TECHNICAL SPECIFICATION

MINIMUM REQUIREMENTS FOR STRUCTURAL DESIGN AND ENGINEERING

DEP 34.00.01.30-Gen.

July 1998

DESIGN AND ENGINEERING PRACTICE

PREFACE

DEP (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell International Oil Products B.V. (SIOP)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users 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 companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by SIOP, SIEP or SIC, in most cases under Service Agreements primarily with companies of the Royal Dutch/Shell Group and other companies receiving technical advice and services from SIOP, SIEP or SIC. Consequently, three categories of users of DEPs can be distinguished:

1) Operating companies having a Service Agreement with SIOP, SIEP, SIC or other Service Company. The use of DEPs by these Operating companies is subject in all respects to the terms and conditions of the relevant Service Agreement.

2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements.

3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, SIOP, SIEP and SIC disclaim any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any DEP, combination of DEPs or any part thereof. The benefit of this disclaimer shall inure in all respects to SIOP, SIEP, SIC and/or any company affiliated to these companies that may issue DEPs or require the use of DEPs.

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All administrative queries should be directed to the DEP Administrator in SIOP.

NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

TABLE OF CONTENTS

APPENDICES

1. INTRODUCTION

This DEP specifies requirements and gives recommendations for the structural design and engineering of buildings and other structures for the supporting of vessels, columns, machinery, stacks, tanks, piping etc.

This DEP is also applicable to jetties and platforms but these special structures will normally need additional requirements to be specified separately.

This is a revision of the DEP of the same number dated March 1989.

It is intended for use in oil refineries, chemical plants, gas plants, and where applicable, in exploration, production and new ventures.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors nominated by them (i.e. the distribution code is "C", as described in DEP 00.00.05.05-Gen.*).*

This DEP is intended for use by all involved in the creation, maintenance and use of DEPs.

If national and/or local regulations exist in which some of the requirements may 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 as regards 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 with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

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

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

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. 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 word **should** indicates a recommendation.

2. LOADING DATA

2.1 GENERAL

The loads which shall be taken into account in the design of structures are described below. The various combinations of these loads to be used in the calculations are given in (2.14).

2.2 STRUCTURE PROPER

The dead weight of the structure proper shall be calculated, including the weight of the fireproofing.

2.3 ROTATING AND STATIC EQUIPMENT

2.3.1 Weight of Rotating and Static Equipment

The weight of rotating and static equipment shall be derived as far as possible from Vendor data and shall include controls, auxiliary machinery, piping, insulation on equipment and related piping, etc.

2.3.2 Various Load Combinations

The following load combinations of rotating and static equipment shall be included in the calculations.

2.3.2.1 Empty Weight of Rotating and/or Static Equipment

This is the dead weight of the equipment, including insulation, fire protection, protective layers, internals etc., and shall be derived from Vendor data.

See note 5, Table 1 - Load Combination A to E.

2.3.2.2 Operating Weight of Rotating and/or Static Equipment

This is the empty weight (incl. internals) of vessels, columns, etc., plus the weight of their maximum contents during operation of the plant.

2.3.2.3 Hydrostatic Test Load of Rotating and/or Static Equipment

When hydrostatic pressure testing of equipment is required at site, the weight of this equipment completely filled with water shall be incorporated in the design of the supporting structure.

When more than one piece of equipment is supported by one structure, the structure need only be designed on the basis that one piece of equipment will be tested at any one time, and that the others will either be empty or still in operation.

2.4 CRANE LOADS AND MOVING LOADS

Crane loads shall be assumed at their maximum values including lifting capacity as well as the maximum horizontal loads caused by braking or acceleration.

At least one road leading to the main process area(s) shall be designated as heavy equipment route and bridges/culverts including other underground facilities shall be designed for the maximum expected loading condition caused by transportation of heavy equipment.

For the design of each structural element the most unfavourable position of the crane or other moving loads shall be considered. For moving loads an appropriate impact factor shall be applied according to the following guideline:

Loads applied due to cranes and moving sources shall not be less than the following (Ref.: ANSI/ASCE 7-95 CL 4.10 or BS 449 Part 2 - 1969 Chapter 3):

	Electric Operation	Hand Operation
Vertical impact loads - increase maximum wheel loads by:	25%	10%
Horizontal forces on rails - taken as a percentage of the rated capacity of the crane and the weight of the hoist and trolley Transverse to each rail:	10%	5%
Horizontal forces on rails - taken as a percentage of the maximum wheel loads of the crane: Along the rails:	10%	5%

2.5 LIVE LOADS (IMPOSED LOADS)

The following live loads shall be taken into account:

- For floors, platforms, walkways and staircases used for operational/maintenance purposes, the loads shall be derived from Vendor data with a uniformly distributed minimum load of 5.00 kN/m^2 or a minimum single point load of 7.5 kN, whichever is the more unfavourable for the structural element(s) under consideration.
- For floors, platforms, walkways and staircases used for access only, 2 kN/m^2 or a single point load of 3 kN, whichever is the more unfavourable for the structural element(s) under consideration.
- For roofs accessible for inspection and repair only, 1 kN/m^2. In addition all roof members shall be checked for a single load of 2 kN.
- For railings a horizontal force of 1 kN at any one point.
- For buildings see DEP 34.17.00.32-Gen. and DEP 34.17.10.30-Gen.

Note: Where applicable, due regard shall be given to allowable reduction of live loads for multi-storey buildings, or open structures under maximum wind load conditions.

For the design of each structural element the live loads shall be applied in the most unfavourable pattern (checkerboard-type loading).

The supports of heat exchangers with removable bundles shall be calculated on a pulling force of 200% of the weight of the bundle unless the bundles are pulled by means of a mechanical device which acts on the principle of equilibrium of forces.

2.6 WIND LOADS

Wind loads shall be determined in accordance with Appendix 1 of this DEP unless otherwise stipulated by national and/or local regulations, see (1.2).

The wind can blow in any direction and the most unfavourable case shall be considered.

For overhead pipe tracks of 4 m wide or less, the wind load on the three largest pipes shall be taken into account. For overhead pipe tracks of over 4 m wide, the wind load on the four largest pipes shall be taken into account.

2.7 SNOW LOAD/SAND LOAD/WATER LOAD

Where necessary, snow load/sand load shall be taken into account. The load shall be derived from local regulations or experience.

Load due to rainwater accumulation shall also be taken into account.

Note: The maximum rainwater accumulation load with the drains pipes or down spouts blocked shall be assessed.

2.8 DYNAMIC LOADS

A detailed design and vibration analysis shall be made in accordance with the following requirements:

2.8.1 Static deformation

The static deformation for rotating equipment foundations shall be calculated and shown to be within the limits stated by the Vendor of the equipment. The calculations shall include, but not be limited to, the following causes of deformation:

- shrinkage and creep of concrete;
- temperature effects caused by radiation and convection of heat or cold generated by machinery, piping and ducting;
- elastic deformation caused by changing vapour pressure in condensers;
- elastic deformation caused by soil settlement or elastic compression of piles.

2.8.2 Vibration analysis

A three-dimensional vibration analysis for rotating equipment foundations shall be made and shall show that the dynamic amplitudes will not exceed the lower of the following values; see also (2.9.6):

- the maximum allowable values stated by the Manufacturer of the equipment;
- the amplitude (single amplitude) which causes the effective velocity of vibration to exceed:
  a. 2 mm/s at the location of the machine-bearing housings
  b. 2.5 mm/s at any location of the structure

Note: The effective velocity is defined as the square root of the average of the square of the velocity, velocity being a function of time. In the case of a pure sinusoidal function the effective velocity is 0.71 times the peak value of the velocity.

2.8.3 Exciting force

For the vibration analysis of structures and foundations of rotating equipment (subject to vibrations), the exciting forces shall be taken as the maximum values that, according to the Vendor of the equipment, will occur during the lifetime of the equipment.

2.8.4 Schematic mechanical model

The vibration calculation shall be based on a mechanical model wherein the weights and elasticity of both structure and foundation and the weight of the equipment are represented in an appropriate way.

2.8.5 Frequencies

All natural frequencies below 2 times the operating frequency for reciprocating equipment and below 1.5 times the operating frequency for rotating equipment shall be calculated.

It shall be demonstrated that the amplitudes of the natural frequencies between 0.35 and 1.5 times the operating frequency are within the allowable values even assuming that - due to differences between the actual structure and the assumed model - resonance does occur. In this case a reasonable amount of damping should be estimated.

The natural frequency of the supporting structure shall not coincide with any resonant frequency of the equipment.

2.8.6 Dynamic amplitudes

The dynamic amplitudes of any part of the foundation including any reciprocating compressor shall be limited to a peak to peak amplitude of less than 50 µm or as otherwise specified by the Principal or Manufacturer/Supplier of the rotating equipment.

2.9 EXPLOSION AND IMPACT LOADS

Explosion and impact loads shall be included in the design, if required by the Principal or local standards.

Note: Impact loads may be due to explosions or collisions.

2.10 THERMAL EFFECTS

2.10.1 Thermal loads

When thermal expansion results in friction between equipment and supports, the friction force shall be taken as the operating load on the support times the applicable friction coefficient given in the table below.

Surfaces	Friction coefficient
Steel to steel (not corroded)	0.30
Stainless Steel to PTFE	0.08
PTFE to PTFE	0.08
Graphite to graphite	0.15

Note: The maximum sliding bearing pressures of above materials shall be taken into account.

In the design of pipe supporting beams, the horizontal slip forces exerted by expanding or contracting pipes on steel pipe racks shall be assumed to be 15% of the operating weight on the beam. These 'slip forces' shall not be distributed to the foundations.

A concrete pipe rack beam shall be designed for an arbitrary horizontal pipe anchor force of 15 kN acting at mid span, which likewise shall not be distributed to the foundations.

For pipe anchor forces transferred by longitudinal girders to structural anchors (bracing), an arbitrary force of 5% of the total pipe load per layer shall be taken into account, unless design calculations dictate a higher force. These forces shall be distributed to the foundations.

2.10.2 Thermo-mechanical forces and stresses

Foundations and liquid retaining structures (including fireproofing) which are subject to thermo-mechanical effects shall also be designed for the thermal loads and for any temperature difference that may occur.

Heat transfer calculations shall be used to determine the effects of:

a) thermo-mechanical forces and stresses;
b) changing of any properties of materials used.

The temperature of concrete shall not exceed 70 °C.

2.11 LOADS DURING ERECTION AND MAINTENANCE

All possible loading conditions during erection and maintenance shall be taken into account. The most unfavourable condition shall be taken into account for each member.

The loads of scaffolding, including the wind loads, due to erection and maintenance shall be taken into account for the design of the structure.

Heavy equipment lowered onto a supporting structure can introduce extreme point loads on structural members, exceeding any operating or test load. After placing of equipment, the exact positioning (lining out and levelling) can also introduce extreme point loads. The above should be interpreted on the basis of Contractor's practical experience and Vendor information.

Beams and floor slabs in multi-storey structures, e.g. fire decks, shall be designed to carry the full construction loads imposed by the props supporting the structure immediately above. A note shall be added on the relevant construction drawings to inform the field engineer of the adopted design philosophy.

2.12 EARTHQUAKE LOADS

Where applicable, earthquake loads shall be taken into account.

The frequency of occurrence of earthquakes, their intensity and duration shall be derived from seismological data and/or accelerograms (i.e. recordings of actual ground accelerations during an earthquake), local regulations or as specified by the Principal.

Expansion joints shall be so designed that members of the structure do not collide.

Where necessary a special soil investigation shall be made to predict the possibility of ground displacements, settlements and soil liquefaction.

The origin of the earthquake data shall be given in the calculations.

Note: The “Uniform Building Code, UBC 1997, Volume 2” shall be used to obtain earthquake loads.

2.13 DIFFERENTIAL SETTLEMENT

The variability of the soil strata may result in differential settlement. The resulting bending moments, shear and axial forces shall be considered.

2.14 LOAD COMBINATIONS

Piles, structures and members of structures as well as their support and fixing points shall be designed for the various loading combinations given in Table 1, in which the following components shall be used:

a	- weight of structure proper	(2.2)
b	- weight of rotating equipment	(2.3.1)
c	- crane loads and movable loads	(2.4)
d	- empty weight of rotating and/or static equipment	(2.3.2.1)
e	- operating weight of rotating and/or static equipment	(2.3.2.2)
f	- hydrostatic test load of rotating and/or static equipment	(2.3.2.3)
g	- live loads	(2.5)
h	- wind loads	(2.6)
i	- snow/sand/water loads	(2.7)
k	- dynamic loads	(2.8)
l	- thermal effects	(2.10)
m	- loads during erection and maintenance	(2.11)
n	- earthquake loads	(2.12)
o	- differential settlement	(2.13)

TABLE 1 LOAD COMBINATIONS A TO E

	Load	Operation		Test	Erection	Earthquake
		without wind	with wind		Maintenance	
		A	B	C	D	E
a	weight of structure proper	x	x	x	x	x
b	weight of rotating and/or rotating equipment	x	x	x	x	x
c	crane and movable loads	x		x	x	
d	empty weight of rotating and/or static equipment		x[1]		x[5]	
e	operating weight of rotating and/or static equipment	x	x[1]			x
f	hydrostatic test load of rotating and/or static equipment			x		
g	live loads	x	x	x	x	x
h	wind loads		x	x[3] [4]	x[4]	
j	snow/sand/water loads	x			x	x
k	dynamic loads	x	x	x[2]		x
l	thermal effects	x	x			x
m	loads during erection and maintenance				x	
n	earthquake loads					x
o	differential settlement	x	x	x		x

Notes:

1. The most unfavourable load combination 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 50% wind load shall be taken into account.

4. The effect of wind forces acting on temporary scaffolding erected during construction or for subsequent 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 should 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% closed surface and shape factor 1.

5. Temporary load situations of empty weight of equipment during erection shall be taken into account.

3. SITE INVESTIGATION AND FOUNDATION ENGINEERING

A site investigation shall be carried out to determine the character and variability of the soil strata underlying the foundations of the proposed structures.

Reference is made to DEP 34.11.00.10-Gen. which contains guidelines for the determination of the extent and scope of site investigations and associated reports.

The selection of foundation types (i.e. whether piled, soil bearing, etc.) shall be based on the results of a site investigation. The geotechnical aspects of foundation design and engineering are covered in DEP 34.11.00.12-Gen.

For the design of reinforced concrete foundations reference is made to DEP 34.19.20.31-Gen.

4. DESIGN AND CALCULATIONS

4.1 BASIC DESIGN

Prior to starting detailed design, a basic design shall be made consisting of:

- a basic sketch (4.1.1),
- calculation (4.1.2)
- stability check (4.1.3), and
- main structural members (4.1.4).

4.1.1 Basic sketch

The sketch shall show the proposed structure (in perspective and/or a series of cross sections).

Structural members may be shown as single lines.

The sketch shall include the foundations, and also which part(s) of the structure will be steel and which part(s) concrete.

If steel structures need to be fireproofed, e.g. air cooled heat exchanger structures, pipe racks etc., maximum use shall be made of prefabricated concrete members.

All applied loads shall be shown on the sketch, excluding the weight of the structure proper. The applied loads shall be classified in accordance with (2.1) to (2.14).

4.1.2 Calculation

The calculation shall give the design philosophy and shall follow all loads, including the estimated dead weights of the relevant structural components.

The calculation shall state the loads in the main structural members (axial loads, bending moments, shear and possibly torsion), and shall include the loads on the foundation (load per pile or per unit of area).

The calculation shall take into account the soil investigation report (3.).

If any computer programs are to be used for the detailed design, these shall be identified during the basic design stage and all required documentation shall be supplied to demonstrate their accuracy and applicability.

4.1.3 Stability check

The stability of the structure shall be checked for the non-factored load combinations B, C and D and, if applicable, E, (see 2.14).

The following stability ratios shall be used in calculations to prevent foundations from overturning owing to horizontal loads:

- for load combinations B, C and D a minimum factor of 1.5.
- for load combination E a minimum factor of 1.25.

4.1.4 Main structural members

In the assessment of the sizes and dimensions of the main structural members the most critical load combination shall be considered.

Structural details, such as connections of steel beams and columns or details of reinforcing steel over the full length of a reinforced concrete beam, need not be shown. However, when prefabricated concrete elements are used the connections between the various elements shall be shown.

4.2 DETAILED DESIGN

The detailed design shall be based on the basic design (4.1).

The calculation shall clearly indicate:

1. The table of contents
2. Design philosophy
3. Applicable codes, formulas, graphs/tables
4. References to literature, etc., for subjects not covered by applicable codes
5. Loading tables with loading location diagrams
6. If computer programs are used, the following information shall be supplied:

    a) Logic and theory used
    b) User's manual
    c) Analytical model of the structure used for computer analysis
    d) A manual calculation to prove the validity of the computer analysis
    e) Loads and load combinations

5. DRAWINGS AND RELATED DOCUMENTS

5.1 GENERAL

Drawings shall be of the standard sizes given in DEP 02.00.00.10-Gen.They shall be suitably prepared to facilitate electronic storage (e.g. CD-ROM) and incorporate a revision numbering and indication system, also in accordance with the above DEP publication.

Dimensions on the drawings shall be in the SI system, unless otherwise specified. See DEP 00.00.20.10-Gen.

Levels shall be indicated in metres, all other dimensions in millimetres.

Lay-out drawings shall show the highest point of grade, 0.00, and the reference of this level to the local datum level.

All text shall be in English.

Each drawing shall bear the following information, in the bottom right-hand corner:

- order number of the Principal
- name of plant
- name of unit
- name of part of the unit

Example:

- order number
- catalytic cracking unit
- compressor building
- portal frames

Only drawings marked "Released for construction" shall be used at the site.

This mark "Released for construction" can be given only by the Contractor responsible for design and engineering.

Drawings shall be submitted together with the relevant calculations, including those required for submission to local authorities.

Claim to all drawings prepared by the Contractor under any order placed by the Principal shall be vested in the Principal, and the latter shall have the right to use these drawings for any purpose without any obligation to the Contractor.

The Contractor shall not disclose or issue to third parties without written consent of the Principal any documents, drawings, etc., placed at his disposal by the Principal or any documents prepared by himself in connection with enquiries and orders for purposes other than the preparation of a quotation or carrying out these orders.

5.2 STRUCTURAL CONCRETE

5.2.1 Plan drawing

On this drawing the general information/data shall be shown as General Notes on the right-hand side of the drawing.

The general notes shall state that:

1. Levels are expressed in metres, with reference to the highest point of grade
2. Dimensions are expressed in millimetres
3. Bar diameters are expressed in millimetres

Furthermore, the general notes shall list:

4. The quality (or qualities) of concrete*
5. The quality (or qualities) of steel reinforcing bars*
6. The quality (or qualities) of cement to be used*

* Including an indication for which part(s) each quality is to be used.

7. Concrete blinding (location, quality and thickness)
8. Polyethylene sheeting, if applicable (location and quality)
9. The concrete cover on bars (type of construction, location and thickness)
10. The list of reference drawings and related documents stating their title and number

5.2.2 Detail drawings

On each of the detail drawings, the following information/data shall be listed:

1. For general notes, see Drawing No. .... (5.2.1)
2. This detail drawing refers to Drawing No. ....
3. For bar bending list(s), see No. ......, sheet 1 to .... (5.2.3)
4. For weight list(s), see No. ...., sheet 1 to .... (5.2.3)
5. Quantity of concrete (for each quality of concrete separately, including environmental classes of the location where the concrete will be applied)

5.2.3 Bending and weight lists

These lists shall always be made, unless explicitly stated otherwise. The lists shall preferably be prepared on separate sheets.

5.2.4 Scale of drawings

Plan drawings shall be made to a scale of 1:50 and detail drawings to a scale of 1:20.

5.3 STRUCTURAL STEEL

5.3.1 General

Part of the information/data supplied by the Principal may be in the form of one or more instruction drawings. If instruction drawings are provided, all the dimensions shown on these drawings shall also appear on the Contractor's drawings.

5.3.2 General arrangement drawings

This drawing shall show the complete structure to be supplied. All main dimensions and the section to be used shall be included.

All members to be fireproofed shall be marked FP, as defined in DEP 34.19.20.11-Gen.

The fireproofing zone, as defined in DEP 34.19.20.11-Gen., shall be indicated on the general arrangement drawing.

For the preparation of the general arrangement drawing, the Contractor may use a reproducible of the instruction drawing(s).

For small and simple structures this drawing may be combined with the base plate drawing (5.3.3).

5.3.3 Base plate drawing

This drawing shall show all dimensions and details of the base plate including holding-down bolts, which shall be taken into account in the design of the (concrete) foundation.

When the need for a slight adjustment of the holding-down bolts during erection is expected, this shall be indicated on the drawing.

The scale for details shall be at least 1:10.

For small and simple structures this drawing may be combined with the general arrangement drawing (5.3.2).

5.3.4 Construction drawings

These drawings shall clearly show all constructional details of the structure to be supplied.

The location of the various parts in the structure shall be indicated.

5.3.5 Scale of drawings

Drawings shall be made on an appropriate scale.

5.3.6 Mark drawing

On this drawing each part of the structure shall be properly marked for identification purposes.

5.3.7 Bills of material

Bills of material shall show the weights of all large members, for the purposes of transportation and erection at site, and also the total weight of the structure.

6. REFERENCES

In this specification, reference is made to the following publications.

Note: The latest issue of each publication shall be used together with any amendments/supplements/ revisions to such publications.

It is particularly important that the effect of revisions to international, national or other standards shall be considered when they are used in conjunction with DEPs, unless the standard referred to has been prescribed by date.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
The use of SI units	DEP 00.00.20.10-Gen.
Preparation and microfilming of technical drawings	DEP 02.00.00.10-Gen.
Site investigation	DEP 34.11.00.10-Gen.
Geotechnical and foundation engineering	DEP 34.11.00.12-Gen.
Reinforced control buildings	DEP 34.17.10.30-Gen.
Minimum requirements for design and engineering of buildings	DEP 34.17.00.32-Gen.
Fire hazards and fireproofing/cold splash protection of steel structures	DEP 34.19.20.11-Gen.
Reinforced concrete foundations and structures	DEP 34.19.20.31-Gen.

INTERNATIONAL STANDARDS

Model code for concrete chimneys, part A, “The Shell”	CICIND
Model code for steel chimneys	CICIND

Issued by:
Perran House
Barnaby Mead Gillingham
Dorset SP8 4AL ENGLAND

AMERICAN STANDARD

1997 Uniform Building Code : volume 2 : structural engineering design provisions	UBC 1997, Volume 2

Issued by:
ICBO Headquarters,
5360 Workman Mill Road
Whittier, California 90601 - 2298

Minimum design loads for buildings and other structures	ANSI/ASCE 7-95

Issued by:
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017-2398

BRITISH STANDARD

Specification for the use of structural steel in buildings	BS 449, Part 2: 1969

Issued by:
British Standards Institution,
389 Chiswick High Road
London W4 4AL, England

APPENDIX 1 CALCULATION OF WIND LOADS

1. WIND GUST DESIGN SPEED

Note: For a list of symbols, see Section 7 of this Appendix.

The Principal shall specify the mean hourly wind speed V_{10} (m/s) at a height of 10 m, which shall be accounted for in the design.

Note : Normally the mean hourly wind speed can vary from 20 m/s up to 40 m/s. In some areas with tornadoes, cyclones, hurricanes or typhoons, the mean hourly wind speed can even exceed 40 m/s and values between 50 m/s and 65 m/s can occur. The values shall be taken from meteorological measurements.

All structures shall be designed for a 10-second gust, except for towers, stacks and in general smaller protruding parts (e.g. ladders) for which a 3-second gust shall used in the design.

For steel and concrete chimneys the requirements of the CICIND CODE for Steel and Concrete Chimneys shall apply. U_z (in m/s) is the design wind speed at height z, hence:

$$U_z = F x \overline{V}_{10} x \left(\frac{z}{10}\right)^{1/\gamma}$$

F and $1/\gamma$ vary with gust duration and category of the locality, see Table 1.

TABLE 1

Category	Topography	F		$1/\gamma$
		3-second gust	10-second gust	
1	Extreme exposure - large expanses of open water and grassland	1.5	1.3	1/14
2	Open country with low obstructions - trees, hedges, 2-storey buildings, etc.	1.7	1.4	1/11
3	Built-up areas and areas with high obstructions such as towns and cities	2.0	1.6	1/8

2. WIND PRESSURES ON CLOSED OR FULLY CLAD STRUCTURES

Wind pressure per unit area acting on a structure in the direction of the wind at height z is p_z

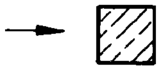
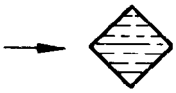
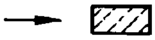
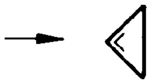
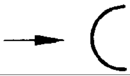
$p_z = 0.637 \times U_z^2 \times C_f \times K$ (N/m^2)

Values of C_f - the shape coefficient for infinitely long bodies - are presented in Table 2.

Values of K - the correction factor for aspect ratio - are presented in Table 3.

The designer shall divide the height of the structure into sections, select values of C_f and K appropriate to each section, and compute the average wind pressure on each section.

TABLE 2 VALUES OF SHAPE COEFFICIENT C_f

Sectional shape		C_f
(a) Simple geometric shapes		
	Flat plate	2.0
	Flat plate with one edge on ground (wall)	1.2[1)]
	Square with face to wind	2.0(1.2)[2)]
	Square with corner to wind	1.5(1.5)[2)]
	Rectangle with narrow face to wind	1.4(0.6)[2)]
	Rectangle with wide face to wind	2.2(1.6)[2)]
	Equilateral triangle with apex to wind	1.2(1.1)[2)]
	Right-angle triangle	1.56
	Equilateral triangle with face to wind	2.0(1.3)[2)]
	Circular	1.2(0.7)[3)]
	12-sided polygon	1.3(1.0)[3)]
	Semi-circle: concave to wind	2.3
	Semi-circle: convex to wind	1.2

Sectional shape		C_f
(b) Structural members		
	I-beam, web facing wind	2.0
	I-beam, flange facing wind	1.8
	Angle	2.0
	Angle	1.8
	Angle	1.45

NOTES:

1. This shape coefficient is applicable to all lengths of plate greater than the height.
2. The shape coefficients for sharp-edged bodies are substantially reduced by rounding the edges. The values in parentheses refer to the values obtained with a corner radius 1/4 the length of a side and decrease still further when the value of DU_z increases beyond a critical value.
3. The shape coefficients for rounded bodies are influenced by the aerodynamic scale and by the surface roughness. The values quoted are applicable to values of the product DU_z>7. For DU_z> 7 and circular pipes or tubes of normal surface roughness, the coefficient varies widely but does not exceed 0.7. For every rough surfaces and for the 12-side polygonal section, a coefficient of 1.0 is more applicable.

TABLE 3 CORRECTION FACTOR K FOR ASPECT RATIO FOR SOLID BODIES OR SHEETED IN STRUCTURES

Aspect ratio λ	K
0 to 4	0.6
4 to 8	0.7
8 to 40	0.8
above 40	1.0

Notes:

1. When one end of a body rests on the ground, as for a chimney stack, λ = 2h/D where D = external diameter.
2. The influence of aspect ratio is much less for open structures for which no correction factors are applicable.
3. λ = aspect ratio, i.e. length to width of the aspect of a body normal to wind direction.

3. WIND PRESSURES ON CONVENTIONAL BUILDINGS

The wind pressures acting on sheeting or cladding of conventional closed buildings per unit area is p_z,

where $p_z = 0.637 \times U_z^2 \times C$ (N/m^2)

in which C is (C_{pe} - C_{pi}) or C_f:

C_{pe}, external pressure coefficient;

C_{pi}, internal pressure coefficient.

The pressure coefficients (C_{pe}) are given for a particular surface or part of the surface of a building. The total windload on a building is obtained by vectorial summation of the loads acting on all the surfaces in a direction normal to that surface.

Local coefficients shall only be used for calculating windloads in the designated areas and not for calculating the load on entire structural elements (i.e. walls/roof or structure as a whole).

Force coefficients (C_f) can be used for finding the total wind load on the building as a whole. This (C_f) value differs from the pressure coefficients (C_{pe}) acting on different faces of the building. As the pressure coefficients represent the worst possible values the critical value shall be determined for each wind direction. However, these values shall not be used for vectorial summation.

For buildings which are partly open or provided with wide doors at the windward side and the other sides of the building closed, an over pressure coefficient (C_{pi}) of +0.8 shall be used.
In buildings as aforementioned but partly open or having wide doors at the leeward side, an under pressure coefficient of -0.4 shall be used. For closed buildings, C_{pi} shall be taken as the more onerous of +0.3 and -0.3.

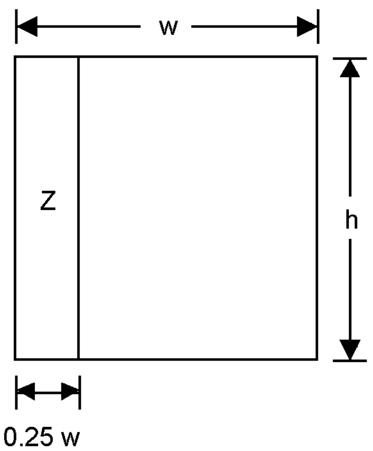
For certain buildings of special shape, frictional drag shall be taken into account. For low pitched roofs of large areas compared with the wall area (e.g. multiple-span roofs), the contribution of frictional drag acting in the wind direction may become significant. An approximate value for the frictional coefficient is 0.05.

WIND LOAD COEFFICIENTS FOR BUILDINGS

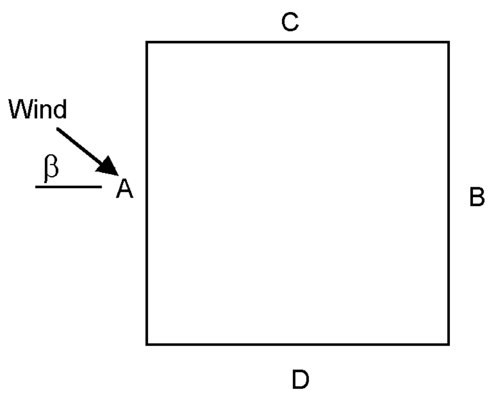
PRESSURE COEFFICIENTS C_{pe} FOR THE WALLS OF RECTANGULAR CLAD BUILDINGS

Building height ratio	Building plan ratio	Wind Angle ß degrees	C_{pe} for surface				Local Coefficients for Area 'Z'
			A	B	C	D	
h/w < 1/2	1 < L/W < 3/2	0	+0.7	-0.2	-0.5	-0.5	-0.8
		90	-0.5	-0.5	+0.7	-0.2	
	3/2 < L/W < 4	0	+0.7	-0.25	-0.6	-0.6	-1.0
		90	-0.5	-0.5	+0.7	-0.7	
1/2 < h/w < 3/2	1 < L/W < 3/2	0	+0.7	-0.25	-0.6	-0.6	-1.1
		90	-0.6	-0.6	+0.7	-0.25	
	3/2 < L/W < 4	0	+0.7	-0.3	-0.7	-0.7	-1.1
		90	-0.5	-0.5	+0.7	-0.1	
3/2 < h/w < 6	1 < L/W < 3/2	0	+0.8	-0.25	-0.8	-0.8	-1.2
		90	-0.8	-0.8	+0.8	-0.25	
	3/2 < L/W < 4	0	+0.7	-0.4	-0.7	-0.7	-1.2
		90	-0.5	-0.5	+0.8	-0.1	

Note: h is the height to eaves of parapet, L is the greater horizontal dimension of a building and w is the lesser horizontal dimension of a building as indicated below.



Elevation



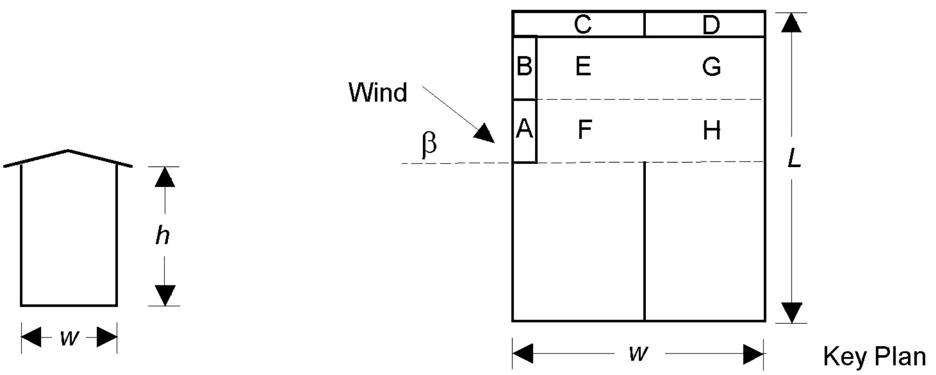
Plan

PRESSURE COEFFICIENTS C_{pe} FOR PITCH ROOFS OF RECTANGULAR CLAD BUILDINGS

Building height ratio	Roof angle degrees	Wind angle β = 0°		Wind angle β = 90°		Local coefficients			
		EF	GH	EG	FH	a	b	c	d
h/w > 1/2	0	-0.8	-0.4	-0.8	-0.4	-2.0	-2.0	-2.0	-
	5	-0.9	-0.4	-0.8	-0.4	-1.4	-1.2	-1.2	-1.0
	10	-1.2	-0.4	-0.8	-0.6	-1.4	-1.4		-1.2
	20	-0.4	-0.4	-0.7	-0.6	-1.0			-1.2
	30	0	-0.4	-0.7	-0.6	-0.8			-1.1
	45	+0.3	-0.5	-0.7	-0.6				-1.1
	60	+0.7	-0.6	-0.7	-0.6				-1.1
1/2 < h/w < 3/2	0	-0.8	-0.6	-1.0	-0.6	-2.0	-2.0	-2.0	
	5	-0.9	-0.6	-0.9	-0.6	-2.0	-2.0	-1.5	-1.0
	10	-1.1	-0.6	-0.8	-0.6	-2.0	-2.0	-1.5	-1.2
	20	-0.7	-0.5	-0.8	-0.6	-1.5	-1.5	-1.5	-1.0
	30	-0.2	-0.5	-0.8	-0.8	-1.0			-1.0
	45	+0.2	-0.5	-0.8	-0.8				-1.0
	60	+0.6	-0.5	-0.8	-0.8				
3/2 < h/w < 6	0	-0.7	-0.6	-0.9	-0.7	-2.0	-2.0	-2.0	-
	5	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.0
	10	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.2
	20	-0.8	-0.6	-0.8	-0.8	-1.5	-1.5	-1.5	-1.2
	30	-1.0	-0.5	-0.8	-0.7	-1.5			
	40	-0.2	-0.5	-0.8	-0.7	-1.0			
	50	+0.2	-0.5	-0.8	-0.7				
	60	+0.5	-0.5	-0.8	-0.7				

Note 1 *h* is the height to eaves or parapet and *w* is the lesser horizontal dimension of a building.

2 The pressure coefficient on the underside of any roof overhang should be taken as that on the adjoining wall surface. Where no local coefficients are given the overall coefficients apply.

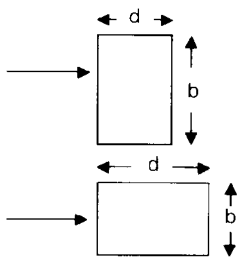


y = h or 0.15 w
whichever is the lesser

FORCE COEFFICIENTS C_f FOR RECTANGULAR CLAD BUILDINGS WITH FLAT ROOFS (ACTING IN THE DIRECTION OF THE WIND)

$\frac{L}{w}$	$\frac{b}{d}$	C_f for height/width ratio						
		Up to ½	1	2	4	6	10	12
≥ 4	≥ 4	1.2	1.3	1.4	1.5	1.6		
	≤ 1/4	0.7	0.7	0.75	0.75	0.75		
3	3	1.1	1.2	1.25	1.35	1.4		
	1/3	0.7	0.75	0.75	0.75	0.8		
2	2	1.0	1.05	1.1	1.15	1.2		
	1/2		0.75	0.75	0.8	0.85	0.9	
1 1/2	1 1/2	0.95	1.0	1.05	1.1	1.15		
	2/3	0.8	0.85	0.9	0.95	1.0		
1	1	0.9	0.95	1.0	1.05	1.1	1.2	1.4

Note: b is the dimension of the building normal to the wind, d is the dimension of the building measured in the direction of the wind, L is the greater horizontal dimension of a building and w is the lesser horizontal dimension of a building.



4. WIND FORCES ON OPEN STRUCTURES

1. The total wind force on a frame at a height z is given by the formula:

$$P_z = A \times 0.637 \times U_z^2 \times C_{fs} \qquad (N)$$

2. For multi-frame structures with similar windward and leeward frames the total wind load on the structures is:

$$P_z = A \times 0.637 \times U_z^2 \times C_{fm} \qquad (N)$$

$$\text{where } C_{fm} = C_{fs} \times \frac{1-\alpha^n}{1-\alpha} \text{ for } \alpha \neq 1$$

(for α = 1, $C_{fm} = C_{fs}$ x n)

In this formula: n = number of frames

α = shielding factor, see Table 5

TABLE 5 - SHIELDING FACTOR α

σ \ ϕ	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
0.5	0.93	0.75	0.56	0.38	0.19	0.00	0.00	0.00
1.0	0.99	0.81	0.65	0.48	0.32	0.15	0.15	0.15
2.0	1.00	0.87	0.73	0.59	0.44	0.30	0.30	0.30
4.0	1.00	0.90	0.78	0.65	0.52	0.40	0.40	0.40
6.0	1.00	0.93	0.83	0.72	0.61	0.50	0.50	0.50
10.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

3. The dependence of C_{fs} on ϕ for single frames with flat-sided or round members is given in Table 6.

TABLE 6 - SHAPE COEFFICIENTS FOR A SINGLE FRAME OR TRUSS

Solidity ratio ϕ	Shape coefficients C_{fs}		
	Flat sided members	Round members	
		$DU_z < 7$	$DU_z > 7$
0 to 0.1	2.0	1.2	0.8
0.1 to 0.3	1.8	1.3	0.9
0.3 to 0.6	1.6	1.5	1.1

Note: D refers to the individual member.

Within ± 0.02 of the common boundary of the ranges of ϕ, the mean values of C_{fs} for the two ranges may be used.

4. For practical values of ϕ, the influence of aspect ratio on the shape coefficient for a single frame, C_{fs} may be disregarded.
5. The above methods give wind loads where wind direction is normal to a face of a structure. Maximum loads may be 20% higher when the wind is directed along a diagonal of the section.
6. In deviation from the previous paragraphs, the following simple relationships may be used for triangular section towers when $\phi < 0.4$:

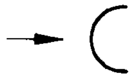
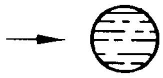
$C_{fm} = 3.5 - 4\,\phi$ for structures with flat-sided members, and

$C_{fm} = 2.5 - 3\,\phi$ for structures with round members, with maximum loads occurring when wind is normal to a face.

5. WIND FORCES ON SOME SHORT BODIES

Values for the shape coefficients are given in the following table:

TABLE 7 VALUES OF C_f FOR SOME SHORT BODIES γ = 1)

	Shape	C_f
	Circular disc	1.2
	Circular bowl concave to wind*	From 1.2 for flat to 1.4 for hemispherical bowl
	Circular bowl convex to wind	From 1.2 for flat disc to 1.4 hemispherical bowl
	Hemisphere	1.2
	Sphere	0.47 for $DU_z < 7$ 0.20 for $DU_z > 7$

* The wind force in a direction normal to the face of the bowl reaches a maximum in a wind inclined 30 to 60 degrees to the normal.

6. VORTEX FORMATION

Most bluff obstructions in a wind stream shed eddies alternately on one side and then on the other, forming what is known as a von Karman vortex in the wake.
The eddy shedding may cause cyclic sideways loading in the structure, and nearby downstream structures may also experience cyclic sideways loading from the vortex street.
In the case of tall slender structures and chimneys which are susceptible to oscillation, problems may arise if the cyclic loading coincides with the natural frequency of the structure.
For slender structures, such as chimneys, the eddy shedding frequency equals:

$$\frac{S\bar{V}}{D} \quad \text{(Hz)}$$

where S = 0.20 for structures of circular cross section
S = 0.15 for structures of square cross section and for flat plates

The natural frequencies of susceptible structures and structural elements shall be checked to ensure that they do not coincide with the eddy shedding frequency. Alternatively, the structure shall be stiff enough to prevent excessive sway, or measures shall be taken to prevent vortex formation.

Note: For concrete or steel chimneys reference shall be made to the CICIND MODEL CODES for Steel or Concrete Chimneys

7. LIST OF SYMBOLS

D	transverse dimension of the body normal to the wind direction, (m)
U	design wind speed for specified period of less than 60 seconds, (m/s)
U_z	U at height z
V	design wind speed for specified period longer than 60 seconds, (m/s)
$\overline{V}$	mean hourly wind speed, (m/s)
$F = U/V$	gust factor
A	total projected area of all individual members of one frame, (m2)
K	correction factor, depending on aspect ratio
C_f	shape coefficient
C_{fs}	shape coefficient for a single frame
C_{fm}	shape coefficient for a total multi-frame structure
C_p	pressure coefficient
p_z	wind pressure at height z (N/m^2), on closed or fully clad structures (Appendix 1; section 2), or wind pressure at height z on conventional buildings (Appendix 1; section 3), (N/m^2)
P_z	total wind force at height z
h	height of building or structure, (m)
n	number of frames
z	height above ground, (m)
α	shielding factor
β	wind direction
$1/\gamma$	an exponent giving variation of the design wind speed with height
λ	aspect ratio, i.e. length to width of the aspect of a body normal to wind direction
σ	spacing ratio, equals the distance, centre to centre, between the frames divided by the least overall dimension of the frame, beam or girder measured at right angles to the direction of the wind
ϕ	solidity ratio, i.e. ratio of the projected area of the individual members of a frame to the total area enclosed by the frame
N	Newton
m	metre
s	second