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## **Bases for design of structures — Actions due to the self-weight of structures, non-structural elements and stored materials — Density**

*Bases de calculs des constructions — Actions dues au poids propre des structures, des éléments non structuraux et des matériaux entreposés — Masses volumiques*

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## Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 9194 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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# Bases for design of structures — Actions due to the self-weight of structures, non-structural elements and stored materials — Density

## 0 Introduction

General principles on reliability of structures are given in ISO 2394.

Since at the moment, only insufficient statistical data of densities are available, the values given in this International Standard are deterministic ones. In general they may be interpreted as mean values of densities.

Even these mean values are in some cases different for the same material from one country to another. This is the reason for giving a range of two values for one material in this International Standard.

Each country in its relevant standards should use its traditional values which are in the indicated range.

## 1 Scope and field of application

This International Standard defines the actions due to the self-weight of structures, non-structural elements and stored materials. It gives the numerical values of their densities.

These actions are to be determined by multiplying the densities by the gravitational acceleration and by the actual volume. The actions caused by the weight of the earth placed on the structures are similarly calculated.

## 2 Reference

ISO 2394, *General principles on reliability of structures*.

## 3 General

**3.1** The most important value in determining actions due to the self-weight of structures, non-structural elements and/or that of stored materials is the density.

**3.2** For materials having all three dimensions of the same order of magnitude, the densities are expressed in kilograms per cubic metre ( $\text{kg/m}^3$ ). For roofings (sheeting materials) having one dimension of smaller order of magnitude than the other two dimensions, the similar quantity will be surface

density, expressed in kilograms per square metre ( $\text{kg/m}^2$ ) (mass related to surface area).

**3.3** In some countries roofings are considered to be external load, causing pressure on the structure (by analogy with, for example, snow load) — consequently these are expressed in newtons per square metre ( $\text{N/m}^2$ ) or in pascals<sup>1)</sup>.

For this reason, roofings (see annex A) are given as surface pressures, together with the values of surface density.

**3.4** Densities of stored materials substantially depend on how they are placed. Usually two methods of stocking are distinguished:

- a) disorderly storage of materials;
- b) orderly storage of materials.

Disorderly or bulky stored materials are stored without bales, forming a natural heap. Orderly stored materials are stored in stocks or piles with or without bales.

## 4 Density values

**4.1** The representative value of the density of materials and/or components of structures, non-structural elements and stored materials is in general determined by the mean value.

The representative value is generally represented by a unique value. In actual design situations, densities may alter due to the difference in quality of workmanship, moisture content, etc. The representative value of the density of earth is represented in the same manner, bearing compactness in mind.

**4.2** The representative values of densities of structures and non-structural elements are given in a table in annex A; the representative values of densities of stored materials and densities of earth placed on structures are similarly given in annex B.

**4.3** Where the tables give only one density value for one material (or soil), this means that the corresponding nominal values do not normally differ significantly (up to  $\pm 5\%$ ) in dif-

1)  $1 \text{ Pa} = 1 \text{ N/m}^2$

ferent countries and the indicated mean value is the average of the nominal values. The range of two values of densities given in the annexes for one material indicates that the mean values of densities for different countries vary between the indicated ones.

This also refers to the angles of repose. However, it should be emphasized that in accordance with the national practice

of different countries, angles of repose differ up to  $\pm 30\%$  from those indicated in annex B. Thus values of angles of repose given in annex B are approximate.

**4.4** For the time being, only limited statistical data are available and the values given in annexes A and B are based on relevant national practice.

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## Annex A

## Representative values of densities of structural and of non-structural elements

(This annex forms an integral part of the Standard).

This annex gives representative values of the densities of structural and non-structural elements in the form of a table.

Material	Density kg/m <sup>3</sup>	Material	Density kg/m <sup>3</sup>
<b>Wood and substitutes<sup>1)</sup> (air-dried, about 15 % humidity)</b>		<b>Building bricks and blocks</b>	
Hardwood		Solid burnt clay brick	
Beech tree ( <i>Fagus sylvatica</i> )	680	up to 14 MPa (inclusive) compressive strength	1 600
Oak tree ( <i>Quercus</i> )	690	over 14 Mpa compressive strength	1 800
Peduncular oak ( <i>Quercus robur</i> )	640	Perforated brick (holes through the brick exceed 25 % of its volume)	
Brazilian rosewood ( <i>Dalbergia nigra</i> )	800	hollow brick	820 to 1 350
Turkey oak ( <i>Quercus cerris</i> )	640 to 770	perforated brick	1 150 to 1 450
Yew tree ( <i>Taxus baccata</i> )	640	Lime-sand brick	1 700
Australian hardwood		Cob brick, adobe	1 600
Box, grey ( <i>Eucalyptus microcarpa</i> )	1 120	Refractory brick for general purposes	
Penda, brown ( <i>Xanthostemon chrysanthus</i> )	1 120	fireclay	1 850
Softwood		high-strength fireclay	2 100
Black pine ( <i>Pinus laricio</i> )	570	silica (dinas)	1 800
Larch tree ( <i>Larix decidua</i> )	550	magnesite	2 800
Norway spruce ( <i>Picea</i> )	430	chrome magnesite	3 000
Spruce fir ( <i>Pinus eccelsa</i> )	380 to 440	corundum	2 600
Scotch pine ( <i>Pinus silvestris</i> )	490	Covering bricks	
White willow ( <i>Salix alba</i> )	330	inside wall-covering	1 600
Giant poplar ( <i>Populus alba</i> )	410	outside façade covering	1 800
Trembling poplar ( <i>Populus tremula</i> )	450	clinker brick	2 000
Ocume ( <i>Ocume</i> )	410	Gas silicate block	
Conifers	400 to 600	with 2 MPa compressive strength	500
Extruded chipboard	500 to 750	with 5 MPa compressive strength	700
Fibreboard		with 7,5 MPa compressive strength	900
hard	900 to 1 100	Acid-resistant brick	2 000
medium-hard	600 to 850	Tuff block with 5 MPa compressive strength	1 100
porous insulating	250 to 400	Glass brick, double-walled	870 to 1 100
Plywood	750 to 850		
Coreboard	450 to 650	<b>Mortars</b>	
<b>Natural building stones</b>		Lime mortar	1 200 to 1 800
Magmatic plutonic rocks	2 650 to 3 000	Lime cement mortar	1 750 to 2 000
Magmatic vulcanites	2 500 to 2 850	Cement mortar (with 2,5 MPa or greater compressive strength)	2 100
Volcanic tuffs	1 400 to 2 000	Rock floor mortar	1 600
Sedimentary rocks		Gypsum mortar	1 200 to 1 800
sandstone	2 700	Fireclay mortar	1 900
marl	2 300	Pearlite mortar	
porous limestone	1 700 to 2 200	lime	340
fresh-water limestone	2 400	gypsum	370
compact limestone	2 650 to 2 800	cement	440
dolomite	2 800	Bitumen mortar with river sand	1 700
Transformed rocks		<b>Concrete<sup>2)</sup></b>	
clay slate	2 600	Gravel concrete	2 250 to 2 500
marble	2 700	Basalt concrete	2 300 to 2 500

Material	Density kg/m <sup>3</sup>	Material	Density kg/m <sup>3</sup>
Crushed rock concrete C3-C35	2 300 to 2 500	Tuff concrete, medium size building block	1 200
Blast furnace foam slag concrete C3-C10	1 600 to 1 900	Gas silicate, medium size building block 1,5 to 2,5 MPa compressive strength	600 to 800
Aerated and gas concrete C1,5-C5	600 to 1 500	2,5 to 5 MPa compressive strength	800 to 1 100
Expanded clay gravel concrete C1,5-C16	700 to 1 700	5 to 10 MPa compressive strength	900 to 1 300
Perlite concrete C1,5-C2	350 to 700	10 to 20 MPa compressive strength	1 000 to 1 600
Tuff concrete C3-C6	1 400 to 1 600	Inside wall-covering brick	1 700
Lightweight aggregate concrete using sintered pulverized fuel ash aggregates	1 600 to 1 850	Outside façade brick	1 900
Heat insulating gas concrete	300 to 900	Clinker brick	2 000
Heat insulating perlite brick and pipseshell	260	Fireclay brick (in fireclay mortar)	2 000
<b>Aggregates and fillers</b>		Acid-resistant brick (in bitumen mortar)	1 900
Sand	1 550	Glass brick, double-walled (in cement mortar)	1 100
Sand gravel of 0 to 40 mm grain size	1 700	Glass brick, coupled on one side (in cement mortar)	870
Gravel	1 500 to 1 600	<b>Metals for structures</b>	
Blast furnace foam slag	1 700	Structural steel	7 850
Blast furnace slag, granulated	1 200	Cast iron structure	7 100
Crushed slag stone of 5 to 40 mm grain size	1 500	Aluminium	2 700
Aerated silicate	1 000	<b>Covering and other building material</b>	
Pulverized fuel ash (pozzolan) for use as a cementitious component in concrete (bulk density)	800 to 1 050	Asphalt, pure	2 200
Lightweight concrete aggregate (Lytag) (bulk density)	750 to 1 000	Bitumen	1 000 to 1 400
Lightweight aggregate using sintered pulverized fuel ash/natural sand	1 700 to 2 000	Tar (pitch)	1 100 to 1 400
<b>Masonry from natural stones</b>		Asbestos cement roofing and covering board	1 800 to 2 100
Rocks of initial setting		Asbestos cement corrugated board	1 600
basalt malphir, diorit, gabbro	3 000	Asbestos cement pipe	1 800
basalt lava	2 400	Cellulose acetate panel	1 300
diabase	2 900	Cement tile	2 400
granite, syngenit, porphyt	2 800	Mosaic tile	2 200
trachyt	2 600	Concrete flagstone	2 200
Sedimentary rock		Tile	1 750 to 2 000
graywacke, sandstone, puddingstone	2 700	Face brick (hard façade brick)	2 500
dense limestone, dolomite, shell limestone and marble	2 800	Stoneware tile	2 400
limestone conglomerate (e.g. travertin, etc.)	2 600	Soft covering brick	
volcanic tuff	2 000	holed	1 350
Transformed rocks		solid	1 600
gneiss, granulite	3 000	Epoxy resin	
slate	2 800	without filler	1 150
serpantine	2 700	with mineral matter	2 000
<b>Brick masonry<sup>3)</sup></b>		with fibreglass	1 800
Ordinary brick	1 500	Fenoplast	1 500
Solid burnt clay brick		Rubber floor	1 800
up to 14 MPa (inclusive) compressive strength	1 500 to 1 700	Plastic tile	1 100
over 14 MPa compressive strength	1 900	Polyamide (e.g. diamid)	1 100
Walls made from brick with holes or ceramic blocks (depending on the type of brick and blocks used)	1 150 to 1 450	Polyester resin, without filler	1 350
		Polyethylene	930
		Polyisobutylene-base board	1 350
		Polymethylacrylate	1 150
		Polypropylene	930
		PVC hardboard	1 400
		PVC flooring board	1 600
		PVC flooring tile	1 700
		Flat glass	2 600
		Armoured glass	3 000

Material	Surface pressure N/m <sup>2</sup>	Surface density kg/m <sup>2</sup>
<b>Roof shells, roofings<sup>4)</sup></b>		
<b>Tile roofings</b>		
flat tile, burnt clay	380	38
pressed tile, burnt clay	480	48
flat tile, single roofing	350	35
flat tile, double roofing	700	70
flat concrete roofing tile	600	60
concrete tile, single roofing	400 to 500	40 to 50
<b>Metal plate roofings</b>		
galvanized steel plate (tin plate) roofing, 0,53 mm thick, folded or battened	40	4
double standing welt roofing from galvanized steel sheet roofing, 0,63 mm thick	55	5,5
zinc-plate roofing, 0,75 mm thick, welded	45	4,5
double-welt copper roof covering, 0,6 mm thick	60	6
aluminium sheet roofing		
0,6 mm thick	20	2
0,7 mm thick	25	2,5
lead-plate roofing, 2 mm thick, soldered	240	24
steel pantile roofing (galvanized)	150	15
sectional steel-plate roofing	75 to 240	7,5 to 24
<b>Other plate roofings</b>		
soft plastic roofing, 1 mm thick	90	9
bitumenized board roofing		
2 layer, nailed	80	8
3 layer with stuck gravel scattering	250	25
<b>Asbestos cement corrugated board roofings or reinforced with other fibres</b>		
standard roofing and corrugated board roofing	200	20
double board roofing	250	25
plastic corrugated board roofing, 1,5 mm thick	20	2
<b>Smearred and scattered roofing</b>		
plastic-bitumen roofing, 4 mm thick coating	50	5
synthetic glass roofing, 1 mm thick coating	60	6
flat glass roofing, 6 mm thick	200	20
armoured glass roofing, 6 mm thick	250	25
corrugated, armoured glass roofing, 6 mm thick	300	30
sectional glass roofing		
single	200	20
double	400	40

1) The body density of the wood should be increased by 120 kg/m<sup>3</sup> where in a state saturated with water and by 80 kg/m<sup>3</sup> in the case of a structure standing outdoors and not protected against atmospheric humidity.

2) For concrete grades (C), see ISO 3893 : 1977, *Concrete -- Classification by compressive strength*.

The value of the density of reinforced concrete shall be that as given for the appropriate concrete increased by 100 kg/m<sup>3</sup> where the reinforcement percentage is 1,25 or less. Appropriate adjustments shall be made for concrete reinforced to higher values.

3) The mass density of the masonry is taken without plaster but with mortar-filled voids. The mass density of concrete, light-weight concrete and reinforced concrete walls corresponds to the mass density value of the materials supplied.

4) The values do not include the fixing and supporting structures of the shell.

## Annex B

## Representative values of densities and angles of repose of stored materials

(This annex forms an integral part of the Standard.)

This annex gives the representative values of densities and angles of repose of stored materials in the form of a table.

Material	Density <sup>1)</sup> kg/m <sup>3</sup>		Angle of repose degrees
	natural heap <sup>2)</sup>	stack or pile <sup>3)</sup>	
<b>Building and construction materials</b>			
Basalt flagstone	—	2 750 to 3 000	—
Boulder clay	—	2 100	—
Brick sand, brick hardcore, brick chippings, moist earth	1 500	—	25 to 40
Cement	1 100 to 1 200	1 300 to 1 600	18 to 28
Clay			
fluorine, dry	1 100	—	—
heavy, air-dried	1 600	—	—
Cork grit	—	60	—
Coke ash	750	—	25
Crushed foamed slag	900	—	35
Expanded clay gravel			
light	250	—	30 to 35
medium	400	—	30 to 35
heavy	550	—	30 to 35
Fibreglass	—	160 to 180	—
Foamed scoria, crushed, moist earth	1 000	—	35
Glass wool	—	100 to 110	—
Granite flagstone	—	2 600 to 2 800	—
Gravel and dry sand or moist earth	1 800	—	30 to 36
Heat-insulating gas concrete	—	500	—
Heat-insulating perlite brick	—	260	—
Heat-insulating perlite pipe shell	—	260	—
Lime hydrate	500	600	25
Lime			
lumps	850 to 1 300	—	45
ground	600 to 1 300	1 000 to 1 100	25
Limestone powder	—	1 300	—
Magnesite (caustic magnesite), ground	—	1 200	—
Mineral wool and derivatives	—	75 to 260	—
Plaster	1 000	1 100 to 1 500	25
Plastics			
polyethylene, polystyrol, granulated	—	650	—
polyvinylchloride, powdered	—	600	—
polyester resin	—	1 200	—
Perlite	—	70 to 250	—
Reed sheet of roofing	—	150 to 220	—
Powdered coal ash	900	1 000 to 1 200	25
Silt	—	1 800	—
Slag wool	—	200 to 300	—
Slag, granulated	1 100	—	30
Slaked lime	—	1 300 to 1 400	—
Trass, ground	—	1 500	—
Wood-wool	—	300 to 380	—

Material	Density <sup>1)</sup> kg/m <sup>3</sup>		Angle of repose degrees
	natural heap <sup>2)</sup>	stack or pile <sup>3)</sup>	
<b>Combustibles and fuels</b>			
Coal			
mineral coal	900 to 1 200	—	30 to 35
coke	450 to 650	—	35 to 45
briquette			
eggett	800	—	25
cornered coal	700	—	35
brown coal			
dry	800	—	35
moist earth	1 000	—	30
briquette	800	—	30
coke	1 000	—	40
brown coal dust	500	—	25
Charcoal	250	—	—
Oils			
fuel, diesel oil	800 to 1 000	—	—
crude oil	980	—	—
Petrol (gasoline)	750 to 800	—	—
Petroleum	800	—	—
Liquid gas			
propane	500	—	—
butane	580	—	—
Wood (air-dried, about 15 % moisture)			
hard wood			
chopped	400 to 600	—	45
logs	500	600 to 700	50
soft wood			
chopped	250	400	45
logs	300	400 to 600	—
fire-wood	400	—	45
Brush wood	—	200	—
Peat	300 to 600	500 to 900	—
<b>Foodstuffs and agricultural products</b>			
Alcohol	800	—	—
Barley	500 to 800	—	30
Barley in bags	—	650 to 750	—
Beer			
in tanks	1 050	—	—
in barrels	—	900	—
Butter			
in barrels	—	550	—
cased or boxed	—	500 to 800	—
Cocoa in bags	—	550	—
Coffee in bags	—	550 to 700	—
Clover-seed in bags	—	750	—
Conserves in bottles or boxes	—	800	—
Dry fodder			
baled	—	350	—
ensiled	1 000	—	—
Edible oil			
in barrels	—	750	—
bottled, in crates	—	550	—
Eggs in egg-stands	—	550	—
Fat, boxed	—	800	—
Fish			
in barrels	—	600	—
cased	—	800	—
Flax in bales	—	1 300	—
Flax-seed in bags	—	700	—