2

Civil and Environmental Engineering

Properties of Dressed Lumber

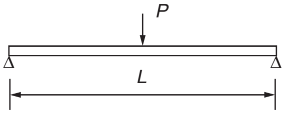
Standard Size Width × Depth	S4S Dressed Size Width × Depth	Cross-Sectional Area *A* (in.²)	Moment of Inertia I (in.⁴)	Section Modulus *S* (in.³)	Weight in Pounds per Lineal Foot[a]
1 × 4	¾ × 3½	2.63	2.68	1.53	0.64
1 × 6	¾ × 5¼	4.13	10.40	3.78	1.00
1 × 8	¾ × 7¼	5.44	23.82	6.57	1.32
1 × 12	¾ × 11¼	8.44	88.99	15.82	2.01
2 × 4	1½ × 3½	5.25	5.36	3.06	1.28
2 × 6	1½ × 5½	8.25	20.80	7.56	2.01
2 × 8	1½ × 7¼	10.88	47.64	13.14	2.64
2 × 10	1½ × 9¼	13.88	98.93	21.39	3.37
2 × 12	1½ × 11¼	16.88	177.98	31.64	4.10
4 × 2	3½ × 1½	5.25	.98	1.31	1.28
4 × 4	3½ × 3½	12.25	12.51	7.15	2.98
4 × 6	3½ × 5½	19.25	48.53	17.65	4.68
4 × 8	3½ × 7¼	25.38	111.15	30.66	6.17
6 × 2	5½ × 1½	8.25	1.55	2.06	2.01
6 × 4	5½ × 3½	19.25	19.65	11.23	4.68
6 × 6	5½ × 5½	30.25	76.26	27.73	7.35
6 × 8	5½ × 7¼	41.25	193.36	51.53	10.03
8 × 2	7¼ × 1½	10.88	2.04	2.72	2.64
8 × 4	7¼ × 3½	25.38	25.90	14.80	6.17
8 × 6	7¼ × 5½	41.25	103.98	37.81	10.03
8 × 8	7¼ × 7¼	56.25	263.67	70.31	13.67

[a] Weights are for wood with a density of 35 pounds per cubic foot.

From Alexander, A., Design and construction of concrete formwork, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **4**-4.

Beam Formulas

Simply Supported Beam with Concentrated Load at Center

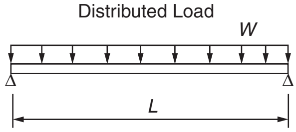


$$M_{max} = \frac{PL}{4}$$

$$\Delta = \frac{PL^3}{48EI}$$

$$V_{max} = \frac{P}{2}$$

Simply Supported Beam with Uniformly Distributed Load

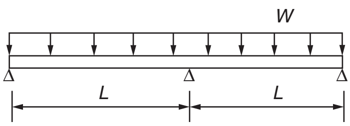


$$M_{max} = \frac{wL^2}{8}$$

$$\Delta_{max} = \frac{5wL^4}{384\,EI}$$

$$V_{max} = \frac{wL}{2}$$

Two Span Continuous Beam with Uniformly Distributed Load

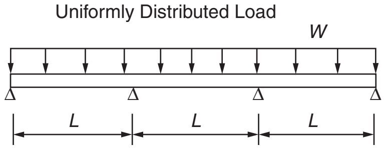


$$M_{max} = \frac{wL^2}{8}$$

$$\Delta_{max} = \frac{wL^4}{185EI}$$

$$V_{max} = \frac{5wL}{8}$$

Three Span Continuous Beam with Uniformly Distributed Load

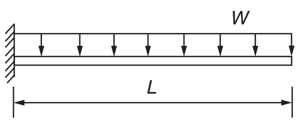


$$M_{max} = \frac{wL^2}{10}$$

$$\Delta_{max} = \frac{wL^4}{145EI}$$

$$V_{max} = .6wL$$

Cantilever Beam with Uniformly Distributed Load

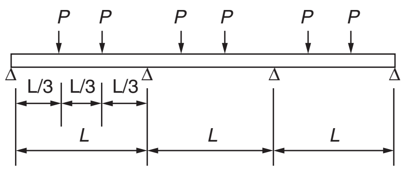


$$M_{max} = \frac{wL^2}{2}$$

$$\Delta_{max} = \frac{wL^4}{8EI}$$

$$V_{max} = wL$$

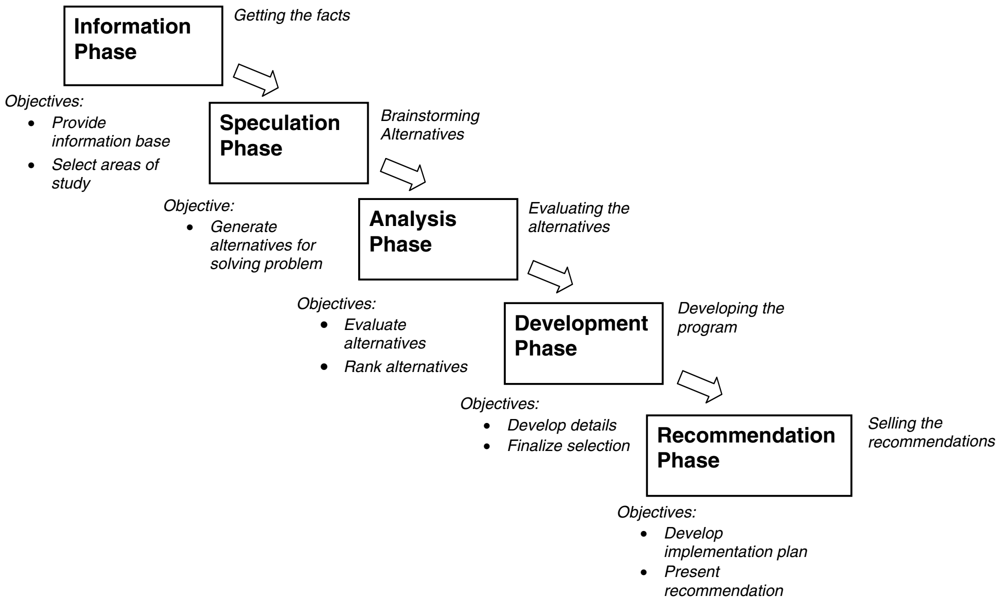
Three Span Continuous Beam with Concentrated Loads at Span Third Points



$$M_{max} = .267PL$$

$$V_{max} = 1.27P$$

From Alexander, A., Design and construction of concrete formwork, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **4**-23.



Phases in the value engineering job plan. From Chua, D.K.H., Value improvement methods, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **7**-2.

Maximum Contaminant Concentrations Allowable in Drinking Water (Action Levels)

	Authority		
Parameter	U.S. PHS[a]	U.S. EPA[b,c]	WHO[d]
	Pathogens and Parasites		
Total coliform bacteria (no./100mL)	1	<5% positive samples in a set of = 40 per month, or <1 sample positive in a set of <40 per month	0
	Inorganic Poisons (mg/L)		
Antimony	—	0.006	—
Arsenic	0.05	0.05 (Interim)	0.05
Asbestos (Million fibers > 10 μM per liter)	—	7	—
Barium	1	2	—
Beryllium	—	0.004	—
Cadmium	0.01	0.005	0.005
Chromium (Total)	0.05	0.1	0.05
Copper	—	1.3 90th percentile action level, requires corrosion control	—
Cyanide	0.2	0.2	0.1
Fluoride	See nuisances	4	—
Lead	0.05	0.015 90th percentile action level, requires corrosion control	0.05
Mercury (inorganic)	—	0.002	0.001
Nickel	—	0.1	—
Nitrate (as N)	10	10	10
Nitrite (as N)	—	1	—
Nitrate plus nitrite (as N)	—	10	—
Selenium	0.01	0.05	0.01
Sulfate	—	Deferred (400 to 500?)	—
Thallium	—	0.002	—
	Organic Poisons (μg/L, Except as Noted)		
Acrylamide	—	Use in treatment, storage, and distribution; restricted	—
Alachor	—	2	—
Aldicarb	—	3	—
Aldicarb sulfoxide	—	4	—
Aldicarb Sulfone	—	3	—
Aldrin and Dieldrin	—	—	0.03
Atrazine	—	3	—
Benzene	—	5	10
Benzo[a]pyrene	—	0.2	0.01
Bromobenzene	—	Monitor	—
Bromochloromethane	—	Monitor if ordered	—
Bromodichloromethane	—	Monitor	—
Bromoform	—	Monitor	—
Bromomethane	—	Monitor	—
n-Butylbenzene	—	Monitor if ordered	—
sec-Butylbenzene	—	Monitor if ordered	—
tert-Butylbenzene	—	Monitor if ordered	—
Carbofuran	—	40	—
Carbon chloroform extract	200	—	—

Maximum Contaminant Concentrations Allowable in Drinking Water (Action Levels) (continued)

Parameter	Authority: U.S. PHS[a]	U.S. EPA[b,c]	WHO[d]
Carbon tetrachloride	—	5	—
Chlordane	—	2	0.3
Chlorobenzene	—	100	—
Chlorodibromomethane	—	Monitor	—
Chloroethane	—	Monitor	—
Chloroform	—	Monitor	30
Chloromethane	—	Monitor	—
m-Chlorotoluene	—	Monitor	—
p-Chlorotoluene	—	Monitor	—
2,4-D	—	70	100
Dalapon	—	200	—
DDT	—	—	1
1,2-Dibromo-3-chloropropane (DBCP)	—	0.2	—
Dibromomethane	—	Monitor	—
m-Dichlorobenzene	—	Monitor	—
o-Dichlorobenzene	—	600	—
p-Dichlorobenzene	—	75	—
Dichlorodifluoromethane	—	Monitor if ordered	—
1,1-Dichloroethane	—	Monitor	—
1,2-Dichloroethane	—	5	10
1,1-Dichloroethylene	—	7	0.3
cis-1,2-Dichloroethylene	—	70	—
trans-1,2-Dichloroethylene	—	100	—
Dichloromethane	—	5	—
1,2-Dichloropropane	—	5	—
1,3-Dichloropropane	—	Monitor	—
2,2-Dichloropropane	—	Monitor	—
1,1-Dichloropropene	—	Monitor	—
1,3-Dichloropropene	—	Monitor	—
Di(2-ethylhexyl)adipate	—	400	—
Di(2-ethylhexyl)phthalate	—	6	—
Dinoseb	—	7	—
Dioxin (2,3,7,8-TCDD)	—	30×10^{-9}	—
Diquat	—	20	—
Endothall	—	100	—
Endrin	—	2	—
Epichlorhydrin	—	Use in treatment, storage, and distribution; restricted	—
Ethylbenzene	—	700	—
Ethylene dibromide (EDB)	—	0.05	—
Fluorotrichloromethane	—	Monitor if ordered	—
Glyphosate (aka Rodeo™ and Roundup™)	—	700	—
Heptachlor	—	0.4	0.1
Heptachlor epoxide	—	0.2	—
Hexachlorobenzene	—	1	0.01
Hexachlorobutadiene	—	Monitor if ordered	—
Hexachlorocyclopentadiene (HEX)	—	50	—
Isopropylbenzene	—	Monitor if ordered	—
p-Isopropyltolulene	—	Monitor if ordered	—
Lindane	—	0.2	3
Methoxychlor	—	40	30
Naphthalene	—	Monitor if ordered	—
Oxamyl (Vydate)	—	200	—
Pentachlorophenol	—	1	10

Maximum Contaminant Concentrations Allowable in Drinking Water (Action Levels) (continued)

Parameter	Authority U.S. PHS[a]	U.S. EPA[b,c]	WHO[d]
PCB (polychlorinate biphenyl)	—	0.5	—
Picloram	—	500	—
n-Propylbenzene	—	Monitor if ordered	—
Silvex (2,4,5-TP)	—	50	—
Simazine	—	4	—
Styrene	—	100	—
2,3,7,8-TCDD (Dioxin)	—	30×10^{-6}	—
1,1,1,2-Tetrachloroethane	—	Monitor	—
1,1,2,2-Tetrachloroethane	—	Monitor	—
Tetrachloroethylene	—	5	—
Toluene	—	1000	—
Toxaphene	—	3	—
1,2,3-Trichlorobenzene	—	Monitor if ordered	—
1,2,4-Trichlorobenzene	—	70	—
1,1,1-Trichloroethane	—	200	—
1,1,2-Trichloroethane	—	5	—
Trichloroethylene	—	5	—
1,2,3-Trichloropropane	—	Monitor	—
2,4,6-Trichlorophenol	—	—	10
Trihalomethanes (Total)	—	100	—
2,4-Trimethylbenzene	—	Monitor if ordered	—
1,3,5-Trimethylbenzene	—	Monitor if ordered	—
Vinyl chloride	—	2	—
Xylene (Total)	—	10,000	—
m-Xylene	—	Monitor	—
o-Xylene	—	Monitor	—
p-Xylene	—	Monitor	—
Radioactivity (pCi/L, except as noted)			
Gross alpha (excl. Ra, u)	—	15	2.7
Gross beta	1000	—	27
Gross beta/photon (mrem/yr)	—	4	—
Radium-226	10		—
Radium-226 and 228	—	5	—
Radon-222	—	300	—
Strontium-90	3	—	—
Uranium (mg/L)	—	.03	—
Nuisances (mg/L, except as noted)			
Alkyl benzene sulfonate	0.5	—	—
Aluminum	—	—-	0.2
Chloride	250	250	250
Color (Pt-Co Units)	15	15	15
Copper	1	See above	1
Corrosivity (Langelier Index)	—	—[e]	—
Fluoride	0.8–1.7 Depending on air temperature	See above	—
Hardness (as $CaCO_3$)	—	—	500
Hydrogen sulfide	—	—	—[f]
Iron	0.3	0.3	0.3
Manganese	0.05	0.05	0.1
Methylene blue active substances	—	0.5	—

Maximum Contaminant Concentrations Allowable in Drinking Water (Action Levels) (continued)

Parameter	Authority: U.S. PHS[a]	U.S. EPA[b,c]	WHO[d]
Odor (threshold odor no.)	3	3	—[g]
pH	—	6.5/8.5	6.5/8.5
Phenol (μg/L)	1	—	—
Silver	0.05	0.05	—
Sodium	—	—[e]	200
Sulfate	250	500	400
Taste	—	—	—[g]
Total dissolved solids	500	500	1000
Turbidity (nephelometric units)	5	All samples = ≤5; 95% of samples ≤ 0.5	5
Zinc	5	5	5
Disinfectants and Disinfection Byproducts (mg/L)			
Chlorine	—	4.	—
Chloramines		4.	—
Chlorine dioxide	—	0.8	—
Total trihalomethanes	—	0.080	—
Haloacetic acids	—	0.060	—
Chlorite	—	1.0	—
Bromate	—	0.010	—
Total organic carbon	—	Treatment	—

[a] Hopkins, O. C. 1962. *Public Health Service Drinking Water Standards 1962*. U.S. Department of Health Education, and Welfare, Public Health Service, Washington, DC.
[b] Pontius, F. W. 1990. "Complying with the New Drinking Water Quality Regulations," *Journal of the American Water Works Association,* 82(2): 32.
[c] Auerbach, J. 1994. "Cost and Benefits of Current SDWA Regulations," *Journal of the American Water Works Association,* 86(2): 69.
[d] Anonymous. 1984. *Guidelines For Drinking Water Quality*: Volume 1. Recommendations. World Health Organization, Geneva, Switzerland.
[e] To be monitored and reported to appropriate agency and/or public.
[f] Not detectable by consumer.
[g] Not offensive for most consumers.

From Sykes, R.M., Water and wastewater planning, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, pp. **8**-3 to **8**-6.

National Ambient Air Quality Standards

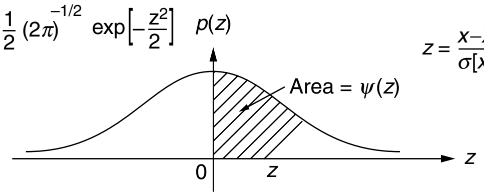
Criteria Pollutant	Averaging Period	Primary NAAQS ($\mu g/m^3$)	Secondary NAAQS ($\mu g/m^3$)
PM_{10}	Annual	50	150
	24 hours	150	150
$PM_{2.5}$	Annual[a]	15	15
	24 hours[a]	65	65
Sulfur dioxide (SO_2)	Annual	80	
	24 hours	365	
	3 hours		1300
Nitrogen dioxide (NO_2)	Annual	100	100
Ozone	1 hour	235	235
	8 hours[a]	157	157
Carbon monoxide (CO)	8 hours	10,000	10,000
	1 hour	40,000	40,000
Lead	Quarterly	1.5	1.5

[a] The 1997 Revised $PM_{2.5}$ and 8-hour ozone were challenged in court and were the subject of a significant question regarding the constitutionality of EPA's power to make policy without legislative review and EPA's responsibility to consider economic implications of policymaking. A February 27, 2001, ruling by the Supreme Court found the EPA could move forward with the $PM_{2.5}$ standard but must review the proposed ozone standard. The revised standards were cleared of remaining legal hurdles in March 2002.

From Jacko, R.B. and LaBreche, T.M.C., Air pollution, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **12**-4.

Standard Normal Probability

$$\text{for } z > 2.2,\ \psi(z) \approx \frac{1}{2} - \frac{1}{2}(2\pi)^{-1/2} \exp\left[-\frac{z^2}{2}\right]$$



$$z = \frac{x - \bar{x}}{\sigma[x]}$$

z	0	1	2	3	4	5	6	7	8	9
0	0	.003969	.007978	.011966	.015953	.019939	.023922	.027903	.031881	.035856
.1	.039828	.043795	.047758	.051717	.055670	.059618	.063559	.067495	.071424	.075345
.2	.079260	.083166	.087064	.090954	.094835	.098706	.102568	.106420	.110251	.114092
.3	.117911	.121720	.125516	.129300	.133072	.136831	.140576	.144309	.148027	.151732
.4	.155422	.159097	.162757	.166402	.170031	.173645	.177242	.180822	.184386	.187933
.5	.191462	.194974	.198466	.201944	.205401	.208840	.212260	.215661	.219043	.222405
.6	.225747	.229069	.232371	.235653	.238914	.242154	.245373	.248571	.251748	.254903
.7	.258036	.261148	.264238	.267305	.270350	.273373	.276373	.279350	.282305	.285236
.8	.288145	.291030	.293892	.296731	.299546	.302337	.305105	.307850	.310570	.313267
.9	.315940	.318589	.321214	.323814	.326391	.328944	.331472	.333977	.336457	.338913
1.0	.341345	.343752	.346136	.348495	.350830	.353141	.355428	.357690	.359929	.362143
1.1	.364334	.366500	.368643	.370762	.372857	.374928	.376976	.379000	.381000	.382977
1.2	.384930	.386861	.388768	.390651	.392512	.394350	.396165	.397958	.399727	.401475
1.3	.403200	.404902	.406582	.408241	.409877	.411492	.413085	.414657	.416207	.417736
1.4	.419243	.420730	.422196	.423641	.425066	.426471	.427855	.429219	.430563	.431888
1.5	.433193	.434476	.435745	.436992	.438220	.439429	.440620	.441792	.442947	.444083
1.6	.445201	.446301	.447384	.448449	.449497	.450529	.451543	.452540	.453521	.454486
1.7	.455435	.456367	.457284	.458185	.459070	.459941	.460796	.461636	.462462	.463273
1.8	.464070	.464852	.465620	.466375	.467116	.467843	.468557	.469258	.469946	.470621
1.9	.471283	.471933	.472571	.473197	.473610	.474412	.475002	.475581	.476148	.476705
2.0	.477250	.477784	.478308	.478822	.479325	.479818	.480301	.480774	.481237	.481691
2.1	.482136	.482571	.482997	.483414	.483823	.484222	.484614	.484997	.485371	.485738
2.2	.486097	.486447	.486791	.487126	.487455	.487776	.488089	.488396	.488696	.488989
2.3	.489276	.489556	.489830	.490097	.490358	.490613	.490863	.491106	.491344	.491576
2.4	.491802	.492024	.492240	.492451	.492656	.492857	.493053	.493244	.493431	.493613
2.5	.493790	.493963	.494132	.494297	.494457	.494614	.494766	.494915	.495060	.495201
2.6	.495339	.495473	.495604	.495731	.495855	.495975	.496093	.496207	.496319	.496427
2.7	.496533	.496636	.496736	.496833	.496928	.497020	.497110	.497197	.497282	.497365
2.8	.497445	.497523	.497599	.497673	.497744	.497814	.497882	.497948	.498012	.498074
2.9	.498134	.498193	.498250	.498305	.498359	.498411	.498462	.498511	.498559	.498605
3.0	.498650	.498694	.498736	.498777	.498817	.498856	.498893	.498930	.498965	.498999
3.1	.499032	.499065	.499096	.499126	.499155	.499184	.499211	.499238	.499264	.499289
3.2	.499313	.499336	.499359	.499381	.499402	.499423	.499443	.499462	.499481	.499499
3.3	.499517	.499534	.499550	.499566	.499581	.499596	.499610	.499624	.499638	.499651
3.4	.499663	.499675	.499687	.499698	.499709	.499720	.499730	.499740	.499749	.499758
3.5	.499767	.499776	.499784	.499792	.499800	.499807	.499815	.499822	.499828	.499835
3.6	.499841	.499847	.499853	.499858	.499864	.499869	.499874	.499879	.499883	.499888
3.7	.499892	.499896	.499900	.499904	.499908	.499912	.499915	.499918	.499922	.499925
3.8	.499928	.499931	.499933	.499936	.499938	.499941	.499943	.499946	.499948	.499950
3.9	.499952	.499954	.499956	.499958	.499959	.499961	.499963	.499964	.499966	.499967

From Harr, M.E., Accounting for variability, in *The Civil Engineering Handbook,* 2nd ed., Chen. W.F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **16**-11.

Typical Values of Elastic Modulus and Poisson's Ratio for Granular Soils

	Elastic Modulus, E_s		
Type of Soil	MPa	lb/in.^{2}	Poisson's ratio, μ
Loose sand	10–24	1,500–3,500	0.20–0.40
Medium dense sand	17–28	2,500–4,000	0.25–0.40
Dense sand	35–55	5,000–8,000	0.30–0.45
Silty sand	10–17	1,500–2,500	0.20–0.40
Sand and gravel	69–170	10,000–25,000	0.15–0.35

From Humphrey, D.N., Strength and deformation, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **17**-8. Originally from Das, B. M. 1990. *Principles of Foundation Engineering,* 2nd ed., p. 161. PWS-Kent Publishing Co., Boston. With permission.

Representative Applications and Controlling Functions of Geotextiles

Primary Function	Application	Secondary Functions
Separation	Unpaved roads (temporary and permanent)	Filter, drains, reinforcement
	Paved roads (secondary and primary)	Filter, drains
	Construction access roads	Filter, drains, reinforcement
	Working platforms	Filter, drains, reinforcement
	Railroads (new construction)	Filter, drains, reinforcement
	Railroads (rehabilitation)	Filter, drains, reinforcement
	Landfill covers	Drains, reinforcement
	Preloading (stabilization)	Drains, reinforcement
	Marine causeways	Filter, drains, reinforcement
	General fill areas	Filter, drains, reinforcement
	Paved and unpaved parking facilities	Filter, drains, reinforcement
	Cattle corrals	Filter, drains, reinforcement
	Coastal and river protection	Filter, drains, reinforcement
	Sports fields	Filter, drains
Drainage-transmission	Retaining walls	Separation, filter
	Vertical drains	Separation, filter
	Horizontal drains	Reinforcement
	Below membranes (drainage of gas and water)	Reinforcement
	Earth dams	Filter
	Below concrete (decking and slabs)	—
Reinforcement	Pavement overlays	—
	Concrete overlays	—
	Subbase reinforcement in roadways and railways	Filter
	Retaining structures	Drains
	Membrane support	Separation, drains, filter
	Embankment reinforcement	Drains
	Fill reinforcement	Drains
	Foundation support	Drains
	Soil encapsulation	Drains, filter separation
	Net against rockfalls	Drains
	Fabric retention systems	Drains
	Sandbags	—
	Reinforcement of membranes	—
	Load redistribution	Separation
	Bridging nonuniformity soft soil areas	Separation
	Encapsulated hydraulic fills	Separation
	Bridge piles for fill placement	—
Filter	Trench drains	Separation, drains
	Pipe wrapping	Separation, drains
	Base course drains	Separation, drains
	Frost protection	Separation, drainage, reinforcement
	Structural drains	Separation, drains
	Toe drains in dams	Separation, drains
	High embankments	Drains
	Filter below fabric-form	Separation, drains
	Silt fences	Separation, drains
	Silt screens	Separation
	Culvert outlets	Separation
	Reverse filters for erosion control:	
	Seeding and mulching	
	Beneath gabions	
	Ditch amoring	
	Embankment protection, coastal	
	Embankment protection, rivers and streams	
	Embankment protection, lakes	
	Vertical drains (wicks)	Separation

From Holtz, R.D., Geosynthetics, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **24**-3. Originally from Christopher, B. R., and Holtz, R. D. 1989. *Geotextile Design and Construction Guidelines.*, U.S. Federal Highway Administration, National Highway Institute, Report No. FHWA-HI-90-001.

Physical Properties of Water in SI Units*

Temperature, °F	Specific Weight γ, lb/ft³	Density ρ, slugs/ft³	Viscosity $\mu \times 10^5$, lb·s/ft²	Kinematic Viscosity $\nu \times 10^5$, ft²/s	Surface Tension $\sigma \times 10^2$ lb/ft	Vapor Pressure p_u, psia	Vapor Pressure Head p_u/γ, ft	Bulk Modulus of Elasticity $E_u \times 10^{-3}$, psi
0	9.805	999.8	1.781	1.785	0.0756	0.61	0.06	2.02
5	9.807	1000.0	1.518	1.519	0.0749	0.87	0.09	2.06
10	9.804	999.7	1.307	1.306	0.0742	1.23	0.12	2.10
15	9.798	999.1	1.139	1.139	0.0735	1.70	0.17	2.14
20	9.789	998.2	1.002	1.003	0.0728	2.34	0.25	2.18
25	9.777	997.0	0.890	0.893	0.0720	3.17	0.33	2.22
30	9.764	995.7	0.798	0.800	0.0712	4.24	0.44	2.25
40	9.730	992.2	0.653	0.658	0.0696	7.38	0.76	2.28
50	9.689	988.0	0.547	0.553	0.0679	12.33	1.26	2.29
60	9.642	983.2	0.466	0.474	0.0662	19.92	2.03	2.28
70	9.589	977.8	0.404	0.413	0.0644	31.16	3.20	2.25
80	9.530	971.8	0.354	0.364	0.0626	47.34	4.96	2.20
90	9.466	965.3	0.315	0.326	0.0608	70.10	7.18	2.14
100	9.399	958.4	0.282	0.294	0.0589	101.33	10.33	2.07

* In this table and in the others to follow, if $\mu \times 10^5 = 3.746$ then $\mu = 3.746 \times 10^{-5}$ lb·s/ft², etc. For example, at 80°F, $\sigma \times 10^2 = 0.492$ or $\sigma = 0.00492$ lb/ft and $E_u \times 10^{-3} = 322$ or $E_u = 322{,}000$ psi.

From Lyn, D.A., Fundamentals of hydraulics, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **29**-27. Originally from Daugherty, R.L., Franzini, J.B., and Finnemore, E.J. (1985) *Fluid Mechanics with Engineering Applications*, 8th ed., McGraw-Hill, New York. With permission.

Physical Properties of Air at Standard Atmospheric Pressure in English Units

Temperature		Density	Specifc Weight	Viscosity	Kinematic Viscosity
T, °F	T, °C	$\rho \times 10^3$, slugs/ft³	$\gamma \times 10^2$, lb/ft³	$\mu \times 10^7$, lb·s/ft²	$\nu \times 10^4$, ft²/s
–40	–40.0	2.94	9.46	3.12	1.06
–20	–28.9	2.80	9.03	3.25	1.16
0	–17.8	2.68	8.62	3.38	1.26
10	–12.2	2.63	8.46	3.45	1.31
20	–6.7	2.57	8.27	3.50	1.36
30	–1.1	2.52	8.11	3.58	1.42
40	4.4	2.47	7.94	3.62	1.46
50	10.0	2.42	7.79	3.68	1.52
60	15.6	2.37	7.63	3.74	1.58
70	21.1	2.33	7.50	3.82	1.64
80	26.7	2.28	7.35	3.85	1.69
90	32.2	2.24	7.23	3.90	1.74
100	37.8	2.20	7.09	3.96	1.80
120	48.9	2.15	6.84	4.07	1.89
140	60.0	2.06	6.63	4.14	2.01
160	71.1	1.99	6.41	4.22	2.12
180	82.2	1.93	6.21	4.34	2.25
200	93.3	1.87	6.02	4.49	2.40
250	121.1	1.74	5.60	4.87	2.80

From Lyn, D.A., Fundamentals of hydraulics, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **29**-28. Originally from Daugherty, R.L., Franzini, J.B., and Finnemore, E.J. (1985) *Fluid Mechanics with Engineering Applications*, 8th ed., McGraw-Hill, New York. With permission.

Physical Properties of Common Liquids at Standard Atmospheric Pressure in SI Units

Liquid	Temperature T, °F	Density ρ, kg/m^3	Specific Gravity, s	Viscosity $\mu \times 10^4$, N·s/m^2	Surface Tension σ, N/m	Vapor Pressure p_u, kN/m^2, abs	Modulus of Elasticity $E_u \times 10^{-6}$, N/m^2
Benzene	20	895	0.90	6.5	0.029	10.0	1030
Carbon tetrachloride	20	1588	1.59	9.7	0.026	12.1	1100
Crude oil	20	856	0.86	72	0.03		
Gasoline	20	678	0.68	2.9	……	55	
Glycerin	20	1258	1.26	14,900	0.063	0.000014	4350
Hydrogen	–257	72	0.072	0.21	0.003	21.4	
Kerosene	20	808	0.81	19.2	0.025	3.20	
Mercury	20	13,550	13.56	15.6	0.51	0.00017	26,200
Oxygen	–195	1206	1.21	2.8	0.015	21.4	
SAE 10 oil	20	918	0.92	820	0.037		
SAE 30 oil	20	918	0.92	4400	0.036		
Water	20	998	1.00	10.1	0.073	2.34	2070

From Lyn, D.A., Fundamentals of hydraulics, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **29**-29. Originally from Daugherty, R.L., Franzini, J.B., and Finnemore, E.J. (1985) *Fluid Mechanics with Engineering Applications*, 8th ed., McGraw-Hill, New York. With permission.

Physical Properties of Common Gases at Standard Sea-Level Atmosphere and 68°F in English Units

Liquid	Chemical Formula	Molecular Weight	Specific Weight, γ, lb/ft^3	Viscosity $\mu \times 10^7$, lb·s/ft^2	Gas Constant R, ft·lb/(slug·°R) [= ft^2/(s^2·°R)]	Specific Heat, ft·lb/(slug·°R) [= ft^2/(s^2·°R)] c_p	c_u	Specific Heat Ratio $k = c_p/c_u$
Air		29.0	0.0753	3.76	1715	6000	4285	1.40
Carbon dioxide	CO_2	44.0	0.114	3.10	1123	5132	4009	1.28
Carbon monoxide	CO	28.0	0.0726	3.80	1778	6218	4440	1.40
Helium	He	4.00	0.0104	4.11	12,420	31,230	18,810	1.66
Hydrogen	H_2	2.02	0.00522	1.89	24,680	86,390	61,710	1.40
Methane	CH_4	16.0	0.0416	2.80	3100	13,400	10,300	1.30
Nitrogen	N_2	28.0	0.0728	3.68	1773	6210	4437	1.40
Oxygen	O_2	32.0	0.0830	4.18	1554	5437	3883	1.40
Water vapor	H_2O	18.0	0.0467	2.12	2760	11,110	8350	1.33

From Lyn, D.A., Fundamentals of hydraulics, in *The Civil Engineering Handbook*, 2nd ed., Chen, W.-F. and Liew J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **29**-30. Originally from Daugherty, R.L., Franzini, J.B., and Finnemore, E.J. (1985) *Fluid Mechanics with Engineering Applications*, 8th ed., McGraw-Hill, New York. With permission.

Typical Physical Properties of and Allowable Stresses for Some Common Materials (in U.S. Customary System Units)

Material	Unit Weight (lb/in.^{3})	Ultimate Strength (ksi)			Yield Strength (ksi)		Allow Stresses (psi)		Elastic Moduli ($\times 10^{-6}$ psi)		Coefficient of Thermal Expansion ($\times 10^6$/°F)
		Tension	Compression	Shear	Tension	Shear	Tension or Compression	Shear	Tension or Compression	Shear	
Aluminum alloy (extruded)											
2024-T4	0.100	60	—	32	44	25			10.6	4.00	12.9
6061-T6		38	—	24	35	20			10.0	3.75	13.0
Cast iron											
gray	0.276	30	120	—	—	—			13	6	5.8
malleable		54	—	48	36	24			25	12	6.7
Concrete											
8 gal/sack	0.087	—	3	—	—	—	–1350	66	3	—	6.0
6 gal/sack		—	5	—	—	—	–2250	86	5	—	—
Magnesium alloy, AM100A	0.065	40	—	21	22	—	—	—	6.5	2.4	14.0
Steel											
0.2% carbon (hot rolled)		65	—	48	36	24	±24,000	14,500			
0.6% carbon (hot rolled)	0.283	100	—	80	60	36			30	12	6.5
0.6% carbon (quenched)		120	—	100	75	45					
3½% Ni, 0.4% C		200	—	150	150	90					
Wood											
Douglas fir (coast)	0.018	—	7.4	1.1	—	—	±1900	120	1.76	—	—
Southern pine (longleaf)	0.021	—	8.4	1.5	—	—	±2250	135	1.76	—	—

From Pan, A.D.E. and Popov, E.P., Mechanics of materials, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **46**-7.

Typical Physical Properties of and Allowable Stresses for Some Common Materials (in SI System Units)

Material	Unit Mass ($\times 10^3$ kg/m^3)	Ultimate Strength (MPa)			Yield Strength (MPa)		Allow Stresses (MPa)		Elastic Moduli (GPa)		Coefficient of Thermal Expansion ($\times 10^{-6}$/°C)
		Tension	Compression	Shear	Tension	Shear	Tension or Compression	Shear	Tension or Compression	Shear	
Aluminum alloy (extruded)											
2014-T6	2.77	414	—	220	300	170			73	27.6	23.2
6061-T6		262	—	165	241	138			70	25.9	23.4
Cast iron											
gray	7.64	210	825	—	—	—			90	41	10.4
malleable		370	—	330	250	165			170	83	12.1
Concrete											
0.70 water-cement ratio	2.41	—	20	—	—	—	–9.31	0.455	20	—	10.8
0.53 water-cement ratio		—	35	—	—	—	–15.5	0.592	35	—	
Magnesium alloy, AM100A	1.80	275	—	145	150	—	—	—	45	17	25.2
Steel											
0.2% carbon (hot rolled)		450	—	330	250	165	+165.0	100			
0.6% carbon (hot rolled)	7.83	690	—	550	415	250			200	83	11.7
0.6% carbon (quenched)		825	—	690	515	310					
3½% Ni, 0.4% C		1380	—	1035	1035	620					
Wood											
Douglas fir (coast)	0.50	—	51	7	—	—	+13.1	0.825	12.1	—	—
Southern pine (longleaf)	0.58	—	58	10	—	—	+15.5	0.930	12.1	—	—

From Pan, A.D.E. and Popov, E.P., Mechanics of materials, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **46**-8.

Some Distribution Types

Distribution	PMF ($p_X(x)$) or PDF ($f_X(x)$)	Mean, $E[X]$	Variance, Var$[X]$
Binomial	$p_X(x) = \binom{n}{x} p^x (1-p)^{n-x}$ $x = 0, 1, 2, \ldots, n$	np	$np(1 - p)$
Poisson	$p_X(x) = \frac{(\nu t)^x}{x!} e^{-\nu t}$	νt	νt
Normal	$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$ $-\infty < x < \infty$	μ	σ^2
Lognormal	$f_X(x) = \frac{1}{x\zeta\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \lambda}{\zeta}\right)^2\right]$ $0 < x < \infty$	$e^{\left(\lambda + \frac{1}{2}\zeta^2\right)}$	$e^{\left(2\lambda + \zeta^2\right)}\left[e^{\zeta^2} - 1\right]$
Rayleigh	$f_X(x) = \frac{x}{\alpha^2} \exp\left[-\frac{1}{2}\left(\frac{x}{\alpha}\right)^2\right]$ $0 \le x < \infty$	$\alpha\sqrt{\frac{\pi}{2}}$	$\left(2 - \frac{\pi}{2}\right)\alpha^2$
Exponential	$f_X(x) = \lambda \exp\left[-\lambda(x - \tau)\right]$ $\tau \le x < \infty$	$\tau + \frac{1}{\lambda}$	$\frac{1}{\lambda^2}$
Gumbel type I maximum	$f_X(x) = \alpha \exp\left[-\alpha(x-u) - e^{-\alpha(x-u)}\right]$ $-\infty < x < \infty$	$u + \frac{0.5772}{\alpha}$	$\frac{\pi^2}{6\alpha^2}$
Fretchet type II maximum	$f_X(x) = \frac{k}{\nu - \tau}\left(\frac{\nu - \tau}{x - \tau}\right)^{k+1} \exp\left[-\left(\frac{\nu - \tau}{x - \tau}\right)^k\right]$ $\varepsilon < x < \infty$	$(\nu - \tau)\Gamma\left(1 - \frac{1}{k}\right) + \tau$	$(\nu - \tau)^2\left[\Gamma\left(1 - \frac{2}{k}\right)\right] - \Gamma^2\left(1 - \frac{1}{k}\right)$
Weibull type III minimum	$f_X(x) = \frac{k}{w - \varepsilon}\left(\frac{x - \varepsilon}{w - \varepsilon}\right)^{k-1} \exp\left[-\left(\frac{x - \varepsilon}{w - \varepsilon}\right)^k\right]$ $\varepsilon < x < \infty$	$(w - \varepsilon)\Gamma\left(1 - \frac{1}{k}\right) + \varepsilon$	$(w - \varepsilon)^2\left[\Gamma\left(1 - \frac{2}{k}\right) + \Gamma^2\left(1 - \frac{1}{k}\right)\right]$

From Quek, S.-T., Structural reliability, in *The Civil Engineering Handbook,* 2nd ed., Chen, W.-F. and Liew, J.Y.R., Eds., CRC Press, Boca Raton, FL, 2003, p. **52**-4.

Typical Compound Composition of Ordinary Portland Cement

Chemical Formula	Shorthand Notation	Chemical Name	Weight Percent
$3CaO \cdot SiO_2$	C_3S	Tricalcium silicate	50
$2CaO \cdot SiO_2$	C_2S	Dicalcium silicate	25
$3CaO \cdot Al_2O_3$	C_3A	Tricalcium aluminate	12
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF	Tetracalcium aluminoferrite	8
$CaSO_4 \cdot 2H_2O$	CSH_2	Calcium sulfate dihydrate (gypsum)	3.5

From Mindness, S., Concrete constituent matenaus, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **1**–4.

Properties of Some Lightweight Concretes

Type of Lightweight Concrete	Type of Aggregate	Aggregate Density, kg/m^3	Concrete Density, kg/m^3
Aerated	—	—	400–600
Partially compacted	Expanded vermiculite and perlite	5–240	400–1150
	Foamed slag	480–960	960–1500
	Sintered pulverized-fuel ash	640–960	1100–1300
	Expanded clay or shale	560–1040	950–1200
Structural lightweight aggregate concrete	Foamed slag	480–960	1650–2050
	Sintered pulverized-fuel ash	640–960	1350–1750
	Expanded clay or shale	560–1040	1350–1850

From Mindness, S., Concrete constituent matenaus, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **1**–16.

Mechanical Properties of Hardened Concrete

					Strength, MPa								E
					Compressive*						Splitting-tensile†	Flexura‡	Modulus,§
Mix	MK Content, %	Silica Fume Content, %	W/C or W/C + MK or W/C + SF	Unit Weight, kg/m^3	1 Day	3 Days	7 Days	28 Days	90 Days	180 Days	28 Days	28 Days	GPa 28 Days
CO	0	0	0.40	2350	20.9	25.5	28.9	36.4	42.5	44.2	2.7	6.3	29.6
MK10	10	—	0.40	2330	25.0	32.9	37.9	39.9	43.0	46.2	3.1	7.4	32.0
SF10	—	10	0.40	2320	23.2	28.6	34.7	44.4	48.0	50.2	2.8	7.0	31.1

Note: MK, Metakaolin: W/C, water/cementitous material ratio; SF, silica fume.

* Average of three 102 × 203-mm cylinders.

† Average of two 152 × 305-mm cylinders.

‡ Average of two 102 × 76 × 406-mm prims.

§ Average of two 152 × 305-mm cylinders.

From Malhotra, V.M., Mineral admixtures, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **2**-38. Originally from Zhang, M.H. and Malhotra, V.M. 1995. Characteristics of a thermally activated alumina-silicate pozzolanic material and its use in concrete. *Cement Concrete Res.* 25(8):1713–1725.

ACI 318 Maximum Chloride-Ion Content for Corrosion Protection

Type of Application	Maximum Water-Soluble Chloride Ion (Cl^-) in Concrete, Percent by Weight of Cement
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in serviced	1.00
Other reinforced concrete construction	0.30

From Whitney, D.P., Chemical admixtures, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **3**-9. Originally from ACI 318-95/318R-95 Building Code and Commentary.

Properties of Typical Air-Entraining Admixtures

Name Brand	Manufacturer	Active Ingredient	Dosage	Sp. Gr.
Protex regular	Protex Industries	Neutral vinusol resin	0.3–1.0	1.044
Darex AEA	WR Grace & Co.	Organic acid salts	0.65–1.95	1.00–1.05
Airex "D"	Mulco, Inc.	Sulfonated HC salt	1.5–1.85	1.01–1.03
Plastair	SikaChemical Corp.	Vinusol resin	1.4	—
Plastade	Sternson	Coconut acid amide	0.6–1.9	1.0

From Whitney, D.P., Chemical admixtures, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **3**-11. Originally from Dolch, W.I. 1984. Air-entraining admixtures. In *Concrete Admixtures Handbook Properties, Science, and Technology*, V.S. Ramachandran, ed., pp. 269–302. Noyes Publications, Park Ridge, NJ.

Total Target Air Content for Concrete

Nominal Maximum Aggregate Size, in.	Air Content, %*		
	Severe Exposure†	Moderate Exposure†	Mild Exposure†
⅜	7½	6	4½
½	7	5½	4
¾	6	5	3½
1	6	4½	3
1½	5½	4½	2½
2‡	5	4	2
3‡	4½	3½	1½

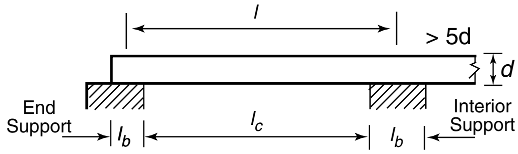
* Project specifications often allow the air content of the delivered concrete to be within –1 to +2 percentage points of the table target values.

† Severe exposure is an environment in which concrete is exposed to wet freeze-thaw conditions, deicers, or other aggressive agents. Moderate exposure is an environment in which concrete is exposed to freezing but will not be continually moist, will not be exposed to water for long periods before freezing, and will not be in contact with deicers or aggressive chemicals. Mild exposure is an environment in which concrete is not exposed to freezing conditions, deicers or aggressive agents.

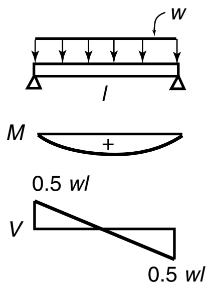
‡ These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1½ in. is removed by hand-picking or sieving and air content is determined on the minus 1½ in. fraction of mix. (Tolerance on air content as delivered applies to this value.) Air content of the total mix is computed from the value determined on the minus 1½ in. fraction.

From Whitney, D.P., Chemical admixtures, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **3**-13. Originally from Kosmatka, S.H. and Panarese, W.C. 1988. *Design and Control of Concrete Mixtures,* 13th ed., Portland Cement Association, Skokie, Ill.

UNIFORMLY LOADED BEAM FORMULAS FOR WOOD DESIGN



ONE SPAN



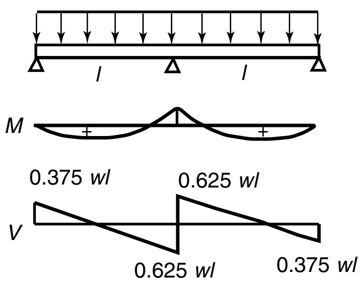
$$\Delta_{max} = \frac{5}{384}\ \frac{wl^4}{E'I}$$

$$M_{max} = wl^2/8$$

$$V_{EM} = \left[0.5\ wl - w\left(d + \frac{l_b}{2}\right)\right]$$

(end, modified)

TWO SPANS



$$\Delta_{max} = \frac{1}{185}\ \frac{wl^4}{E'I}$$

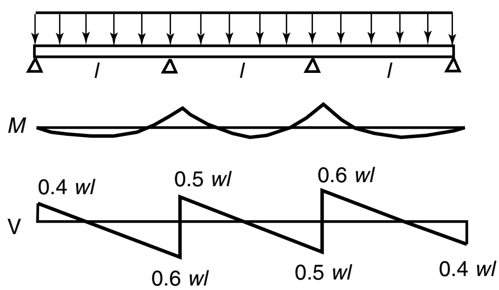
$$M_{max} = wl^2/8$$

$$V_{EM} = \left[0.375\ wl - w\left(d + \frac{l_b}{2}\right)\right]$$

$$V_{IM} = \left[0.625\ wl - w\left(d + \frac{l_b}{2}\right)\right]$$

(interior, modified)

THREE (or more) SPANS



$$\Delta_{max} = \frac{1}{145}\ \frac{wl^4}{E'I}$$

$$M_{max} = wl^2/10$$

$$V_{EM} = \left[0.4\ wl - w\left(d + \frac{l_b}{2}\right)\right]$$

$$V_{IM} = \left[0.6\ wl - w\left(d + \frac{l_b}{2}\right)\right]$$

DESIGN NOTES:

1. If l_b is unknown, use $l_b = 0$ for shear calculations.
2. If d is unknown when calculating shear force, either:
   a) Assume $d = 0$ in calc. and re-evaluate with d determined if shear controls.
   b) Assume a likely value of d and check with an additional iteration when d is determined.

Beam formulas for one-, two-, and three-span conditions. (From Johnston, D.W., Design and construction of concrete formwork, in *Concrete Construction Engineering Handbook,* Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. 7-33.)

Theoretical Maximum Load Ratios on Floor and Prop for Various Shore/Reshore Combinations

	Absolute Maximum Load Ratio		Converged Maximum Load Ratio	
Shore + Reshore	On Floor Slab	On Prop	On Floor Slab	On Prop
1 + 1	1.50	1.0	1.50	1.0
1 + 2	1.34	1.0	1.34	1.0
1 + 3	1.25	1.0	1.25	1.0
1 + 4	1.20	1.0	1.20	1.0
1 + 5	1.17	1.0	1.17	1.0
2 + 0	2.25	2.0	2.00	1.0
2 + 1	1.83	2.0	1.78	1.11
2 + 2	1.75	2.0	1.67	1.17
2 + 3	1.61	2.0	1.60	1.21
2 + 4	1.60	2.0	1.56	1.25
2 + 5	1.55	2.0	1.53	1.24
3 + 0	2.36	3.0	2.00	1.34
3 + 1	2.10	3.0	1.87	1.37
3 + 2	1.97	3.0	1.80	1.40
3 + 3	1.84	3.0	1.76	1.42
3 + 4	1.77	3.0	1.72	1.43
3 + 5	1.77	3.0	1.70	1.43

From Ghosh, S.K., Construction loading in high-rise buildings, in *Concrete Construction Engineering Handbook*, Nawy, E.G., Ed., CRC Press, Boca Raton, FL, 1998, p. **8**-7. Originally from Lasisi, M.Y. and Ng, S.F. 1979. Construction loads imposed on high-rise floor slabs. *Concrete Int.* 1(2):24–29.

Selected Earthquakes Since 1900 (Fatalities Greater than 1,000)[a]

Year	Day-Month	Location	Latitude	Longitude	Deaths	M	Comments/Damage ($ millions)
1902	19-Apr	Guatemala	14N	91W	2,000	7.5	
	16-Dec	Turkestan	40.8N	72.6E	4,500	6.4	
1903	19-Apr	Turkey	39.1N	42.4E	1,700		
	28-Apr	Turkey	39.1N	42.5E	2,200	6.3	
1905	04-Apr	India, Kangra	33.0N	76.0E	19,000	8.6	
	08-Sep	Italy, Calabria	39.4N	16.4E	2,500	7.9	
1906	31-Jan	Colombia	1N	81.5W	1,000	8.9	
	16-Mar	Taiwan, Kagi	23.6N	120.5E	1,300	7.1	
	18-Apr	San Francisco, CA	38N	123W	2,000+	8.3	Conflagration
	17-Aug	Chile, Santiago	33S	72W	20,000	8.6	Conflagration
1907	14-Jan	Jamaica, Kingston	18.2N	76.7W	1,600	6.5	Conflagration
	21-Oct	Central Asia	38N	69E	12,000	8.1	
1908	28-Dec	Italy, Messina	38N	15.5E	70,000	7.5	Deaths possibly 100,000
1909	23-Jan	Iran	33.4N	49.1E	5,500	7.3	
1912	09-Aug	Turkey, Marmara Sea	40.5N	27E	1,950	7.8	
1915	13-Jan	Italy, Avezzano	42N	13.5E	29,980	7.5	
1917	21-Jan	Indonesia, Bali	8.0S	115.4E	15,000		
	30-Jul	China	28.0N	104.0E	1,800	6.5	
1918	13-Feb	China, Canton	23.5N	117.0E	10,000	7.3	
1920	16-Dec	China, Gansu	35.8N	105.7E	200,000	8.6	Major fractures, landslides
1923	24-Mar	China	31.3N	100.8E	5,000	7.3	
	25-May	Iran	35.3N	59.2E	2,200	5.7	
	01-Sep	Japan, Kanto	35.0N	139.5E	143,000	8.3	$2800, conflagration

Selected Earthquakes Since 1900 (Fatalities Greater than 1,000)[a] (continued)

Year	Day-Month	Location	Latitude	Longitude	Deaths	M	Comments/Damage ($ millions)
1925	16-Mar	China, Yunnan	25.5N	100.3E	5,000	7.1	
1927	07-Mar	Japan, Tango	35.8N	134.8E	3,020	7.9	
	22-May	China, nr Xining	36.8N	102.8E	200,000	8.3	Large fractures
1929	01-May	Iran	38N	58E	3,300	7.4	
1930	06-May	Iran	38.0N	44.5E	2,500	7.2	
	23-Jul	Italy	41.1N	15.4E	1,430	6.5	
1931	31-Mar	Nicaragua	13.2N	85.7W	2,400	5.6	
1932	25-Dec	China, Gansu	39.7N	97.0E	70,000	7.6	
1933	02-Mar	Japan, Sanriku	39.0N	143.0E	2,990	8.9	
	25-Aug	China	32.0N	103.7E	10,000	7.4	
1934	15-Jan	India, Bihar-Nepal	26.6N	86.8E	10,700	8.4	
1935	20-Apr	Formosa	24.0N	121.0E	3,280	7.1	
	30-May	Pakistan, Quetta	29.6N	66.5E	30,000	7.5	Deaths possibly 60,000
	16-Jul	Taiwan	24.4N	120.7E	2,700	6.5	
1939	25-Jan	Chile, Chillan	36.2S	72.2W	28,000	8.3	$100
	26-Dec	Turkey, Erzincan	39.6N	38E	30,000	8	
1940	10-Nov	Romania	45.8N	26.8E	1,000	7.3	
1942	26-Nov	Turkey	40.5N	34.0E	4,000	7.6	
	20-Dec	Turkey, Erbaa	40.9N	36.5E	3,000	7.3	Some reports of 1,000 killed
1943	10-Sep	Japan, Tottori	35.6N	134.2E	1,190	7.4	
	26-Nov	Turkey	41.0N	33.7E	4,000	7.6	
1944	15-Jan	Argentina, San Juan	31.6S	68.5W	5,000	7.8	Deaths possibly 8,000
	01-Feb	Turkey	41.4N	32.7E	2,800	7.4	Deaths possibly 5,000
	07-Dec	Japan, Tonankai	33.7N	136.2E	1,000	8.3	
1945	12-Jan	Japan, Mikawa	34.8N	137.0E	1,900	7.1	
	27-Nov	Iran	25.0N	60.5E	4,000	8.2	
1946	31-May	Turkey	39.5N	41.5E	1,300	6	
	10-Nov	Peru, Ancash	8.3S	77.8W	1,400	7.3	Landslides, great destruction
	20-Dec	Japan, Tonankai	32.5N	134.5E	1,330	8.4	
1948	28-Jun	Japan, Fukui	36.1N	136.2E	5,390	7.3	Conflagration
	05-Oct	Turkmenistan	38.0N	58.3E	110,000	7.3	
1949	05-Aug	Ecuador, Ambato	1.2S	78.5E	6,000	6.8	Large landslides
1950	15-Aug	India, Assam; Tibet	28.7N	96.6E	1,530	8.7	Great topographical changes
1954	09-Sep	Algeria, Orleansvl.	36N	1.6E	1,250	6.8	
1957	27-Jun	USSR (Russia)	56.3N	116.5E	1,200		
	02-Jul	Iran	36.2N	52.7E	1,200	7.4	
	13-Dec	Iran	34.4N	47.6E	1,130	7.3	
1960	29-Feb	Morocco, Agadir	30N	9W	10,000	5.9	Deaths possibly 15,000
	22-May	Chile	39.5S	74.5W	4,000	9.5	Deaths possibly 5,000
1962	01-Sep	Iran, Qazvin	35.6N	49.9E	12,230	7.3	
1963	26-Jul	Yugoslavia, Skopje	42.1N	21.4E	1,100	6	Shallow depth just under city
1966	19-Aug	Turkey, Varto	39.2N	41.7E	2,520	7.1	
1968	31-Aug	Iran	34.0N	59.0E	12,000	7.3	Deaths possibly 20,000
1969	25-Jul	Eastern China	21.6N	111.9E	3,000	5.9	
1970	04-Jan	Yunnan, China	24.1N	102.5E	10,000	7.5	
	28-Mar	Turkey, Gediz	39.2N	29.5E	1,100	7.3	
	31-May	Peru	9.2S	78.8W	66,000	7.8	Great rockslide; $500
1972	10-Apr	Iran, southern	28.4N	52.8E	5,054	7.1	
	23-Dec	Nicaragua	12.4N	86.1W	5,000	6.2	Managua
1974	10-May	China	28.2N	104.0E	20,000	6.8	
	28-Dec	Pakistan	35.0N	72.8E	5,300	6.2	

Selected Earthquakes Since 1900 (Fatalities Greater than 1,000)[a] (continued)

Year	Day-Month	Location	Latitude	Longitude	Deaths	M	Comments/Damage ($ millions)
1975	04-Feb	China	40.6N	122.5E	10,000	7.4	
	06-Sep	Turkey	38.5N	40.7E	2,300	6.7	
1976	04-Feb	Guatemala	15.3N	89.1W	23,000	7.5	$6,000
	06-May	Italy, northeastern	46.4N	13.3E	1,000	6.5	
	25-Jun	New Guinea	4.6S	140.1E	422	7.1	West Irian
	27-Jul	China, Tangshan	39.6N	118.0E	255,000	8	Deaths possibly 655,000; $2,000
	16-Aug	Philippines	6.3N	124.0E	8,000	7.9	Mindanao
	24-Nov	Iran-USSR border	39.1N	44.0E	5,000	7.3	
1977	04-Mar	Romania	45.8N	26.8E	1,500	7.2	
1978	16-Sep	Iran, Tabas	33.2N	57.4E	15,000	7.8	$11
1980	10-Oct	Algeria, El Asnam	36.1N	1.4E	3,500	7.7	
	23-Nov	Italy, southern	40.9N	15.3E	3,000	7.2	
1981	11-Jun	Iran, southern	29.9N	57.7E	3,000	6.9	
	28-Jul	Iran, southern	30.0N	57.8E	1,500	7.3	
1982	13-Dec	W. Arabian Peninsula	14.7N	44.4E	2,800	6	
1983	30-Oct	Turkey	40.3N	42.2E	1,342	6.9	
1985	19-Sep	Mexico, Michoacan	18.2N	102.5W	9,500	8.1	Deaths possibly 30,000
1986	10-Oct	El Salvador	13.8N	89.2W	1,000	5.5	
1987	06-Mar	Colombia-Ecuador	0.2N	77.8W	1,000	7	
1988	20-Aug	Nepal-India border	26.8N	86.6E	1,450	6.6	
	07-Dec	Armenia, Spitak	41.0N	44.2E	25,000	7	$16,200
1990	20-Jun	Iran, western	37.0N	49.4E	40,000	7.7	Deaths possibly 50,000
	16-Jul	Philippines, Luzon	15.7N	121.2E	1,621	7.8	Landslides, subsidence
1991	19-Oct	India, northern	30.8N	78.8E	2,000	7	
1992	12-Dec	Indonesia, Flores	8.5S	121.9E	2,500	7.5	Tsunami wave height 25 m
1993	29-Sep	India, southern	18.1N	76.5E	9,748	6.3	
1995	16-Jan	Japan, Kobe	34.6N	135E	6,000	6.9	$100,000, conflagration
	27-May	Sakhalin Island	52.6N	142.8E	1,989	7.5	
1997	10-May	Iran, northern	33.9N	59.7E	1,560	7.5	4,460 injured; 60,000 homeless
1998	04-Feb	Afghanistan	37.1N	70.1E	2,323	6.1	Also Tajikistan
	30-May	Afghanistan	37.1N	70.1E	4,000	6.9	Also Tajikistan
	17-Jul	Papua New Guinea	2.96S	141.9E	2,183	7.1	Tsunami
1999	25-Jan	Colombia	4.46N	75.82W	1,185	6.3	
	17-Aug	Turkey	40.7N	30.0E	17,118	7.4	50,000 injured; $7,000
	20-Sep	Taiwan	23.7N	121.0E	2,297	7.6	8,700 injured; 600,000 homeless
2001	26-Jan	India, Bhuj	23.3 N	70.3 E	19,988	7.7	166,812 injured; 600,000 homeless
Total Events = 108			Total Deaths = 1,762,802				

[a] Magnitude scale varies.

From Scawthorn, C., Earthquakes: A historical perspective, in *Earthquake Engineering Handbook*, Chen, W.-F. and Scawthorn, C., Eds., CRC Press, Boca Raton, FL, 2003, pp. **1**-2 to **1**-4. Originally from National Earthquake Information Center, Golden, CO, http://neic.usgs.gov/neis/eqlists/eqsmajr.html.

Selected U.S. Earthquakes[a]

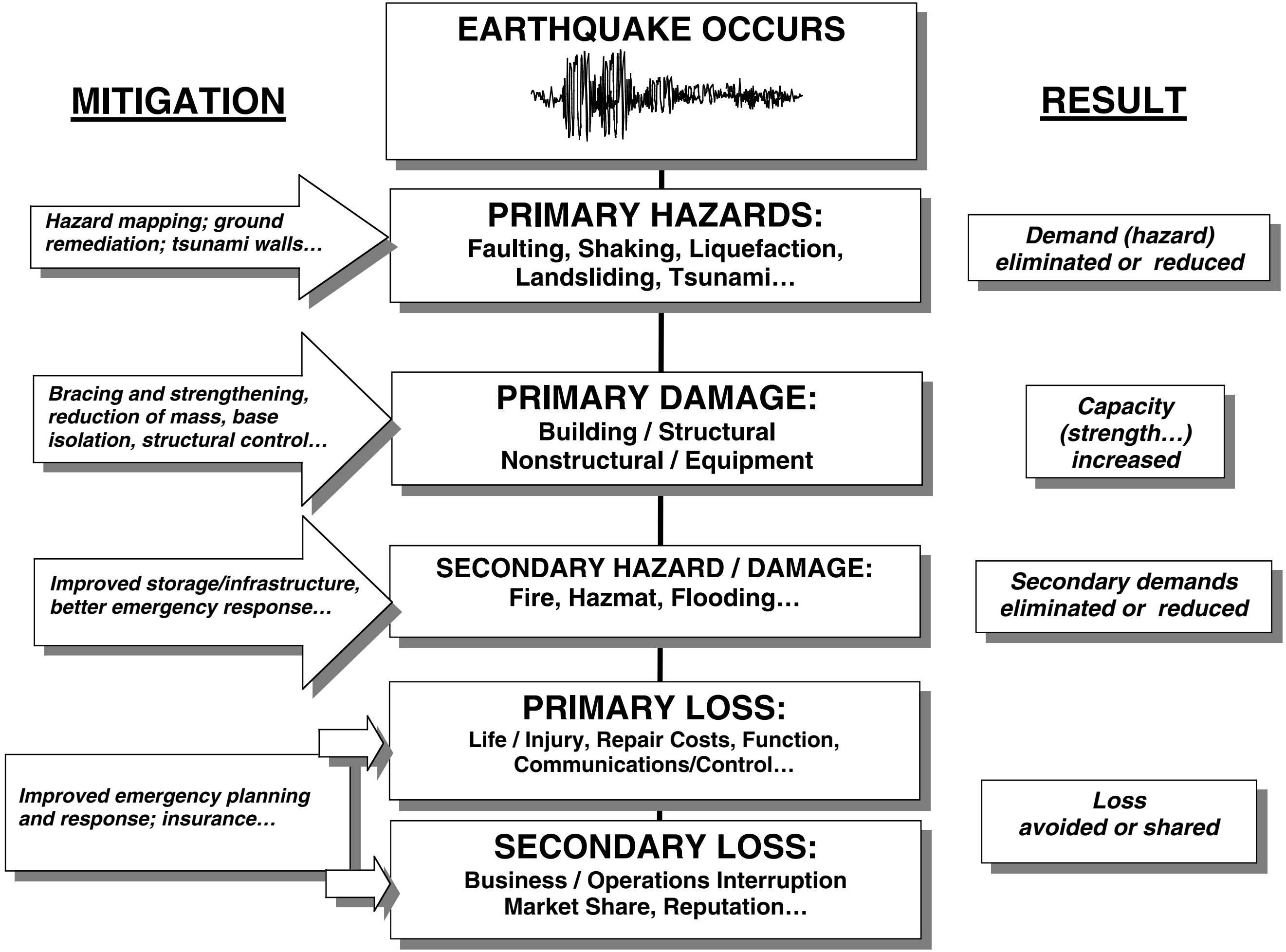
Year	Month	Day	Latitude	Longitude	M	MMI	Fatalities	Damage US $ (millions)	Locale
1755	11	18				8			Massachusetts, Nr Cape Ann
1774	2	21				7			Eastern Virginia (MMI from Sta)
1791	5	16				8			Connecticut, E. Haddam (MMI from Sta)
1811	12	16	36N	90W	8.6				Missouri, New Madrid
1812	1	23	36.6N	89.6W	8.4	12			Missouri, New Madrid
	2	7	36.6N	89.6W	8.7	12			Missouri, New Madrid
1817	10	5				8			Massachusetts, Woburn (MMI from Sta)
1836	6	10	38N	122W		10			California
1838	6	0	37.5N	123W		10			California
1857	1	9	35N	119W	8.3	7			California, Central
1865	10	8	37N	122W		9			California, San Jose, Santa Cruz
1868	4	3	19N	156W		10	81		Hawaii
	10	21	37.5N	122W	6.8	10	3		California, Hayward
1872	3	26	36.5N	118W	8.5	10	50		California, Owens Valley
1886	9	1	32.9N	80W	7.7	9	60	5	South Carolina, Charleston
1892	2	24	31.5N	117W		10			California, San Diego County
	4	19	38.5N	123W		9			California, Vacaville, Winters
	5	16	14N	143W					Guam, Agana
1897	5	31			5.8	8			Virignia, Giles County (M_b from Sta)
1899	9	4	60N	142W	8.3				Alaska, Cape Yakataga
1906	4	18	38N	123W	8.3	11	2,000	400	California, San Francisco (fire)
1915	10	3	40.5N	118W	7.8				Nevada, Pleasant Valley
1925	6	29	34.3N	120W	6.2		13	8	California, Santa Barbara
1927	11	4	34.5N	121W	7.5	9			California, Lompoc
1933	3	11	33.6N	118W	6.3		115	40	California, Long Beach
1934	12	31	31.8N	116W	7.1	10			California, Baja, Imperial Valley
1935	10	19	46.6N	112W	6.2		2	19	Montana, Helena
1940	5	19	32.7N	116W	7.1	10	9	6	California, southeast of El Centro
1944	9	5	44.7N	74.7W	5.6			2	New York, Massena
1949	4	13	47.1N	123W	7	8	8	25	Washington, Olympia
1951	8	21	19.7N	156W	6.9				Hawaii
1952	7	21	35N	119W	7.7	11	13	60	California, Kern County
1954	12	16	39.3N	118W	7	10			Nevada, Dixie Valley
1957	3	9	51.3N	176W	8.6			3	Alaska
1958	7	10	58.6N	137W	7.9		5		Alaska, Lituyabay (landslide)
1959	8	18	44.8N	111W	7.7				Montana, Hebgen Lake
1962	8	30	41.8N	112W	5.8			2	Utah
1964	3	28	61N	148W	8.3		131	540	Alaska
1965	4	29	47.4N	122W	6.5	7	7	13	Washington, Seattle
1971	2	9	34.4N	118W	6.7	11	65	553	California, San Fernando
1975	3	28	42.1N	113W	6.2	8		1	Idaho, Pocatello Valley
1975	8	1	39.4N	122W	6.1			6	California, Oroville Reservoir
	11	29	19.3N	155W	7.2	9	2	4	Hawaii
1980	1	24	37.8N	122W	5.9	7	1	4	California, Livermore
	5	25	37.6N	119W	6.4	7		2	California, Mammoth Lakes
	7	27	38.2N	83.9W	5.2			1	Kentucky, Maysville
	11	8	41.2N	124W	7	7	5	3	California, northern coast
1983	5	2	36.2N	120W	6.5	8		31	California, central, Coalinga
	10	28	43.9N	114W	7.3		2	13	Idaho, Borah Peak
	11	16	19.5N	155W	6.6	8		7	Hawaii, Kapapala
1984	4	24	37.3N	122W	6.2	7		8	California, Morgan Hill
1986	7	8	34N	117W	6.1	7		5	California, Palm Springs
1987	10	1	34.1N	118W	6	8	8	358	California, Whittier
	11	24	33.2N	116W	6.3	6	2		California, Superstition Hills
1989	6	26	19.4N	155W	6.1	6			Hawaii
	10	18	37.1N	122W	7.1	9	62	6,000	California, Loma Prieta
1990	2	28	34.1N	118W	5.5	7		13	California, southern, Claremont, Covina

Selected U.S. Earthquakes[a] (continued)

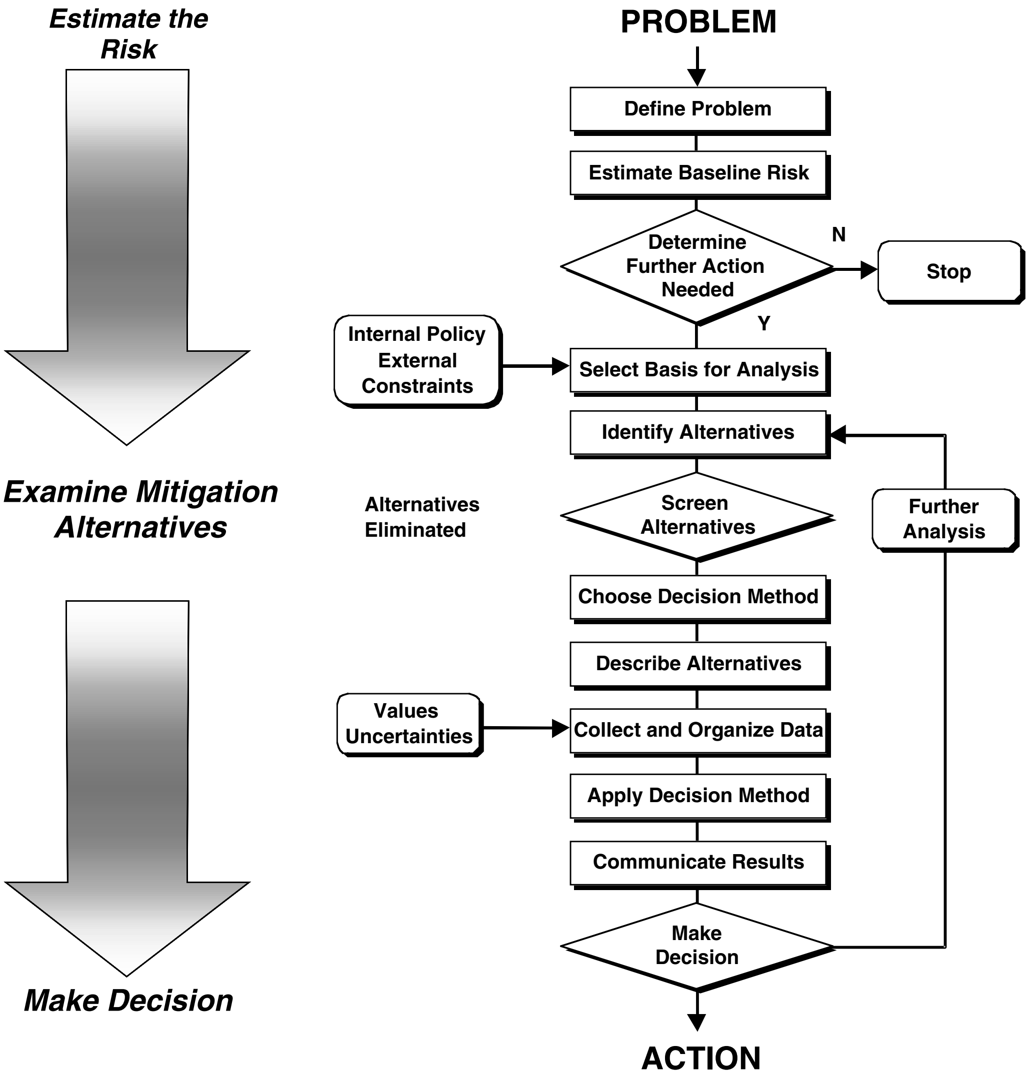
Year	Month	Day	Latitude	Longitude	M	MMI	Fatalities	Damage US $ (millions)	Locale
1992	4	23	34N	116W	6.3	7			California, Joshua Tree
	4	25	40.4N	124W	7.1	8		66	California, Humboldt, Ferndale
	6	28	34.2N	117W	6.7	8			California, Big Bear
	6	28	34.2N	116W	7.6	9	3	92	California, Landers, Yucca Valley
	6	29	36.7N	116W	5.6				California-Nevada border T.S.
1993	3	25	45N	123W	5.6	7			Washington-Oregon
	9	21	42.3N	122W	5.9	7	2		Oregon, Klamath Falls
1994	1	16	40.3N	76W	4.6	5			Pennsylvania (felt Canada)
	1	17	34.2N	119W	6.8	9	57	30,000	California, Northridge
	2	3	42.8N	111W	6	7			Wyoming, Afton
1995	10	6	65.2N	149W	6.4				Alaska (oil pipeline damaged)

[a] Magnitude scale varies.

From Scawthorn, C., Earthquakes: A historical perspective, in *Earthquake Engineering Handbook*, Chen, W.-F. and Scawthorn, C., Eds., CRC Press, Boca Raton, FL, 2003, pp. **1**-4 to **1**-5. Originally from National Earthquake Information Center (1996). Database of Significant Earthquakes Contained in Seismicity Catalogs, Golden, CO.



Earthquake loss process. (From Scawthorn, C., Earthquake risk management: An overview, in *Earthquake Engineering Handbook*, Chen, W.-F. and Scawthorn, C., Eds., CRC Press, Boca Raton, FL, 2003, p. **2**-7.)

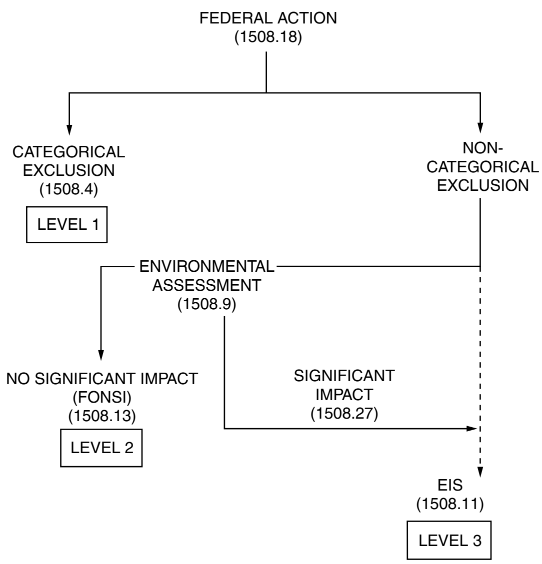


Earthquake risk management decision process. (From Scawthorn, C., Earthquake risk management: An overview, in *Earthquake Engineering Handbook,* Chen, W.-F. and Scawthorn, C., Eds., CRC Press, Boca Raton, FL, 2003, p. 2-9.)

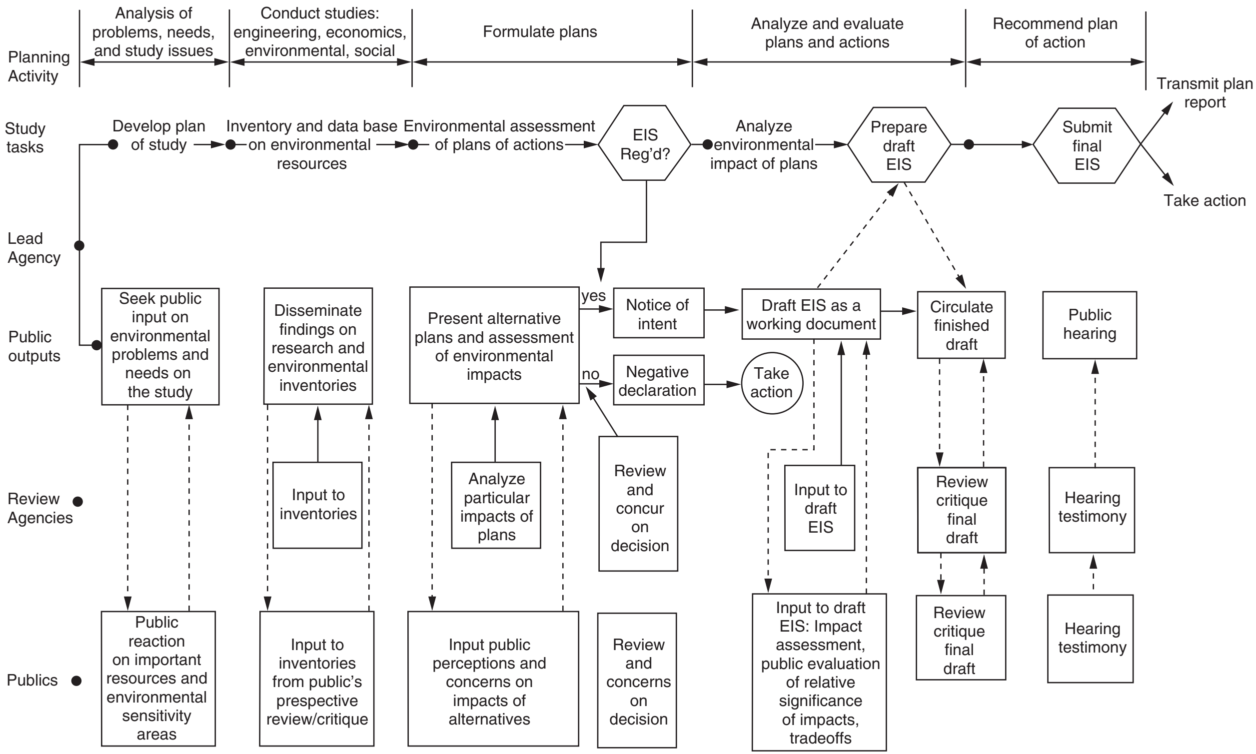
Principle Elemental Components of Structural Steel

Carbon	Principal hardening element in steel, increases strength and hardness, decreases ductility, toughness, and weldability
	Moderate tendency to segregate
Manganese	Increases strength and toughness
	Controls negative effects of sulfur
Phosphorus	Increases strength and hardness, decreases ductility and toughness
	Considered as an impurity, but sometimes added for atmospheric corrosion resistance
	Strong tendency to segregate
Sulfur	Considered undesirable except for machineability. Decreases ductility, toughness, and weldability
	Adversely affects surface quality
	Strong tendency to segregate
Silicon	Used to deoxidize or "kill" molten steel
	Increases strength
Aluminum	Used to deoxidize or "kill" molten steel
	Refines grain size, thus increasing strength and toughness
Vanadium and	Small additions increase strength
Columbium	Refines grain size, thus increasing strength and toughness
Titanium	Small amounts refine the grain size, thus increasing toughness
Nickel	Increases strength and toughness
Chromium	Increases strength
	Increases atmospheric corrosion resistance
Copper	Primary contributor to atmospheric corrosion resistance
	Increases strength
Nitrogen	Increases strength and hardness
	May decrease ductility and toughness
Boron	Small amounts increase hardenability, used only in aluminum-killed steels
	Most cost effective at low carbon levels

From Hamburger, R.O. and Nazir, N.A., Seismic design of steel structures, in *Earthquake Engineering Handbook*, Chen, W.-F. and Scawthorn, C., CRC Press, Boca Raton, FL, 2003, p. 12-10.



Three levels of analysis in the EIA process. Number in parentheses denotes paragraph in CEQ regulations which contains definition. (From Canter, L.W., Background conceptual and administrative information, in *Environmental Engineers' Handbook,* 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 43.)



Public participation in environmental impact assessment. (From Canter, L.W., Background conceptual and administrative information, in *Environmental Engineers' Handbook,* 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 45.)

Priority Chemicals Targeted in the 33/50 Project for the Industrial Sector Pollution Prevention Strategy

Target Chemicals	Million Pounds Released in 1988
Benzene	33.1
Cadmium	2.0
Carbon Tetrachloride	5.0
Chloroform	26.9
Chromium	56.9
Cyanide	13.8
Dichloromethane	153.4
Lead	58.7
Mercury	0.3
Methyl Ethyl Ketone	159.1
Methyl Isobutyl Ketone	43.7
Nickel	19.4
Tetrachloroethylene	37.5
Toluene	344.6
1,1,1-Trichloroethane	190.5
Trichloroethylene	55.4
Xylene	201.6

From Liu, D.H.F., Regulations and definitions, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 85. Originally from U.S. Environmental Protection Agency, 1992, *Pollution prevention 1991: Research program*, EPA/600/R-92/189 (September). (Washington, D.C.: Office of Research and Development).

Main Membrane Separation Processes: Operating Principles and Application

Separation Process	Membrane Type	Driving Force	Method of Separation	Range of Application
Microfiltration	Symmetric microporous membrane, 0.1 to 10 μA pore radius	Hydrostatic pressure difference, 0.1 to 1 bar	Sieving mechanism due to pore radius and adsorption	Sterile filtration clarification
Ultrafiltration	Asymmetric microporous membrane, 1 to 10 μA pore radius	Hydrostatic pressure difference, 0.5 to 5 bar	Sieving mechanism	Separation of macromolecular solutions
Reverse osmosis	Symmetric skin-type membrane	Hydrostatic pressure, 20 to 100 bar	Solution–diffusion mechanism	Separation of salt and microsolutes from solutions
Dialysis	Symmetric microporous membrane, 0.1 to 10 μA pore size	Concentration gradient	Diffusion in convection-free layer	Separation of salts and microsolutes from macromolecular solutions
Electrodialysis	Cation and anion exchange membranes	Electrical potential gradient	Electrical charge of particle and size	Desalting of ionic solution
Gas operation	Homogeneous or porous polymer	Hydrostatic pressure concentration gradient	Solubility, diffusion	Separation from gas mixture
Supported liquid membranes	Symmetric microporous membrane with adsorbed organic liquid	Chemical gradient	Solution diffusion via carrier	Separation
Membrane distillation	Microporous membrane	Vapor-pressure	Vapor transport into hydrophobic membrane	Ultrapure water concentration of solutions

From Liu, D.H.F., Separation and recycling systems, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 140. Originally from E. Orioli, R. Molinari, V. Calabrio, and A.B. Gasile, 1989, Membrane technology for production—integrated pollution control systems, Seminar on the Role of the Chemical Industry in Environmental Protection, CHEM/SEM. 18/R. 19, Geneva.

Summary of NAAQSs

Pollutant	Averaging Time	Standard (@ 25°C and 760 mm Hg) Primary	Secondary
Particulate matter	Annual arithmetic mean	50 μg/m³	Same as primary
10 micrometers (PM_{10})	24-hour	150 μg/m³	Same as primary
Sulfur dioxide (SO_2)	Annual arithmetic mean	0.03 ppm (80 μg/m³)	Same as primary
	24-hour	0.14 ppm (365 μg/m³)	Same as primary
	3-hour	None	0.5 ppm (1300 μg/m³)
Carbon monoxide (CO)	8-hour	9 ppm (10 mg/m³)	Same as primary
	1-hour	35 ppm (40 mg/m³)	Same as primary
Ozone (O_3)	1-hour per day	0.12 ppm (235 μg/m³)	Same as primary
Nitrogen dioxide (NO_2)	Annual arithmetic mean	0.053 ppm (100 μg/m³)	Same as primary
Lead (Pb)	Quarterly arithmetic mean	1.5 μg/m³	Same as primary

Notes: All standards with averaging times of 24 hours or less, and all gaseous fluoride standards, are not to have more than one actual or expected exceedance per year.

μg/m³ or mg/m³ = microgram or milligram per cubic meter

From Zegel, W.C., Setting standards, in *Environmental Engineers' Handbook*, 2nd Ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 189. Originally from CFR Title 40, Part 50. Environmental Protection Agency, U.S. Government Printing Office, 1993.

National Emission Standards for Hazardous Air Pollutants

Affected Facility	Emission Level	Monitoring
	Asbestos	
Asbestos mills	No visible emissions or meet equipment standards	No requirement
Roadway surfacing	Contain no asbestos, except temporary use	No requirement
Manufacturing	No visible emissions or meet equipment standards	No requirement
Demolition/renovation	Wet friable asbestos or equipment standards and no visible emissions	No requirement
Spraying friable asbestos		
Equipment and machinery	No visible emissions or meet equipment standards	No requirement
Buildings, structures, etc.	<1 percent asbestos dry weight	No requirement
Fabricating products	No visible emissions or meet equipment standards	No requirement
Friable insulation	No asbestos	No requirement
Waste disposal	No visible emissions or met equipment and work practice requirements	No requirement
Waste disposal sites	No visible emissions; design and work practice requirements	No requirement
	Beryllium	
Extraction plants	1. 10 g/hour, or	1. Source test
Ceramic plants	2. 0.01 μ/m³ (thirty-day)	2. Three years CEM[a]
Foundries		
Incinerators		
Propellant plants		
Machine shops (Alloy >5 percent by weight beryllium)		

National Emission Standards for Hazardous Air Pollutants (continued)

Affected Facility	Emission Level	Monitoring
Rocket motor test sites		
Closed tank collection of combustion products	75 μg min/m³ of air within 10 to 60 minutes during two consecutive weeks	Ambient concentration during and after test
	2 g/hour, maximum 10 g/day	Continuous sampling during release
	Mercury	
Ore processing	2300 g/24 hour	Source test
Chlor-alkali plants	2300 g/24 hour	Source test or use approved design, maintenance and housekeeping
Sludge dryers and incinerators	3200 g/24 hour	Source test or sludge test
	Vinyl Chloride (VC)	
Ethylene dichloride (EDC) manufacturing	1. EDC purification: 10 ppm[b]	Source test/CEM[a]
	2. Oxychlorination: 0.2 g/kg of EDC product	Source test
VC manufacturing	10 ppm[b]	Source test/CEM[a]
Polyvinyl chloride (PVC) manufacturing		
Equipment	10 ppm[b]	Source test/CEM[a]
Reactor opening loss	0.02 g/kg	Source test
Reactor manual vent valve	No emission except emergency	
Sources after stripper	Each calendar day:	Source test
	1. Strippers—2000 ppm (PVC disposal resins excluding latex); 400 ppm other	
	2. Others—2 g/kg (PVC disposal resins excluding latex); 0.4 g/kg other	Source test
EDC/VC/PVC manufacturing		
Relief valve discharge	None, except emergency	
Loading/unloading	0.0038 m³ after load/unload or 10 ppm when controlled	Source test
Slip gauge	Emission to control	
Equipment seals	Dual seals required	
Relief valve leaks	Rupture disc required	
Manual venting	Emissions to control	
Equipment opening	Reduce to 2.0 percent VC or 25 gallon	
Sampling (>10 percent by weight VC)	Return to process	
LDAR[d]	Approved program required	Approved program
In-process wastewater	10 ppm VC before discharge	Source test
	Inorganic Arsenic	
Glass melting furnace	Existing: <2.5 Mg/year[c] or 85 percent control	Method 108
	New or modified: <0.4 Mg/year or 85 percent control	Continuous opacity and temperature monitor for control
Copper converter	Secondary hooding system	Methods 5 and 108A
	Particle limit 11.6 mg/dscm[d]	Continuous opacity for control

National Emission Standards for Hazardous Air Pollutants (continued)

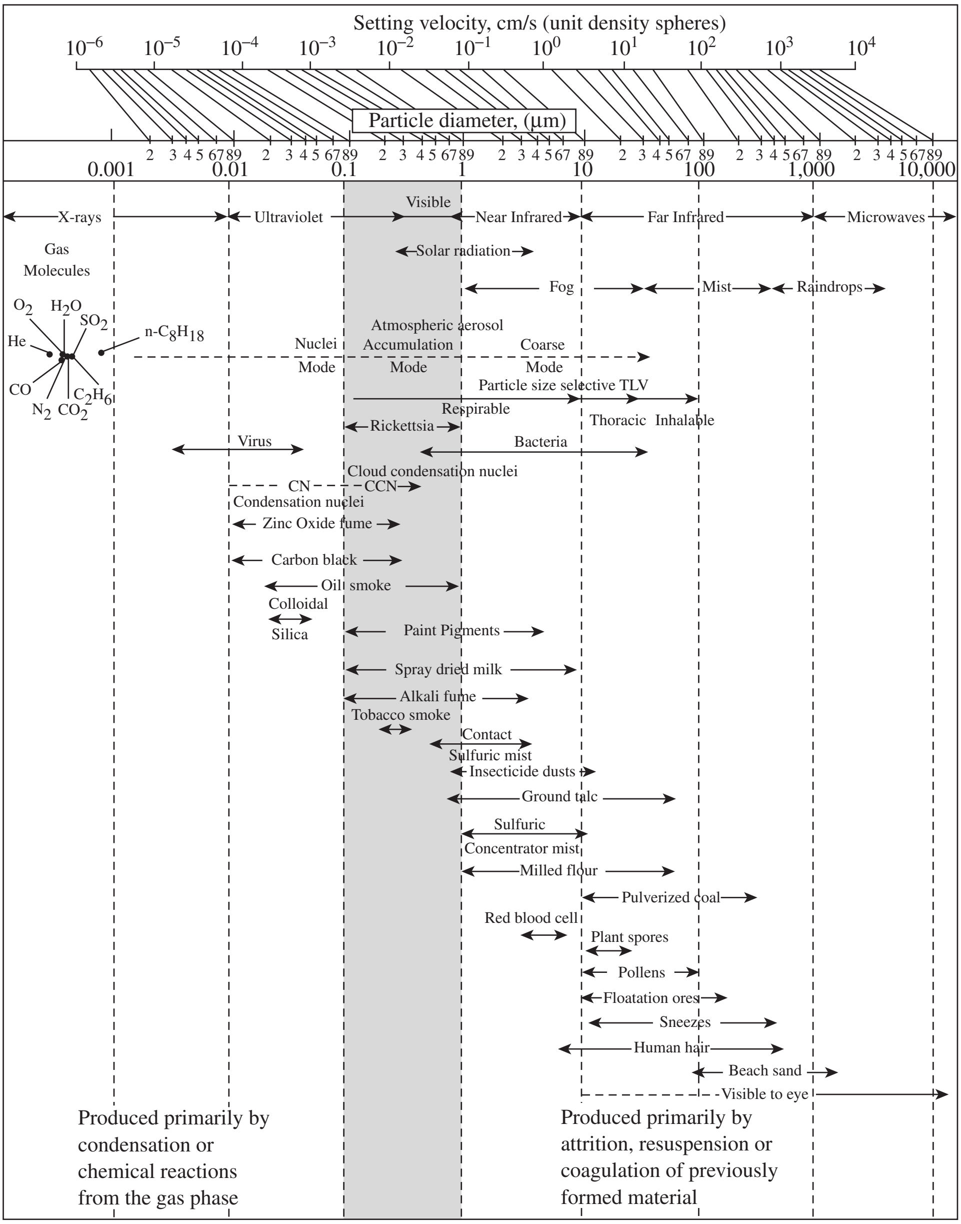
Affected Facility	Emission Level	Monitoring
	Approved operating plan	Airflow monitor for secondary hood
Arsenic trioxide and metallic arsenic plants using roasting/condensation process	Approved plan for control of emissions	Opacity monitor for control
		Ambient air monitoring
	Benzene	
Equipment leaks (Serving liquid or gas ⩾10 percent by weight benzene; facilities handling 1000 Mg/year and coke oven by-product exempt)	Leak is 10,000 ppm using Method 21; no detectable emissions (NDE) is 500 ppm using Method 21	
Pumps	Monthly LDAR,[e] dual seals, 95 percent control or NDE[f]	Test of NDE[f]
Compressors	Seal with barrier fluid, 95 percent control or NDE[f]	Test for NDE[f]
Pressure relief valves	NDE[f] or 95 percent control	Test for NDE[f]
Sampling connection systems	Closed purge or closed vent	
Open-end valves/lines	Cap, plug, or second valve	
Valves	Monthly LDAR[e] (quarterly if not leaking for two consecutive months) or NDE[f]	Test for NDE[f]
Pressure relief equipment	LDAR[e]	
Product accumulators	95 percent control	
Closed-vent systems and control devices	NDE or 95 percent control	Monitor annually
Coke by-product plants		
Equipment and tanks	Enclose source, recover, or destroy. Carbon adsorber or incinerator alternate	Semiannual LDAR,[e] annual maintenance
Light-oil sumps	Cover, no venting to sump	Semiannual LDAR[e]
Napthalene equipment	Zero emissions	
Equipment leaks (serving ⩾10 percent by weight)	See 40 CFR 61, subpart J.	
Exhauster (⩾1 percent by weight)	Quarterly LDAR[e] or 95 percent control or NDE[f]	Test for NDE[f]
Benzene storage vessels		
Vessels with capacity >10,000 gallon	Equipped with:	
	1. Fixed roof with internal floating roof-seals, or	Periodic inspection
	2. External floating roof with seals, or	Periodic inspection
	3. Closed vent and 95 percent control	Maintenance plant and monitoring
Benzene transfer		
Producers and terminals (loading >1,300,000/year)	Vapor collection and 95 percent control	Annual recertification
Loading racks (marine rail, truck)	Load vapor-tight vessels only	Yes
Exemptions:		
Facilities loading <70 percent benzene		
Facilities loading less than required of >70 percent benzene		
Both of above subject to record-keeping		
Waste Operations		

National Emission Standards for Hazardous Air Pollutants (continued)

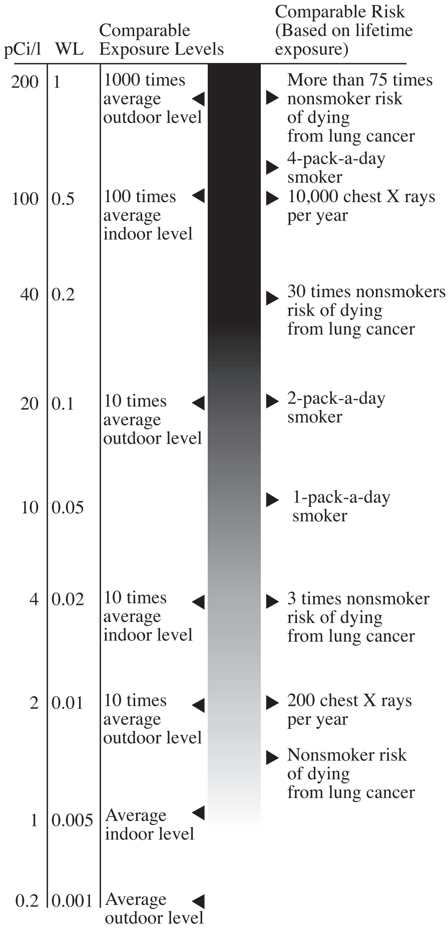
Affected Facility	Emission Level	Monitoring
Chemical manufacturing plants	1. Facilities ≥10 Mg/year in aqueous wastes must control streams ≥10 ppm. Control to 99 percent or <10 ppm	Monitor control and treatment. Also, periodically monitor certain equipment for emissions >500 ppm and inspect equipment
Petroleum refineries	2. If >10 ppm in wastewater treatment system: Wastes in <10 ppm Total in <1 Mg/year	
Coke by-product plants	3. >1 Mg/year to <10 Mg/year	Report annually
TSDF[g] treating wastes from the three preceding	4. <1 Mg facilities	One-time report
	Radionuclides	
DOE facilities (radon not included)	10 mrem/year[b] radionuclides (any member of the public)	Approved EPA computer model and Method 114 or direct monitoring (ANSIN13.1-1969)
NRC licensed facilities and facilities not covered by subpart H	10 mrem/year[h] radionuclides (any member of the public) 3 mrem/year iodine (any member of the public)	Approved EPA computer model or Appendix E Emissions determined by Method 114 or direct monitoring (ANSIN13.1-1969)
Calciners and nodulizing kilns at elemental phosphorus plants	2 curies per year (polonium-210)	Method 111
Storage and disposal facilities for radium-containing material, owned/operated by DOE	20 pCi/m^2 per second[i] (radon-222)	None specified
Phosphogypsum stacks (waste from phosphorus fertilizer production)	20 pCi/m^2 per second[i] (radon-222)	Method 115
Disposal of uranium mill trailings (operational)	20 pCi/m^2 per second[i] (radon-222)	Method 115

[a] CEM = continuous emission monitor.
[b] Before opening equipment, VC must be reduced to 2.0 percent (volume) or 25 gallons, whichever is larger.
[c] Mg/year = megagrams per year.
[d] mg/dscm = milligrams per dry standard cubic meter.
[e] LDAR = leak detection and repair.
[f] NDE = no detectable emissions.
[g] TSDF = treatment, storage, and disposal facilities.
[h] mrem/year = millirems per year (the rem is the unit of effective dose equivalent for radiation exposure).
[i] pCi/m^2 per second = picocuries per square meter per second.

From Zegel, W.C., Technology standards, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, pp. 193–196. Originally adapted from David R. Patrick, Ed., *Toxic Air Pollution Handbook*, Van Nostrand Reinhold, New York, 1994.



Molecular and aerosol particle diameters, copyright © P.C. Reist. Molecular diameters calculated from viscosity data. From Altwicker, E.R. et al., Air pollution, in *Environmental Engineers' Handbook,* 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 334. Originally adapted from Lapple, 1961, *Stanford Research Institute Journal,* 3rd quarter; and J.S. Eckert and R.F. Strigle, Jr., 1974, *JAPCA,* 24:961–965.



Radon risk evaluation chart. This chart shows how the lung cancer risks of radon exposure compare to other causes of the disease. For example, breathing 20 pCi/l poses about the same lung cancer risk as smoking two packs of cigarettes a day. From Altwicker, E.R. et al., Air pollution, in *Environmental Engineers' Handbook,* 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 437. Originally reprinted from U.S. Environmental Protection Agency.

Mechanical Characteristics of Sound Waves

	RMS Sound Pressure (dynes/cm²)	RMS Sound Particle Velocity (cm/sec)	RMS Sound Particle Motion at (1,000 Hz cm)	Sound Pressure Level (dB 0.0002 bar)
Threshold of hearing	0.0002	0.0000048	0.76×10^{-9}	0
	0.002	0.000048	7.6×10^{-9}	20
Quiet room	0.02	0.00048	76.0×10^{-9}	40
	0.2	0.0048	760×10^{-9}	60
Normal speech at 3′	2.0	0.048	7.6×10^{-6}	80
Possible hearing impairment	20.0	0.48	76.0×10^{-6}	100
	200	4.80	760×10^{-6}	120
Threshold of pain	2000	48.0	7.6×10^{-3}	140
Incipient mechanical damage	20×10^3	480	76.0×10^{-3}	160
	200×10^3	4800	760×10^{-3}	180
Atmospheric pressure	2000×10^3	48000	7.6	200

From Liu, D.H.F. and Roberts, H.C., The physics of sound and hearing, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 452.

Representative Sound Pressures and Sound Levels

Source and Distance	Sound Pressure (dynes/cm²)	Sound Level (decibels 0.0002 μ bar
Saturn rocket motor, close by	1,100,000	195
Military rifle, peak level at ear	20,000	160
Jet aircraft takeoff; artillery, 2500′	2000	140
Planing mill, interior	630	130
Textile mill	63	110
Diesel truck, 60′	6	90
Cooling tower, 60′	2	80
Private business office	.06	50

Source	Acoustic Power of Source
Saturn rocket motor	30,000,000 watts
Turbojet engine	10,000 watts
Pipe organ, forte	10 watts
Conventional voice	10 microwatts
Soft whisper	1 millimicrowatt

From Liu, D.H.F. and Roberts, H.C., The physics of sound and hearing, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 454.

Typical Wastewater Flow Rates from Residential Sources

Source	Unit	Flow, gal/unit·d Range	Typical
Apartment:			
High-rise	Person	35–75	50
Low-rise	Person	50–80	65
Hotel	Guest	30–55	45
Individual residence:			
Typical home	Person	45–90	70
Better home	Person	60–100	80
Luxury home	Person	75–150	95
Older home	Person	30–60	45
Summer cottage	Person	25–50	40
Motel:			
With kitchen	Unit	90–180	100
Without kitchen	Unit	75–150	95
Trailer park	Person	30–50	40

Note: 1 = gal × 3.7854.

From Adams Jr., C.E. et al., Nature of wastewater, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 517. Originally from Metcalf and Eddy, Inc., *Wastewater Engineering*, 3rd ed., McGraw-Hill, New York, 1991.

Estimated Distribution of World's Water

	Volume 1000 km^3	Percentage of Total Water
Atmospheric water	13	0.001
Surface water		
Salt water in oceans	1,320,000	97.2
Salt water in lakes and inland seas	104	0.008
Fresh water in lakes	125	0.009
Fresh water in stream channels (average)	1.25	0.0001
Fresh water in glaciers and icecaps	29,000	2.15
Water in the biomass	50	0.004
Subsurface water		
Vadose water	67	0.005
Groundwater within depth of 0.8 km	4200	0.31
Groundwater between 0.8 and 4 km depth	4200	0.31
Total (rounded)	1,360,000	100

From Chae, Y.C. and Hamidi, A., Groundwater and aquifers, in *Environmental Engineers' Handbook*, 2nd ed., Liu, D.H.F. and Liptak, B.G., Eds., CRC Press, Boca Raton, FL, 1997, p. 1009. Originally from Bouwer, H., *Groundwater Hydrology*, McGraw-Hill, Inc., New York, 1978.

Currently Developed Types of Fuel Cells and Their Characteristics and Applications

Fuel Cell Type	Electrolyte	Charge Carrier	Operating Temperature	Fuel	Electric Efficiency (System)	Power Range/Application
Alkaline FC (AFC)	KOH	OH^-	60–120°C	Pure H_2	35–55%	<5 kW, niche markets (military, space)
Proton exchange membrane FC (PEMFC)[a]	Solid polymer (such as Nafion)	H^+	50–100°C	Pure H_2 (tolerates CO_2)	35–45%	Automotive, CHP (5–250 kW), portable
Phosphoric acid FC (PAFC)	Phosphoric acid	H^+	~220°C	Pure H_2 (tolerates CO_2, approx. 1% CO)	40%	CHP (200 kW)
Molten carbonate FC (MCFC)	Lithium and potassium carbonate	CO_3^{2-}	~650°C	H_2, CO, CH_4, other hydrocarbons (tolerates CO_2)	>46%	200 kW–MW range, CHP and stand-alone
Solid oxide FC (SOFC)	Solid oxide electrolyte (yttria, zirconia)	O^{2-}	~1000°C	H_2, CO, CH_4, other hydrocarbons (tolerates CO_2)	>46%	2 kW–MW range, CHP and stand-alone

[a] Also known as a solid polymer fuel cell (SPFC).

From Hoogers, G., Introduction, in *Fuel Cell Technology Handbook*, Hoogers, G., Ed., CRC Press, Boca Raton, FL, 2003, p. **1**-4.

Hydrogen Storage Properties for a Range of Metal Hydrides

Metal Hydride System	Mg/MgH_2	Ti/TiH_2	V/VH_2	Mg_2Ni/Mg_2NiH_4	$FeTi/FeTiH_{1.95}$	$LaNi_5/LaNi_5H_{5.9}$	LH_2[b]
Hydrogen content as mass fraction (%)	7.7	4.0	2.1	3.2	1.8	1.4	100.0
Hydrogen content by volume (kg/dm^3)	0.101	0.15	0.09	0.08	0.096	0.09	0.077
Energy content (MJ/kg) (based on HHV)	9.9	5.7	3.0	4.5	2.5[a]	1.95	143.0
Energy content (MJ/kg) (LHV)[a]	8.4	4.8	2.5	3.8	2.1	1.6	120.0
Heat of reaction (kJ/Nm^3) (H_2)	3360	5600	—	2800	1330	1340	—
Heat of reaction (kJ/mol)[a]	76.3	127.2	—	63.6	30.2	30.4	—
Heat of reaction (as fraction of HHV, %)[a]	26.7	44.5	—	22.2	10.6	10.6	—
Heat of reaction (as fraction of LHV, %)[a]	31.6	52.6	—	26.3	12.5	12.6	—

[a] Raw data taken from *Ullmann's Encyclopedia of Industrial Chemistry*, Sixth ed., Wiley-VCH, 2001. Data recalculated by the author.

[b] LH_2: liquid hydrogen.

From Hoogers, G., The fueling problem: Fuel cell systems, in *Fuel Cell Technology Handbook*, Hoogers, G., Ed., CRC Press, Boca Raton, FL, 2003, p. **5**-6.

Typical Gas Composition of Biogas from Organic Household Waste

Component	Concentration (Wet Gas)
Methane	60–75%
Carbon dioxide	< 35%
Water vapor	0–10%
Nitrogen	< 5%
Oxygen	< 1%
Carbon monoxide	0.2%
Siloxanes	<10 mg per m^3 CH_4
Hydrogen sulfide	150 ppm

From Hoogers, G., The fueling problem: Fuel cell systems, in *Fuel Cell Technology Handbook*, Hoggers, G., Ed., CRC Press, Boca Raton, FL, 2003, p. **5**-20.

Performance of Different Battery Types

Battery Type	Specific Energy Storage (Wh/kg)	Specific Power (for 30 sec at 80% capacity) (W/kg)	Specific Cost, ($/kWh)	Cycle Life (Charges and Discharges to 80% of Capacity)
Lead–acid	35 (55)[a] [171][b]	200 (450)	125 (75)	450 (2000)
Nickel–cadmium	40 (57) [217]	175 (220)	600 (110)	1250 (1650)
Nickel–metal hydride	70 (120)	150 (220)	540 (115)	1500 (2200)
Lithium ion	120 (200)	300 (350)	600 (200+)	1200 (3500)

[a] Values in parentheses represent projections for the next five years.
[b] Values in brackets represent the theoretical limit on specific energy.

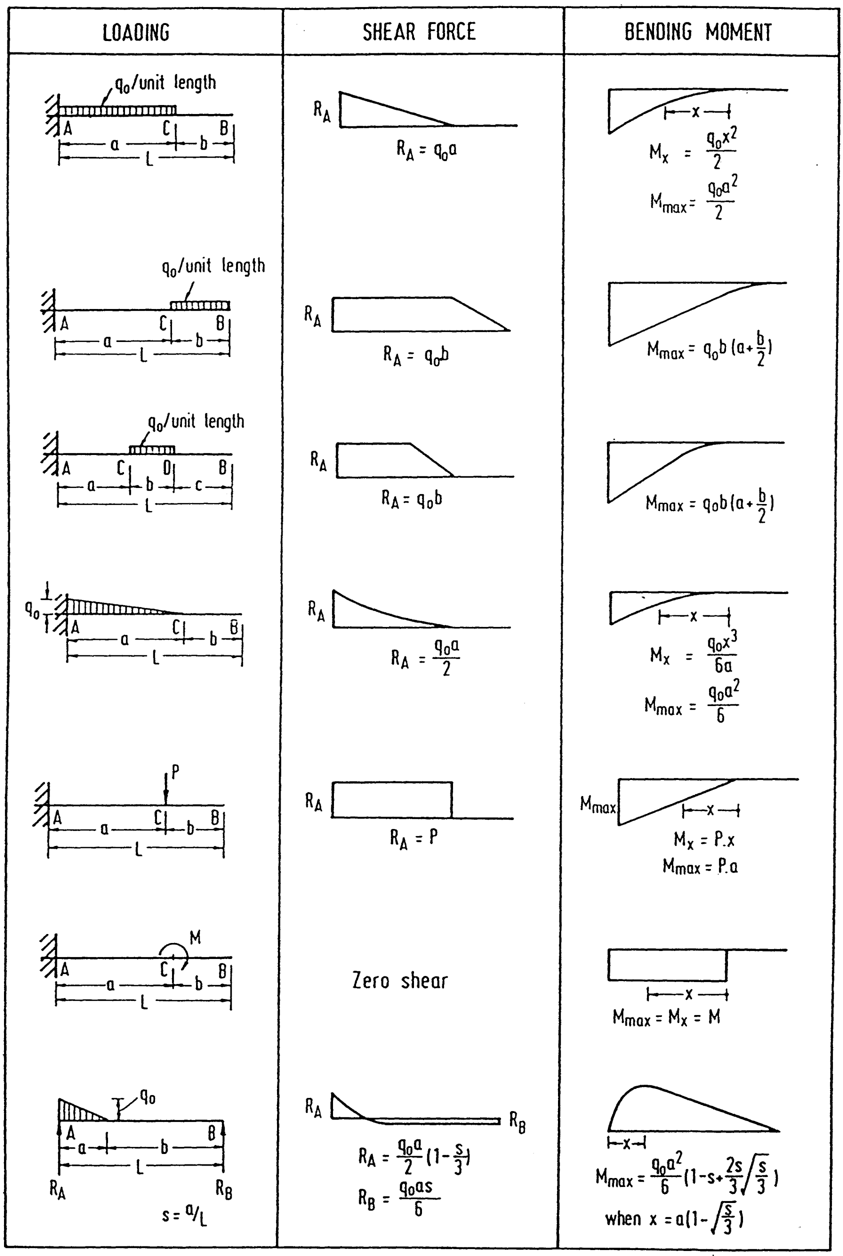
From Stone, R., Competing technologies for transportation, in *Fuel Cell Technology Handbook*, Hoogers, G., Ed., CRC Press, Boca Raton, FL, 2003, p. **11**-17. Theoretical limits on specific energy from Rand, R.A.J. et al., *Batteries for Electric Vehicles*, Research Studies Press, Baldock, U.K., 1998; other data from Ashton, R., in *Design of a Hybrid Electric Vehicle*, University of Oxford, Oxford, 1998.

Thermodynamic Data for Selected Chemical Compounds

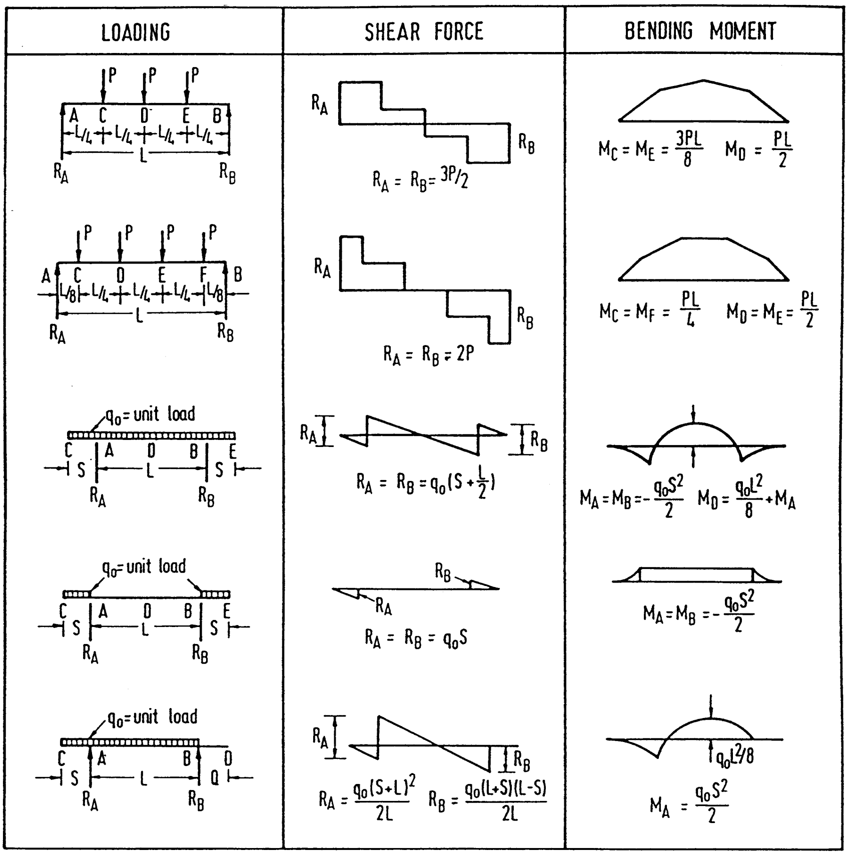
Compound (gaseous/liquid)	Common Name	Molar Mass (g/mol)	ΔH_f (kJ/mol)	ΔG_f (kJ/mol)
H_2O (l)	water	18,02	–285,83	–237,13
H_2O (g)	water (steam)	18,02	–241,82	–228,57
CH_4	methane	16,04	–74,81	–50,72
C_3H_6 (g)	propane	42,08	20,42	62,78
C_4H_{10} (g)	butane	58,13	–126,15	–17,03
C_8H_{18} (l)	octane	114,23	–249,90	6,40
C_8H_{18} (l)	iso-octane	114,23	–255,10	—
CH_3OH (l)	methanol	32,04	–238,66	–166,27
CH_3OH (g)	methanol	32,04	–200,66	–161,96
C_2H_5OH (l)	ethanol	46,07	–277,69	–174,78
C_2H_5OH (g)	ethanol	46,07	–235,10	–168,49
CO	carbon monoxide	28,01	–110,53	–137,17
CO_2	carbon dioxide	44,01	–393,51	–394,36
H_2	hydrogen	2,02	0	0
O_2	oxygen	32,00	0	0

Note: Tabulated are the standard heat of formation, ΔH_f, and the Gibbs free energy, ΔG_f, at 10^5 Pa and 298 K.

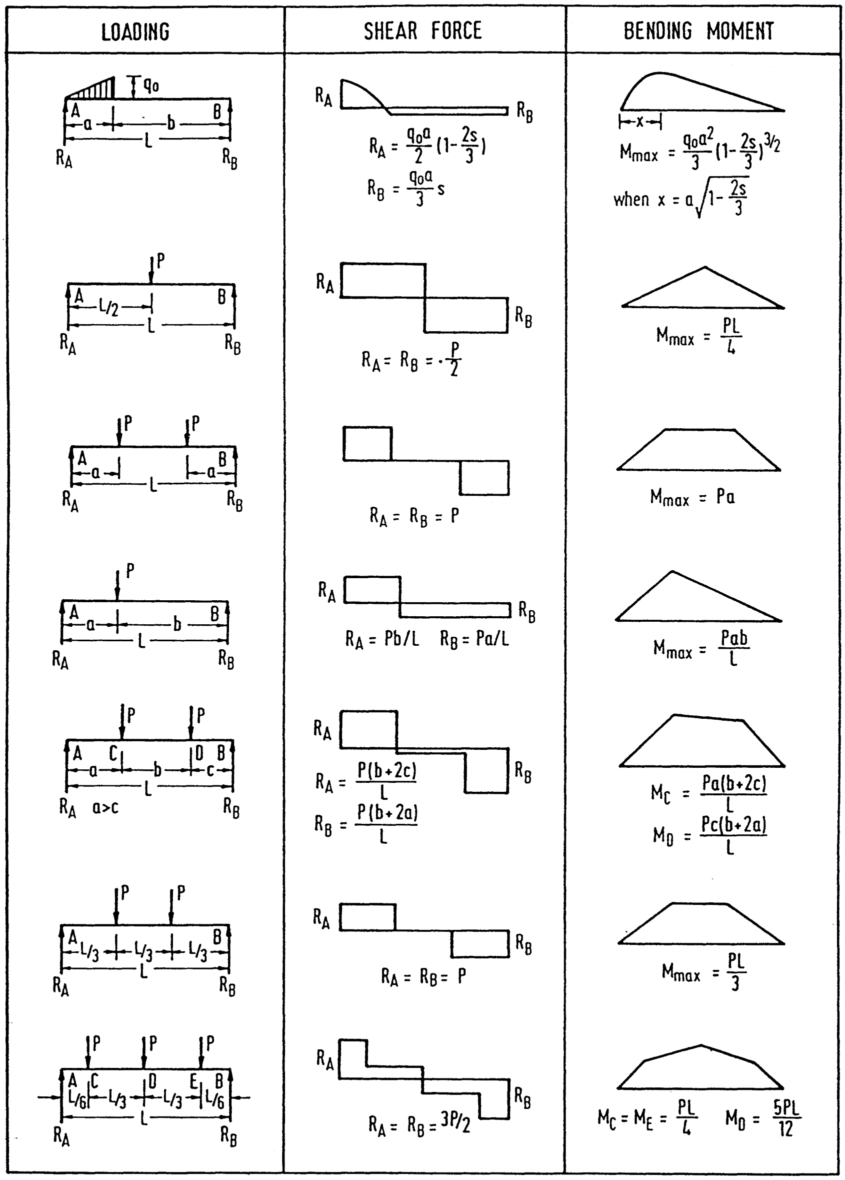
From Hoogers, G., Ed., Appendix 1: Thermodynamic data for selected chemical compounds, in *Fuel Cell Technology Handbook*, Hoggers, G., Ed., CRC Press, Boca Raton, FL, 2003, p. **A1**-1.



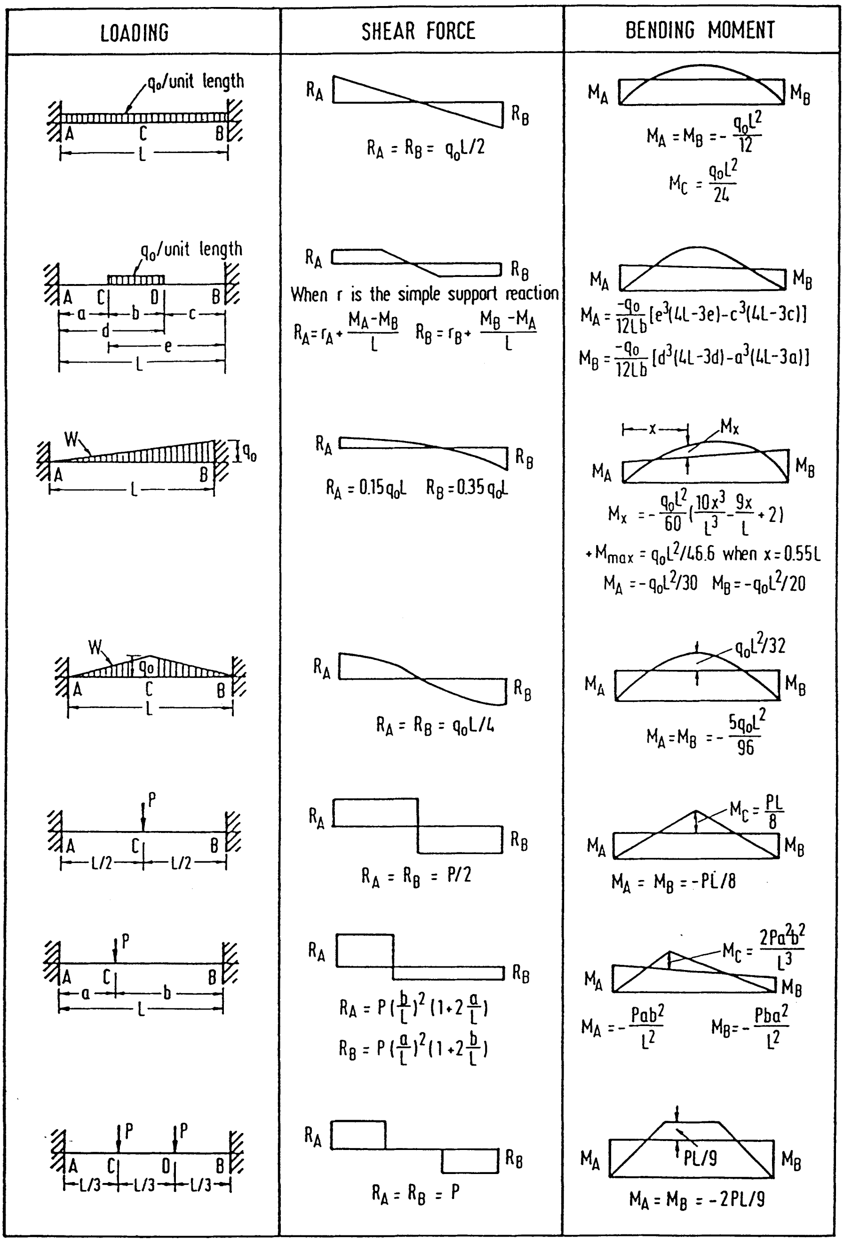
Shear force and bending moment diagrams for beams with simple boundary conditions subjected to selected loading cases. (From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-8 to **2**-10.)



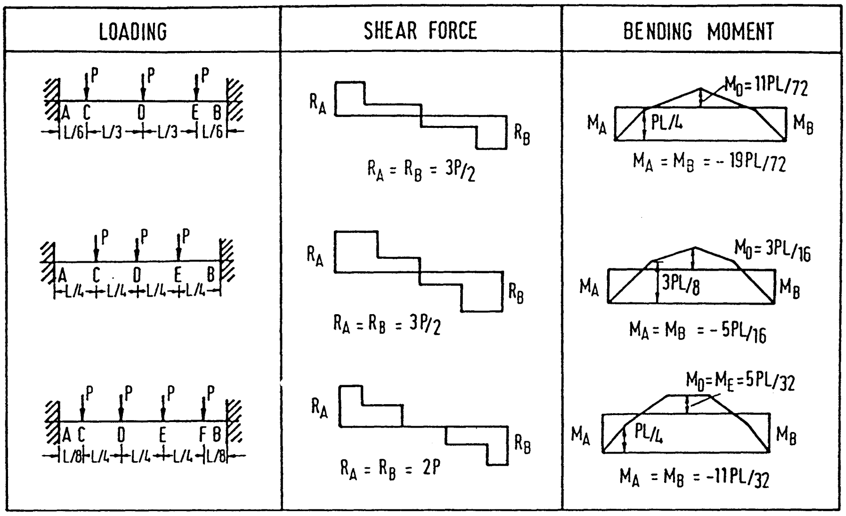
(*Continued*) Shear force and bending moment diagrams for beams with simple boundary conditions subjected to selected loading cases.



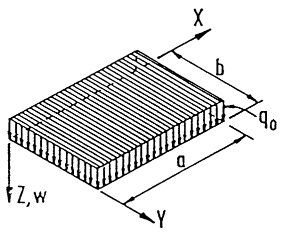
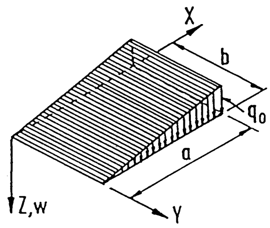
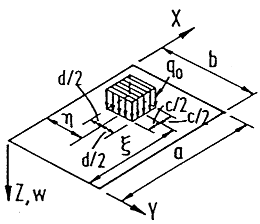
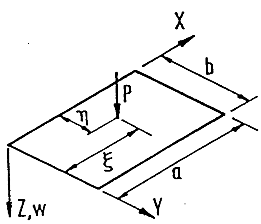
(*Continued*) Shear force and bending moment diagrams for beams with simple boundary conditions subjected to selected loading cases.



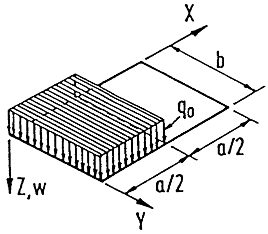
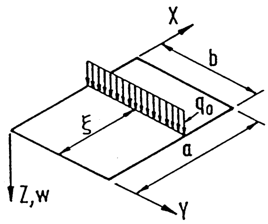
Shear force and bending moment diagrams for built-up beams subjected to typical loading cases. (From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-12 to **2**-13.)



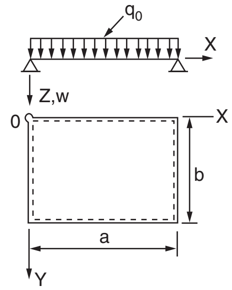
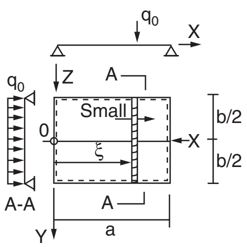
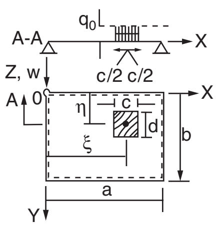
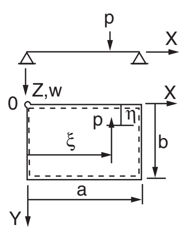
(*Continued*) Shear force and bending moment diagrams for built-up beams subjected to typical loading cases.

No.	Load $q(x,y) = \sum_m \sum_n q_{mn} \sin\frac{m\pi x}{a} \sin\frac{n\pi y}{b}$	Expansion Coefficients q_{mn}
1		$q_{mn} = \frac{16q_0}{\pi^2 mn}$ $(m, n = 1, 3, 5, \ldots.)$
2		$q_{mn} = \frac{-8q_0 \cos m\pi}{\pi^2 mn}$ $(m, n = 1, 3, 5, \ldots.)$
3		$p_{mn} = \frac{16q_0}{\pi^2 mn} \sin\frac{m\pi\xi}{a} \sin\frac{n\pi\eta}{b} \times \sin\frac{m\pi c}{2a} \sin\frac{n\pi d}{2b}$ $(m, n = 1, 3, 5, \ldots.)$
4		$q_{mn} = \frac{4q_0}{ab} \sin\frac{m\pi\xi}{a} \sin\frac{n\pi\eta}{b}$ $(m, n = 1, 2, 3, \ldots.)$

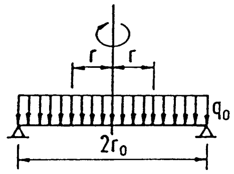
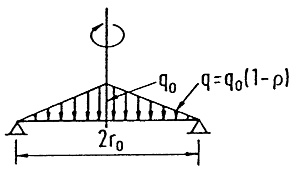
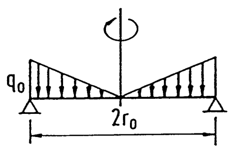
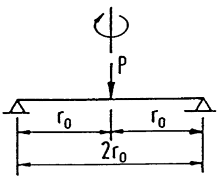
Typical loading on plates and loading functions. (From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-46 to **2**-47.)

No.	Load $q(x,y) = \sum_{M}\sum_{n} q_{mn} \sin\frac{m\pi x}{a} \sin\frac{n\pi y}{b}$	Expansion coefficients q_{mn}
5		$q_{mn} = \frac{8q_0}{\pi^2 mn}$ for $m,n = 1,3,5,\ldots.$ $q_{mn} = \frac{16q_0}{\pi^2 mn}$ for $\begin{cases} m = 2,6,10,\ldots. \\ n = 1,3,5,\ldots \end{cases}$
6		$q_{mn} = \frac{4q_0}{\pi a n} \sin\frac{m\pi\xi}{a}$ $(m,n = 1,2,3,\ldots.)$

(*Continued*) Typical loading on plates and loading functions.

Case No.	Sructural System and Static Loading	Deflection and Internal Forces
1		$$w = \frac{16q_0}{\pi^6 D}\sum_m\sum_a \frac{\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}}{mn\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)^2}$$ $$m_x = \frac{16q_0a^2}{\pi^4}\sum_m\sum_n \frac{\left(m^2+\nu\frac{n^2}{\varepsilon^2}\right)\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}}{mn\left(m^2+\frac{n^2}{\varepsilon^2}\right)^2}$$ $$m_y = \frac{16q_0a^2}{\pi^4}\sum_m\sum_n \frac{\left(\frac{n^2}{\varepsilon^2}+\nu m^2\right)\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}}{mn\left(m^2+\frac{n^2}{\varepsilon^2}\right)^2}$$ $\varepsilon = \frac{b}{a}$, $m = 1, 3, 5, \ldots, \infty$; $n = 1, 3, 5, \ldots, \infty$
2		$$w = \frac{a^4}{D\pi^4}\sum_{m=1}^{\infty}\frac{P_m}{m^4}\left(1-\frac{2+\alpha_m\tanh\alpha_m}{2\cosh\alpha_m}\cos\lambda_m y + \frac{\lambda_m y\sinh\lambda_m y}{2\cosh\alpha_m}\right)\sin\lambda_m x$$ where $P_m = \frac{2q_0}{a}\sin\frac{m\pi\xi}{a}$ $\lambda_m = \frac{m\pi}{a}$ $m = 1, 2, 3, \ldots$ $\alpha_m = \frac{m\pi b}{2a}$
3		$$w = \frac{16q_0}{D\pi^6}\sum_m\sum_n \frac{\sin\frac{m\pi\xi}{a}\sin\frac{n\pi\eta}{b}\sin\frac{m\pi c}{b}\sin\frac{n\pi d}{2b}}{mn\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)^2}$$ $$\times\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}$$ $m = 1, 2, 3, \ldots$ $n = 1, 2, 3, \ldots$
4		$$w = \frac{4P}{D\pi^4 ab}\sum_m\sum_n \frac{\sin\frac{m\pi\xi}{a}\sin\frac{n\pi\eta}{b}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}}{\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)^2}$$ $m = 1, 2, 3, \ldots$ $n = 1, 2, 3, \ldots$

Typical loading and boundary conditions for rectangular plates. (From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-49.)

Case No.	Structural System and Static Loading	Deflection and Internal Forces
1		$w = \frac{q_0 r_0^4}{64D(1+\nu)}[2(3+\nu)C_1 - (1+\nu)C_0]$ $m_r = \frac{q_0 r_0^2}{16}(3+\nu)C_1$ $\rho = \frac{r}{r_0}$ $m_\theta = \frac{q_0 r_0^2}{16}[2(1-\nu) - (1+3\nu)C_1]$ $C_0 = 1 - \rho^4$ $q_r = \frac{q_0 r_0}{2}\rho$ $C_1 = 1 - \rho^2$
2		$w = \frac{q_0 r_0^4}{14400D}\left[\frac{3(183+43\nu)}{1+\nu} - \frac{10(71+29\nu)}{1+\nu}\rho^2 + 225\rho^4 - 64\rho^5\right]$ $(m_r)_{\rho=0} = (m_\varphi)_{\rho=0} = \frac{q_0 r_0^2}{720}(71+29\nu);$ $(q_r)_{\rho=1} = -\frac{q_0 r_0}{6}$ $\rho = \frac{r}{r_0}$
3		$w = \frac{q_0 r_0^4}{450D}\left[\frac{3(6+\nu)}{1+\nu} - \frac{5(4+\nu)}{1+\nu}\rho^2 + 2\rho^5\right]$ $(m_r)_{\rho=0} = (m_\varphi)_{\rho=0} = \frac{q_0 r_0^2}{45}(4+\nu);$ $(q_r)_{\rho=1} = -\frac{q_0 r_0}{3}$ $\rho = \frac{r}{r_0}$
4		$w = \frac{P r_0^2}{16\pi D}\left[\frac{3+\nu}{1+\nu}C_1 + 2C_2\right]$ $C_1 = 1 - \rho^2$ $m_r = \frac{P}{4\pi}(1+\nu)C_3$ $C_2 = \rho^2 \ln \rho$ $m_\varphi = \frac{P}{4\pi}[(1-\nu) - (1+\nu)C_3]$ $C_3 = \ln \rho$ $q_r = \frac{P}{2\pi r_0 \rho}$ $\rho = \frac{r}{r_0}$

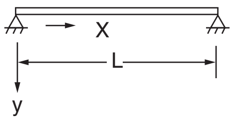
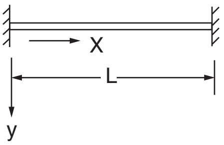
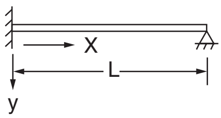
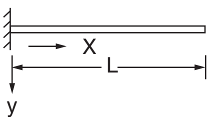
Typical loading and boundary conditions for circular plates. (From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-52.)

Frequencies and Mode Shapes of Beams in Flexural Vibration

$$f_n = \frac{k_n}{2\pi}\sqrt{\frac{EI}{mL^4}}\ \text{HZ}$$

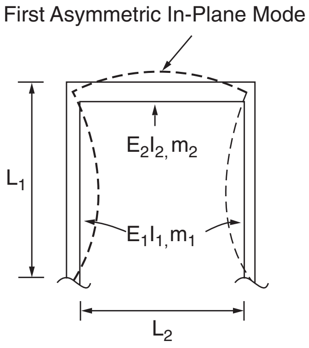
$n = 1, 2, 3\ldots$

L = Length (m)
EI = Flexural Rigidity (Nm^2)
M = Mass per unit length (kg/m)

Boundary Conditions	K_n; n = 1, 2, 3	Mode Shape $y_n\left(\frac{x}{L}\right)$	A_n; n = 1, 2, 3…
Pinned - Pinned 	$(n\pi)^2$	$\sin\frac{n\pi x}{L}$	
Fixed - Fixed 	22.37 61.67 120.90 199.86 298.55 $(2n + 1)\frac{\pi^2}{4}$; n > 5	$\cosh\frac{\sqrt{K_n}x}{L} - \cos\frac{\sqrt{K_n}x}{L} - A_n\left(\sinh\frac{\sqrt{K_n}x}{L} - \sin\frac{\sqrt{K_n}x}{L}\right)$	0.98250 1.00078 0.99997 0.99999 1.0; n > 5
Fixed - Pinned 	15.42 49.96 104.25 178.27 272.03 $(4n + 1)^2\frac{\pi^2}{4}$; n > 5	$\cosh\frac{\sqrt{K_n}x}{L} - \cos\frac{\sqrt{K_n}x}{L} - A_n\left(\sinh\frac{\sqrt{K_n}x}{L} - \sin\frac{\sqrt{K_n}x}{L}\right)$	1.00078 1.00000 1.0; n > 3
Cantilever 	3.52 22.03 61.69 120.90 199.86 $(2n + 1)^2\frac{\pi^2}{4}$; n > 5	$\cosh\frac{\sqrt{K_n}x}{L} - \cos\frac{\sqrt{K_n}x}{L} - A_n\left(\sinh\frac{\sqrt{K_n}x}{L} - \sin\frac{\sqrt{K_n}x}{L}\right)$	0.73410 1.01847 0.99922 1.00003 1.0; n > 4

From Liew, J.Y.R., Shanmugan, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **2**-173.

Fundamental Frequencies of Portal Frames in Asymmetrical Mode of Vibration

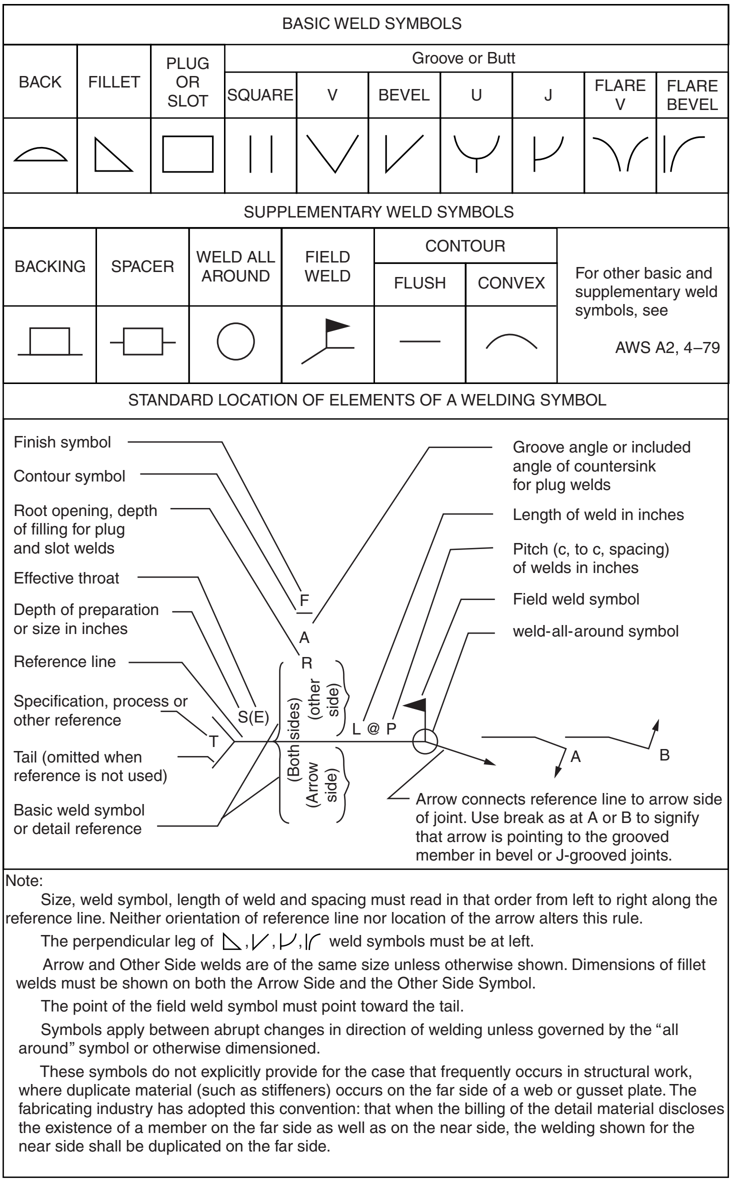


$$f = \frac{\lambda^2}{2\pi L_1^2}\left(\frac{E_1 I_1}{m_1}\right)^{1/2} \text{HZ}$$

E = Modulus of elasticity
I = Area moment of inertia
m = mass per unit length

		λ value									
		Pinned Bases					Clamped Bases				
$\frac{m_1}{m_2}$	$\frac{E_1 I_1}{E_2 I_2}$	L_1/L_2					L_1/L_2				
		0.25	0.75	1.5	3.0	6.0	0.25	0.75	1.5	3.0	6.0
0.25	0.25	0.6964	0.9520	1.1124	1.2583	1.3759	0.9953	1.3617	1.6003	1.8270	2.0193
	0.75	0.6108	0.8961	1.0764	1.2375	1.3649	0.9030	1.2948	1.5544	1.7999	2.0051
	1.5	0.5414	0.8355	1.0315	1.2093	1.3491	0.8448	1.2323	1.5023	1.7649	1.9853
	3.0	0.4695	0.7562	0.9635	1.1610	1.3201	0.7968	1.1648	1.4329	1.7096	1.9504
	6.0	0.4014	0.6663	0.8737	1.0870	1.2702	0.7547	1.1056	1.3573	1.6350	1.8946
0.75	0.25	0.8947	1.1740	1.3168	1.4210	1.4882	1.2873	1.7014	1.9262	2.0994	2.2156
	0.75	0.7867	1.1088	1.2776	1.3998	1.4773	1.1715	1.6242	1.8779	2.0733	2.2026
	1.5	0.6983	1.0368	1.2281	1.3707	1.4617	1.0979	1.5507	1.8218	2.0390	2.1843
	3.0	0.6061	0.9413	1.1516	1.3203	1.4327	1.0373	1.4698	1.7454	1.9838	2.1516
	6.0	0.5186	0.8314	1.0485	1.2414	1.3822	0.9851	1.3981	1.6601	1.9072	2.0983
1.5	0.25	1.0300	1.2964	1.4103	1.4826	1.5243	1.4941	1.9006	2.0860	2.2090	2.2819
	0.75	0.9085	1.2280	1.3707	1.4616	1.5136	1.3652	1.8214	2.0390	2.1842	2.2695
	1.5	0.8079	1.1514	1.3203	1.4326	1.4982	1.2823	1.7444	1.9837	2.1515	2.2521
	3.0	0.7021	1.0482	1.2414	1.3821	1.4694	1.2141	1.6583	1.9070	2.0983	2.2206
	6.0	0.6011	0.9279	1.1335	1.3024	1.4191	1.1570	1.5808	1.8198	2.0234	2.1693
3.0	0.25	1.1597	1.3898	1.4719	1.5189	1.5442	1.7022	2.0612	2.1963	2.2756	2.3190
	0.75	1.0275	1.3202	1.4326	1.4981	1.5336	1.5649	1.9834	2.1515	2.2520	2.3070
	1.5	0.9161	1.2412	1.3821	1.4694	1.5182	1.4752	1.9063	2.0982	2.2206	2.2899
	3.0	0.7977	1.1333	1.3024	1.4191	1.4896	1.4015	1.8185	2.0233	2.1693	2.2595
	6.0	0.6838	1.0058	1.1921	1.3391	1.4395	1.3425	1.7382	1.9366	2.0964	2.2094
6.0	0.25	1.2691	1.4516	1.5083	1.5388	1.5545	1.8889	2.1727	2.2635	2.3228	2.3385
	0.75	1.1304	1.3821	1.4694	1.5181	1.5440	1.7501	2.0980	2.2206	2.2899	2.3268
	1.5	1.0112	1.3023	1.4191	1.4896	1.5287	1.6576	2.0228	2.1693	2.2595	2.3101
	3.0	0.8827	1.1919	1.3391	1.4395	1.5002	1.5817	1.9358	2.0963	2.2095	2.2802
	6.0	0.7578	1.0601	1.2277	1.3595	1.4502	1.5244	1.8550	2.0110	2.1380	2.2309

From Liew, J.Y.R., Shanmugam, E., and Yu, C.H., Structural analysis, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **2**-176.



Basic weld symbols. (From Lui, E.M., Structural steel design, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **3**-74.)

Strength of Welds

Types of Weld and Stress	Material	ASD Allowable Stress	LRFD ϕF_{BM} or ϕF_W	Required Weld Strength Level[a,b]
		Full Penetration Groove Weld		
Tension normal to effective area	Base	Same as base metal	0.90 F_y	"Matching" weld must be used
Compression normal to effective area	Base	Same as base metal	0.90 F_y	Weld metal with a strength level equal to or less than "matching" must be used
Tension of compression parallel to axis of weld	Base	Same as base metal	0.90 F_y	
Shear on effective area	Base weld electrode	0.30 × nominal tensile strength of weld metal	0.90[0.60 f_y] 0.80[0.60 F_{EXX}]	
		Partial Penetration Groove Welds		
Compression normal to effective area	Base	Same as base metal	0.90 F_y	Weld metal with a strength level equal to or less than "matching" weld metal may be used
Tension or compression parallel to axis of weld[c]				
Shear parallel to axis of weld	Base weld electrode	0.30 × nominal tensile strength of weld metal	0.75[0.60 F_{EXX}]	
Tension normal to effective area	Base weld electrode	0.30 × nominal tensile strength of weld metal ≤0.18 × yield stress of base metal	0.90 F_y 0.80[0.60 F_{EXX}]	
		Fillet Welds		
Stress on effective area	Base weld electrode	0.30 × nominal tensile strength of weld metal	0.75[0.60 F_{EXX}] 0.90 F_y	Weld metal with a strength level equal to or less than "matching" weld metal may be used
Tension or compression parallel to axis of weld[c]	Base	Same as base metal	0.90 *Fy*	
		Plug or Slot Welds		
Shear parallel to faying surfaces (on effective area)	Base weld electrode	0.30 × nominal tensile strength of weld metal	0.75[0.60 F_{EXX}]	Weld metal with a strength level equal to or less than "matching" weld metal may be used

[a] See AWS D1.1 for "matching" weld material.
[b] Weld metal one strength level stronger than "matching" weld metal will be permitted.
[c] Fillet welds partial-penetration groove welds joining component elements of built-up members such as flange-to-web connections may be designed without regard to the tensile or compressive stress in these elements parallel to the axis of the welds.

From Lui, E.M., Structural steel design, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **3**–75.

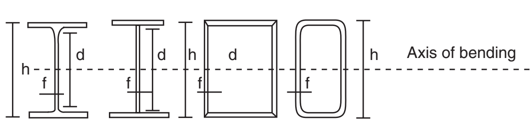
Reinforcing Bar Dimensions and Weights

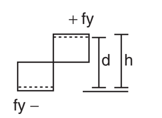
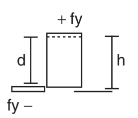
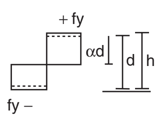
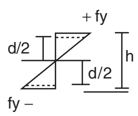
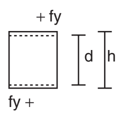
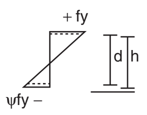
	Nominal Dimensions					
	Diameter		Area		Weight	
Bar Number	(in.)	(nm)	(in.^{2})	(cm^2)	(lb/ft)	(kg/m)
3	0.375	9.5	0.11	0.71	0.376	0.559
4	0.500	12.7	0.20	1.29	0.668	0.994
5	0.625	15.9	0.31	2.00	1.043	1.552
6	0.750	19.1	0.44	2.84	1.502	2.235
7	0.875	22.2	0.60	3.87	2.044	3.041
8	1.000	25.4	0.79	5.10	2.670	3.973
9	1.128	28.7	1.00	6.45	3.400	5.059
10	1.270	32.3	1.27	8.19	4.303	6.403
11	1.410	35.8	1.56	10.06	5.313	7.906
14	1.693	43.0	2.25	14.52	7.65	11.38
18	2.257	57.3	4.00	25.81	13.60	20.24

From Grider, A., Ramirez, J.A., and Yun, Y.M., Structural concrete design, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **4**–6.

Eurocode 4 Maximum Width-to-Thickness Ratios for Steel Webs

Webs: elements perpendicular to axis of bending



Class	Web subject to bending	Web subject to compression	Web subject to bending and compression
Stress distribution (Compression positive)			
1	d/t ≤ 72 ε	d/t ≤ 33 ε	when α > 0.5 d/t ≤ 396 ε/(13α–1) when α < 0.5 d/t ≤ 36 ε/α
2	d/t ≤ 83 ε	d/t ≤ 38 ε	when α > 0.5 d/t ≤ 456 ε/(13α–1) when α < 0.5 d/t ≤ 41.5 ε/α
Stress distribution (compression positive)			
3	d/t ≤ 124 ε	d/t ≤ 42 ε	when ψ > –1 d/t ≤ 42 ε/(0.67+0.33 ψ) when ψ ≤ –1 d/t ≤ 62 ε/(1–ψ)/ψ

ε = 235/f_y				
	f_y (N/mm^1)	235	275	355
	ε	1.0	0.92	0.81

From Consenza, E. and Zandonini, R., Composite construction, in *Handbook of Structural Engineering,* Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **6**-29.

Mechanical Properties of Steels Referred to in the AISI 1996 Specification

Steel Designation	ASTM Designation	Yield Point, F_y (ksi)	Tensile Strength, F_u (ksi)	Elongation (%) In 2-in. Gage Length	Elongation (%) In 8-in. Gage Length
Structural steel	A36	36	58–80	23	—
High-strength low-allow structural steel	A242 (3/4 in. and under)	50	70	—	18
	(3/4 in. to 1-1/2 in.)	46	67	21	18
Low and intermediate tensile strength carbon plates, shapes and bars	A283 Gr. A	24	45–60	30	27
	B	27	50–65	28	25
	C	30	55–75	25	22
	D	33	60–80	23	20
Cold-formed welded and seamless carbon steel structural tubing in rounds and shapes	A500				
	Round tubing				
	A	33	45	25	—
	B	42	58	23	—
	C	46	62	21	—
	D	36	58	23	—
	Shaped tubing				
	A	39	45	25	—
	B	46	58	23	—
	C	50	62	21	—
	D	36	58	23	—
Structural steel with 42 ksi minimum yield point	A529 Gr. 42	42	60–85	—	19
	50	50	70–100	—	18
Hot-rolled carbon steel sheets and stripes of structural quality	A570 Gr. 30	30	49	21–25	—
	33	33	52	18–23	—
	36	36	53	17–22	—
	40	40	55	15–21	—
	45	45	60	13–19	—
	50	50	65	11–17	—
High-strength low-alloy columbium-vanadium steels of structural quality	A572 Gr. 42	42	60	24	20
	50	50	65	21	18
	60	60	75	18	16
	65	65	80	17	15
High-strength low-alloy structural steel with 50 ksi minimum yield point	A588	50	70	21	18
Hot-rolled and cold-rolled high-strength low-alloy steel sheet and strip with improved corrosion resistance	A60				
	Hot-rolled as rolled coils; annealed or normalized; and cold-rolled	45	65	22	—
	Hot-rolled as rolled cut lengths	50	70	22	—
Hot-rolled and cold-rolled high-strength low-alloy columbium and/or vanadium steel sheet and strip	A607 Gr. 45	45	60 (55)	Hot-rolled 23–25	
				Cold-rolled 22	
	50	50	65 (60)	Hot-rolled 20–22	—
				Cold-rolled 20	—
	55	55	70 (65)	Hot-rolled 18–20	—
				Cold-rolled 18	—
	60	60	75 (70)	Hot-rolled 16–18	—
				Cold-rolled 16	—
	65	65	80 (75)	Hot-rolled 14–16	—
				Cold-rolled 15	—
	70	70	85 (80)	Hot-rolled 12–14	—
				Cold-rolled 14	—

Mechanical Properties of Steels Referred to in the AISI 1996 Specification (continued)

Steel Designation	ASTM Designation	Yield Point, F_y (ksi)	Tensile Strength, F_u (ksi)	Elongation (%) In 2-in. Gage Length	Elongation (%) In 8-in. Gage Length
Cold-rolled carbon structural steel sheet	A611 Gr. A	25	42	26	—
	B	30	45	24	—
	C	33	48	22	—
	D	40	52	20	—
	E	80	82	—	—
Zinc-coated steel sheets of structural quality	A653 SQ Gr. 33	33	45	20	—
	37	37	52	18	—
	40	40	55	16	—
	50 (class 1)	50	65	12	—
	50 (class 3)	50	70	12	—
	80	80	82	—	—
	HSLA Gr. 50	50	60	20	—
	60	60	70	16	—
	70	70	80	12 (14)	—
	80	80	90	10 (12)	—
Hot-rolled high-strength low-alloy steel sheets and strip with improved formability	A715 Gr. 50	50	60	22–24	—
	60	60	70	20–22	—
	70	70	80	18	—
	80	80	90	14	—
Aluminum-zinc alloy-coated by the hot-dip process general requirements	A792 Gr. 33	33	45	20	—
	37	37	52	18	—
	40	40	55	16	—
	50	50	65	12	—
	80	80	82	—	—

Notes:
1. The tabulated values are based on ASTM Standards.
2. 1 in. = 25.4 mm; 1 ksi = 6.9 MPa.
3. A653 Structural Quality Grade 80, Grade E of A611, and Structural Quality Grade 80 of A792 are allowed in the AISI Specification under special conditions. For these grades, F_y = 80 ksi, F_u = 82 ksi, elongations are unspecified. See AISI Specification for reduction of yield point and tensile strength.
4. For A653 steel, HSLA Grades 70 and 80, the elongation in 2-in. gage length given in the parenthesis is for Type II. The other value is for Type I.
5. For A607 steel, the tensile strength given in the parenthesis is for Class 2. The other value is for Class I.

From Yu, W.-W., Cold-formed steel structures, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, pp. **7**–8 to **7**–9.

Some Nominal Properties of Aluminum Alloys

Property	Value
Weight	0.1 lb/in.^{3}
Modulus of elasticity	
Tension and compression	10,000 ksi
Shear	3,750 ksi
Poisson's ratio	1/3
Coefficient of thermal expansion (68 to 212°F)	0.000013 per °F

From Fridley, M.J., Aluminum structures, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **8**–2. Originally from Gaylord and Gaylord, *Structural Engineering Handbook*, McGraw-Hill, New York, 1990.

Minimum Mechanical Properties

Alloy and Temper	Product	Thickness Range, in.	Tension		Compression YS	Shear		Bearing	
			TS	YS		US	YS	US	YS
3003-H14	Sheet and plate	0.009–1.000	20	17	14	12	10	40	25
5456-H116	Sheet and plate	0.188–1.250	46	33	27	27	19	87	56
6061–T6	Sheet and plate	0.010–4.000	42	35	35	27	20	88	58
6061-T6	Shapes	All	38	35	35	24	20	80	56
6063–T5	Shapes	to 0.500	22	16	16	13	9	46	26
6063-T6	Shapes	All	30	25	25	19	14	63	40

Note: All properties are in ksi. TS is tensile strength, YS is yield strength, and US is ultimate strength.

From Fridley, M.J., Aluminum structures, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **8**–3. Originally from The Aluminum Association, *Structural Design Manual*, 1994.

Steel Plate Materials

Group	Class	Specification	Specified Minimum Yield Stress (ksi)[a]	Specified Minimum Tensile Stress (ksi)[a]
I	C	ASTM A36 (to 2 in. thick)	36	58
		ASTM A131 Grade A (to ½ in. thick)	34	58
		ASTM A285 Grade C (to ¾ in. thick)	30	55
I	B	ASTM A131 Grades B, D	34	58
		ASTM A516 Grade 65	35	65
		ASTM A573 Grade 65	35	65
		ASTM A709 Grade 36T2	36	58
I	A	ASTM A131 Grades CS, E	34	58
II	C	ASTM A572 Grade 42 (to 2 in. thick)	42	60
		ASTM A591 required over ½ in. thick		
		ASTM A572 Grade 50 (to 2 in. thick)	50	65
		ASTM A591 required over ½ in. thick		
II	B	ASTM A709 Grades 50T2, 50T3	50	65
		ASTM A131 Grade AH32	45.5	68
		ASTM A131 Grade AH36	51	71
II	A	API Spec 2H Grade 42	42	65
		API Spec 2H Grade 50 (to 2½ in. thick)	50	70
		API Spec 2H Grade 50 (over 2½ in. thick)	47	70
		API Spec 2W Grade 42 (to 1 in. thick)	42	62
		API Spec 2W Grade 42 (over 1 in. thick)	42	62
		API Spec 2W Grade 50 (to 1 in. thick)	50	65
		API Spec 2W Grade 50 (over 1 in. thick)	50	65
		API Spec 2W Grade 50T (to 1 in. thick)	50	70
		API Spec 2W Grade 50T (over 1 in. thick)	50	70
		API Spec 2Y Grade 42 (to 1 in. thick)	42	62
		API Spec 2Y Grade 42 (over 1 in. thick)	42	62
		API Spec 2Y Grade 50 (to 1 in. thick)	50	65
		API Spec 2Y Grade 50 (over 1 in. thick)	50	65
		API Spec 2Y Grade 50T (to 1 in. thick)	50	70
		API Spec 2Y Grade 50T (over 1 in. thick)	50	70
		ASTM A131 Grades DH32, EH32	45.5	68
		ASTM A131 Grades DH36, EH36	51	71
		ASTM A537 Class I (to 2½ in. thick)	50	70
		ASTM A633 Grade A	42	63
		ASTM A633 Grades C, D	50	70
		ASTM A678 Grade A	50	70
III	A	ASTM A537 Class II (to 2½ in. thick)	60	80
		ASTM A678 Grade B	60	80
		API Spec 2W Grade 60 (to 1 in. thick)	60	75
		API Spec 2W Grade 60 (over 1 in. thick)	60	75
		ASTM A710 Grade A Class 3 (to 2 in. thick)	75	85
		ASTM A710 Grade A Class 3 (2 in. to 4 in. thick)	65	75
		ASTM A710 Grade A Class 3 (over 4 in. thick)	60	70

[a] 1 ksi = 6.895 MPa

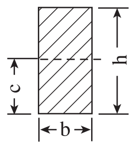
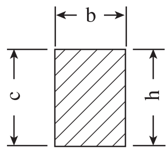
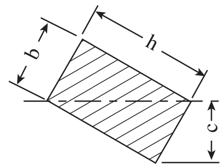
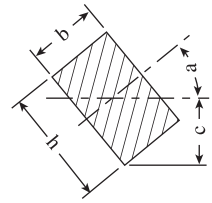
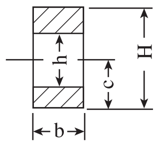
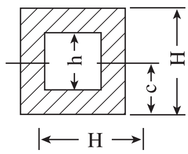
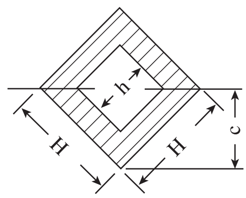
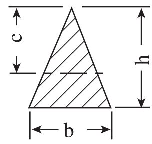
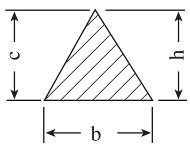
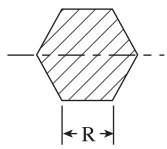
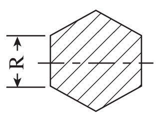
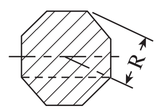
From Miller, C.D., Shell structures in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **11**-4.

Mechanical Properties of Common Design Materials

Material	Yield Strength, σ_Y (ksi)	Ultimate Tensile Strength, σ_u (ksi)	Modulus of Elasticity, E (psi)	Percent Elongation (%)	Absorbed Elastic Energy, $\sigma_Y^2/2E$ (psi)
Mild steel	35	60	30×10^6	35	20.4
Medium carbon steel	45	85	30×10^6	25	33.7
High carbon steel	75	120	30×10^6	8	94.0
A514 Steel	100	115–135	30×10^6	18	166.7
Gray cast iron	6	20	15×10^6	5	1.2
Malleable cast iron	20	50	23×10^6	10	8.7
5056-H18 Aluminum alloy	59	63	10×10^6	10	174.1

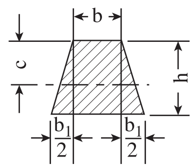
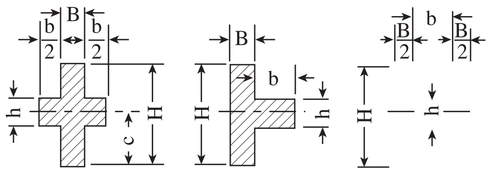
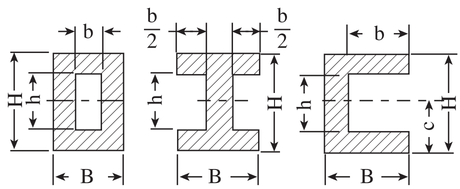
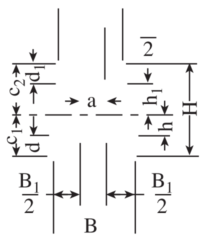
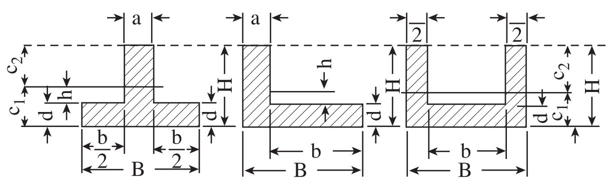
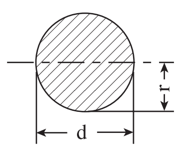
From Blodgett, O.W. and Miller, D.K., Basic principles of shock loading, in *Handbook of Structural Engineering*, Chen, W.-F., Ed., CRC Press, Boca Raton, FL, 1998, p. **21**-7.

Properties of Sections

			
$I = \frac{bh^3}{12}$	$\frac{bh^3}{3}$	$\frac{b^3h^3}{6(b^2+h^2)}$	$\frac{bh}{12}(h^2\cos^2 a + b^2\sin^2 a)$
$\frac{I}{c} = \frac{bh^2}{6}$	$\frac{bh^2}{3}$	$\frac{b^2h^2}{6\sqrt{b^2+h^2}}$	$\frac{bh}{6}\left(\frac{h^2\cos^2 a + b^2\sin^3 a}{h\cos a + b\sin a}\right)$
$r = \frac{h}{\sqrt{12}} = 0.289h$	$\frac{h}{\sqrt{3}} = 0.577h$	$\frac{bh}{\sqrt{6(b^2+h^2)}}$	$\sqrt{\frac{h^2\cos^2 a + b^2\sin^2 a}{12}}$
			
$I = \frac{b}{12}(H^3 - h^3)$	$\frac{H^4-h^4}{12}$	$\frac{H^4-h^4}{12}$	$\frac{bh^3}{36};\ c = \frac{2}{3}h$
$\frac{I}{c} = \frac{b}{6}\frac{H^3-h^3}{H}$	$\frac{1}{6}\frac{H^4-h^4}{H}$	$\frac{\sqrt{2}}{12}\frac{H^4-h^4}{H}$	$\frac{bh^2}{24}$
$r = \sqrt{\frac{H^3-h^3}{12(H-h)}}$	$\sqrt{\frac{H^2+h^2}{12}}$	$\sqrt{\frac{H^2+h^2}{12}}$	$\frac{h}{\sqrt{18}}$
			
$I = \frac{bh^3}{12}$	$\frac{5\sqrt{3}}{16}R^4$		$\frac{1+2\sqrt{2}}{6}R^4$
$\frac{I}{c} = \frac{bh^3}{12}$	$\frac{5}{8}R^3$	$\frac{5\sqrt{3}}{16}R^3$	$0.6906R^3$
$r = \frac{h}{\sqrt{6}}$	$\sqrt{\frac{5}{24}}R$		$0.475R$

Square, axis same as first rectangle, side = h; $I = h^4/12$; $I/c = h^3/6$; $r = 0.289h$.
Square, diagonal taken as axis: $I = h^4/12$; $I/c = 0.1179h^3$; $r = 0.289h$.

Properties of Sections (continued)

Equilateral Polygon A = area R = rad circumscribed circle r = rad inscribed circle n = no. sides a = length of side Axis as in preceding section of octagon	$I = \frac{A}{24}\left(6R^2 - a^2\right)$ $= \frac{A}{48}\left(12r^2 + a^2\right)$ $= \frac{AR^2}{4}$ (approx)	$\frac{I}{c} = \frac{I}{r}$ $= \frac{I}{R\cos\frac{180°}{n}}$ $= \frac{AR}{4}$ (approx)	$\sqrt{\frac{6R^2 - a^2}{24}} \approx \frac{R}{2}$ $\sqrt{\frac{12r^2 + a^2}{48}}$
	$I = \frac{6b^2 + 6bb_1 + b_1^2}{36\left(2b + b_1\right)} h^3$ $c = \frac{1}{3}\frac{3b + 2b_1}{2b + b_1} h$	$\frac{I}{c} = \frac{6b^2 + 6bb_1 + b_1^2}{12\left(3b + 2b_1\right)} h^2$	$\frac{h\sqrt{12b^2 + 12bb_1 + 2b_1^2}}{6\left(2b + b_1\right)}$
		$I = \frac{BH^3 + bh^3}{12}$ $\frac{I}{c} = \frac{BH^3 + bh^3}{6H}$	$\sqrt{\frac{BH^3 + bh^3}{12\left(BH + bh\right)}}$
		$I = \frac{BH^3 - bh^3}{12}$ $\frac{I}{c} = \frac{BH^3 + bh^3}{6H}$	$\sqrt{\frac{BH^3 - bh^3}{12\left(BH - bh\right)}}$
	$I = ⅓\left(Bc_1^3 - B_1h^3 + bc_2^3 - b_1h_1^3\right)$ $c_1 = \frac{1}{2}\frac{aH^2 + B_1d^2 + b_1d_1\left(2H - d_1\right)}{aH + B_1d + b_1d_1}$	$\sqrt{\frac{I}{\left(Bd + bd_1\right) + a\left(h + h_1\right)}}$	
		$I = ⅓\left(Bc_1^3 - bh^3 + ac_2^3\right)$ $c_1 = \frac{1}{2}\frac{aH^2 + bd^2}{aH + bd}$ $c_2 = H - c_1$ $r = \sqrt{\frac{I}{\left[Bd + a\left(H - d\right)\right]}}$	
	$I = \frac{\pi d^4}{64} = \frac{\pi r^4}{4} = \frac{A}{4} r^2$ $= 0.05d^4$ (approx)	$\frac{I}{c} = \frac{\pi d^3}{32} = \frac{\pi r^3}{4} = \frac{A}{4} r$ $= 0.1d^2$ (approx)	$\frac{r}{2} = \frac{d}{4}$

From Bolz, R.E. and Tuve, G.L., Structures and materials, in *CRC Handbook of Tables for Applied Engineering Science,* CRC Press, Boca Raton, FL, pp. 628–629.

Components of the Atmosphere*

Average Composition of Dry Air

For most engineering applications the following accepted values for the "average" composition of the atmosphere are adequate. These values are for sea level or any land elevation. Proportions remain essentially constant to 50,000 ft (15,240 m) altitude.

Gas	Molecular Weight	Percentage by Volume, mol fraction	Percentage by Weight
Nitrogen	N_2 = 28.016	78.09	75.55
Oxygen	O_2 = 32.000	20.95	23.13
Argon	Ar = 39.944	0.93	1.27
Carbon dioxide	CO_2 = 44.010	0.03	0.05
		100.00	100.00

For many engineering purposes the percentages 79% N_2–21% O_2 by volume and 77% N_2–23% O_2 by weight are sufficiently accurate, the argon being considered as nitrogen with an adjustment of molecular weight to 28.16.

Other gases in the atmosphere constitute less than 0.003% (actually 27.99 parts per million by volume), as given in the following table.

Minor Constituents of Dry Air

Gas	Molecular Weight	Parts per Million By Volume	Parts per Million By Weight
Neon	Ne = 20.183	18.	12.9
Helium	He = 4.003	5.2	0.74
Methane	CH_4 = 16.04	2.2	1.3
Krypton	Kr = 83.8	1.	3.0
Nitrous oxide	N_2O = 44.01	1.	1.6
Hydrogen	H_2 = 2.0160	0.5	0.03
Xenon	Xe = 131.3	0.08	0.37
Ozone	O_3 = 48.000	0.01	0.02
Radon	Rn = 222.	(0.06×10^{-12})	

Minor constituents may also include dust, pollen, bacteria, spores, smoke particles, SO_2, H_2S, hydrocarbons, and larger amounts of CO_2 and ozone, depending on weather, volcanic activity, local industrial activity, and concentration of human, animal, and vehicle population. In certain enclosed spaces the minor constituents will vary considerably with industrial operations and with occupancy by humans, plants, or animals.

The above data do not include water vapor, which is an important constituent in all normal atmospheres.

* Compiled from several sources.

From Bolz, R.E. and Tuve, G.L., Atmosphere, earth, and ocean, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 649.

Sound Transmission Through Partition Walls*

Dry-Wall Construction

The following table presents typical results selected from approximately 100 tests in the National Research Council of Canada Building Research series. The tests were conducted in accordance with ASTM E90–66T, "Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions." The gypsum board samples represented extremes of density and thickness (as allowed under CSA Standards); they included the fire-resistant and the vinyl-covered types, with no significant differences in performance.

			Transmission Loss, db, at Octave Frequencies of[a]					
Number	Description of Wall	Transmission Loss, Nominal Average	125	250	500	1000	2000	4000
	Single-Leaf or Board on One Side of Studs Only							
1	3/8-in. plasterboard[b]	26	12	17	23	28	33	23
2	1/2-in. plasterboard[b]	28	15	20	25	30	33	27
3	5/8-in. plasterboard[b]	29	16	21	27	31	29	30
4	22-gage galvanized iron	27	13	17	22	28	34	39
5	1/2-in. plasterboard + 3/16-in. plywood[c]	28	16	20	25	29	32	31
6	1/2-in. plasterboard + 1/2-in. fiberboard[d]	30	16	22	28	33	32	30
	Two-Leaf Walls—Wallboard Both Sides							
7	1/2-in. plasterboard, 3 5/8-in. space	35	15	28	32	41	46	38
8	1/2-in. plasterboard, 2-in. fill[e]	40	22	33	35	43	47	40
9	Staggered studs + 2-in. fill[f]	46	26	37	45	50	50	47
10	Plasterboard + plywood + fiberboard[g]	46	22	36	46	54	56	56
11	5/8-in. plasterboard, 3 5/8-in. space	36	21	25	34	41	36	42
12	5/8-in. plasterboard, 4-in. fill[h]	45	28	40	45	48	40	45
13	Staggered studs + no fill[j]	39	27	25	37	46	38	49
14	Staggered studs, 4-in. fill[k]	46	32	36	47	50	42	52
15	Multilayer, steel studs, glass fiber[m]	53	36	45	49	55	55	56

[a] The quoted report included test data on the following additional frequencies: 160, 200, 315, 400, 630, 1,250, 1,600, 2,500, 3,150, and 5,000 hz.
[b] Joints taped for plasterboard walls.
[c] Sheets joined by contact cement on faces.
[d] Plasterboard and wood fiberboard laminated with gypsum joint compound.
[e] Glass fiber batts, 2-in. thick, between studs; 1/2-in. plasterboard.
[f] Staggered wood studs, 2-in. × 4-in., 3 5/8-in. space, 2-in. thick glass fiber batts, 1/2-in. plasterboard, both faces.
[g] 1/2-in. plasterboard and 3/16-in. plywood on both faces; 2-in. × 4-in. wood studs on 16-in. wood fiberboard between studs.
[h] 4-in. low-density glasswool batts, compressed into stud space between 3 5/8-in. steel-channel studs.
[j] 2-in. × 4-in. wood studs, staggered, 3 5/8-in. space, 5/8-in. plasterboard, no fill.
[k] Same as No. 13 but 4-in. low-density glasswool batts in space between 2-in. × 4-in. wood studs.
[m] Three 1/2-in. layers, one 5/8-in. layer plasterboard; 3 5/8-in. steel channel studs, 24-in. centers; 2 1/2-in. glass fiber.

General Notes

With studs of low torsional rigidity, such as steel channels, sound transmission via the studs appears to be negligible. The simpler constructions have been tested by several laboratories, and results have been found to be reasonably reproducible.

The test specimens were mounted and caulked into an opening 10-ft wide by 8-ft high that separated two reverberation rooms. The test signal consisted of third-octave bands of "pink" noise.

The test results were not critically sensitive to normal variations in thickness, density, or techniques of erection.

Several of the additional tests included multi-layer constructions and the additions of resilient bars, horizontal or vertical. Highest sound attenuation was 53 db (test No. 15 in table).

From Bolz, R.E. and Tuve, G.L., Sound and acoustics, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 696. Originally from T.D. Northwood, "Transmission Loss of Plasterboard Walls," Building Research Note 66, Division of Building Research, National Research Council, revised July 1970.

Sound-Absorption Coefficients

Sound-absorption data on various materials are presented here in terms of the acoustic properties of rooms; these data are also valuable for other applications, such as the acoustic treatments for ducts and tunnels. Architectural applications include the control of noise level in offices, stores, restaurants, and other occupied spaces, and the control of reverberation time and elimination of echoes in concert and lecture halls.

Non-absorbent surfaces. Solid walls, floors, or ceilings finished with glazed tile, marble, terrazzo, very smooth concrete, or with linoleum, rubber, cork, or plastic tile cemented directly to concrete, are not sound absorbent. The absorption coefficient (in percentage of incident energy absorbed) is seldom more than 1 or 2 percent at all wavelengths from 125 hz to 4,000 hz.

Poor sound absorbers. Brick surfaces, painted concrete blocks, hardwood floors, gypsum board, or smooth nonporous plaster (lime or gypsum) are all poor absorbers. With solid structural backing these finishes seldom afford as much as 10 percent absorption at any wavelength from 125 hz to 4,000 hz. Ordinary window areas may absorb up to 25 percent of the low-frequency sounds (125 to 250 hz) but much less at the higher frequencies.

Sound-absorbing materials. Carpets, drapes, and upholstered seats are fair-to-good sound absorbers.

	Absorption Coefficients, % (Percentage of Incident Energy Absorbed)					
	Sound Frequency, hz					
Materials	125	250	500	1000	2000	4000
Heavy carpet on concrete or solid floor	2	6	14	37	60	65
Heavy carpet on heavy hairfelt or elastic pad	8	25	50	60	65	65
Heavy drapes (1 lb/sq yd) draped 2 to 1 area	10	30	50	75	70	65
Light hung fabric	3	4	11	17	24	35
Unoccupied wood or metal chairs[a]	15	20	25	40	40	30
Unoccupied upholstered seating[a]	45	55	65	70	70	60
Full audience, occupying upholstered seats[a]	70	75	85	95	90	85

[a] Equivalent values based on floor area.

Acoustic Treatments

The following data apply mainly to acoustic ceiling treatments, but other surfaces may be similarly treated. These data do not apply to through-transmission of sound. Low sound transmission accompanies high density or weight of material.

	Absorption Coefficients, % (Percentage of Incident Energy Absorbed)					
	Sound Frequency, hz					
Class Description[b]	125	250	500	1000	2000	4000
Porous, lightweight fiber board or tile ¾ in. thick; perforated or fissured; painted; on ¾ in. furring strips	20	58	61	80	80	68
Porous fireproof mineral tile, ⅝ in. thick; perforated or fissured; painted; direct solid application to structural surface	10	26	70	89	75	60
Porous fireproof mineral tile, ¾ in. thick, drop ceiling or large air space; metal supports	70	66	72	92	88	75
Bonded wood or mineral fibers; thickness about 1½ in.	41	59	88	85	76	65
Perforated metal pans or hardboard backed with 1½ in. loose pad	36	56	87	94	74	56

[b] Data on each class based on five or more commercial products.

From Bolz, R.E. and Tuve, G.L., Sound and acoustics, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 697.