Dimensional Tolerance: Limits and Fits

Limits and Fits

When parts are assembled together, engineers have to decide *how they will fit together* and the *economics* associated with it.

- *How they will fit together?*
  - Clearance fit
  - Transition fit
  - Interference fit
- Economics?
  - Interchangability

→ **Standards**
BS4500
ANSI B4.1

Limits and Fits - Definitions

- Basic size /nominal size - the reference size of hole/shaft to which the limit of size are fixed, the basic size is the same for both members of a fit.
- Limits of size - the maximum and minimum sizes permitted for a feature.
- Maximum limit of size - the greater of the 2 limits of size.
- Minimum limit of size - the smaller of the 2 limits of size.

Limits and Fits - Definitions

- Tolerance is the difference between the maximum limit of size and the minimum limit of size.
- Fit expresses the relationship between a mating parts with respect to the amount of clearance or interference which exists when they are assembled together.

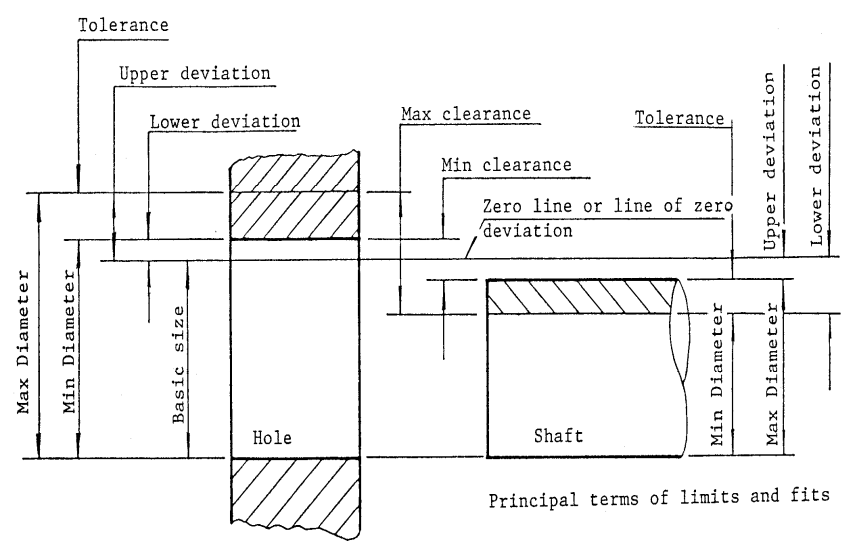
Limits and Fits - Definitions

- Hole - designate all INTERNAL features of a part, including parts which are not cylindrical.
- Shaft - designate all EXTFRNAL features of a part, including parts which are not cylindrical.
- Upper deviation - difference between the maximum limit of size and the corresponding basic size. This is designated 'ES' for a hole and 'es' for a shaft.

Limits and Fits - Definitions

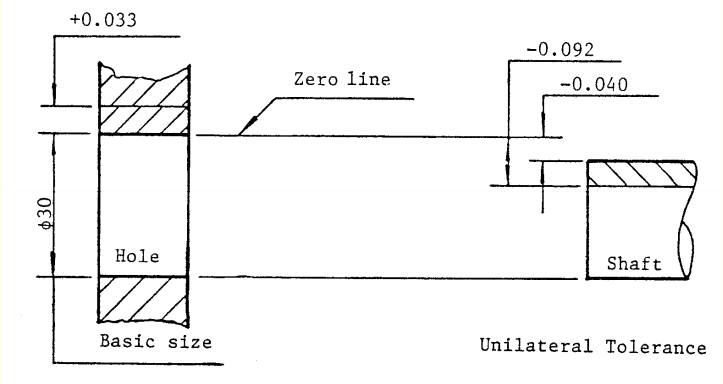
- Lower deviation - difference between the minimum limit of size and the corresponding basic size. This is designated 'EI' for a hole and 'ei' for a shaft.
- Grade of Tolerance - Group of tolerances with the same level of accuracy for all basic sizes.
- Clearance - difference between the size of the hole and shaft (positive)
- Clearance - difference between the size of the hole and shaft (negative)

Limits and Fits - Definitions



Unilateral Tolerance

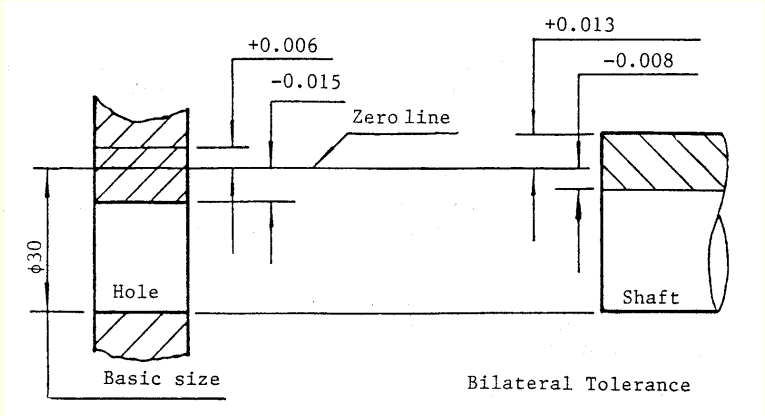
The upper and lower deviations are all positive or all negative. *hole* $\phi 30\ ^{+0.033}_{0}$ *shaft* $\phi 30\ ^{-0.040}_{-0.092}$



Bilateral Tolerance

The tolerance is split above and below the basic size

hole $\phi 30\ ^{+0.006}_{-0.015}$ *shaft* $\phi 30\ ^{+0.013}_{-0.008}$



Fundamental Deviations (BS4500)

- The 27 deviations for HOLES are:
- A B C CD D E.EF F G H JS J K M N P R S T U V X Y Z ZA ZB ZC
- The 27 deviations for SHAFTS are:
- a b c cd d e ef f g h js j k m n p r s t u v x y z za zb zc

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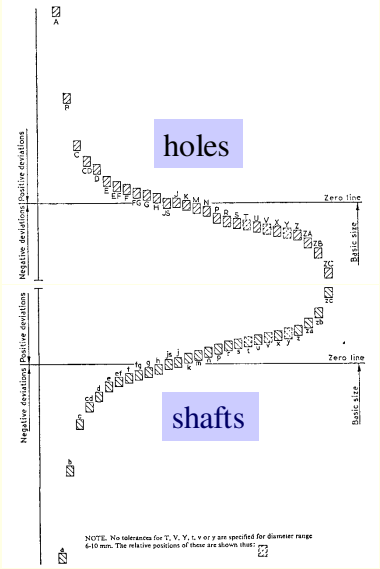
Fundamental Deviations

Grade 7 tolerance zone for the diameter range 6-10 mm



Grades of Tolerances

- There are 18 grades of tolerances IT01, IT0, and IT1 to IT16. (IT - ISO series Tolerances)
- IT01 and IT0 are very fine grades
- IT16 is the most coarse grade reflecting the precision of the process.
- The degree of error increases with:
  - the precision of the process (IT grade), and
  - the size of the component.

Grades of Tolerances

	Class of Work and Process	Tolerance for sample size (1/1000 mm) Nominal size (mm) Over 3 to 6	Over 50 to 80	Over 120 to 180
IT1	Slip blocks, reference gauges.	1.0	2	3.5
IT2	High quality gauges, plug gauges.	1.5	3	5
IT3	Good quality gauges, gap gauges.	2.5	5	8
IT4	Gauges, fit of extreme precision produced by lapping.	4	8	12
IT5	Ball bearings, machine lapping, fine grinding.	5	13	18
IT6	Grinding, fine honing.	8	19	25
IT7	High quality turning, broaching, honing.	12	30	40
IT8	Centre lathe work, capstan and automatic.	18	46	63
IT9	Worn capstan or automatic, horizontal and vertical boring.	30	74	100
IT10	Milling, slotting, planing, metal rolling or extrusion.	48	120	160
IT11	Drilling, rough turning, boring, precision tube drawing.	75	190	250
IT12	Light press work, tube drawing.	120	300	400
IT13	Press work - tube rolling.	180	460	630
IT14	Die casting or moulding, rubber moulding.	300	750	1000
IT15	Stamping.	480	1200	1600
IT16	Sand casting, flame cutting.	750	1900	2500

Limits and Fits Designation

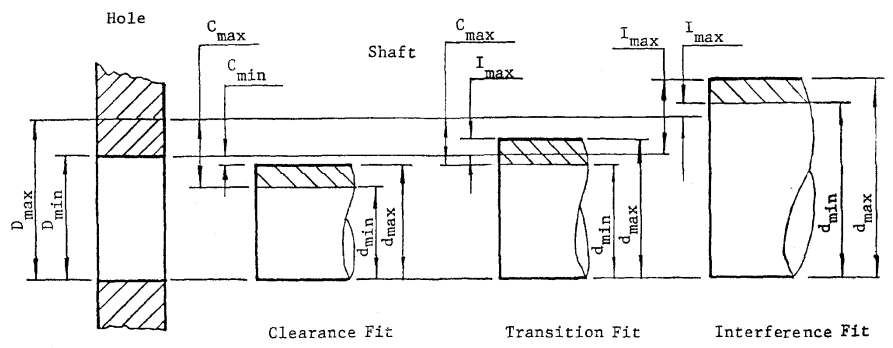
- A hole tolerance with deviation 'H' and tolerance grade IT7 is designated 'H7'.
- A shaft tolerance with deviation 'p' and tolerance grade IT6 is designated 'p6'.
- Appropriate tolerance designation for a feature of 45 mm, e.g. 45H7 or 45p6.
- A fit combines the basic size of both features and their designations. The designation of hole limits should always be quoted first. E.g. 4SH7-p6 or 45H7/p6.

Three Classes of Fit

- Clearance fit - A fit provides a clearance. The tolerance zone of the hole is entirely above that of the shaft.
- Transition fit - A fit provides either a clearance or an interference. The tolerance zones of the hole and the shaft overlaps.
- Interference fit - A fit provides an interference. The tolerance zone of the hole is entirely below that of the shaft.

Hole Basis System of Fit

- Associating various shafts with a single hole
- ISO - the lower deviation of the hole is zero

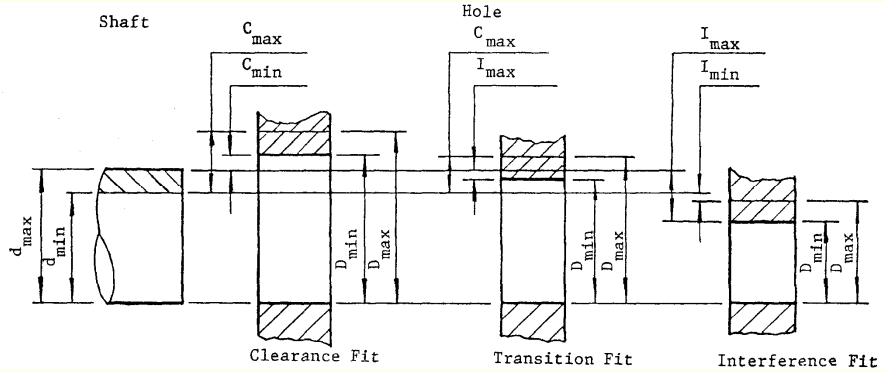


Hole Basis System of Fit

- More commonly used
- It is easier to manufacture shaft to the tolerance values and measure those values

Shaft Basis System of Fit

- Associating holes with a single shaft
- ISO - upper deviation of shaft is zero



Shaft Basis System of Fit

- Less commonly used
- Preferable when a shaft may have to accommodate a variety of accessories such as couplings, bearings, collars, gears, etc. - constant shaft diameter with varying bores of accessories to obtain different types of fits.

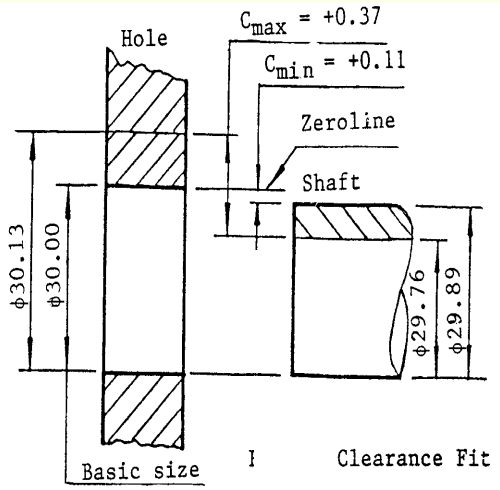
Example - Clearance Fit

Clearance fit, $\phi 30$ H11/c11

Hole dimension $\phi 30$ H11$\left(^{+0.13}_{0}\right)$

Shaft dimension $\phi 30$ c11$\left(^{-0.11}_{-0.24}\right)$

Largest hole	= 30.13
Small shaft	= 29.76
Max clearance	+0.37
Smallest hole	= 30.00
Largest shaft	= 29.89
Min clearance	+0.11



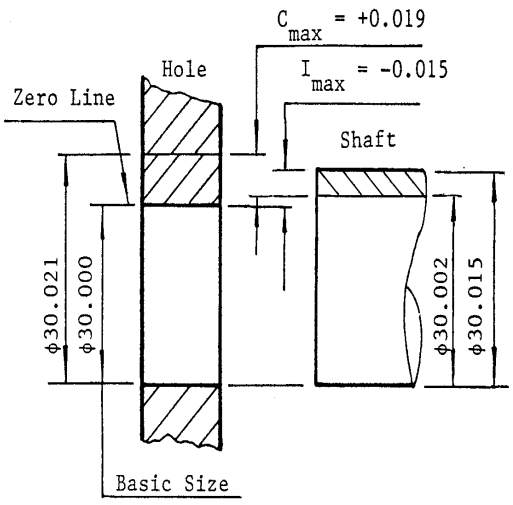
Example - Transition Fit

Transition fit, $\phi 30$ H7/k6

Hole dimension $\phi 30$ H7$\left(^{+0.021}_{0}\right)$

Shaft dimension $\phi 30$ k6$\left(^{+0.015}_{+0.002}\right)$

Largest hole	= 30.021
Smallest shaft	= 30.002
Max. clearance	+0.019
Smallest hole	= 30.000
Largest shaft	= 30.015
Max. interference	-0.015



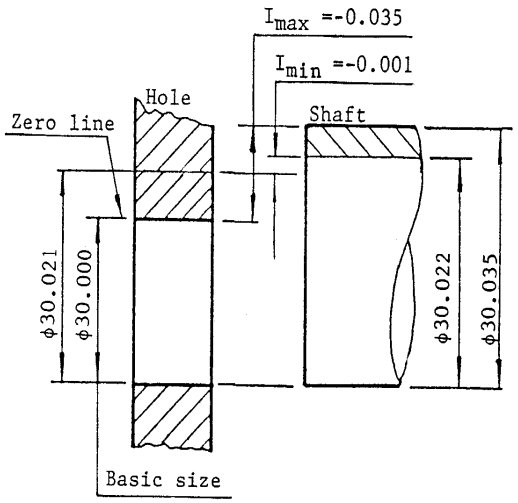
Example - Interference Fit

Interference fit, ϕ 30 H7/p6

Hole dimension ϕ 30 H7($^{+0.021}_{0}$)

Shaft dimension ϕ 30 p6($^{+0.035}_{+0.022}$)

Largest hole	= 30.021
Smallest shaft	= 30.022
Min. interference	-0.001
Smallest hole	= 30.000
Largest shaft	= 30.035
Max. inteference	-0.035



Drawing

$32^{+0.15}_{-0.20}$

32 ± 0.1

$32^{0}_{-0.02}$

(a) For shafts

ϕ30f7

or ϕ30f7($^{-0.020}_{-0.041}$)

or ϕ30f7($^{29.980}_{29.959}$)

(b) For holes

ϕ30H8

or ϕ30H8($^{+0.033}_{0}$)

or ϕ30H8($^{30.033}_{30.000}$)

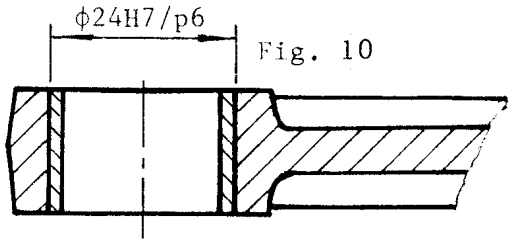


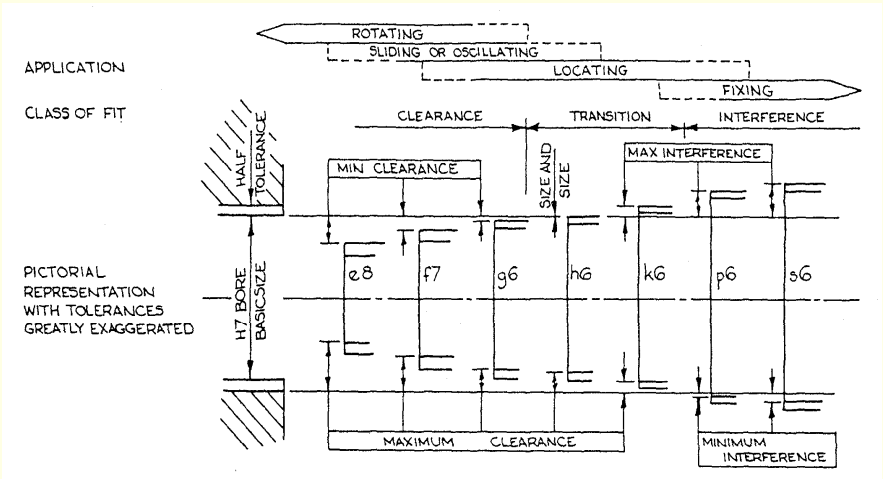
Fig. 10

ISO Fit (size 6-180 mm)

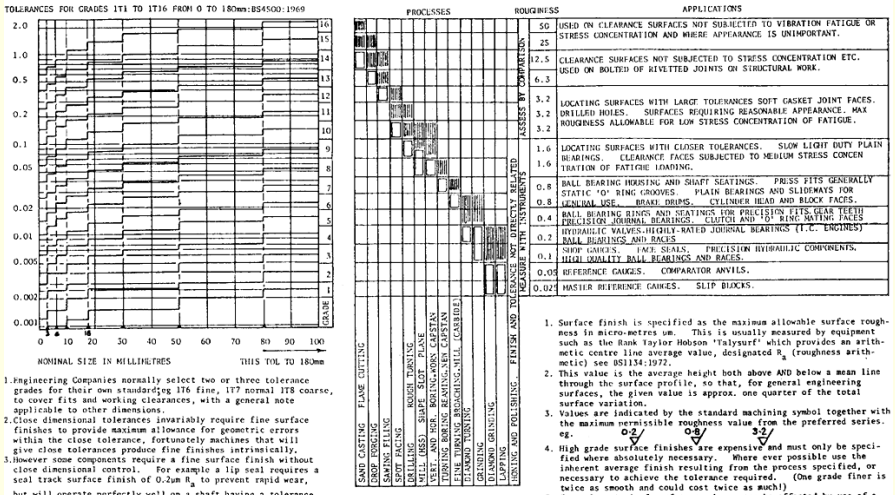
- Easy running - H7/e8
- Normal running - H7/f7
- Slide - H7/g6
- Location - H7/h6
- Push - H7/k6
- Light press - H7/p6
- Heavy press - H7/s6

Shafts and exposed bores should have chamfers

ISO Fit (size 6-180 mm)



TOLERANCE AND MACHINING PROCESSES RELATED TO SURFACE FINISH AND APPLICATIONS



1. Engineering Companies normally select two or three tolerance grades for their own standard eg IT6 fine, IT7 normal IT8 coarse, to cover fits and working clearances, with a general note applicable to other dimensions.
2. Close dimensional tolerances invariably require fine surface finishes to provide maximum allowance for geometric errors within the close tolerance, fortunately machines that will give close tolerances produce fine finishes intrinsically.
3. However some components require a fine surface finish without close dimensional control. For example a lip seal requires a seal track surface finish of 0.2um R_a to prevent rapid wear, but will operate perfectly well on a shaft having a tolerance grade of IT7 or even IT8 (rather than the grade IT4 normally associated with a 0.2um R_a surface finish).
4. Tolerance grades 1 to 5 are commonly used for gauges with grades 6 to 11 for fits. However, for high precision fits, grades 5 and 4 are frequently used, similarly grades 6 or 7 are adequate for gauges used to inspect coarse work.

Shaded panels show normal production capability: lower unshaded panels indicate finer work possible with extra care (and therefore extra cost).

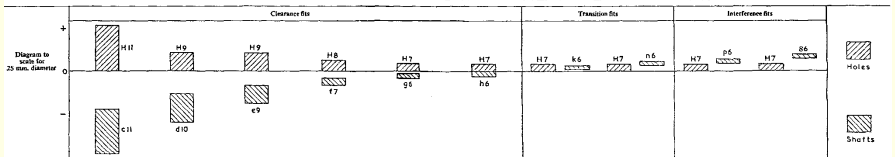
1. Surface finish is specified as the maximum allowable surface roughness in micro-metres um. This is usually measured by equipment such as the Rank Taylor Hobson 'Talysurf' which provides an arithmetic centre line average value, designated R_a (roughness arithmetic) see BS1134:1972.
2. This value is the average height both above AND below a mean line through the surface profile, so that, for general engineering surfaces, the given value is approx. one quarter of the total surface variation.
3. Values are indicated by the standard machining symbol together with the maximum permissible roughness value from the preferred series. eg. 0.2 / 0.8 / 3.2
4. High grade surface finishes are expensive and must only be specified where absolutely necessary. Where ever possible use the inherent average finish resulting from the process specified, or necessary to achieve the tolerance required. (One grade finer is twice as smooth and could cost twice as much!)
5. General control of surface roughness can be effected by use of a note: MACHINER SURFACES 3.2 um R_a MAX EXCEPT WHERE SHOWN OTHERWISE (For precision products 1.6 um R_a may be the normal standard)

Extracted from BS 4500 : 1969

BRITISH STANDARD

SELECTED ISO FITS—HOLE BASIS

Data Sheet 4500A
Issue 1. February 1970



Nominal sizes		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Nominal sizes	
Over	To	H11	c11	H9	d10	H9	e9	H8	F7	H7	g6	H7	h6	H7	k6	H7	n6	H7	p6	H7	s6	Over	To
mm	mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	mm	mm
—	3	+ 60 0	− 60 − 120	+ 25 0	− 20 − 60	+ 25 0	− 14 − 39	+ 14 0	− 6 − 16	+ 10 0	− 2 − 8	+ 10 0	− 6 0	+ 10 0	+ 6 + 0	+ 10 0	+ 10 + 4	+ 10 0	+ 12 + 6	+ 10 0	+ 20 + 14	—	3
3	6	+ 75 0	− 70 − 145	+ 30 0	− 30 − 78	+ 30 0	− 20 − 50	+ 18 0	− 10 − 22	+ 12 0	− 4 − 12	+ 12 0	− 8 0	+ 12 0	+ 9 + 1	+ 12 0	+ 16 + 8	+ 12 0	+ 20 + 12	+ 12 0	+ 27 + 19	3	6
6	10	+ 90 0	− 80 − 170	+ 36 0	− 40 − 98	+ 36 0	− 25 − 61	+ 22 0	− 13 − 28	+ 15 0	− 5 − 14	+ 15 0	− 9 0	+ 15 0	+ 10 + 1	+ 15 0	+ 19 + 10	+ 15 0	+ 24 + 15	+ 15 0	+ 32 + 23	6	10
10	18	+ 110 0	− 95 − 205	+ 43 0	− 50 − 120	+ 43 0	− 32 − 75	+ 27 0	− 16 − 34	+ 18 0	− 6 − 17	+ 18 0	− 11 0	+ 18 0	+ 15 + 1	+ 18 0	+ 23 + 12	+ 18 0	+ 29 + 18	+ 18 0	+ 39 + 28	10	18
18	30	+ 130 0	− 110 − 240	+ 52 0	− 65 − 149	+ 52 0	− 40 − 92	+ 33 0	− 20 − 41	+ 21 0	− 7 − 20	+ 21 0	− 13 0	+ 21 0	+ 15 + 2	+ 21 0	+ 28 + 15	+ 21 0	+ 35 + 22	+ 21 0	+ 48 + 35	18	30
30	40	+ 160 0	− 120 − 280																			30	40
40	50	+ 160 0	− 130 − 290	+ 62 0	− 80 − 180	+ 62 0	− 50 − 112	+ 39 0	− 25 − 50	+ 25 0	− 9 − 25	+ 25 0	− 16 0	+ 25 0	+ 18 + 2	+ 25 0	+ 33 + 17	+ 25 0	+ 42 + 26	+ 25 0	+ 59 + 43	40	50
50	65	+ 190 0	− 140 − 330																			50	65
65	80	+ 190 0	− 150 − 340	+ 74 0	− 100 − 220	+ 74 0	− 60 − 134	+ 46 0	− 30 − 60	+ 30 0	− 10 − 29	+ 30 0	− 19 0	+ 30 0	+ 21 + 2	+ 30 0	+ 39 + 20	+ 30 0	+ 51 + 32	+ 30 0	+ 78 + 59	65	80
80	100	+ 220 0	− 170 − 390																			80	100
100	120	+ 220 0	− 180 − 400	+ 87 0	− 120 − 260	+ 87 0	− 72 − 159	+ 54 0	− 36 − 71	+ 35 0	− 12 − 34	+ 35 0	− 22 0	+ 35 0	+ 25 + 3	+ 35 0	+ 45 + 23	+ 35 0	+ 59 + 37	+ 35 0	+ 93 + 71	100	120
120	140	+ 250 0	− 200 − 450																	+ 40 0	+ 117 + 92	120	140
140	160	+ 250 0	− 210 − 460	+ 100 0	− 145 − 305	+ 100 0	− 84 − 185	+ 63 0	− 43 − 83	+ 40 0	− 14 − 39	+ 40 0	− 25 0	+ 40 0	+ 28 + 3	+ 40 0	+ 52 + 27	+ 40 0	+ 68 + 43	+ 40 0	+ 125 + 100	140	160
160	180	+ 250 0	− 230 − 480																	+ 40 0	+ 133 + 108	160	180
180	200	+ 290 0	− 240 − 530																	+ 46 0	+ 151 + 122	180	200
200	225	+ 290 0	− 260 − 550	+ 115 0	− 170 − 355	+ 115 0	− 100 − 215	+ 72 0	− 50 − 96	+ 46 0	− 15 − 44	+ 46 0	− 29 0	+ 46 0	+ 33 + 4	+ 46 0	+ 60 + 31	+ 46 0	+ 79 + 50	+ 46 0	+ 159 + 130	200	225
225	250	+ 290 0	− 280 − 570																	+ 46 0	+ 169 + 140	225	250
250	280	+ 320 0	− 300 − 620	+ 130 0	− 190 − 400	+ 130 0	− 110 − 240	+ 81 0	− 56 − 108	+ 52 0	− 17 − 49	+ 52 0	− 32 0	+ 52 0	+ 36 + 4	+ 52 0	+ 66 + 34	+ 52 0	+ 88 + 56	+ 52 0	+ 140 + 108	250	280
280	315	+ 320 0	− 330 − 650																	+ 52 0	+ 202 + 170	280	315
315	355	+ 360 0	− 360 − 720	+ 140 0	− 210 − 440	+ 140 0	− 125 − 265	+ 89 0	− 62 − 119	+ 57 0	− 18 − 54	+ 57 0	− 36 0	+ 57 0	+ 40 + 4	+ 57 0	+ 73 + 37	+ 57 0	+ 98 + 62	+ 57 0	+ 226 + 190	315	355
355	400	+ 360 0	− 400 − 760																	+ 57 0	+ 244 + 208	355	400
400	450	+ 400 0	− 440 − 840	+ 155 0	− 230 − 480	+ 155 0	− 135 − 290	+ 97 0	− 68 − 131	+ 63 0	− 20 − 60	+ 63 0	− 40 0	+ 63 0	+ 45 + 5	+ 63 0	+ 80 + 40	+ 63 0	+ 108 + 68	+ 63 0	+ 272 + 232	400	450
450	500	+ 400 0	− 480 − 880																	+ 63 0	+ 292 + 252	450	500