

DEP SPECIFICATION

DESIGN OF BUILDINGS - ONSHORE

DEP 34.17.10.32-Gen.

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DESIGN AND ENGINEERING PRACTICE

DEM1



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PREFACE

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These views are based on the experience acquired during involvement with the design, construction, operation and maintenance of processing units and facilities. Where deemed appropriate DEPs are based on, or reference international, regional, national and industry standards.

The objective is to set the standard for good design and engineering practice to be applied by Shell companies in oil and gas production, oil refining, gas handling, gasification, chemical processing, or any other such facility, and thereby to help achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to Shell companies for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual Operating Units to adapt the information set forth in DEPs to their own environment and requirements.

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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the design and engineering of new buildings in oil refineries, gas plants, chemical plants, power generation plants, utility plants, onshore exploration and production facilities and, supply/marketing installations.

This new DEP combines and replaces the following two DEPs:

- DEP 34.17.00.32-Gen. Design and engineering of buildings;
- DEP 34.17.10.30-Gen. Design of blast resistant onshore buildings, control rooms and field auxiliary rooms

DEP 80.00.10.11-Gen. defines when a building needs to be designed to resist blast loads.

The requirements for human factors engineering are defined in DEP 30.00.60.20-Gen.

Additional requirements for specific buildings are specified in the following documents:

Control Rooms	DEP 30.00.60.15-Gen.
Analyser houses	DEP 32.31.50.13-Gen.
	Standard Drawing S 17.001
	Standard Drawing S 17.002
Fire stations	DEP 80.47.10.33-Gen.
Laboratories	DEP 34.17.10.31-Gen.
Substations and switch houses	DEP 33.64.10.10-Gen.
	Standard Drawing S 68.040
Workshops	DEP 70.08.10.11-Gen.
	DEP 70.08.10.13-Gen.

This DEP is not applicable for buildings on offshore facilities.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 - Application of Technical Standards.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorisation to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local

regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

1.3.2 Specific definitions

Term	Definition
Blast Load	Load generated by an explosion.
Blast Resistant	Describes those structures or structural components which are designed for, or verified to withstand, the design blast loads.
Blast Wave	A transient change in the gas density, pressure and velocity of the air surrounding an explosion.
Ductility Ratio	A measure of the energy absorbing capacity of a structural member/element. The ratio is defined as the element's maximum deformation divided by its yield deformation.
Duration	The time from initial change in pressure to return to ambient pressure.
Dynamic Increase Factor	The ratio of dynamic to static strength that is used to compute the effect of a rapidly applied load to the strength of a structural element.
Free Field	Air or ground blast waves that are unimpeded by obstructions in the path of the wave.
Impulse	The integrated area under the over-pressure time curve.
Linear	A response limited to the elastic range
Non-linear	A response which includes the elastic-plastic and/or plastic ranges.
Non-Plant Building	Generic term for buildings not related to plant process operating activities, e.g., administration building/office, training centre, canteen, warehouse, workshop, chemical store, laboratory, gate/guard house, security office or fire station.

Term	Definition
Occupied building	Building that personnel occupy while doing a major part of their work, such as control rooms, laboratories, office buildings, maintenance work areas, outside operator buildings, etc.; or a building with a primary purpose that necessitates people to occupy it, such as field labs, lunch rooms, locker facilities used to change clothes, showers, restrooms or toilets (lightweight plastic porta-toilets are excluded from this definition), etc. Other buildings that have a primary purpose to house or store equipment or materials are considered an "occupied building" if an individual spends on average 10 hours or more a week inside the building, 10 or more people are in the building at any given time, or a group spends an average of 200 hours or more a week inside the building. Observation shelters provided for weather protection for the marine, road, or rail loading operator may, in consultation with the Principal's relevant Technical Authority, be excluded from the definition of an occupied building. By nature, such buildings are small and require a large amount of window area to satisfy operational safety requirements with the loading operations. For the purpose of this DEP, the requirements for occupied buildings also apply to those buildings containing safety critical equipment
Over-pressure	Pressure rise above ambient produced by a shock wave or pressure wave
Peak Side-on Over-Pressure	Initial peak pressure rise, above ambient, produced by a shock wave or a pressure wave as felt by a flat surface orientated parallel to the direction of wave propagation.
Plant Building	Generic term for control building (including plant laboratory), field auxiliary room, analyser house, electrical substation, compressor building or other related buildings for plant process operating activities.
Positive Phase	The portion of the pressure time history where the pressure is above ambient pressure.
Pressure Wave	A blast wave that produces a gradual rise in pressure.
Process Risk Tool (PRT)	A tool to assess vapour explosions risk at petrochemical processing facilities, e.g. SHEPHERD.
Reflected Over-Pressure	The rise in pressure produced by a shock wave or a pressure wave as felt by a flat surface oriented perpendicular to the direction of wave propagation.
Resistance-Deflection Function	The value of the stress in a structural element as the deformation is increased from zero through the elastic range, the elastic-plastic range, ultimate capacity, and finally to failure of the element.
Safety Glass	laminated glass planes with intermediate layer of polymer that prevents the glass from shattering in case of impact
Shock Wave	A blast wave that produced a near instantaneous rise in pressure.

Term	Definition
Sideways	The lateral movement of a structure due to vertical or horizontal loads.
Strain Rate	The speed at which a load is applied to material. The higher the strain rate, the higher the observed material strength.
Strength Increase Factor	The ratio of actual to nominal strength of a material. This factor takes into account conservatism in the manufacturing process.
Support Rotation	A measure of the blast absorbing capacity of a structural element. This is the same as hinge rotation except that the angle is computed at the member's support location.
Ultimate Capacity	The load applied to a structural element as the final plastic hinge, or collapse mechanism, is formed.
Ultimate Strength	A method of design in which structural members are proportioned by total section capacities rather than by extreme fibre allowable stresses.
Very toxic (substances)	Substances that are very hazardous for the environment or human health. "Toxic" substances are classified as such in databases such as the European Chemical Substances Information System (ESIS) and the Globally Harmonised System of Classification and Labelling (GHS). This DEP further classifies very toxic substances as "very toxic - acute", "very toxic - chronic" and "very toxic - environment". Where a substance has been deemed "very toxic acute" on the basis of the definitions in (4) of this document, there may be over conservativeness in specifying equipment if the classification has been reached as a result of R34, R35 (causes (severe) burns) or H314/H318 (causes severe skin burns and eye damage). .

1.3.3 Abbreviations

Term	Definition
CFR	Combustion Fuel Reference
DIF	Dynamic Increase Factor
FAR	Field Auxiliary Room
HVAC	Heating, Ventilation and Air Conditioning
ITP	Standard Inspection and Test Plans
MCT	Multi Cable Transit
MDOF	Multi Degree Of Freedom
PI	Pressure Impulse
PRT	Process Risk Tool

Term	Definition
PVB	Polyvinyl-Butyral
QCR	Quality Control Records
SDOF	Single Degree Of Freedom
SIF	Strength Increase Factor
WC	Water Closet, toilet, bathroom

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets (). Other documents referenced by this DEP are listed in (15).

1.5 SUMMARY OF MAIN CHANGES

This is a new DEP.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://swwww.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. LOCATION CONSIDERATIONS

1. Refer to DEP 80.00.10.11-Gen. for requirements related to the siting of buildings.

These requirements specify when a building needs to be designed to resist blast loads.

3. LAYOUT OF BUILDINGS

3.1 GENERAL

1. Batteries for emergency power supply shall not be located under wash and toilet areas on the floor above.
2. Batteries for emergency power supply shall be located in separate rooms with dedicated separate exhaust facilities.
3. The spaces provided for mechanical equipment, instrument and computer equipment shall have sufficient free working space for maintenance.
4. When smoking areas are included in the building, areas shall be classified as either smoking-free areas or smoking permitted areas:
 - a. Signs posted outside each entrance to a smoking permitted area shall indicate "Smoking Permitted Area".

All other areas are smoke-free areas and do not require signs.
 - b. Smoking permitted areas shall have dedicated air extraction systems.
5. For horizontal access clearances, refer to DEP 30.00.60.20-Gen.

3.2 LAYOUT OF THE CONTROL BUILDING

3.2.1 General

1. For requirements related to layout and design of the control room, refer to DEP 30.00.60.15-Gen.
2. The main laboratory (as defined in DEP 34.17.10.31-Gen.) shall not be part of the control building.
 - a. The main laboratory shall be located in an area remote from the process plants close to the administration area.
3. The control building may be designed to include a basement if sufficient space is not available.
 - a. All utilities and E/I equipment should be located in the basement.

3.2.2 Computer room

1. A separate room for the accommodation of process computers shall be incorporated in the control building.
2. The computer room shall not be located in a basement (if provided).
3. The computer room shall not be located adjacent to rooms with equipment which could cause electrical interference, such as rotating electrical machinery, transformers or electrical switchgear, unless precautions have been taken to safeguard the proper functioning of the computer equipment.

3.2.3 Electrical equipment and battery room

1. Equipment shall not be installed against external walls unless sufficient space is provided between the equipment and the external wall to allow for designed wall deflections under blast loading.

2. For location of batteries for emergency power supply, see DEP 33.64.10.10-Gen. section 6.1.3.4.

3.2.4 HVAC machine room

1. The entrance to the machine room should be located so that the HVAC maintenance personnel can reach the machine room without having to pass through the instrument, computer or electrical areas.

3.2.5 First-aid compartment/HSSE office

1. A closet compartment shall be provided in the control building for first aid equipment.
2. Local medical policy shall be consulted to determine what is to be provided in the first aid kit.
 - a. The compartment space shall be sized for spare safety equipment such as helmets, gloves and spectacles, and a collapsible stretcher for the transport of injured personnel.
3. Cabinets for portable breathing apparatus shall be installed inside the control building, at the exits, for immediate use should the need arise.

3.2.6 Interconnections

1. There shall be no direct connection between the control room and the other rooms in the building by direct doors, by slots in walls, or via the drainage system with exception of the following rooms:
 - a. Office (for shift supervisor);
 - b. Mess room;
 - c. Computer auxiliary room (computer office).
2. All rooms not in direct connection should be connected with the control room and its basement via air locks or corridors (with at least 2 doors to pass).
3. The plant laboratory (per DEP 34.17.10.31-Gen.), where provided in the control building, shall be designed and located as to prevent gases from entering the control room, offices or other occupied areas of the building.
 - a. Refer to Section 3 of DEP 34.17.10.31-Gen. for the layout requirements for plant laboratories.

3.3 LAYOUT OF THE FIELD AUXILIARY ROOM (FAR)

1. The FAR should be designed as unoccupied without offices or amenities.

FAR buildings are normally unmanned.
2. Sufficient space shall be provided around the process control and safeguarding equipment to allow for its installation, inspection and maintenance.

3.4 LAYOUT OF LOCKER ROOMS

1. Two lockers for each shift worker shall be provided.
 - a. Typical dimensions should be 300 mm to 350 mm (12 in - 14 in) wide, 500 mm to 550 mm (1 ft 8 in - 22 in) deep, and 1800 mm to 2000 mm (6 ft - 6 ft 8 in) high.
 - b. The internal top hanger rack/shelf should be height-adjustable and not more than 1700mm (rest of world) or 1800mm (US/EU regions) from the finished floor surface in front of locker.
 - c. Lockers should be raised above finished floor level by a steel support frame or plinth.
2. The lockers shall have natural ventilation.

3. The area above the lockers shall be in accordance with one of the following to prevent accumulation of dirt and placing of items on top of the lockers:
 - a. be fully enclosed;
 - b. have a sloping steel cap.
4. Seating shall be provided by either in bench seating integrated with and front of the lockers or by island bench seating.

3.5 LAYOUT OF ELECTRICAL SUBSTATIONS AND ANALYSER HOUSES

1. The layout of electrical substations should follow the Standard Drawing S 68.040.
2. The layout of analyser houses should follow the Standard Drawings S 17.001 and S 17.002.
3. Modular analyser houses and electrical substations may be utilised.

3.6 LAYOUT OF WAREHOUSES

3.6.1 Emergency exits

1. Emergency exits other than those afforded by the main doors shall be provided to meet the requirements in (10.1, Item 5).
2. Escape should be possible from any enclosed area in at least two directions.
3. Emergency exits should be clearly marked with exit sign lighting and provided with panic bars.

3.6.2 Other accommodation

1. There should be no offices, mess rooms or changing rooms built as an integral part of warehouses that contain hazardous materials.
2. Where there are offices, mess rooms or changing rooms within a warehouse holding flammable materials, they shall be separated from the warehouse by fire walls and self-closing fire doors, both with a minimum fire resistance of 90 minutes.

3.6.3 Handling facilities

1. The design should take into account whether stock is to be manually or mechanically handled.
2. Where large drums are to be manually handled, warehouses should be constructed so that the height of the loading area is at the height of the vehicle bed.
3. A covered loading bay shall be provided to facilitate loading operations in wet weather.
4. Marked walkways shall be provided to segregate pedestrians from vehicles.
5. Physical barriers should be provided to segregate pedestrians from vehicles where it is practical to do so.
6. Warehouses containing toxic materials, chemicals and hydrocarbons shall be provided with a 250mm high bund wall at the edge of the building to contain spillages and retain contaminated firefighting water.
 - a. No drainage shall be provided within this bund.

4. DESIGN LOADS

4.1 GENERAL

1. New buildings shall be designed to resist the minimum loads defined in accordance with applicable local design codes, standards, regulations, the actual loading situation and government requirements.

2. In the absence of local building codes, the design loads in (Appendix E) shall be used.
3. Any requirements for gas tightness (gas proof) and thermal radiation loads shall be determined through consultation with the Principal's technical safety specialist and reference to DEP 80.00.10.11-Gen.

4.2 DESIGN BLAST LOADS

1. When a building needs to be designed to resist blast loads, refer to DEP 80.00.10.11-Gen. for applicable requirements.
2. The design blast loads (specified in free field) SHALL [PS] be based on a blast pressure and blast duration corresponding to the 1/10,000 year frequency (1E-4) as calculated by the Process Risk Tool (PRT) or equivalent risk assessment approved by Principal's designated Technical Authority (TA-2).
3. The following parameters shall be used to define the blast load:
 - a. Peak side-on positive over-pressure, positive phase duration, rise time and the corresponding positive impulse.
 - b. Peak side-on negative pressure, negative phase duration and the corresponding negative impulse.

*This will result in essentially the same impulse, but in the negative direction.
The negative pressures are generally ignored because they are relatively small or are difficult to quantify.*
4. The design of the structural components of the building shall allow for the rebound effects.

Directional requirements of the blast load are specified in (6.1).
5. The following shall be applied to buildings that are to be designed as blast resistant:
 - a. Fragment or projectile impacts do not need to be included in the design.
 - b. Thermal radiation does not need to be included in the design provided either the safety distances detailed in DEP 80.00.10.11-Gen. are met or it is demonstrated not to be required by a risk assessment approved by the Principal.
6. When potential blast pressure is > 65 kPa (> 9.43 psi), the Principal shall be consulted for added guidelines or requirements.

5. GENERAL DESIGN CONSIDERATIONS FOR BLAST RESISTANT BUILDINGS

5.1 CONFIGURATION OF BLAST RESISTANT BUILDINGS

1. Blast resistant buildings should be as compact as possible, rectangular in shape without re-entrant angles or protruding canopies.
2. The roof shall have a maximum pitch of 10°.
3. The overall height of the building and the flat span of the roof should be minimized to limit the effects of an explosion.
4. Roofs shall not be covered with objects that could become flying hazards in the event of an explosion (e.g., gravel or loose concrete tiles).
5. Foundations or floor slabs shall not be elevated above ground level or include a ventilated air space under them.
6. Air-conditioning units should be located either outside the building at ground level or inside the building.
7. Control buildings designed to resist blast loads should only be sized to accommodate the personnel and equipment required for the safe and reliable operation of the plant.

8. Control buildings designed to resist blast loads should be built as a one-story building.
9. FARs designed to resist blast loads should be built as a one-story building without a basement or windows.

6. STRUCTURAL DESIGN OF BLAST RESISTANT BUILDINGS

6.1 DESIGN METHODS AND PROCEDURES

1. Blast resistant buildings and their structural components SHALL [PS] be designed using the methods provided in ASCE 41088 "Design of Blast Resistant Buildings in Petrochemical Facilities" and meet the following two requirements:
 - a. The selected analysis method models the dynamic response of the structure to the applied blast loads and the structural component interaction;
 - b. Not to use the equivalent static method.
2. Doors, windows and other items filling openings in the structure shall be designed for the same blast load as the wall or roof they are set in.
3. The blast load shall be applied to the building for a minimum of two separate cases with the blast direction being perpendicular and then parallel to one face of the building.
 - a. This requirement may be relaxed where the layout of the building in relation to the blast sources enables a more economic design if the blast loads are considered only from one direction, subject to the following:
 - i. Relaxation is agreed with the Principal.
 - ii. Limitations in the blast design are recorded in the design documentation and in the Principal's PRT model.
 - iii. Major Hazard Management specialists are consulted when calculating the risk levels for the building.
4. For a Single Degree-of-Freedom (SDOF) analysis, the following shall apply:
 - a. The required resistance for each structural component shall be determined by the peak blast pressure (or load) and duration, the natural period of the component, and the maximum allowable response (deformation).
 - b. A SDOF analysis may be used where the connected component differs in natural period by a factor of 2 or more.
 - c. The formulas and charts provided in ASCE 41088 for the approximate solution of the elastic-plastic SDOF system may be used in determining the required resistance.
5. For a Multi Degree-of-Freedom (MDOF) analysis, the following shall apply
 - a. A MDOF analysis shall be used where the structural component interaction cannot be adequately modelled using SDOF methods.
 - b. The MDOF method shall include finite element analysis, requiring the use of a special or general-purpose structural analysis computer program with non-linear transient dynamic analysis capability
6. The Contractor shall develop building damage level curves (PI curves) for blast resistant occupied buildings which have been designed to this DEP using the PI exceedance curve from the PRT analysis.

6.2 MATERIALS AND COMPONENT PROPERTIES

6.2.1 General

1. Brittle constructions, such as un-reinforced concrete, pre-stressed concrete, un-reinforced masonry (bricks or blocks) and cement based corrugated panels, SHALL [PS] not be used for load carrying components of blast resistant buildings.
2. Newly developed materials, such as composites, may be used if adequate test data is available to confirm their satisfactory performance for the intended application, and with the Principal's prior written approval.
 - a. Test data shall include the ultimate capacity and behaviour of the material under dynamic conditions representative of the design blast loading.

Performance under seismic conditions below ultimate strength is not sufficient to indicate blast load resistance capacity.

3. Reinforced concrete or fully grouted reinforced masonry of appropriate strength and thickness should be used as external wall construction in special cases where fragment or projectile impact resistance is specifically required; (see 4.2, item 5).
4. Occupied buildings subject to very toxic (acute and chronic) gas clouds exposure SHALL [PS] be designed and detailed to prevent gas entry from a plant emergency.

Homogeneous materials of construction (such as reinforced concrete) for the outer building shell are optimal.

6.2.2 Dynamic material strength

1. Dynamic yield stress, F_{dy} , shall be computed as Equation 1:

$$F_{dy} = F_y \times SIF \times DIF \quad \text{Equation 1}$$

Where:

F_y is the specified minimum static yield stress;

SIF is the strength increase factor as defined in (6.2.3);

DIF is the dynamic increase factor as defined in (6.2.4).

2. Dynamic design stress, F_{ds} , used to compute the dynamic capacity of structural components shall be as listed in Table 4 for structural steel and Table 5 for reinforcing steel.

3. Dynamic ultimate strength, F_{du} shall be computed as Equation 2:

$$F_{du} = F_u \times DIF \quad \text{Equation 2}$$

Where:

F_u is the specified ultimate strength.

DIF is the dynamic increase factor as defined in (6.2.4).

6.2.3 Strength Increase Factor (SIF)

1. A strength increase factor from Table 1 shall be applied to the specified minimum yield strength of structural materials to estimate the actual static value.

Table 1 Strength Increase Factors for Structural Materials

Structural Material	SIF
Structural Steel with a Yield of 355 MPa (51 ksi) or Less	1.1
Concrete Reinforcing Steel Hot rolled mild or high yield strength of 460 MPa (67 ksi) or less	1.1
Cold Formed Steel Cladding Panels (BS 5970) with yield strength of 460 MPa (67 ksi) or less	1.2
Concrete and Masonry	1.0
Other Materials	1.0

6.2.4 Dynamic Increase Factor (DIF)

- To account for strain rate effects caused by rapidly applied blast loads, dynamic increase factors shall be applied to the static material yield and ultimate strengths to determine their dynamic values in accordance with Table 2 and Table 3.

Table 2 Dynamic Increase Factors for Reinforced Concrete/Masonry

Stress Type	DIF			
	Reinforcing Bars		Concrete	Masonry
	(F_{dy}/F_y)	(F_{du}/F_u)	(f'_{dc}/f'_c)	(f'_{dm}/f'_m)
Flexure	1.17	1.05	1.19	1.19
Compression	1.10	1.00	1.12	1.12
Diagonal Tension	1.00	1.00	1.00	1.00
Direct Shear	1.10	1.00	1.10	1.00
Bond	1.17	1.05	1.00	1.00

Table 3 Dynamic Increase Factors for Steel and Aluminium

Material	DIF		
	Yield Stress		Ultimate
	Bending/Shear	Tension/compression	Stress
	(F_{dy}/F_y)	(F_{dy}/F_y)	(F_{du}/F_u)
EN 10025 or ASTM A36	1.29	1.19	1.10
EN 10025 or ASTM A588	1.19	1.12	1.05
Stainless Steel Type 304	1.18	1.15	1.00
ISO/TR 11069 Aluminium, 6061-T6	1.02	1.00	1.00

Table 4 Dynamic Design Stress for Structural Steel

Type of Stress	Maximum Ductility Ratio	Dynamic Design Stress (F_{ds})
All	$\mu < 10$	F_{dy}
All	$\mu > 10$	$F_{dy} + (F_{du} - F_{dy}) / 4$
F_{du} = dynamic ultimate strength; F_{dy} = dynamic yield stress		

Table 5 Dynamic Design Stress for Concrete Reinforcing Steel

Type of Stress	Type of Reinforcement	Maximum support Rotation (degrees)	Dynamic Design F_{ds}
Bending	Tension and Compression	$0 < \theta < 2$ $2 < \theta < 5$ $5 < \theta < 12$	F_{dy} $F_{dy} + (F_{du} - F_{dy})/4$ $(F_{dy} + F_{du})/2$
Direct Shear	Diagonal Bars	$0 < \theta < 2$ $2 < \theta < 5$ $5 < \theta < 12$	F_{dy} $F_{dy} + (F_{du} - F_{dy})/4$ $(F_{dy} + F_{du})/2$
Diagonal Tension	Stirrups	All	F_{dy}
Compression	Column	All	F_{dy}
F_{du} = dynamic ultimate strength; F_{dy} = dynamic yield stress; θ = support rotation (degrees)			

6.2.5 Response (deformation) range

Buildings that are subject to blast loading will respond (deform).

1. Structural members shall be designed for the maximum response (deformation) level defined in Table 6 consistent with the performance requirements or permissible damage level.
2. The maximum response for control rooms, FARs and occupied buildings SHALL [PS] not exceed the "Low" response in Table 6 and the limits provided in Table 7, Table 8 and Table 9 for structural steel, reinforced concrete, and reinforced masonry, respectively.
3. The "Medium" response in Table 6 may be used for substations and analyser houses.
4. The "High" response in Table 6 may be used for sheds and compressor houses.
5. Where "Medium" or "High" response in Table 6 is used, the response criteria (limits) shall be obtained from ASCE 41088 "Design of Blast Resistant Buildings in Petrochemical Facilities".

Table 6 Response Categories

Response	Description
Low	Localised building/component damage. Building is still capable to fulfil its functional requirements. Minor repair may be required. Total cost of repairs is of the order of 10% of replacement cost.
Medium	Widespread building/component damage. Building cannot fulfil its functional requirements until repaired. Total cost of repairs is up to 50% of replacement cost.
High	Building/component has lost structural integrity and cannot fulfil its functional requirements. It may collapse due to environmental conditions (e.g., wind, snow or rain). Total cost of repairs approach replacement cost of building.

Table 7 Low Response (Deformation) Limits for Structural Steel

Element Type	Ductility Ratio, μ_a	Support Rotation θ (degrees)
Beams, Girders, Purlins	3	2
Frame members ⁽¹⁾	1.5	1
Single Sheet Metal Panels	1.75	1.25
Open Web Joists	1	1
Plates	5	3
Notes: (1) Sideways deflection (δ) limits for steel frames: = $H/50$, (where H = story height)		

Table 8 Low Response (Deformation) Limits for Reinforced Concrete

Element Type	Controlling Stress	Ductility Ratio, μ_a	Support Rotation $\theta^{(2)}$ (degrees)
Beams	Flexure	N/A	1
	Shear: ⁽¹⁾		
	concrete only	1.3	
	concrete + stirrups	1.6	
	stirrups only	3.0	
	Compression	1.3	
Slabs	Flexure	N/A	2
	Shear ⁽¹⁾	1.3	
Beam-Columns	Flexure	N/A	1
	Compression	1.3	
	Tension ⁽³⁾		
	Shear ⁽¹⁾	1.3	
Shear Walls, Diaphragms	Flexure	3	1
	Shear ⁽¹⁾	1.5	
NOTES: (1) Shear controls when shear resistance is less than 120 % of flexural resistance.			
(2) Stirrups are required for support rotations greater than 2 degrees.			
(3) Ductility ratio = $0.05 (\rho - \rho')$, where ρ and ρ' are the tension and compression reinforcement ratios, respectively. Ductility ratio shall be < 10 .			

Table 9 Low Response (Deformation) Limits for Reinforced Masonry

Element Type	Ductility Ratio, μ_a	Support Rotation, θ (degrees)
		Low
One-way	1	0.5
Two-way	1	0.5

6.2.6 Structural framing

- Design of the overall structural framing system SHALL [PS] include analysis of global response including sideways, overturning, and sliding.
- Sideways analysis SHALL [PS] be performed for both of the following:
 - with leeward side (rear wall) blast loads;
 - without leeward side (rear wall) blast loads.

6.3 LOAD COMBINATIONS

1. Blast resistant structures SHALL [PS] be designed for the blast load condition as Equation 3.

$$U_{(t)} = D + (A \times L) + B_{(t)} \quad \text{Equation 3}$$

Where:

$U_{(t)}$ = total applied time dependent load or its effect

D = static dead load (unfactored)

$B_{(t)}$ = time dependent blast load or its effect (horizontal & vertical). For Design blast load (specified as free-field) see (4.2, Item 2)

L = conventional static live load (unfactored)

A = reduction factor (normally zero) applied to conventional live loads to reflect the portion of live load expected to occur simultaneously with the blast load. See (6.3, Item 3)

2. The mass calculation should not include live loads which would be blown away by a blast wave or live loads that will not increase the inertia of a supported member (e.g., personnel and furniture).

This means that in most cases the reduction factor will be zero.

- a. In cold climates where snow regularly remains on building roofs for prolonged periods, 50% of snow loading should be included in the live load.
3. The blast load combination shall consider either the direct loads or their effects.
 - a. In combining blast load effects with those from static dead and live loads, the time dependence of the blast loading shall be taken into consideration.
 4. Wind and seismic loads shall not be combined with blast loading.
 5. Rebound effects shall be computed and combined with the effects of negative phase blast loads, if any, based on time dependent response.

6.4 COMPONENT DETAIL DESIGN

6.4.1 General

1. Ultimate strength (Limit State) methods shall be used for designing structural components for blast resistance.
2. The ultimate strength capacity shall be determined in accordance with the applicable codes, practices and guides as specified, subject to the following additional requirements:

- a. In-plane and secondary bending stresses shall be accounted for in the design.
- b. Interaction of forces in two directions, including biaxial bending, shall be considered.

Information may be obtained from the ASCE 41088 "Design of Blast Resistant Buildings in Petrochemical Facilities".

- c. Dynamic strength properties shall be used to reflect increased material strength under rapidly applied loads.
- d. Load factors shall be taken as equal to 1.0 in all blast load combinations.

- e. Composite sections may be used for design subject top having adequate rebound resistance to ensure satisfactory response under rebound or negative phase loads.
- f. Components shall be laterally braced to prevent premature buckling failure during the positive and rebound response.
- g. Connections shall be designed for 120 % of the member's controlling resistance (flexure or shear, whichever is lower).
 - i. To use the deformation limits indicated in Table 7, Table 8, and Table 9, the member's shear capacity shall be at least 120 % of the flexural capacity.

Except as noted for reinforced concrete members, the deformation limits indicated in Table 7, Table 8, and Table 9 are based on flexure controlled resistance.
- h. Design for compression elements, such as load bearing walls and columns, should consider bending effects including secondary effect (P-delta effects) and slenderness (i.e., the secondary effect on shears, axial forces and moments of frame members that are induced by the vertical loads acting on the laterally displaced building system).

6.4.2 Reinforced concrete components

- 1. Refer to DEP 34.19.20.31-Gen. for requirements for reinforced concrete components
- 2. Deformation limits as noted for shear shall be used where the member's shear capacity is not at least 120 % of the flexural capacity.
- 3. For existing concrete structures, the compressive strength shall be determined by means of destructive tests.
- 4. Hot-rolled steel bars with yield strength (f_y) between 240 MPa and 500 MPa (36 ksi and 73 ksi) shall be used for reinforcement of the concrete.
 - a. For existing reinforced bars, the type of bar shall be determined by means of a destructive test.
 - b. To ensure ductility, cold rolled bars and meshes shall not be used.
- 5. Walls and roofs should be designed for a ductile response in order to absorb blast energy without transmitting it to the supporting elements.
 - a. Internal shear walls may be used.
- 6. Slenderness effects shall be included for load bearing walls and members with significant axial loads.
- 7. Support shall be provided for roof slabs to prevent failure during rebound.
 - a. Headed studs may be used for roof slab support.
 - b. Headed studs should be located and spaced to minimise composite action unless composite action is required and specifically designed for.
- 8. The concrete walls and slabs shall be reinforced on each side in the main direction to the following minimum extent:
 - a. For steel bars with a yield strength (f_y) of 240 MPa (36 ksi), 1 % on both sides of the concrete cross section.
 - b. For steel bars with a yield strength of 460 MPa (67 ksi), 0.6 % on both sides of the concrete cross section
 - c. For steel bars with yield strengths other than aforementioned, the minimum percentage shall be $(240/f_y)$ % where f_y is in MPa.

9. In the other direction on both sides, a distribution reinforcement of at least 20 % of that in the main direction shall be applied.
 - a. Maximum spacing of bars shall be 150 mm (6 in) centre to centre.

It is preferable for the wall and roof thickness to be between the limits of 250 mm (10 in) and 400 mm (16 in) in order to facilitate the placing of the required reinforcing bars.
10. If the dynamic calculation indicates that more reinforcement is required, it shall be provided and not use strength reduction or reductions of development lengths to meet the design conditions.
11. Criteria intended to reduce cracking at service load levels shall not be applied to load combinations that include blast loads.
12. Shear reinforcement shall be applied in beams only.
13. Shear reinforcement shall be a combination of stirrups and horizontal side bars as follows:

This combination is known as web reinforcement.

 - a. When the shear stress is less than 1.3 MPa (189 psi), web reinforcement is not required.
 - b. When the shear stress is more than 1.3 MPa (188 psi) but less than 4.5 MPa (653 psi) web reinforcement will be required for this acting shear stress minus 1.3 MPa (188 psi).
 - c. At least 50 % of the bottom main reinforcement shall extend over the face of the support providing a good anchorage between the supports.
14. The design should ensure continuity and a minimum of local stress concentration with adequate lapping of reinforcement.
15. Pre-stressed or post tensioned concrete shall not be used due to its non-ductile behaviour and potential loss of strength in fires.

6.4.3 Structural steel components

1. Refer to DEP 34.28.00.31-Gen. for requirements for structural steel components.
2. Bolts with a yield stress > 660 MPa (92 ksi) shall not be used for structural connections and holding down bolts.
3. Steel members shall be sufficiently laterally braced and connected to avoid buckling and instability problems, so that large deformation, without failure, can be achieved.
4. Member materials with a specified yield strength of 355 MPa (50 ksi) or less shall be used for flexural design.
5. Oversize holes shall not be used in connections that are part of the lateral force resisting system.
6. Column base plates shall be designed to develop the peak member reactions applied as a static load.
 - a. Dynamic material properties may be taken into account in the design of base plates.
7. Flexural members shall be laterally braced on both faces to provide consistent moment capacity in both positive and rebound response.