by the Engineering Manager prior to issue. The Engineering Manager checks that the document is fit for purpose, that the latest information have been taken into account.

The design is also checked during design reviews conducted as described in the previous sections: HAZID, P&ID review, HAZOP review, 3D model reviews.

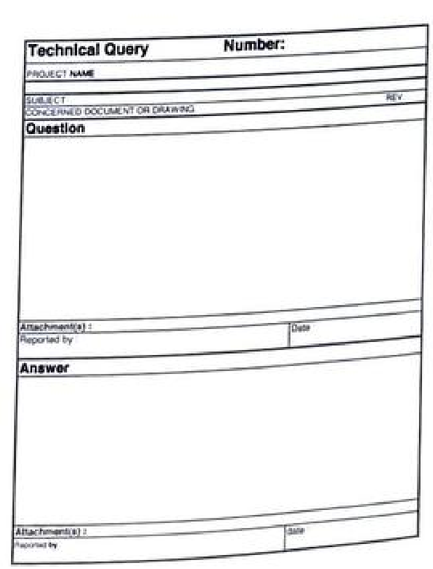
Each document issuer maintains a **MASTER** copy of its documents on which all changes to be made in the next revision are collected.

Engineering disciplines work as per their **Quality Plan** which includes:



- A Contract review, to assess that contractual requirements are known, understood and that the organization and resources are adequate,
- The definition of roles and responsibilities of all personnel of the discipline, i.e., who is authorized to sign calculation notes, etc.
- The definition of the discipline objectives and indicators. This could be, for instance, not exceeding the discipline budgeted manhours, not exceeding so many % between the initial and final Equipment purchase order prices (for Equipment/Mechanical discipline), number of revisions after IFP (for Process data sheets) or IFC, timely issue of critical documents, no more than 3% of documents rejected by the Client, etc.
- The identification of risks and their mitigations

Engineering queries


Technical Query | Number:
PROJECT NAME
SUBJECT | REV
CONCERNED DOCUMENT OR DRAWING
Question
Attachment(s) : | Date
Reported by
Answer
Attachment(s) : | date
Reported by

Additional technical information to that of the Contract shall be controlled and traced.

To this end, an Engineering query system shall be put in place: any new technical information required by the Engineer shall be requested from the Client by means of a numbered form, called Engineering Query. A log shall be maintained with date of issue to the Client, status of answer, to allow follow-up and expediting.

Interface Management

Technical Interfaces with third parties, such as contractors at battery limits, must be properly identified and managed to ensure timely transfer of information.

An example of such interface is the one with the Contractor installing the Plant inlet pipeline. The technical data to be exchanged not only consist of the coordinates and elevation of the connection point, the type of connection (welded, flanged), the material and thickness (for welded connection), but also more subtle data, such as the load (longitudinal force that could amount to several hundred kN) transferred from one side of the pipeline to the other.

The vehicle for the information exchange is the Interface Agreement.

INTERFACE AGREEMENT

Interface No:	**Rev:**	**Page: of**	**Revision Date:**

Title:	
Short Description:	**Need Date:**

Supplier: Interface contact: Technical contact:	Receiver: Interface contact: Technical contact:

Interface Details (Deliverable Description)

Discussion / Comments:

Reference documents and attachments:

Section/Step 1

Interface Agreement Approval			
Supplier: Printed Name:	Date:	Receiver: Printed Name:	Date:

Provided Interface Deliverable (description and document coding)

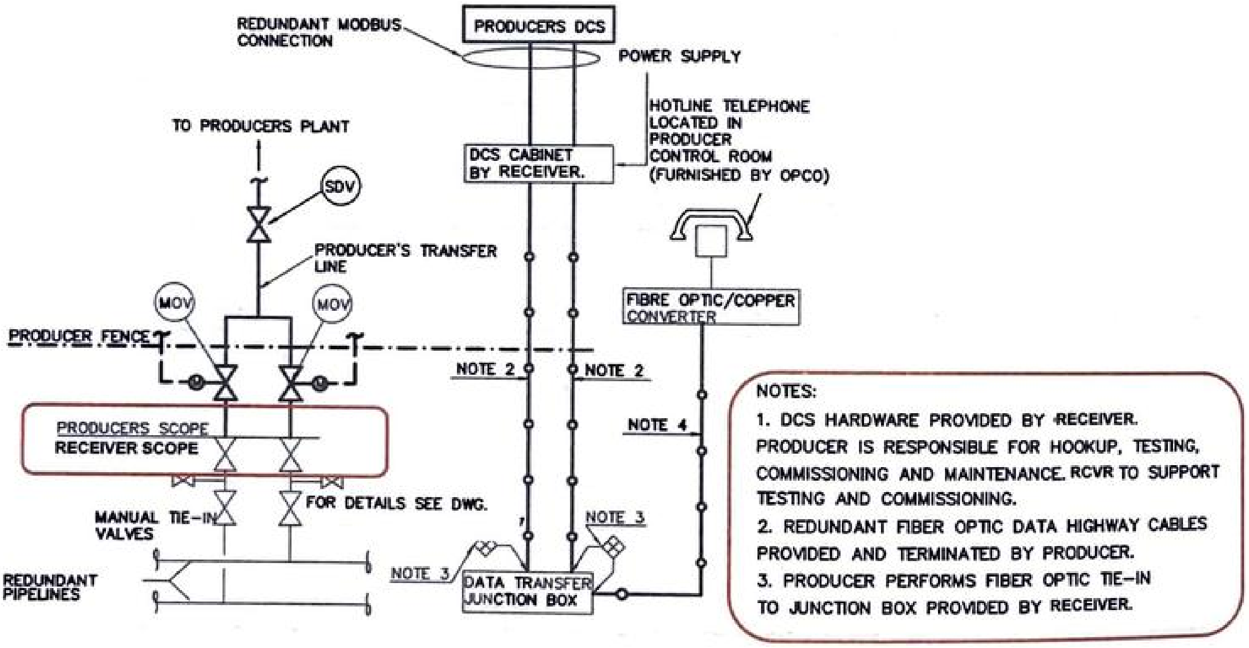
Section/Step 2

Interface Agreement Close-Out			
Supplier: Printed Name:	Transmittal Date:	Receiver: Printed Name:	Closed-out *Date:*

Interface management entails:

- Identification of all interfaces,
- Identification, for each interface, of the information to be exchanged, which party will supply the information and when. Section 1 of the Interface Agreement is filled at this stage. It is useful to describe what the information will be used for. Defining the submission date allows the receiving party to plan its work.
- Provision of the actual interface data. Section 2 of the Interface Agreement is filled at this stage and an Engineering drawing is usually attached.
- Closing of the Interface Agreement by the receiving party, which confirms that the received information is adequate.

An example of interface definition between a Producer and a Receiver is shown below.



The Interface Management process and progress of Interface Agreements is monitored vide the Interface Register.

Management of design changes

Changes can be classified in 2 types:

- Changes to the Contract, i.e., changes to the scope of work or addition of technical requirements to that of the Contract,
- Changes that normally occur as part of Design Development,

1) Changes to the Contract

The first type of changes shall be detected and properly addressed as they could jeopardize the Project cost and schedule. These changes usually come from requests made by the Client (Plant Owner), during meetings, reviews, via comments on documents, correspondence or less formal exchanges.

The Client review of engineering documents should consist of reviewing their compliance with the Contract requirements. In fact the Client representatives tend to make comments which are actually additional requirements to those of the Contract. Implementing these comments could result in significant extra costs and delays. To avoid such impacts, it is essential to put a system in place to (i) detect and (ii) properly address these extra contractual requirements:

Any request that constitutes a change to the Contract must be processed as per the Contract "Change in the Work" clause. Such clause usually states that it is the responsibility of the Contractor to detect any request that constitutes an additional requirement to the Contract, promptly notify the Client, advise the cost and schedule impacts and implement the change only if such impacts are approved by the Client.

Very often, a large number of Client comments on documents constitute additional technical requirements to the Contract. In order to avoid wasting time quantifying their cost and schedule impact, it is advisable to ask a formal confirmation by the Client by replying to the comment as shown below.

DOCUMENT COMMENTS

DOCUMENT TITLE: AMENDMENTS TO TECHNICAL SPECIFICATION FOR SHELL AND TUBE HEAT EXCHANGERS
DOCUMENT # :

DOCUMENT REV.: B1
COMMENT CODE : B
COMMENTED BY:

No	DISC.	PAGE	REFERENCE	COMPANY COMMENT	CONTRACTOR REPLY / CONFIRMATION
1	QUA	22 OF 35	PARA 3.5	All bolt threads not exposed to process fluids shall be coated with a high-temperature copper powder base, anti-seizing lubricant, Fel Pro C5-A or equivalent, except as specified in Item 2. Bolt threads that will be exposed to a moist, salt-air environment shall be MIL P 2 (e.g. Exxon's Anti-Rust ND 91, Mobil's Metalgard 360 or equal) or MIL P-6 (e.g. Exxon's Rust Ban 326, Mobil's Mobilarma 798 or equal).	This comment constitutes an additional requirement to the CONTRACT. Such request shall be made by COMPANY pursuant to CONTRACT article 21.1 "COMPANY initiated CHANGE ORDERS"

Such a request for formal instruction will see, in most cases, the Client reconsider its request. For the few confirmed requests that will be made officially, the Engineer will evaluate the cost and schedule impacts and proceed upon the Client approval of the same.

The Client also makes requests during the design reviews: P&ID review, HAZOP, 3D model reviews, etc. It is not always easy to identify what requests shall be considered as extra contractual. Contracts indeed state that the design shall be made as per "good engineering practices" and what constitutes good engineering practice versus nice-to-have is subject of opinion. A ladder, for instance, might be consider fit for the purpose of providing access whereas the Client could prefer a stairway.

For such reason and to avoid a conflict of interest for items related to Safety, the HAZOP is usually carried out by a third party. Changes to the design required as a result of the HAZOP are also sometimes considered as changes in the work, i.e., they are compensated by the Client.

2) Changes that occur as part of normal Design Development

Changes that occur as part of design development are numerous. Most of these changes find their origin in further detailing of the design and incorporation of information from vendors.

Their treatment differs depending on whether they occur before or after the issue of the impacted drawings for construction (IFC) and Material Requisitions for purchase (IFP).

Changes that occur prior to the issue of IFC drawings and IFP Material Requisitions do not need special treatment provided they are incorporated in IFC drawings and IFP Material Requisitions.

Changes occurring after the issue of IFC drawings or IFP Material Requisitions require special treatment including as a minimum:

- A process ensuring that such changes are avoided as much as possible as they generate procurement/construction re-works. Hence a process shall be in place to review and challenge the necessity of any such change and submit it to the suitable hierarchic level for authorization.
- The re-issue (revision) of the concerned drawings and/or Material Requisitions.

For the design changes that impact several disciplines/Project functions, a more complex treatment is required to ensure that all impacts are identified and implemented in the shortest time. This is the case for changes to the P&IDs.

Changes to IFC P&IDs are both inevitable and multiple. Their usual causes are:

- Correction of error, e.g., spec break location, drafting error,
- Interface with Equipment vendor, e.g., connecting flanges size, auxiliary connections, drains/vents, scope of supply, etc.
- Interface with in-line instrument vendor, e.g., flange size,
- Engineering development, usually as a result of further detailing, e.g., drains/vents addition/collection, detailing utility distribution, addition of break flanges/spool piece for maintenance, insulation limit/type change, addition of steam trap, addition of RO/silencer, connections of sample collection, analyzers, etc.
- Formal corrections: wording of notes, tags, symbols, representation,
- Correction of drawing to reflect control details, typical,
- Change of instrument technology,
- Implementation of SIL review results: addition of instruments to provide redundancy,
- Addition of missing line required for start-up,
- Geographical order of lines tapping into a header,
- Implementation of late HAZOP actions,

The procedure described here shall be implemented to any change to IFC P&IDs to:

- Ensure the integrity of the P&IDs by review and approval of any change by Process,
- Ensure the identification of all actions required by all Engineering disciplines and Project functions. Such actions may include purchase of additional materials, holding some construction activities affected by the change, update of 3D model, data bases and all impacted documents,

Changes to IFC P&IDs may be initiated by different disciplines, including Process, Instrumentation, Equipment, Piping, Piping Materials, Civil (for Underground lines), Materials & Corrosion, Safety, Pre-com/com.

Any such change shall be assigned a number and a dedicated form, the **P&ID Modification Sheet (PMS)**, shown hereinafter, to which shall be attached the marked-up P&ID(s) showing the change.

P&ID MODIFICATION SHEET Purpose of the modification:			**Number:**
P&ID Reference: Rev.: WBS Number:		Description of the modification (as deemed necessary): List of other impacted documents :	
REASONS FOR THE MODIFICATION Origin: Client, Licensor, Supplier, Disciplines, Others: Causes: Modification, Error, Normal Engineering Development, Others: Reference documents:			
SAFETY IMPACT: Need for additional HAZOP : ☐ Need for additional SIL: ☐		OTHER IMPACTS (Engineering, Schedule, Supplier, etc):	
COMPANY CHANGE (Yes / No): Change Order # :		COMPANY APPROVAL REQ'd (Yes / No):	
Issued:	**Reviewed:**	**Approved:**	**Approval (by, date):**
Initiating disc.	**Process**	**Project**	
CONTRACTOR			**COMPANY**

DISTRIBUTION:

	For action:	For information :		For action:	For information:
Area Project manager	☐	☐	Piping	☐	☐
Project Eng. in Charge	☐	☐	Pressure Vessel	☐	☐
Engineering Manager	☐	☐	Rotating	☐	☐
Process / PID Team	☐	☐	Construction	☐	☐
Instrumentation	☐	☐	Schedule	☐	☐
Packages	☐	☐	Precom/Com	☐	☐
HSE Design	☐	☐	Contract	☐	☐
Fired Equipment	☐	☐	Cost	☐	☐
Field Engineering	☐	☐	Company	☐	☐

The PMS does not describe in details all actions to be carried out to implement the change. In particular, it does not provide the list of all tasks, documents/data bases to be up-dated, documents to be issued/revised by each discipline. It is the task of each discipline to produce such list.

For I&C discipline such list can be extensive as shown on the Instrument Modification Record, which is issued by I&C discipline following the receipt of each PMS.

	Project N°		Record N°	Rev	Page
	Instrument Modification Record				

Status of IMR: ☐Engineering completed ☐Vendors work completed ☐Site work completed

Issued by: | **Unit:** | **P&ID N°:**

Approved by: | **Date:**

Title:

Source: ☐Client ☐X ☐Y ☐Hazop ☐SIL ☐Site survey ☐ Disciplines
☐Vendor ☐Others ☐ P&ID Modification Sheet ref:

Type: ☐Correction ☐Modification w/o COR ☐Modification with COR ⇨ COR reference:

Equipment references:

Document references:

Description of change:

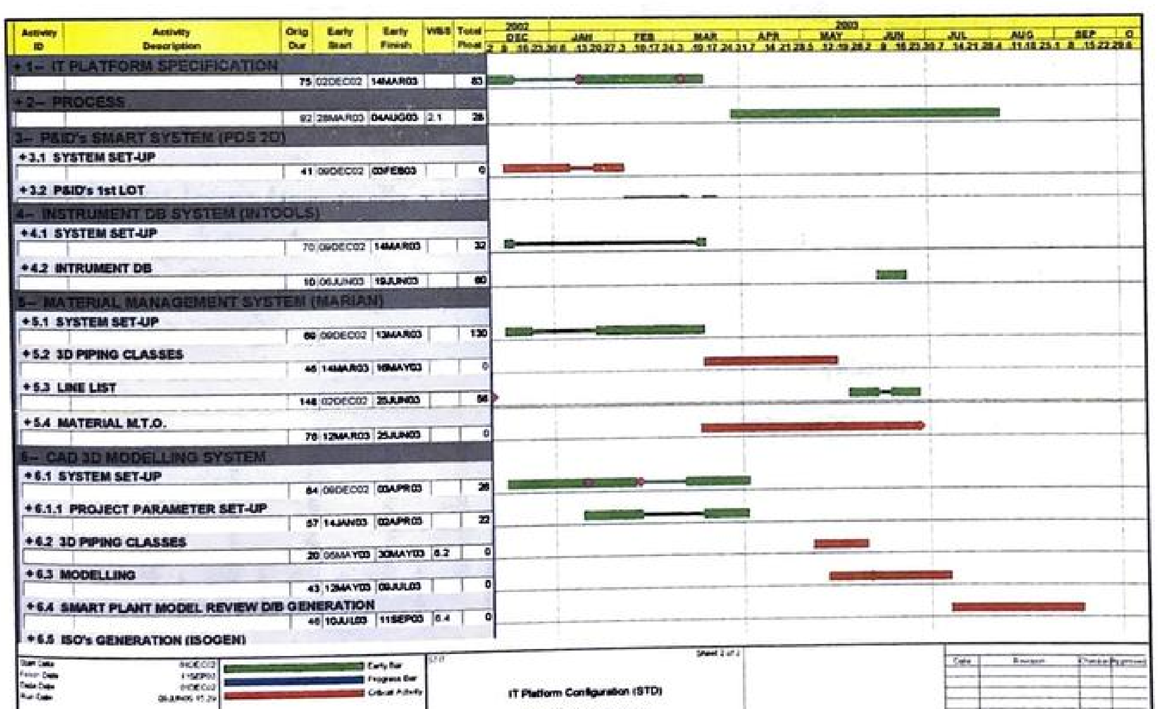
Instrumentation Engineering				Systems		Site work	
	Visa		Visa		Visa		Visa
PIDs		Installation		DCS		Instr Tech room	
☐PID Master instrum		☐Cable schedule (A)		☐MDF		☐MDF cross-wiring	
Intools database		☐Junction box (A)		☐I/O assignment		☐Field cable	
☐Module Index		☐MTO (Cable....) (A)		☐S/W Configuration		☐Power distrib.	
☐Module Wiring (A)		☐Local push button		☐Graphic display		☐Cabinet H/W	
☐Module Hook-up (A)		☐Inst. location dwg (A)		☐Serial Interface		☐Interconnecting	
☐		☐UPS distribution		☐		☐	
System		☐Routing		ESD/FGS/HIPS		Field	
☐DCS control narrative		☐3D model (A)		☐MDF		☐JB Wiring	
☐DCS serial interface Third party (To package)		☐		☐I/O assignment		☐Field instrument	
☐ESD C&E charts		☐		☐Logic		☐Secondary routing	
☐ESD FLD		Package vendor		☐Data for display		☐	
☐F&G C&E		☐Vendor PID		☐F&G detectors		Control room	
☐HMI - Alarms		☐Junction box		☐		☐ICS configuration	
☐		☐Cabinet		MMS		☐Power distrib.	
Field Instrument		☐Instrum. Data sheet		☐Marshal. I/O assignment		☐Routing - Wiring	
☐Requisition		☐Cable schedule		☐Configuration		☐	
☐Data sheet		☐Wiring diagram		☐		Telecom	
☐Level study		☐Logic diagram		Telecom		☐	
☐Vendor		☐Instrument Index		☐		☐	
☐		☐		☐		☐	
Elec. Interface		Tie-In / Interfaces		☐		Others	
☐ Interposing relay pnl		☐ Tie-in		☐		☐Vendor assistance required	
☐ Serial link		☐ Interface		☐		☐	

A log of the PMS shall be maintained and their prompt review, approval, dispatch and implementation controlled.

Chapter 20

Tools

Engineering disciplines use more and more complex and integrated IT tools. They cannot start their work prior to the set-up of these tools which is complex and requires a plan and schedule.

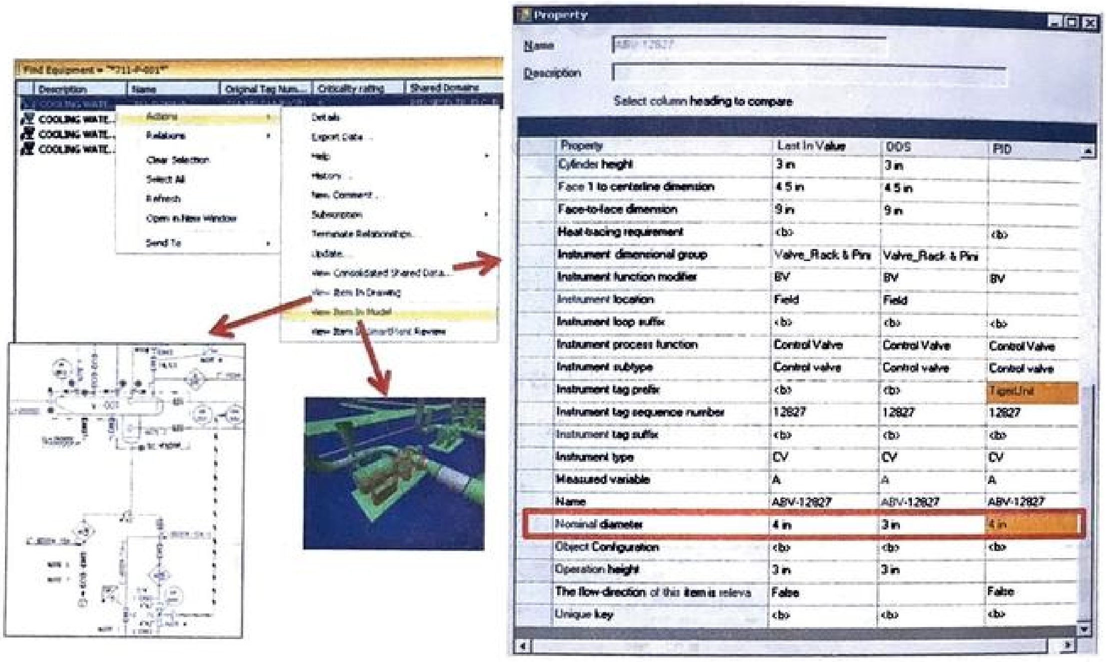


The **3D model** is described in chapter 10. Integration with other tools, such as the one used for P&IDs, the Instrument data base, the Piping Materials Management system, is becoming the norm in order to prevent inconsistencies.

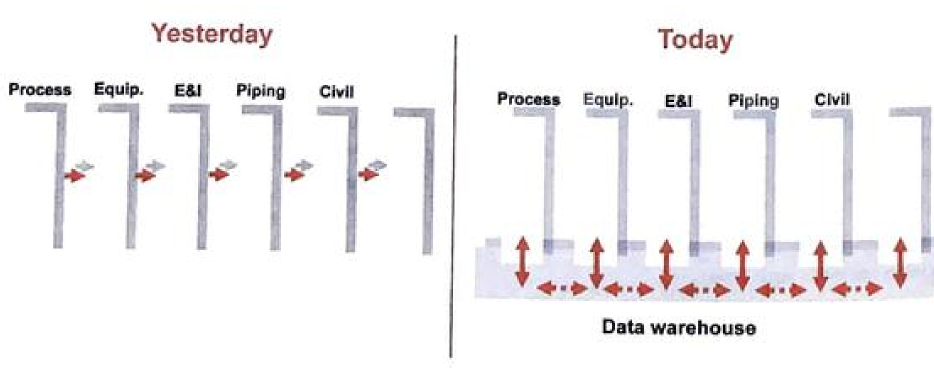
A given technical information, such as the size of a control valve, is indeed repeated on many different engineering documents: the P&ID, the valve data sheet, the piping isometric drawing, etc.

Different tools were used in the past to produce each of these documents: the drafting software for the production of the P&ID, the instrument data base for the production of the data sheet and the 3D model for the isometric.

This could lead to discrepancies, as illustrated below.



In order to prevent such discrepancies, the information that used to be transferred from one discipline to the other is now stored in a common data base accessible to all disciplines. The data in the data base becomes the MASTER data that all disciplines use.



Such shared data include number and technical characteristics of lines, instruments and equipment.

A **Piping Materials Management Software** is required to manage the large quantities and variety of piping materials ordered and the numerous iterations of Piping Material Take-Off and amendment to the purchase orders.

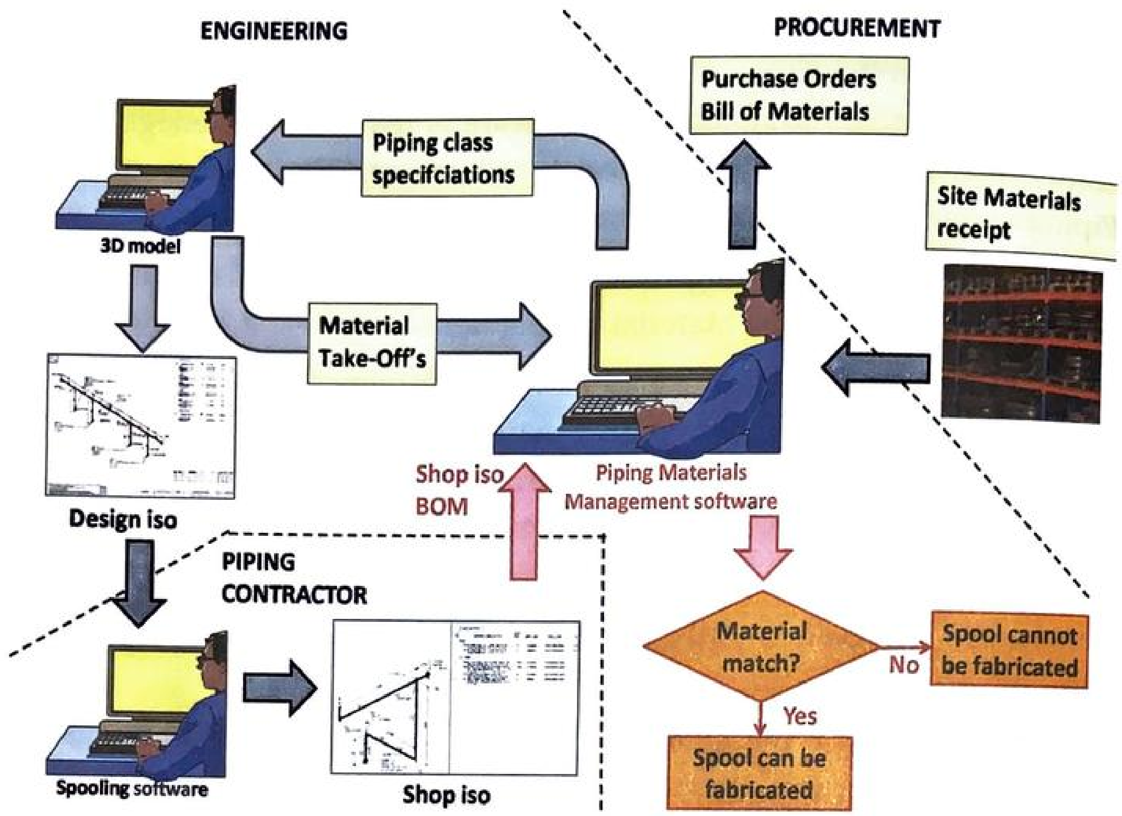
The Piping Materials Management software produces the list of materials to order that is included in the Material Requisitions.

The 3D model and the Piping materials management software are interfaced: the technical specification of the piping materials are set in the Piping Materials management system and transferred to the 3D model, the Piping MTOs extracted from the 3D model are fed into the Piping materials management software.

This Piping Materials Management software tracks deliveries of piping materials and allows to identify if the materials are available at Site to enable fabrication. This is called **material matching**.

Material matching is not done at the level of *design* isometric drawings but at that of shop isometric drawings. Indeed piping is fabricated by spools corresponding to the extent of the line shown on the shop isometric.

Spooling is usually done, and shop isometric drawings issued, by the piping construction contractor and not by Engineering. Spooling is done using a dedicated software. The Bill Of Material (BOM) of shop isometric drawings must be extracted from this software and fed to the Piping Materials Management software to perform Material matching.



Dispatch of documents to all concerned parties, in particular all concerned Engineering disciplines, is critical. This is done using the Electronic Document Management System (EDMS). The EDMS uses a dispatch matrix based on the discipline and document type identified in the document number.

Document			Distributed to											
Issuing discipline	Type of document	Document code	Safety	Process	Piping/layout	Piping/material	Piping/stress	Drafting office	Civil	HVAC	Structure	Electrical	Instrumentation	Equipment
PIPING	LAYOUT DRAWING, PLOT PLAN	M1	X	X	X	X	X	X	X	X	X	X	X	X
	GENERAL ARRANGEMENTS DRAWING	M2	X	X	X		X	X	X		X	X	X	X
	LIST, MATERIAL TAKE-OFF	M4		X	X	X	X	X						
	ISOMETRIC DRAWING	M5			X			X						
	CALCULATION	M6			X		X	X						
	SPECIFICATION	M7			X	X	X	X					X	

A numbering is also imposed to Vendor documents, allowing to identify the commodity and type of document, according to which the dispatch to the concerned Engineering disciplines is done.

Vendor doc dispatch	Commodity		
Doc type	Rotating machinery	Electrical equipment	Pressure Vessel
Foundation drawing	Rotating Civil	Electrical Civil	Pressure Vessels Civil
Cross sectional & assembly drawing	Rotating	Electrical	Pressure Vessels

As emphasized in chapter 14, information from vendors is essential to Engineering development. Therefore an essential task is the control of timely submission of vendor documents. This is done using the EDMS, as follows:

The EDMS is fed with the VDL (Vendor Documents List) deriving from the requirements of the Material Requisition and fine tuned during the Kick-Off Meeting. The VDL includes the list of vendor documents and submission dates.

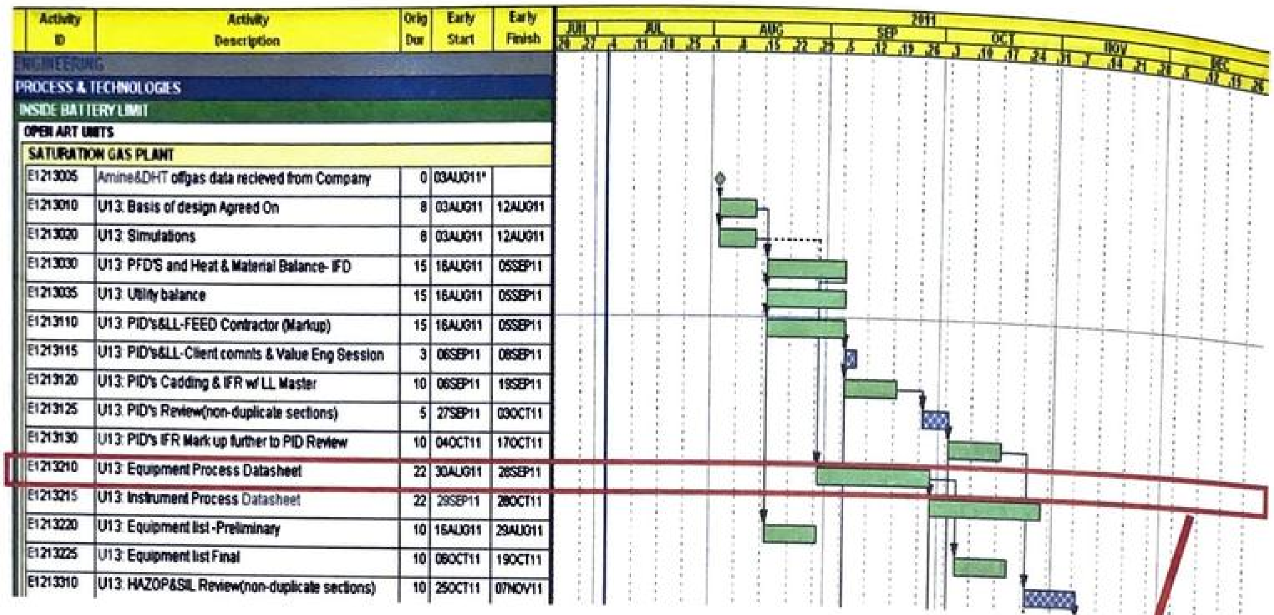
The EDMS records the receipt of vendor documents hence the list of outstanding submissions can be extracted and used to expedite the vendors. The status of reviews of vendor documents by Engineering is also recorded in the EMDS and the list of outstanding reviews can be extracted and used for internal expediting.

Doc Number	Document Title	Supplier Planned	Supplier Actual	To Supplier Due	To Supplier Actual	Review code
GY-VD-GS023145	MECHANICAL DATA SHEET - 3-E-0544 A/B	01/12/2016				
GY-VD-SD023118	GAD -3-E-0544 A/B	19/10/2016	18/11/2016	03/12/2016		
GY-VD-SD023137	NAMEPLATE DRAWING - 3-E-0544 A/B	28/10/2016	18/11/2016	03/12/2016	28/11/2016	2
GY-VD-QC023126	ITP -3-E-0544 A/B	26/09/2016	11/10/2016	26/10/2016	31/10/2016	2
GY-VD-QC023150	ITP – PAINTING -3-E-0544 A/B	10/04/2017				
GY-VD-SC023118	MECHANICAL CALCULATION NOTE - 3-E-0544 A/B	20/09/2016	11/10/2016	26/10/2016	31/10/2016	3

The Engineering timely deliveries, which are essential to keep the Project on schedule, are not controlled at the Project schedule level (level 3 schedule produced by the scheduling software). The work items at that level are indeed not fine enough to provide proper control. The level 3 schedule focuses on interfaces, as explained in chapter 16.

Engineering control is neither performed at the finest possible level, i.e., individual deliverables level (level 5, i.e., Engineering documents register).

The control, and calculation of progress as described in chapter 18, is performed at the level 4 of groups of documents, called deliverables, using neither the scheduling software nor the document control software but an in-house **Engineering progress tool**, which in many cases is simply MS Excel.



Project schedule (level 3)

Work Item Description
UNIT 13 - PROCESS DATA SHEETS - HEATERS
UNIT 13 - PROCESS DATA SHEETS - COLUMNS
UNIT 13 - PROCESS DATA SHEETS - HEAT EXCHANGERS
UNIT 13 - PROCESS DATA SHEETS - AIR COOLERS
UNIT 13 - PROCESS DATA SHEETS - PUMPS

Engineering progress (level 4)

Document Title
PROCESS DATA SHEET - CONDENSATE HEATER 82-F1301
PROCESS DATA SHEET - CONDENSATE HEATER 82-F1301
PROCESS DATA SHEET - HEAVY GASOIL STEAM SUPERHEATER 82-E1309
PROCESS DATA SHEET - CONDENSATE TOWER 82-C1301
PROCESS DATA SHEET - KEROJET STRIPPER 82-C1302
PROCESS DATA SHEET - GASOIL STRIPPER 82-C1303
PROCESS DATA SHEET - VACUUM TOWER 82-C1304
PROCESS DATA SHEET - TOP PA/CONDENSATE EXCHANGER 82-E1301 A-D
PROCESS DATA SHEET - KEROJET CONDENSATE EXCHANGER 82-E1302 A/D

Engineering documents register (level 5)

At the end of each reporting period the Engineering progress is calculated by entering the status of all deliverables in the Engineering progress tool as described in chapter 18. The actual issue date of individual documents could be imported from the EDMS and documents matched to deliverables using document numbers.

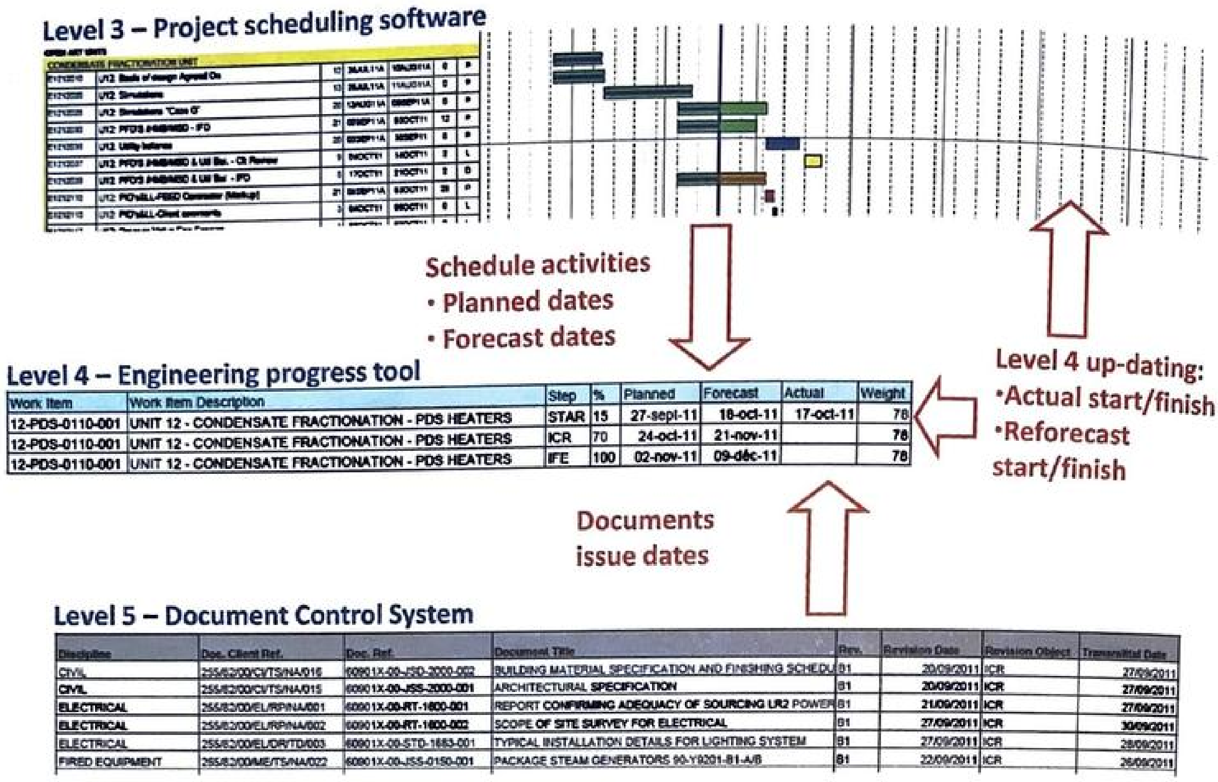
Some Engineering deliverables in the level 4 are reforecast, i.e., start or finish dates are postponed. As the engineering progress tool does not contain logic (predecessor/successor) links between deliverables and with other Project activities, the impact of such re-forecast cannot be assessed. It is therefore necessary to check it at the Project schedule level (level 3) using the Project scheduling software.

In summary, the control of the Engineering timely deliveries involves 3 different systems: the Project scheduling software (level 3), the in-house Engineering progress measurement tool (level 4) and the document control system (level 5).

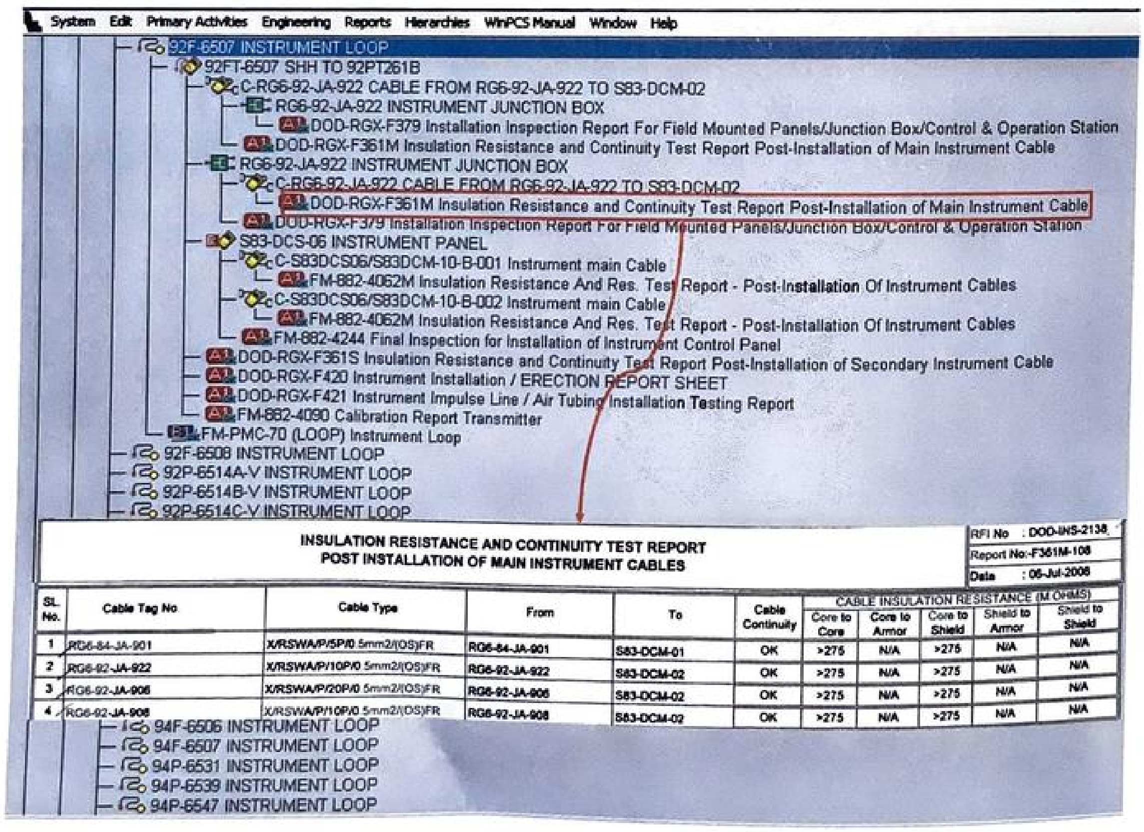
The maintenance (update) of the level 5 schedule (MDR) is done automatically when documents are issued as the EDMS records the issue date.

The maintenance (update) of the Project schedule (level 3) is done by the Project Scheduler as described in chapter 16.

The maintenance (update) of the level 4 schedule is done by the Engineering disciplines who enter the status (actual start/finish dates) and update the forecast start/finish dates of deliverables. Such up-date must be coordinated with that of the Project schedule to identify any impact on the Project.



Engineering data bases are used during pre-commissioning of the Plant when all equipment, instruments, lines are checked. Data bases are interfaced to the pre-commissioning data base which produces the check sheets for each tag.



At the end of the Project, information from Engineering, Pre-commissioning/commissioning and from Vendors, including that related to spare parts, must be handed over to the Client in a format suitable for upload in its Computerized Maintenance Management System.

P& ID	Functional location	Functional location description	Object type	Gross weight	Manu-facturer	Model Number	Construc-tion Year	Serial Number	Purchase Order number	RSPL	Warranty period
106	29-P8701	Pump main list	Pump	603	XXX	CYT E-40 160	2015	4970921	2908	03254	Dec 2019

Chapter 21

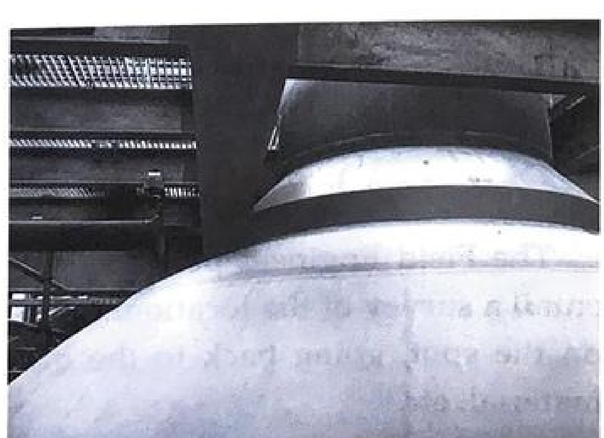
Field Engineering

The Engineering activities described in the previous chapters take place at the home office. When a Project goes in Construction phase, a small multi-disciplinary "Field Engineering" team made of engineers and draftsmen is seconded from the home office to the construction Site.

These Engineers and draftsmen are fully familiar with the engineering documents and drawings that have been produced.

They know on which document to find information.

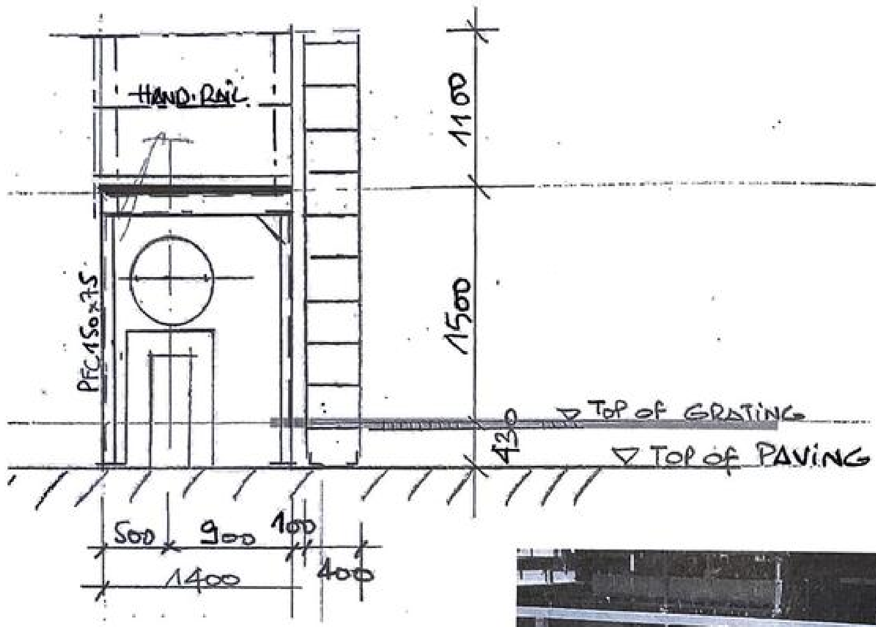
Their first task is to familiarize the Construction contractor(s) working at Site with the Engineering deliverables.

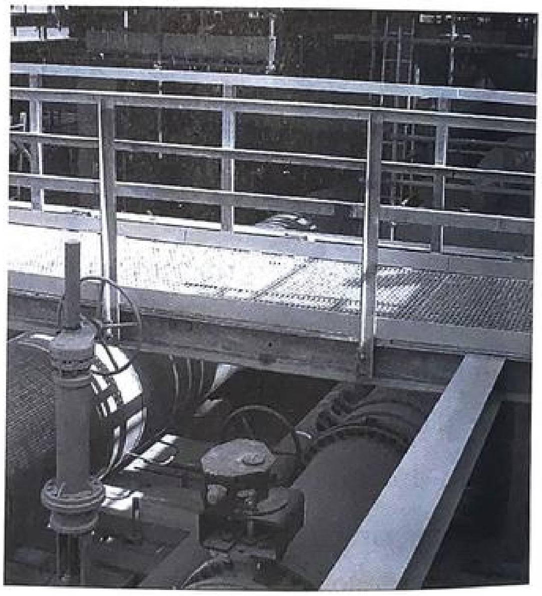


They are also there to solve issues discovered during construction, such as:

- engineering errors, such as interferences between a pipe and a steel structure,
- construction errors, e.g., a foundation has been cast slightly off its designed position and a design change is required to avoid re-cast,

- Site, equipment or material conditions differ from what was anticipated,
- overlooked engineering: the construction contractor needs some information that have not been prepared, e.g., cable routing was not defined in full, etc.,
- additions to the design. During the final inspection of the facility with the client before the hand-over a number of shortcomings are identified in the design, such as lack of access to valves as shown here...





The Field Engineer performs the corresponding design. It would typically entail a survey of the location, dimensional measurements, sketching a solution on the spot, going back to the office to draft the drawings, issue the bill of material, etc.

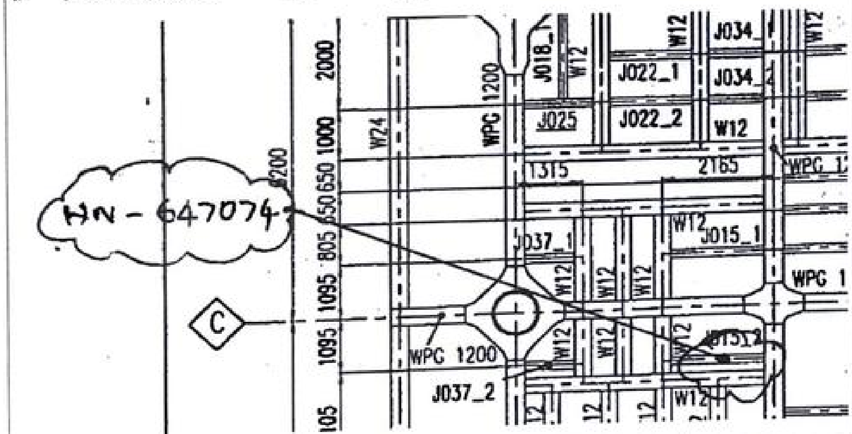
Changes to the design made at the Site must be approved by Engineering. To this end, the **Site Query** system is put in place:

Upon identification of a required change, the construction contractor issues a Site Query to the Engineer.

FROM: Construction Sub-Contractor	**SITE QUERY NO.:**		**Rev.:**
TO: Contractor	**DISCIPLINE:** Piping	**SYSTEM:** -	
SUBJECT: Penetration clash with beams			
REF.: drawing #...			

DESCRIPTION:
Pipe penetration found to clash with the beams on the above drawing
Module-P, line HN-647074.
Contractor to advise on the alternative.

Module	Pipe number	Pipe size(Inch)	Sleeve Size (mm) [F... OD + 100 + Insulation from PDMS]	Sleeve Location East	North	Elevation
P	LA1PD-HN-647074	12"	424	115617	285494	106000



ORIGINATOR:		**POSITION:**	Engineer	**DATE:**
CHECKED BY:		**POSITION:**	Snr. Engineer	**DATE:**
AGREED BY:		**POSITION:**	Proj. Manager	**DATE:**
ANSWER:		**ANSWER REQUIRED BY:**		
ANSWER BY:	**SIGNATURE:**	**POSITION:**		**DATE:**
ANSWER APPROVED BY:	**SIGNATURE:**	**POSITION:**		**DATE:**

The Site query describes the issue encountered and, preferably, proposes a solution. The Engineer checks that the proposed change is acceptable or proposes an alternative.

The changes made at Site may require additional material purchases which, for the case of long lead items, must be properly managed. The changes made by construction must be followed-up by the concerned Field discipline Engineer and compared to the allowances included in the purchased quantities. If necessary, an additional Material Take-Off is done at Site to order a last set of materials. This avoids that material shortages are found at the last minute. The corresponding purchaser order may be placed by the construction contractor, instead of the EPC home office purchaser who may be demobilized.

In order to always work with up-to-date documents, Engineering updates a unique, called MASTER, set of engineering documents, with all changes. Changes are usually marked by hand and in red on the drawings, which are for this reason called "red-line mark-ups". The reference of the change is indicated next to the mark to trace it.

The Master set of red-line mark-ups is the reference on Site to which every party (Construction, Commissioning, etc.) refers.

PESD 94-Y061A

SITE MASTER

EFFECT

1: immediate stop when alarm appears

1C: immediate close when alarm appears

1O: immediate open when alarm appears

CAUSE

94UZ-6866A

Rev	ALARM – TAG ALARM	SENSOR	Description	Signal	Inhibition	Timer	94-Y061A-P001A Seawater booster pump A motor	94-Y061A-P001B Seawater booster pump B motor	94-Y061A-P002A Distillate water pump A motor	94-Y061A-P002B Distillate water pump B motor	94-Y061A-P003A Brine pump A motor	94-Y061A-P003B Brine pump B motor	94-Y061A-P005A Antiscale pump A motor	94-Y061A-P005B Antiscale pump B motor	94-Y061A-X006 Antiscale mixer motor	94-Y061A-P006A Antifoam pump A motor	94-Y061A-P006B Antifoam pump B motor	94-Y061A-X007 Antifoam mixer motor
4	94LAHH-6868A	94LIT-6868A	BR LVL CELL 5 VERY HIGH HIGH	Analog input	-	10 fs	1	1	1	1	1	1	1	1	1	1	1	1
4	94PAHH-6875A	94PIT-6875A	94Y061AX001 DSCH PRES OUT HIGH HIGH	Analog input	[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1
7	94FALL-6880A	94FIT-6880A	94Y061A SWTR CLG RJCT FL LOW LOW	Analog input	[illegible]	10 6s	1	1	1	1	1	1	1	1	1	1	1	1
7	94FALL-6895A	94FIT-6895A	94Y061A DW FL OUT B/L LOW LOW	Analog input	[illegible]	10 fs	1	1	1	1	1	1	1	1	1	1	1	1
7	94FALL-6896A	94FIT-6896A	94Y061A BR FL OUT B/L LOW LOW	Analog input	[illegible]	10 fs	1	1	1	1	1	1	1	1	1	1	1	1
4	94PALL-6884A	94PIT-6884A	94Y061A INSTRUMENT AIR VERY LOW LEVEL	Analog input	-	10 fs	1	1	1	1	1	1	1	1	1	1	1	1

At the end of the Project, red-line mark-ups allow to revise the engineering documents with all changes and issue a final "As-Built" revision. As-built's are part of the final documentation handed over to the client, and are used for the Plant Operation, maintenance, future expansion, etc.

Chapter 22

Revamping

Modifications to an existing Plant, for its expansion, debottlenecking, etc., entail a set of specific engineering tasks and documents which are not found in a "Green Field" (new built) development.

As the modifications of the existing Plant will lead to a change of operating conditions for some of its process equipment, their duty must be checked for the new conditions. This entails the verification of the capacity of rotating equipment, thermal duty of heat exchangers, etc. Some of these verifications will need to be done by the equipment supplier itself, such as verification of compressors for new gas composition, column internals for new gas/liquid traffic, etc.

Additionally, suitability of the equipment and piping for the new pressure and temperature conditions must be checked, including hydraulic calculations.

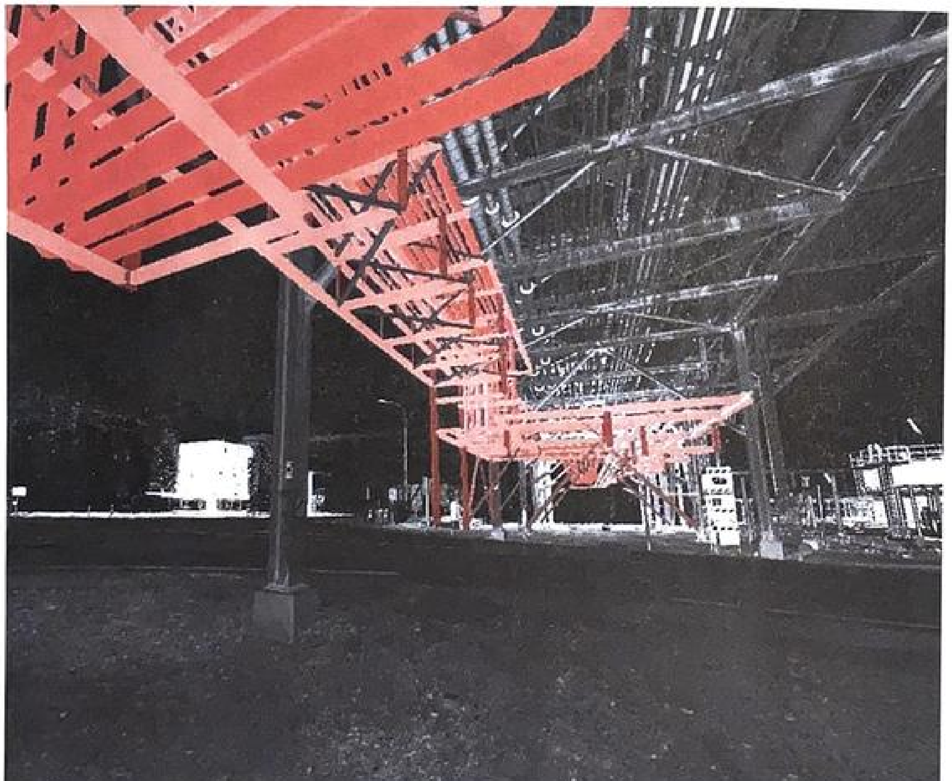
Instruments, such as control valves and pressure safety relief valves must also be checked so that they have adequate capacity to cover the new operating requirements.

In the case of new unit(s) being added to an existing facilities, it is more than likely that the new unit(s) will use some of the existing facility *utilities*. This could include fuel gas, electrical power, cooling medium, instrument air, etc. Care must be taken while evaluating if the existing utilities have enough capacity: The current consumption need to be precisely assessed, taken into account the conditions of maximum consumption. Note that the spare capacity of the existing units might be less than that indicated in their original design documents due to modifications made to the Plant since then!

The additional load must also be estimated with sufficient accuracy. This will avoid a situation where the existing utilities fall short as the new design develops.

Additions to an existing Plant make use of the provision for "future" in the original design. A new built facility indeed includes a certain level of pre-investment, such as 20% free space on pipe-racks, 20% free spare terminals in instrument junction boxes and cores in multi-cables, etc.

Such space, if it has not been used up already, will be used for the expansion. Retrieval of the engineering drawings of the existing showing such free space is only the first step. As these drawings may not have been up-dated with later modifications, a physical check by Site survey is required.



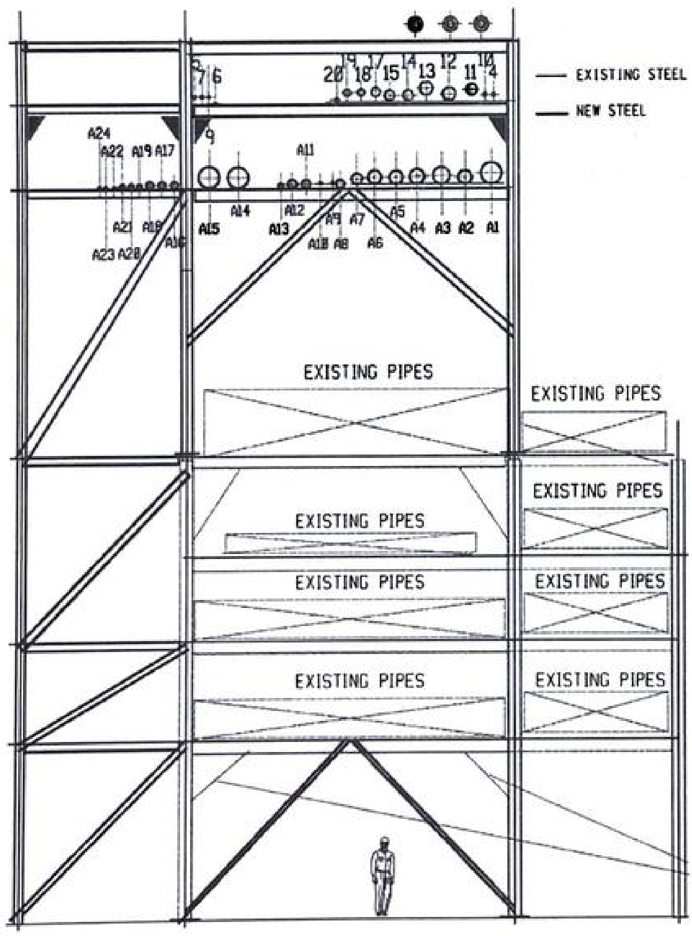
For above ground facilities, surveys range from simple visual or "measuring tape" type to the full 3D survey of an area.

The 3D survey is performed by shooting numerous 2D pictures of an area of the Plant from numerous view points. The pictures are then superimposed, yielding a 3D image. The later can be looked at and navigated in from the engineering office. The 3D picture is coordinated to the local Plant coordinate system and scaled, which allows measurements.

The point cloud 3D image of the existing Plant can also be superimposed to new design in the 3D model, allowing to identify interferences. A 3D survey involves significant field and processing time besides expensive equipment. It is justified in the case of extensive modifications to a congested existing area. It will indeed allow to identify interferences, especially with small items such as small bore pipes, small E/I trays, supports, etc. which do not appear on the existing drawings. In this case, it avoids numerous visits to the job Site. It can also be useful to mitigate unavailability/inaccuracy of existing drawings, provide measurements in inaccessible areas, produce scaled drawings of the existing, etc.

Underground survey is done by means of excavations. The plot of land where a new unit is to be built, for instance, must be free of underground networks, such as pipes, cables, etc. or their positions precisely known. As available drawings may not depict all constructions having taken place over a number of years, an exploratory trench is commonly dug all around the area, up to the lowest level of expected networks, to identify any pipes, cable, etc.

Local excavations of cable trenches allow to confirm that the free space that appears on existing drawings is still available for new cables.



Although surveys might mitigate the unavailability of existing drawings, some existing design documents are necessary.

The addition of new lines on a pipe-rack for instance, will not only require the drawings of the existing steel work (which could be redrawn following survey if not available) but also its calculation note. The latter indeed indicate its loading.

Although the revamping engineer could estimate the pipe weights, the loads sustained by the steel work to ensure pipe flexibility requirements, such as loads at fixed "anchor" points, cannot be guessed. They are found in the steel structure calculation note, as input data resulting from detailed piping stress calculations.

Once free spaces have been identified for the Plant expansion, it needs to be booked. Physical markers are best, such as signs at tie-in locations, warning tape, etc. Experience proves that co-ordination between a large Plant various expansion projects is not often effective, especially between small projects under the Plant Engineering department and larger ones under dedicated Project teams.

Knowledge of concurrent projects is essential for coordination to avoid conflict (both projects use the same plot space for instance).

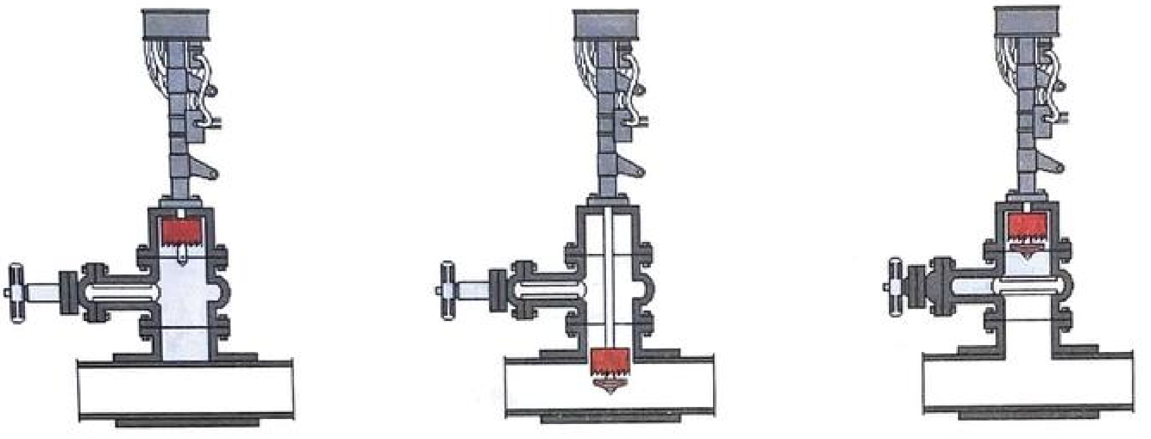
The connections of the new facilities to the existing Plant are called "tie-in's". They consist of connections to the existing facilities pipe-work, electrical power distribution, instrumentation and telecom systems, etc.

Doing some connections requires the existing facility to be shut in, while others can be done while the Plant is in operation. The Engineer minimizes the former by discussing with the Plant operator and finding that, for instance, a piping tie-in can be relocated onto a line that can be temporarily put out of service, etc. The existing design may also allow for tie-in's during operation, such as that to a control system with redundant A/B circuits (operating with B while working on A then reversely), that to an electrical switchboard a section of which can be isolated, etc. Detailed review and optimization of tie-in's will allow to reduce the number of tie-in's requiring Plant shutdown hence reduce downtime.

Tie-in schedules are issued by the concerned disciplines (Piping, Electrical, Instrumentation, Telecom). Process discipline defines the required connections to the existing process and utility lines and initiates the **Piping tie-in's list**.

Piping tie-in's entail the usual "tee" addition, where a branch is added on an existing line by "cut and weld" requiring the line to be shut in.

Addition of a branched connection on a LIVE line is also feasible by performing a "**hot tap**". In such case, a slightly larger and purposely made "tee", split in two halves, is welded to the live line. The tee is then fitted with a flange and an isolation valve. Hot tap operation is shown here below. The hot tapping machine drills through the open valve while containing the fluid coming through the opening. A special device allows retention of the coupon. Once the drill is completed, the drilling equipment is retracted, the valve closed and the hot tap machine dismounted.

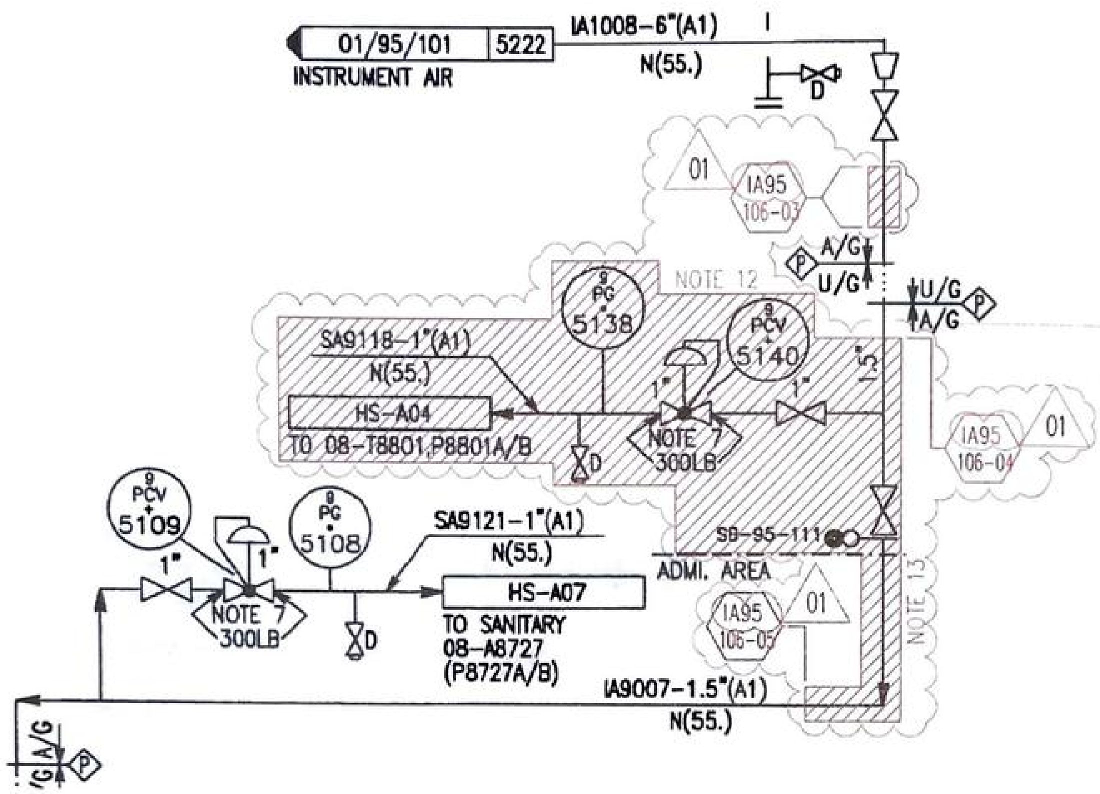


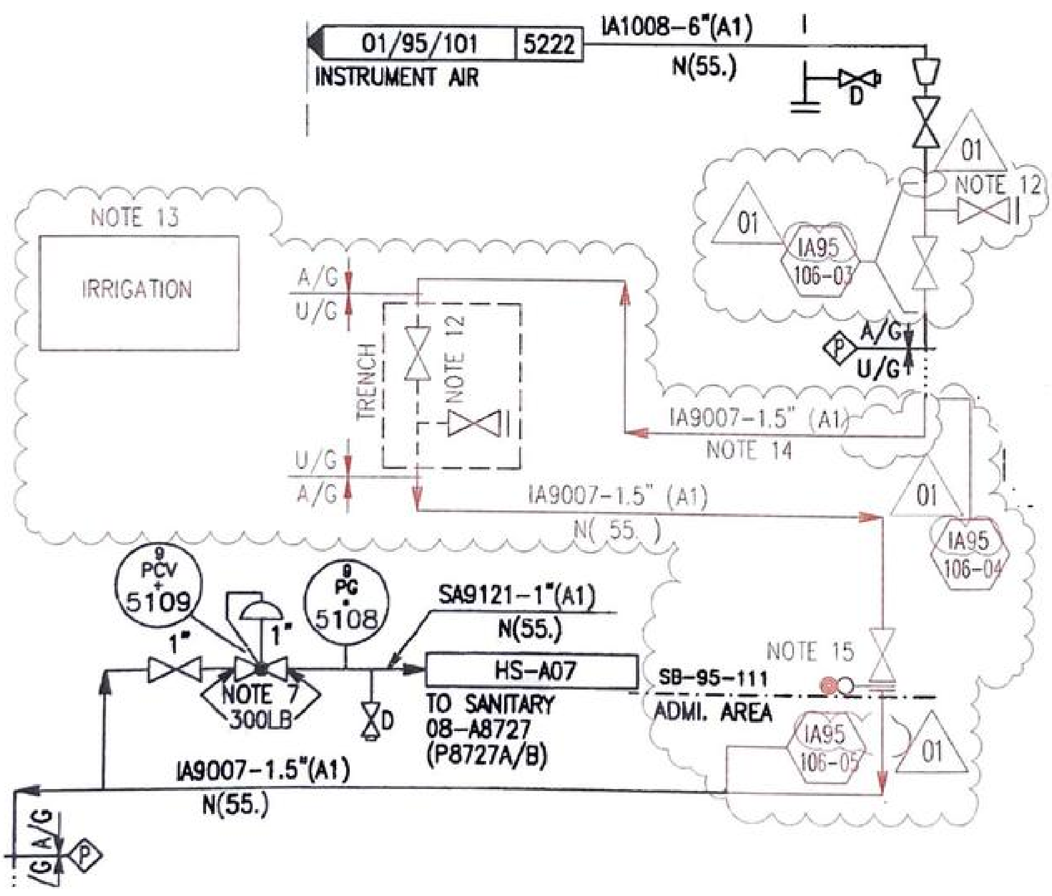
When connecting a new line to an existing line, the flexibility of the system made of the new line and the existing line up to its first anchor point must be checked.

Modification of systems entail that of:

- Old systems, which are hard wired or have a hard logic, such as that contained in a ROM chip, etc. Changes to these systems require their shutdown, for re-wiring, replacement of the old chip with a new one, etc. Some old systems might be obsolete and cannot be extended. I/O cards may for instance no longer be manufactured. Such systems must then be upgraded, i.e., replaced by new ones.
- Recent systems, which have a soft (configured) logic and distributed architecture. Additional controllers can be added on-line while modifications on operators' consoles (addition of mimics, etc.) can be done on each console at a time, without impact on the other consoles. Even the control loops can be modified on the LIVE system, as controllers are usually duplicated A/B so that modifications can be done on A with B controlling, and then on B with A controlling.

Tie-in dossiers are submitted to the Plant owner for review. They include both Dismantling and corresponding Construction drawings.





Up-dating of the Plant existing documentation is rarely done properly. A project often develops new drawings instead of up-dating the existing drawings. The owner ends up with two drawings instead of one, one showing the existing Plant and another one showing what has been added.

Several concurrent projects might also be making modifications to the same part of the Plant hence to the same drawings. A drawing check out/check in system must be put in place: Project B, which "checked out" a certain drawing, must return, i.e., "check in", such drawing before it is provided ("checked out") to Project A.

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THE OIL & GAS ENGINEERING GUIDE

Hervé Baron

3rd ED.

This book provides the reader with:

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- an overall view of the plant design sequence and schedule,
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This book is designed to serve as a map to anyone involved with engineering activities.

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The author began his professional career with an international oil company. Starting out with an interest in the operation of oil & gas facilities, his technical curiosity about their design saw him move to engineering contractors to become expert in this area. As engineering manager of large turn-key projects, he gained the insight on engineering and amassed the knowledge presented in this work.
Hervé Baron is a graduate engineer from IFP school and France's École Polytechnique.

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