طرح نگهداشت و افزایش تولید ۲۷ مخزن

STRUCTURAL DESIGN CRITERIA

نگهداشت و افزایش تولید میدان نفتی بینک

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PAGE	D00	D01	D02	D03	D04
1	X				
2	X				
3	X				
4	X				
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6	X				
7	X				
8	X				
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48					
49					
50					
51					
52					
53					
54					
55					
56					
57					
58					
59					
60					
61					
62					
63					
64					
65					

PAGE	D00	D01	D02	D03	D04
66					
67					
68					
69					
70					
71					
72					
73					
74					
75					
76					
77					
78					
79					
80					
81					
82					
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107					
108					
109					
110					
111					
112					
113					
114					
115					
116					
117					
118					
119					
120					
121					
122					
123					
124					
125					
126					
127					
128					
129					
130					

CONTENTS

1.0 INTRODUCTION

Binak oilfield in Bushehr province is a part of the southern oilfields of Iran, is located 20 km northwest of Genaveh city.

With the aim of increasing production of oil from Binak oilfield, an EPC/EPD Project has been defined by NIOC/NISOC and awarded to Petro Iran Development Company (PEDCO). Also PEDCO (as General Contractor) has assigned the EPC-packages of the Project to "Hirgan Energy - Design and Inspection" JV.

GENERAL DEFINITION

The following terms shall be used in this document.

CLIENT:	National Iranian South Oilfields Company (NISOC)
PROJECT:	Binak Oilfield Development – General Facilities
EPD/EPC CONTRACTOR (GC):	Petro Iran Development Company (PEDCO)
EPC CONTRACTOR:	Joint Venture of : Hirgan Energy – Design & Inspection(D&I) Companies
VENDOR:	The firm or person who will fabricate the equipment or material.
EXECUTOR:	Executor is the party which carries out all or part of construction and/or commissioning for the project.
THIRD PARTY INSPECTOR (TPI):	The firm appointed by EPD/EPC CONTRACTOR (GC) and approved by CLIENT (in writing) for the inspection of goods.
SHALL:	Is used where a provision is mandatory.
SHOULD:	Is used where a provision is advisory only.
WILL:	Is normally used in connection with the action by CLIENT rather than by an EPC/EPD CONTRACTOR, supplier or VENDOR.
MAY:	Is used where a provision is completely discretionary.

2.0 SCOPE

This document covers the data considered in the general design criteria for foundations, concrete structures and steel structures.

3.0 NORMATIVE REFERENCES

3.1 LOCAL CODES AND STANDARDS

- IPS-E-CE-200 Engineering Standard for Concrete Structures
- IPS-E-CE-210 Engineering Standard for Steel Structures
- IPS-E-CE-500 Engineering Standard for Loads
- INBC-6 Iranian National Building Code (Latest Edition) – Loads on The Building
- INBC-8 Iranian National Building Code (Latest Edition) – Masonry Work
- INBC-9 Iranian National Building Code (Latest Edition) – Concrete Structure Design & Construction
- INBC-10 Iranian National Building Code (Latest Edition) – Steel Structure Design & Construction
- INBC-11 Iranian National Building Code – Industrial Design & Execution of Buildings
- ISDCOI-038 Iranian Seismic Design Code for Petroleum Facilities & Structures (3rd Edition)
- STD-2800 Iranian Code of Practice for Seismic Resistant Design of Building (4rd Edition)
- ISIRI14262-2 / S235JR Iranian National Standard Organization – Hot Rolled Structural Steels – part 2
- ISIRI3132 Iranian National Standard Organization – Hot Rolled Steel Rods for Reinforcing Concrete

3.2 INTERNATIONAL CODES AND STANDARDS

- ACI 318M-14 American Concrete Institute – Building Code Requirements for Structural Concrete
- ACI 315R American Concrete Institute – Manual of Standard Reinforced Concrete Structures
- ACI 350R American Concrete Institute – Concrete Sanitary Structures

- ACI 351.3R — American Concrete Institute– Foundation Dynamic Equipment
- AISC 360-10 — American Institute of Steel Construction – Specification for Design , Fabrication & Erection of Steel Structure
- AISC 341-10 — Seismic Provisions for Structural Steel Buildings
- ASCE 7-10 — Minimum Design Loads for Buildings
- ASTM F3125/F3125M — Standard Specification for High Strength Structural Bolts, Steel and Allow Steel, Heat Treated, 830MPa and 1040MPa Minimum Tensile Strength, Metric Dimensions.
- ASTM A563 — Standard Specification for Carbon and Alloy Steel Nuts
- ASTM F436M — American Society for Testing and Materials- Specification for Hardened Steel Washers
- ASTM A325 — Specification for High-Strength Bolts for Structural Steel Joints(Metric)
- ASTM A193 — Standard Specification for Alloy-Steel for High-Temperature Service
- ASTM A194 — Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service
- AWS D1.1 — American Welding Society

3.3 THE PROJECT DOCUMENTS

- BK-GNRAL-PEDCO-000-ST-SP-0001 — Specification for Concrete Work
- BK-GNRAL-PEDCO-000-ST-SP-0003 — Specification for Fabrication of Steel Structures
- BK-GNRAL-PEDCO-000-ST-SP-0005 — Specification for Erection of Steel Structures

3.4 ENVIRONMENTAL DATA

Refer to "Process Basis of Design; Doc. No. BK-GNRAL-PEDCO-000-PR-DB-0001-".

3.5 ORDER OF PRECEDENCE

In case of any conflict between the contents of this document or any discrepancy between this document and other project documents or reference standards, this

issue must be reported to the CLIENT. The final decision in this situation will be made by CLIENT.

4.0 MATERIALS

4.1 STRUCTURAL STEEL

Material for structural steel shall be ISIRI14262-2 S235JR with a minimum yield stress of 240 MPa or approved equivalent.

All steel parts shall be according to “Specification for Fabrication of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0003 & “Specification for Erection of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0005.

4.2 REINFORCEMENT

Plain Mild Steel Bars, Grade I, in accordance with DIN 1045 Specifications with a minimum yield stress of 2200 kg/cm2 or approved equivalent shall not be used as main longitudinal and stirrup reinforcement in concrete structures.

Deformed Steel Bars, Grade II in accordance with DIN 1045 specifications with a minimum yield stress of 3000 kg/cm2 or approved equivalent meeting the specific requirement set forth in ACI318.

Deformed High Tensile Strength Steel Bars, Grade III in accordance with ASTM A706 (Fy=4000 kg/cm2) or ASTM A615 Grade 60 (Fy=4000 kg/cm2) meeting the specific requirements set forth in ACI-318 or approved equivalent.

Reinforcing Fabric Mesh in accordance with BS 4483 or ASTM A497 / ASTM A185M or other approved Standards. Sizes shall be as follows:

- 200 x 100 x 6 x 6 mm
- 200 x 100 x 8 x 8 mm
- 200 x 200 x 6 x 6 mm
- 200 x 200 x 8 x 8 mm
- 150 x 150 x 8 x 8 mm
- 100 x 100 x 6 x 6 mm
- Other sizes shall be subject to approval by EMPLOYER/OWNER.

4.3 WELDING ELECTRODES

Shall be according to “Specification for Fabrication of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0003 & “Specification for Erection of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0005.

4.4 STEEL PIPES AND STRUCTURAL TUBING

Shall be according to “Specification for Fabrication of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0003 & “Specification for Erection of Steel Structures”, Document number: BK-GNRAL-PEDCO-000-ST-SP-0005.

4.5 INSERT PLATES

Insert plates shall be of material S235JR.

4.6 BOLTS, NUTS AND WASHERS

Hexagonal bolts and nuts shall be in accordance with ISIRI or approved equivalent for structural steel connections.
Nuts shall be in accordance with ISIRI5654 and ISIRI9737 for anchor bolts in foundations.
Washers shall be in accordance ISIRI9742 specification or approved equivalent.
Not less than two bolts shall be used in end connections

4.7 CHECKERED PLATE

Steel for checkered plates shall be ASTM A36/A36M or approved; minimum thickness shall be 6+2 mm.

4.8 STEEL GRATINGS

Steel gratings shall be a 30 x 50 mm mesh, with bearing bars 30 x 3 mm and transverse bars of 6x6 mm twisted bars. Steel shall be in compliance with ASTM A36/A36M or approved equivalent. Gratings shall be hot dip galvanized as per ASTM A123.

Maximum span between supports of the gratings should be 1.5 m.

4.9 UNITS

Unless otherwise specified, SI unit shall be applied as the measurement system to the drawings and documents.

5.0 LOAD CASES

5.1 DEAD LOADS

The structural dead load shall be the weight of all structural materials, including fireproofing (if any), weight of all empty equipment, pipes, insulation and electrical conduits, forming permanent parts of the completed structure.

The equipment empty weight shall be the weight of equipment, such as vessels, heat exchangers, stacks, pumps, piping, etc., supported by the structure.

Equipment weights shall be in accordance with the specification and/or drawings provided by vendors and manufacturers.

The lateral earth pressure shall not be considered as dead load.

Actual loads due to roof-mounted HVAC equipment must be applied on the buildings.

The specific gravity of materials shall be based on Iranian National building code part 6 where applicable.

5.1.1 Density of Material

For soil and basic construction materials, the following values shall be assumed, unless an exact evaluation is made:

- Density of soil shall be taken from soil report
- Density of reinforced concrete 2500 kg/m3
- Density of plain concrete 2400 kg/m3
- Density of structural steel 7850 kg/m3

5.1.2 EQUIPMENT LOADS

Equipment empty loads shall be the weight of empty equipment, machinery and pipes supported by the structure.

Equipment operation loads shall be the weight of equipment, machinery and pipes supported by the structure including the weight of contents (liquid, gas, etc.) during operation. The operation load of pipes on pipe racks shall be the actual loads but not less than 200 kg/m2 for longitudinal pipes and 100 kg/m2 for transverse pipes. The cable load on cable trays and electrical raceways shall be taken as 70 kg/m2 per row.

Equipment test load shall be the weight of equipment, machinery and pipes supported by the structure including the weight of water content during test. If the testing procedure allows no concurrent testing of various equipment which supported by the structure, the worst possible combination of full and empty equipment loads shall be used in design.

5.2 LIVE LOAD

Live Load shall be defined as the weight of all movable loads, including personnel, tools, miscellaneous equipment, cranes, hoists, parts of dismantled equipment, and temporarily stored materials.

Generally where applicable, the live loads shall be in accordance with INBC-6, except otherwise stated in this Design Basis.

The live loads shall be considered as uniformly distributed over the horizontal projection of the loaded areas, except for the loads with a concentrated nature.

The following minimum live loads shall be considered:

5.2.1 Pitched Light Weight Roofs

- For roofs with a slope more than 10°, a concentrated load of 100 kg at any point of the roof, wherever is critical.
- For roofs with a slope of equal or less than 10°, uniformly distributed load of 100 kg/m2 or a concentrated load of 100 kg at any point of the roof, whichever is critical.

5.2.2 Flat Roofs

- For flat roofs, uniformly distributed load of 150 kg/m2 or a concentrated load of 100 kg at any point of the roof, whichever is critical.

5.2.3 Platforms

- **Storage Areas**

Uniformly distributed load of 600 kg/m2 for light and 1200 kg/m2 for heavy storage areas or a concentrated load of 900 kg at any point over the platform, whichever is critical (or as recommended by VENDOR/SUPPLIRER).

- **Operating / Maintenance Platforms or Structures**

Uniformly distributed load of 500 kg/m2 or a concentrated load of 900 kg at any point over the platform, whichever is critical.

- **Access Platforms and Walkways**

Uniformly distributed load of 250 kg/m2 or a concentrated load of 500 kg at any point, whichever is critical.

- **Ramps and Landings**

Uniformly distributed or a concentrated load equal to those of the platform.

- **Stairs**

Uniformly distributed load of 350 kg/m2, or Equivalent to relevant platform whichever is greater.

- **Pipe supports and Pipe racks**

One concentrated load of 100 kg at mid-span or two concentrated loads of each 100 kg at quarter points along the span or as specified by piping analysis, whichever is greater.

- **Garages and Parking**

Loads should be determined in accordance with INBC–6.

5.2.4 LATERAL LOADS ON HANDRAILS

Lateral loads on handrails: stairway and balcony railings, both external and internal, should be designed to resist a horizontal thrust of 75Kg per meter, applied perpendicularly to the top railing.

5.3 WIND LOAD

Wind loads on structures shall be calculated according to the Iranian National building code part 6.

According to above code, wind speed shall be considered as V=120 km/h.

5.4 EARTHQUAKE LOADS

Seismic load is defined as the horizontal and vertical forces equivalent in their design effect to the loads induced by ground motion during an earthquake.

- Earthquake design load shall be in accordance Iranian Code of Practice for Seismic Resistant Design of Building (2800-4th Edition)
- Seismic parameters would be specified according to the soil investigation report.

5.5 THERMAL LOADS

Thermal loads are those forces caused by a change in temperature. Such forces shall include those caused by vessel or piping expansion or contraction.

Forces caused by vessel or piping expansion or contraction shall be defined as those required to overcome the static friction between two surfaces in contact and one liable to sliding over the other, and shall be termed as friction forces.

The friction forces applied on the pipe racks and pipe supports shall be taken as per piping discipline instructions, otherwise as described hereinafter. Such friction forces shall be considered both in the longitudinal and transverse direction independently.

Other piping thermal loads including the loads at anchor and guide supports and piping loads including thrust loads are considered in structural design as per requirements of piping discipline. Any required increase in piping loads at junctions and crossings on pipe racks will also be as per piping discipline's instructions.

5.6 SNOW LOAD

In accordance with Iranian National building code part 6, distributed load as 0.25KPa is considered for this subject.

5.7 IMPACT LOAD

Impact load shall be defined as an equivalent static force caused by a moving object.

For structures supporting live loads which induce impact, the assumed live load shall be increased sufficiently to provide for the impact. If not specified, the increase shall be as follows:

Elevator supports	100%
Traveling crane supports	25%
Monorail supports	25%
Reciprocating machinery supports	50%
Rotary machinery supports	50%
Davits	50%
Hangers supporting floors And balconies	33%

Live load stresses produced by traffic vehicles loadings shall be increased to allow for dynamic, vibratory and impact effects .The amount of the impact increment is expressed as a fraction of live load stress, maximum impact fraction 30% for vehicles shall be considered.

The lateral impact loads and crane runway horizontal forces shall be as follows:

- **Crane Runway**

  The transverse or lateral force shall be 20% of the sum of the weights of the lifted load plus crane trolley and hoist (be exclusive of the other parts of the crane). The force shall

  be assumed to be applied at top of the rail, one-half on each side of the runway and shall be considered as acting in either direction normal to the runway rail. The longitudinal force shall be taken as 10% of the maximum wheel loads of the crane applied at the top of the rail and acting in either direction.

- **Monorails**

  The transverse or lateral force shall be 20% of the weight of the lifted load. The longitudinal force shall be 10% of the sum of the weights of the lifted load, the crane trolley and hoist. The transverse and longitudinal forces shall be considered as acting in either direction.

- **Davits**

  Davits shall be designed to withstand a lateral force of 20% of the weight of the lifted load. Transverse and longitudinal impact forces shall not be assumed to act simultaneously.

- **Handrails**

Handrails for stairs, platforms or other uses shall be designed to withstand a uniformly distributed lateral load of 75 kg/m or a concentrated load of 150 kg at any point whichever is critical and shall be applied at the top of the rail, the regulations of INBC–6 shall be also checked.

5.8 OPERATING LOAD

Operating Load shall be the weight of any liquids or solids present within the vessels, equipment and/or piping during normal operation including the weight of all permanently stored materials for operating on vessels/structures according to general arrangement drawings.

5.9 TEST LOAD

Test Load shall be defined as the weight of any liquid necessary to pressure-test vessels, equipment or piping.

5.10 VIBRATION LOAD

Vibration loads are those dynamic forces which are caused by vibrating machineries such as pumps, compressors, blowers, turbo-generators, fans and other similar machineries. Surge forces similar to those acting in fluid cokers, hydroformers and crackers shall also be included. All supports and foundations for vibrating equipment shall be designed to limit vibrations to an acceptable level based on recognized amplitude/ frequency curves.

5.11 ERECTION LOAD

Erection loads are temporary forces caused by erection of structures and/or equipment.

5.12 MAINTENANCE LOAD

Maintenance loads are temporary forces caused by dismantling, repair or painting of equipment. Such forces shall include the bundle-pull force of heat exchangers.

Supports for heat exchangers shall be designed to withstand a longitudinal bundle-pull force equal to 0.7 of the tube-bundle weight or 1000 kg, whichever is greater. The shear force due to bundle pulling shall be assumed to be transmitted solely through the fixed support.

5.13 FRICTION LOAD

Friction loads due to thermal expansion of pipes, vessels, heat exchangers, fired equipment's and ducts shall be taken into account. The following coefficients of static friction shall be used to determine forces at sliding surfaces:

- Teflon on Teflon = 0.1
- Teflon on stainless Steel = 0.1
- Steel on Steel = 0.3
- Steel on Concrete = 0.4

On Piperacks and Pipe Supports with 4 or more lines the friction force shall be taken as 10% of the total Pipe weight tributary to that Piperack or Pipe Support, under operating condition.

On Piperacks and Pipe Supports with 3 or less lines the friction force shall be taken as 20% of the total Pipe weight tributary to that Piperack or Pipe Support, under operating conditions.

6.0 LOADING COMBINATIONS

Foundations, structures and members of structures as well as their support and connections shall be designed for the most severe loading combination given in below Table. This table also shows abbreviations for each load.

Operating and test load and empty weight of vessels and equipment's are considered as dead load in load combinations.

Load Combinations A to E

LOAD	LOAD DESCRIPTION	A		B	C	D	E
		OPERATION		TEST	ERECTION	EARTH-QUAKE	MAINTENANCE
		Without wind	With wind				
DL	Weight of Structure	x	x	x	x	x	x
DLempty	Empty Weight of Vessels and Equipment	x	x (1)	x	x	x	x
Test	Hydrostatic Test Load			x			
LL	Live Load	x	x	x	x	x	x
IMP	Impact Load	x		x	x		x
LLop	Operating Load	x	x (1)			x	
LL_{move}	Moving/Truck Load	x		x	x		x
WL	Wind Load		x	x (3,4)	x (4)		x (3)
EQ	Seismic Load					x	
DY(5)	Dynamic Load	x	x	x (2)		x	
TL	Thermal Load	x	x			x	---
FR	Friction Load	x	x				
ER	Erection Load				x		
ML	Maintenance Load						x
DS	Differential Settlement	x	x	x		x	x
HY	Earth/Water Pressure	x	x	x	x	x	x
BP	Bundle pull						x
TLst	Temperature Load	x					

1) The most unfavorable load shall be taken into account.
2) Only if the structure supports rotating equipment that will be in operation while a vessel is being tested with water.
3) Only 25 percent wind load shall be taken into account.
4) The effect of wind forces acting on temporary scaffolding erected during construction, or later for maintenance, which will be transferred to the vessel or column shall be considered. When considering these effects, the actual projected area of the scaffold members together with the correct shape factor and drag coefficient shall be used. As an initial approximation, the overall width of the scaffolding itself can be taken as 1.5 m on each side of the vessel or column with 50 percent closed surface and shape factor 1.0.
5) Equivalent static load shall be taken into account.

Allowable Stress Design:

Category		Load Combination
Category A	Operation Without Wind	1.0(DL+ DLempty + LLop)
		1.0(DL+ DLempty + LLop + LL + TL ± TLst ± FR)
		1.0(DL+ DLempty + LLop + TL ± TLst ± FR) + 0.75LL + 0.75S
	Operation With Wind	1.0(DL+ DLempty + LLop + TL ± FR) ± WL
		1.0(DL+ DLempty + LLop + TL ± FR) + 0.75LL ± 0.75WL
		1.0(DL+ DLempty + LLop + TL ± FR) + 0.75LL ± 0.75WL + 0.75S
		0.6(DL+ DLempty + LLop+TL + FR) ± WL
Category B	Test	1.0(DL+ DLempty + Test) ± 0.25WL
		1.0(DL+ DLempty + Test) + 0.75LL ± 0.25WL + 0.75S
		0.6(DL+ DLempty + Test) ± 0.25WL
Category C	Erection	1.0(DL+ DLempty + ER ± WL)
		1.0(DL+ DLempty + ER) + 0.75LL ± 0.75WL
		0.6(DL+ DLempty + ER) ± WL
Category D	Earthquake	1.0(DL+ DLempty + LLop + TL) ± 0.7EQ
		1.0(DL+ DLempty + LLop + TL) ± 0.525EQ + 0.75LL + 0.75S
		0.6(DL+ DLempty + LLop+ TL) ± 0.7EQ
Category E	Maintenance	1.0(DL+ DLempty + ML)
		1.0(DL+ DLempty+ ML) + 0.75LL ± 0.25WL
		0.6(DL+ DLempty+ ML) ± 0.25WL

Strength Design:

Category		Load Combination
Category A	Operation Without Wind	1.4(DL+ DLempty + LLop)
		1.2(DL+ DLempty + LLop ± FR + TL ± TLst) +1.6LL
		1.2(DL+ DLempty + LLop ± FR + TL ± TLst) +1.6LL + 0.5S
	Operation With Wind	1.2(DL+ DLempty + LLop ± FR + TL) + 1.0LL ± 1.6WL + 0.5S
		1.2(DL+ DLempty + LLop ± FR + TL) ± 0.8WL + 1.6S
		0.9(DL+ DLempty + LLop ± FR + TL) ± 1.6WL
Category B	Test	1.2(DL+ DLempty + Test) + 1.0LL ± 1.6(0.25WL) + 0.5S
		1.2(DL+ DLempty + Test) + 1.6LL + 0.5S
		0.9(DL+ DLempty + Test) ± 1.6(0.25WL)
Category C	Erection	1.2(DL+ DLempty + ER) + 1.6LL
		1.2(DL+ DLempty + ER) + 1.0LL ± 0.8WL
		0.9(DL+ DLempty + ER) ± 1.6WL
Category D	Earthquake	1.2(DL+ DLempty + LLop + TL) + 1.0LL ± 1.0EQ + 0.2S
		0.9(DL+ DLempty + LLop+ TL) ± 1.0EQ
Category E	Maintenance	1.2(DL+ DLempty + ML) + 1.0LL ± 1.6(0.25WL)
		1.2(DL+ DLempty + ML) + 1.6(LL)
		0.9(DL+ DLempty+ ML) ± 1.6(0.25WL)

7.0 ALLOWABLE STRESSES

The design allowable stresses for steel, concrete, and masonry structures shall be in accordance with relevant codes specified in clause 3.2.

7.1 VERTICAL DEFLECTION

7.1.1 Steel Structures

In cases in which a structural element is loaded by special equipment and similar, the limitations on deflections shall be given by the responsible person/party that is supplying it.

Item	Allowable Deflection
1-purlin and girt of sloped roofs	L/200
2-floor beams supporting equipment for natural operating load *	L/400
3-piperack beams for normal operating load	L/300
4-Crane's runway beams (vertical due to max. wheel loads):	
Monorail /Hoist Beams	L/600
Electric crane of 60m/min. and below in travelling speed	L/600
Electric crane of 90m/min. and below in travelling speed	L/800
Electric crane of above 90m/min in travelling speed	L/1000
5-Cantilever Beams with no equipment	L/150
6-Cantilever Beams with equipment	L/300
7- Beams with live loads only	L/360
8- Beams with Live plus Dead loads	L/240

* provided that manufacturer's recommendations are not violated Where L is the beam span.

7.2 HORIZONTAL DISPLACEMENT

The lateral displacements due to load combinations including wind or seismic loads shall not exceed the following:

- Pipe racks h/180
- Equipment structures h/180
- Occupied buildings h/200
- Un-reinforced masonry buildings h/400

Where 'h' is the height of the pipe racks, structures or buildings.

7.3 FOUNDATION SETTLEMENT

Allowable settlements, due to permanent loads are shown in the following table:

FOUNDATION TYPE	MAXIMUM TOTAL SETTLEMENT	MAXIMUM DIFFERENTIAL SETTLEMENT
Towers and vertical equipment	25 mm	Deviation from vertical line due to differential settlement shall not exceed 0.2%
Horizontal equipment	25 mm	15 mm
Vibrating machinery	10 mm	0
Process structures	25 mm	10 mm
Buildings	25 mm	15 mm
Buildings with Mat Foundation	65~100 mm	According to INBC Part-7 table 7.4.2

8.0 METHODS OF DESIGN

8.1 REINFORCED CONCRETE

Reinforced concrete buildings, foundations and other structures, except tanks for the storage of water shall be designed in accordance with ACI 318, Building Code Requirements for Reinforced Concrete.

Reinforced concrete tanks for the storage of water shall be designed in accordance with ACI 350.3 or BS 8007, "The Structural Use of Concrete for Retaining Aqueous Liquids".

Top of Grout elevation shall be min. 200 mm above Finished Grade level.

The following grades of concrete according to minimum compressive characteristic strength at 28 days (f'c) on cylinder specimen (ASTM C39) shall be used.

- Cast in place concrete f'c= 300 kg/cm2
- Precast concrete f'c= 300 kg/cm2
- Concrete Tanks & reservoirs f'c= 350 kg/cm2
- Foundations for vibrating machines f'c= 300 kg/cm2
- Lean concrete f'c= 150 kg/cm2
- Fire proofing concrete f'c= 250 kg/cm2
- Precast Concrete Pile f'c= 350 kg/cm2
- Paving and ditches f'c= 250 kg/cm2
- Catch basins and Manholes f'c= 250 kg/cm2
- Duct Banks f'c= 200 kg/cm2
- Plain Mass Concrete f'c= 200 kg/cm2

8.2 STRUCTURAL STEELWORK

Structural steelwork should be designed on load and resistance factor design (LRFD) with AISC Specifications.

Connections design shall be based on shop welding and field bolting unless otherwise noted. Field welding is permitted for secondary connections. No riveted connections are permitted.

The minimum thickness of all structural steel members except rolled I – Sections, Channels, Z-Profile, Pipes, Boxes and secondary members should be 6 mm.

Not less than two bolts are to be used in the end connections.

Anchor bolts for foundations shall be of plain mild steel bars with a minimum diameter of 16 mm, unless otherwise stated by the equipment Vendor, and for secondary members.

The thickness of gusset plates shall not be less than 8 mm.

8.3 STABILITY RATIO

The following minimum stability ratios against overturning shall be applied in the design of foundations for the project.

DESIGN CONDITION	STABILITY RATIO
Erection condition	1.5
Test condition	1.5
Operating condition	2
Shutdown condition	2
accidental condition	1

The minimum stability ratio against foundation sliding shall be 1.5 under all conditions, except 1 under accidental condition.

The resisting force against sliding shall be calculated with the value whichever is greater of the followings:

- (100 % friction force between soil and foundation) + (50%soil passive resistance)
- (50% friction force between soil and foundation) + (100%soil passive resistance)

The weight of the earth superimposed over the foundations may be included in the loads causing the resisting frictional force.

8.4 VIBRATING MACHINE FOUNDATIONS

Vibrating machines shall be defined as equipment having reciprocating or rotary masses, engines, pumps, compressors, turbines, generators and other similar equipment are included in these definitions.

A vibrating machine having a gross plan area of more than 30 sq. ft. (2.8 m2) or a total weight greater than 5000 lbs (2270 kg) shall be qualified as a heavy vibrating machine.

Foundations for heavy vibrating machines, reciprocating or centrifugal, shall be designed using a dynamic analysis based on the “Theory of Elastic Half-Space” in addition to static analysis, but the weight ratios and other requirements, as explained hereinafter shall also be satisfied.

Foundations for vibrating machines having a gross area less than 30 sq. ft. (2.8 m2) and a total weight less than 5000 lbs (2270 kg) and an operating speed greater than 1200 r.p.m. may be designed by weight ratio and static analysis, but the other requirements, as explained hereinafter shall also be satisfied.

Dynamic analysis may be dispensed if the mass of rotating elements is less than 1/100 of the mass of the whole system (machine + foundation).

8.4.1 Weight Ratios

- **Reciprocating machines**

The minimum weight of the foundation or pile cap for reciprocating machines shall be at least 5 times for foundation and 4 times for pile cap of the total weight of the machine, the base plate, and the driver and the reducing gear or as recommended by the Vendor, whichever is greater.

- **Centrifugal machines**

The minimum weight of the foundation or pile cap for centrifugal machines shall be at least 3 times the total weight of the machine, the base plate, the driver, and the reducing gear or as recommended by the Vendor, whichever is greater.

8.4.2 General Requirements for Vibrating Machine Foundations

Vibrating machine foundations, reciprocating or centrifugal, designed by static and/or dynamic analysis and proportioned by weight ratio shall also satisfy the following general requirements:

- The minimum thickness of foundation mat or the substructure for all foundations or pile caps shall be 500 mm or 1/10 of its maximum dimension, whichever is greater and should not be less than 1/5 of its minimum dimension.
- All parts of the vibrating machine foundations shall be independent of adjacent foundations.
- Joints with a minimum thickness of 15mm and filled with an approved elastic filler shall be provided between all floor slabs and machinery foundations.
- The minimum clear concrete cover to all reinforcing bars shall be 50 mm.
- The minimum distance between the edges of the foundation or pile cap and the edges of machine base plate or skid shall be 50 mm.
- The minimum distance between the edges of the foundation or pile cap and the centerline of the anchor bolts shall be 100 mm.
- The maximum soil bearing pressure under the foundations or pile forces of reciprocating and centrifugal machines in static case shall not exceed one-half of allowable soil bearing value or pile bearing capacity.
- The maximum soil bearing pressure under the foundations or pile forces of reciprocating and centrifugal machines should not exceed 75% of allowable soil bearing value or pile bearing capacity when static and dynamic loads are applied simultaneously.
- Foundations shall be so proportioned that the following conditions are satisfied:

- The width of the foundation mat or the dimension perpendicular to the crank shaft to be at least 1.5 times greater than the distance from the centerline of the shaft to the bottom of the foundation.
- For elevated foundations (table tops), the length of the foundation mat or the dimension parallel to the crank shaft to be approximately 600 mm (2.0 ft.) greater than the length of the columns supporting the upper deck.
- For elevated foundations (table tops), the width of the foundation mat or the dimension perpendicular to the crank shaft shall be at least 3/4 of the distance from centerline of the shaft to the bottom of the foundation.

For more requirements of the elevated foundations, shall be referred to good experience international references with prior approval of EMPLOYER/OWNER .

Foundations for machines that are qualified as heavy vibrating machines shall be so proportioned that the following conditions are also satisfied:

- The horizontal eccentricity, in any direction, between the centroid of the machine-foundation system and the base centroid of the base contact area shall not exceed 5% of the respective base dimension.
- The center of gravity of the machine-foundation system and the lines of action of the unbalance forces to be as close as possible.
- The total peak to peak amplitude shall comply with the Vendor's recommendation or good experience international references with prior approval of EMPLOYER/OWNER.

The depth of all heavy foundations should be at least one meter below the lowest adjacent final natural grade.

8.4.3 Reciprocating Machines

The static analysis shall take into account the following loads and forces:

- The total weight of the machine, the base plate and the driver and reducing gear.
- The total weight of the foundation or pile cap.
- Earthquake forces or possible live loads.
- Unbalanced forces and couples shall be applied as specified by the Vendor.

The dynamic analysis shall take into account the following loads and forces:

- The lumped mass which shall take into account the following loads and the soil above the foundation mat or pile cap.
- All primary unbalanced forces, couples and moments at specified operating speeds for calculation of the primary amplitudes.
- All secondary unbalanced forces, couples and moments at twice the specified operating speed(s) for calculation of the secondary amplitudes.

8.4.4 Centrifugal Machines

The static analysis shall take into account the following loads and forces:

- The total weight of the machine, the base plate, the driver, and the reducing gear.
- The total weight of the foundation or pile cap.

- Earthquake forces or possible live loads.
- Lateral forces representing 25% of the weight of each machine, including the base plate, applied normal to its shaft at a point midway between its bearings.
- Longitudinal forces representing 25% of the weight of each machine, including its base plate, applied along the axis of the shaft.
- The total lateral and longitudinal forces shall not be considered to act concurrently.
- Short circuit load, as specified by the Vendor. This load shall be assumed not to act concurrently with lateral and longitudinal forces as mentioned above, and may be neglected as an overturning couple.

The dynamic analysis shall take into account the following loads and forces:

- The lumped mass which shall include only the machines, the foundation and the soil above the foundation mat or pile cap.
- Dynamic forces from each rotor can be calculated by the following equation, to determine maximum amplitudes:

  Dynamic force = Wr . Sr /6000

  Where:

  Wr = Weight of the rotor

  Sr = Speed of the rotor (r.p.m.)

- Dynamic forces shall be transversely applied to the shaft midway between the bearings.
- When dynamic forces furnished by the Vendor are greater than those calculated by the above equation, the Vendor forces shall be used.

8.4.5 Frequency Ratios

For heavy vibrating machines, reciprocating or centrifugal, the ratio of natural frequencies to disturbing frequencies shall be kept below 0.7 or greater than 1.4, but if is not possible, the effects of damping shall be considered.

For vibrating machines, reciprocating or centrifugal, which do not qualify as a heavy vibrating machine, the ratio of natural frequencies will be estimated using formulas recommended by good experience international references with the approval of the EMPLOYER/OWNER.