THE ENGINEER'S TOOLBOX

Materials		
Densities		1 t/m^3 = 10 kN/m^3
	Water	1 t/m^3
	Concrete	2.4 t/m^3 normal weight 1.9 t/m^3 light weight
	Steel	7.8 t/m^3
	Timber	0.8 t/m^3
	Carbon fibre	1.5 t/m^3
	Aluminium	2.7 t/m^3
	Snow	0.1 to 0.3 t/m^3
	Sand/gravel	About 1.8 t/m^3 moist
	Rock	About 2.8 t/m^3
Strength and stress limits	Concrete (ult)	Work at about 30% f_{cu} Slabs/beams use fc_{cu} = 40 N/mm^2 Columns use f_{cu} = 40 to 60 N/mm^2 Shear stress: v = say 2.0 N/mm^2 for beams v = say 0.7 N/mm^2 for slabs and walls
	Structural steel Grade 50 (working)	Compressive stress: about 150 N/mm^2 unless slenderness governs Shear: about 100 N/mm^2 Tension: about 225 N/mm^2
	Steel cables (working)	Use 500 N/mm^2 for concept design
	Aluminium (working)	Use 80 N/mm^2
	Timber (working)	8 to 10 N/mm^2 compression or tension (along the grain)
	Glulam timber (working)	About 12 N/mm^2
	Carbon fibre (working)	Use about 200 N/mm^2 (but brittle!!)
	Masonry (working)	215 brick wall: about 200 kN/m run
	Bolts for steelwork (working)	Grade 8.8 16 mm bolt will carry about 4 tonnes (working) in single shear
	Welds for steelwork (working)	6 mm fillet weld will carry 0.48 kN per mm
	Bolts for timber (working)	12 mm diameter in 50 mm timber about 1 kN (100kg)
Stiffness	Concrete	28 kN/mm^2 (short term) 14 kN/mm^2 (long term)
	Steel	205 kN/mm^2
	Timber	6 kN/mm^2
	Aluminium	70 kN/mm^2
	Carbon fibre	120 kN/mm^2
	Sands and gravels	25 mm settlement at normal bearing capacity
	Double the depth	At least quadruple the stiffness

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Loads		
Loads (characteristic)	Average building	1 t/m^2 of floor area (10kN/m^2)
	Imposed loads	Residential: 1.5 to 2.5 kN/m^2
		Offices: 2.5 to 4.0 kN/m^2
		Partitions: 1.0 (light) to 2.5 (heavy) kN/m^2
		Plant rooms: 7.5 kN/m^2
		Car parking: 2.5 kN/m^2
		Factories/warehouses: 10.0 to 30.0 kN/m^2
		Stadia: 4.0 kN/m^2
		Museums: 4.0 to 10.0 kN/m^2
	Wind (UK)	1.0 kN/m^2, 100 kg/m^2 (smooth building, low drag)
		1.8 kN/m^2, 180 kg/m^2 (rough)
	Wind (typhoon)	4.0 kN/m^2, 400 kg/m^2 (medium)
	Earthquake	Up to 25% g horizontally
Ultimate Load factors	Rough first shot for everything	1.5 x working loads
	Dead load	1.4
	Live (imposed) load	1.6
	Wind	0.9 or 1.4
Fire resistance	Residential 2 storey	30 minutes
	Roofs	None
	Office more than 30m	2 hours sprinklered
	Basements	2 or 4 hours
Rough sizing		
Steel and concrete limiting proportions	Simply supported beams	About 18:1
	Continuous beams	About 22:1
	Cantilevers	About 7:1
	Trusses	About 30% deeper than beams
	Arches	About 6:1
	Cables	About 9:1
	Heavily loaded columns	About 12:1
	Lightly loaded columns	About 40:1
Timber	Joists	About 15:1
	Trusses	About 8:1

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Typical spans	Timber floorboards	400 mm
	Concrete composite beam deck	3 m between secondary steel beams
	Timber joists	Up to 5 m
	Rolled steel beams	Up to 18 m
	Steel trusses	Up to 90 m
	Steel arches	Up to 300 m
	Cable stayed roofs	Up to 300 m
	Concrete flat slabs	Up to 12 m
	Concrete beams	Up to 18 m
Typical grids	Offices	6 m by 6 m up to 18 m by 12 m
	Shops	5.5 m to 11 m (to suit units)
	Carparks	Stalls: 4.8 m by 2.4 m Aisles 6.0 m wide
	Factories/warehouse roofs	24 m by 24 m
	Airports/station roofs	36 m to 150 m by 24 m to 36 m
	Stadium roofs	48 m cantilevers
Standard reinforcement sizes		6, 8, 10, 12, 16, 20, 25, 32, 40 mm diameter
Typical storey heights	Residential	3 m
	Offices	4 m (2.7 m clear)
	Carparks	3 m (2.4 m clear)
	Factories/warehouse roofs	8 m to 16 m clear
	Airports/station roofs	About 18 m high
	Stadium roofs	Mustn't obstruct sightlines
Useful Analysis		
Force	Newton	F = ma
Bending moments	Simply supported beam at midspan	$wl^2/8$ (udl) Pl/4
	Cantilever at root	$wl^2/2$ (udl)
	Concrete beams	Design so that Mu applied is about 40% of its ultimate capacity Mr = 0.15.fcu.b.d2
Stiffness	2nd moment of area for a rectangle b wide and d deep	$I = b.d^3/12$
Stresses	Compression or tension	Stress = P/A (also pressure)
	Bending	Stress = M.y/I = M/z
	Shear	Stress = V/b.d (b = web thickness, d = effective depth)
Concrete column sizing	For short columns with minimum dimension = clear height/15:	Area (mm^2) = Load in newtons/18
	For slender columns:	Area (mm^2) = Load in newtons/12
Elastic modulus	z	$= bd^2/6$ (rectangular)

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Dynamics	Earthquake	Normally in the range 0.5 to 2 seconds
	Floor vibration	Typically, Frequency f = 18/√deflection If less than 5 Hz, watch out!
	Buildings	0.1 second per storey height
Deflection limits under working loads	Beams and trusses	1/360th of span under live load, 1/250th under dead load
	Cantilevers	1/180th under live load
	Stability systems under wind load	1/500th of height (whole building) 1/400th (worst storey)
	Between foundations	About 1/300th total
Foundations and retaining walls		
Bearing capacity	Rock	2000 + kN/m^2
	Dense sand/gravel	200 to 500 kN/m^2 (10 x SPT 'N' blows)
	Loose sand/gravel	50 to 100 kN/m^2
	Clays	25 (soft) to 400 kN/m^2 (very stiff)
Piles	Minimum spacing	3 diameters
	Piles in London Clay	(0.45 cu av x shaft perimeter)/3 + (9 cu base x base area)/3
Slope stability	Long term angle of repose	Phi Φ, for sands and gravels use 25° to 30°
	Short term safe(ish) stability Sands and gravels Clays Rock	1 vertical to 3 horizontal 1:1 Vertical but watch out for bedding planes
Pressures on retaining walls	Hydrostatic pressure	$= \rho_w gh$
	Active pressure coefficient	$k_a = \frac{1 - \sin\Phi}{1 + \sin\Phi}$
	Passive pressure coefficient	$K_p = \frac{1 + \sin\Phi}{1 - \sin\Phi}$
	At rest pressure coefficient	About 1.0
	Soil pressure (active, passive, at rest)	$= k.\ \rho_s gh$
Environmental and Climatic Factors		
Wind direction	Prevailing wind in UK	From South West
	Winter storms	From North East
Sun path	Over head at midday in summer, low 20°	Rises in the east, sets in the west
Thermal mass	As night time store	Need about 75 mm of concrete

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Water engineering		
Six most useful equations in practical hydraulics according to Ed	- Continuity	Q = vA
	- Archimedes	Immersed body experiences an up thrust equal to the water displaced
	- Bernoulli	$E = v^2/2g + y + (p/\rho g)$
	- Mannings	$v = 1/n\ (Rh)^{2/3}\ s^{1/2}$
	- weir flow	$q = C_d H1.5$
	- critical depth	$yc = (q^2/g)^{1/3}$
Watery rules of thumb	Flow velocities in UK rivers	are typically between 0.5 and 3 m/s
	Nine out of 10 errors in flood estimation	are a result of not measuring the catchment area correctly
	Flows in pressurised pipe systems	normally have velocities between 0.5 and 1.5 m/s
	Pressures in normal distribution systems	are typically between 1 and 6 bar (10-60 m).
	Gravity drainage systems	typically have velocities between 0.7 and 1.5 m/s
	Typical slopes in gravity drains	are 1:100 – 1:300
	Typical slopes on lowland UK rivers	are between 1:1000 and 1:300.
Pressure		$1t / m^2 / m$ height
Power generation		$Q\rho gh$ (watts)
Costs		
Approx costs	Residential buildings	£ 1500/m² 50 storey £ 1000/m² 3 storey
	Offices	£ 1800/m² 50 storey £ 1100/m² 3 storey
	Factories	£ 400/m² single storey
	Structural steel	£ 1000 per tonne (simple frames)
	Reinforced concrete	£ 150/m³ (simple) £ 250/m³ (complex)
	Timber	£ 1000/m³
	Structural earth fill	£ 15 to 20/m³ £ 12/m3 to dig and re-use clean fill from site £ 40/m³ to dig and dump clean fill from site £ 50 to 100/m³ to remove contaminated material from site
	Facades	£ 150/m² (brick) to £1000/m² curtain wall triple glazed

	Bored piles	600 mm diameter, £ 20 per metre plus £ 5000 mobilisation
	Sheet piles	£ 80/m^2 for 150kg/m^2 piles plus £ 5000 mobilisation
	Diaphragm walls	£ 250/m^2 for 900 thick plus £ 30,000 mobilisation
Reinforcement estimates	Pile caps	150 kg/m^3
(amount of reinforcement per cubic metre of concrete)	Rafts	80 kg/m^3
	Beams	250 kg/m^3
	Slabs	200 kg/m^3
	Columns	300 kg/m^3
	Walls	100 kg/m^3
Other things to ponder	When you are looking at options spend 90% of your effort on your favourite scheme and 10% on the rest	
	If it looks right, it probably is. If it looks wrong lose it!	
	Form follows function	
	God is in the details	
	The Devil is in the detail	
	Nine out of 10 errors in flood estimation are a result of not measuring the catchment area correctly	
	The best design is 10% inspiration 90% perspiration	
	The whole is greater than the sum of the parts (the worst third year projects are produced by groups acting as individuals)	
	Work expands to fill the time available	
	The law of diminishing returns (don't gild the Lily)	
	KISS – keep it simple stupid	
	If someone doesn't do what you asked them to, ask yourself whether you explained yourself clearly.	