e14 - applied mechanics: statics

why do things break? to reliably predict what's going on inside a structure, we need to know the **forces** that act on it. it's **newton's law** that helps us to determine these forces. basically, this course is all about newton's law, force **equilibrium**, and its application to civil, mechanical, aerospace, and biological problems. we explore it for **particles** first, then for two-dimensional, and finally for three-dimensional **systems**. first we look at the structure from the **outside**, then from the **inside**. we learn how to identify, formulate, and solve engineering problems. to do so, you should be familiar with and not afraid of maths, vectors, and basic physics.

ellen kuhl, charbel eid, julianne gould, estevan mendoza, chris ploch

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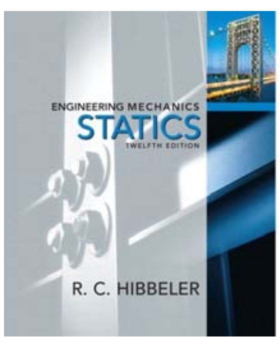
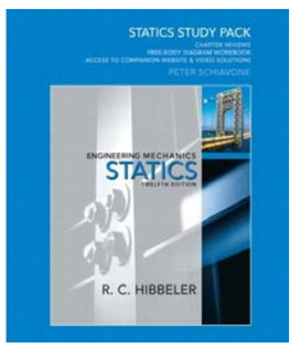


textbook.

russell c. hibbeler
prentice hall, 12th edition

engineering mechanics
statics

statics study pack
for engineering mechanics



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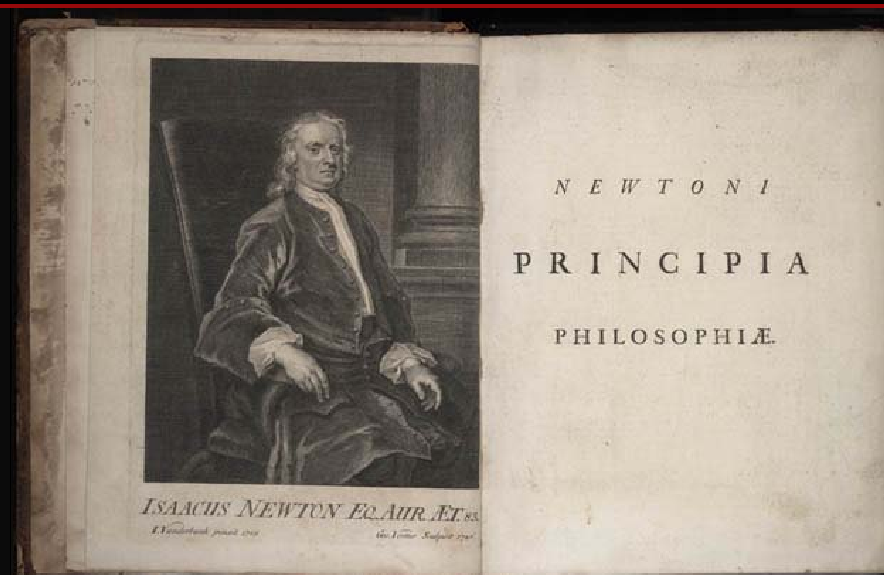

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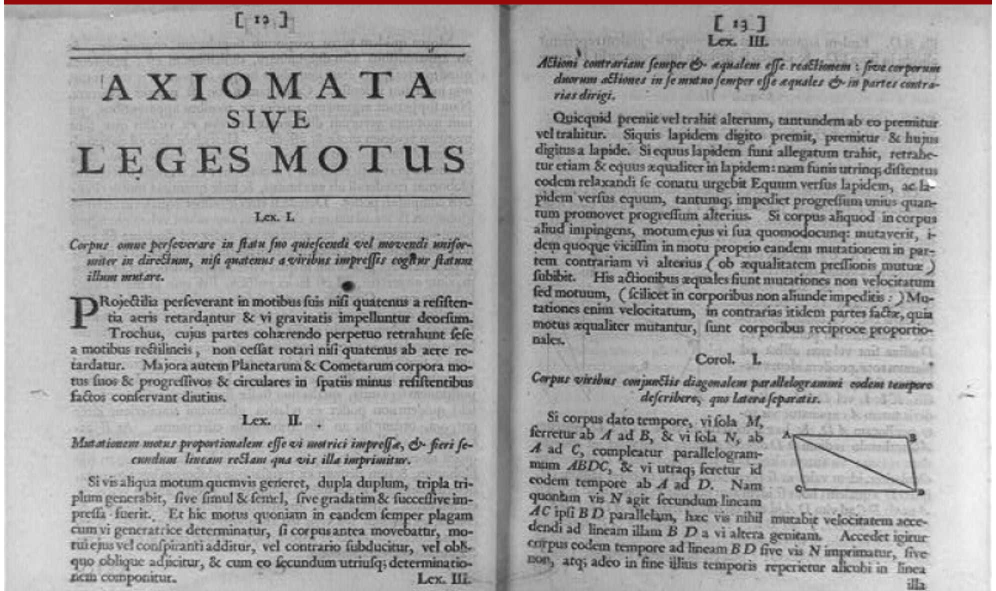

[12]

AXIOMATA SIVE LEGES MOTUS

Lex. I.

Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.

Projectilia perseverant in motibus suis nisi quatenus a resistentia aeris retardantur & vi gravitatis impelluntur deorsum. Trochus, cujus partes cohærendo perpetuo retrahunt sese a motibus rectilineis, non cessat rotari nisi quatenus ab aere retardatur. Majora autem Planetarum & Cometarum corpora motus suos & progressivos & circulares in spatiis minus resistentibus factos conservant diutius.

Lex. II.

Mutationem motus proportionalem esse vi motrici impressæ, & fieri secundum lineam rectam qua vis illa imprimitur.

Si vis aliqua motum quemvis generet, dupla duplum, tripla triplum generabit, sive simul & semel, sive gradatim & successive impressa fuerit. Et hic motus quoniam in eandem semper plagam cum vi generatrice determinatur, si corpus antea movebatur, motui ejus vel conspiranti additur, vel contrario subducitur, vel obliquo oblique adjicitur, & cum eo secundum utriusq; determinationem componitur.

Lex. III.

[13]

Lex. III.

Actioni contrariam semper & æqualem esse reactionem: sive corporum duorum actiones in se mutuo semper esse æquales & in partes contrarias dirigi.

Quicquid premit vel trahit alterum, tantundem ab eo premitur vel trahitur. Siquis lapidem digito premit, premitur & hujus digitus a lapide. Si equus lapidem funi allegatum trahit, retrahetur etiam & equus æqualiter in lapidem: nam funis utrinq; distentus eodem relaxandi se conatu urgebit Equum versus lapidem, ac lapidem versus equum, tantumq; impediet progressum unius quantum promovet progressum alterius. Si corpus aliquod in corpus aliud impingens, motum ejus vi sua quomodocunq; mutaverit, idem quoque vicissim in motu proprio eandem mutationem in partem contrariam vi alterius (ob æqualitatem pressionis mutuæ) subibit. His actionibus æquales fiunt mutationes non velocitatum sed motuum, (scilicet in corporibus non aliunde impeditis:) Mutationes enim velocitatum, in contrarias itidem partes factæ, quia motus æqualiter mutantur, sunt corporibus reciproce proportionales.

Corol. I.

Corpus viribus conjunctis diagonalem parallelogrammi eodem tempore describere, quo latera separatis.

Si corpus dato tempore, vi sola *M*, ferretur ab *A* ad *B*, & vi sola *N*, ab *A* ad *C*, compleatur parallelogrammum *ABDC*, & vi utraq; feretur id eodem tempore ab *A* ad *D*. Nam quoniam vis *N* agit secundum lineam *AC* ipsi *BD* parallelam, hæc vis nihil mutabit velocitatem accedendi ad lineam illam *BD* a vi altera genitam. Accedet igitur corpus eodem tempore ad lineam *BD* sive vis *N* imprimatur, sive non, atq; adeo in fine illius temporis reperietur alicubi in linea illa

... but our real bible is ...

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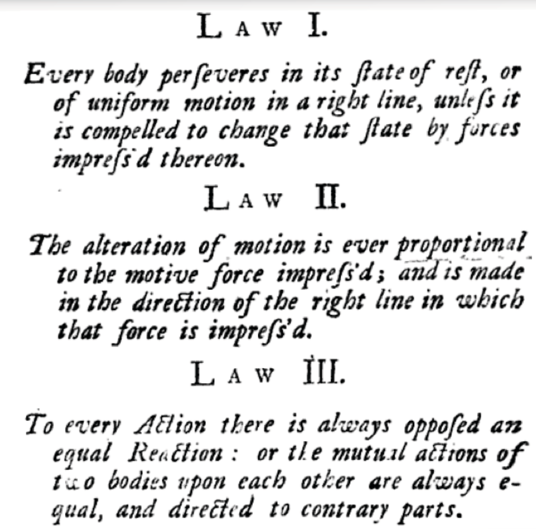

LAW I.

Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impress'd thereon.

LAW II.

The alteration of motion is ever proportional to the motive force impress'd; and is made in the direction of the right line in which that force is impress'd.

LAW III.

To every Action there is always opposed an equal Reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

philosophiae naturalis principia mathematica. isaac newton. [1687]

newton's laws

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day	date		topic	chapter
	w01		**force week**	**ch 1-2**
mon	mar	28	what's statics?	1.1-1.5
wed	mar	30	what's a force?	2.1-2.4
fri	apr	01	what's a force resultant?	2.5-2.9
	w02		**particle week**	**ch 3**
mon	apr	04	what's a free body diagram at a point?	3.1-3.2
wed	apr	06	what's force equilibrium at a point?	3.3-3.4
fri	apr	08	problem session 1	
	w03		**moment week**	**ch 4**
mon	apr	11	what's a moment?	4.1-4.4
wed	apr	13	what's a couple? what's distributed loading?	4.5-4.7
fri	apr	15	problem session 2	
	w04		**practice week**	**ch 1-4**
mon	apr	18	problems, problem, problems ...	
wed	apr	20	midterm 1, in class, closed book, 1 cheat sheet	
fri	apr	22	recover-from-midterm friday / no problem session	
	w05		**2d equilibrium week**	**ch 5**
mon	apr	25	what's a free body diagram of a 2d system?	5.1-5.2
wed	apr	27	what force and moment equilibrium in 2d?	5.3-5.4
fri	apr	29	problem session 3	

syllabus

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	w06		**3d equilibrium week**	**ch 5**
mon	may	02	what's a free body diagram of a 3d system?	5.5
wed	may	04	what force and moment equilibrium in 3d?	5.6-5.7
fri	may	06	problem session 4	
	w07		**structures week**	**ch 6**
mon	may	09	what's truss structure?	6.1-6.3
wed	may	11	what's a frame?	6.6
fri	may	13	problem session 5	
	w08		**internal force week**	**ch 7**
mon	may	16	what's inside?	7.1
wed	may	18	what's a shear and moment diagram?	7.2-7.3
thu	may	19	midterm 2, all day take home, wed 2pm - thu 5pm	
fri	may	20	recover-from-midterm friday / no problem session	
	w09		**friction and center week**	**ch 8-9**
mon	may	23	what's friction?	8.1-8.2
wed	may	25	what's the center?	9.1-9.2
fri	may	27	problem session 6	
	w10		**that's it week**	
mon	may	30	memorial day / no class	
wed	jun	01	what's a was this all about?	
fri	jun	03	end of quarter / no class	2.5-2.9
xxx	jun	xxx	problems, problems, problems ...	
xxx	jun	xxx	final, in class, closed book, 1 cheat sheet	

syllabus

e14 - applied mechanics: statics

homework	20 %	five homework assignments, 4% each
exams	80 %	two midterms, one final, 30%, 25%, 25% each
final grade	≥ 90 A range ≥ 80 B range ≥ 70 C range < 70 lower	

grades, grades, grades ...

e14 - applied mechanics: statics

homework. homework sets will be announced in class and assigned via coursework. homework will be graded for completeness, correctness, and clarity. assignments must be completed in pencil on engineering computation paper. solutions must be legible and orderly, with complete and properly labeled free body diagrams. answers must be clearly boxed. the meaning of variables that you introduce must be clear. if the grader cannot read and follow your work, you will not get credit. you have up to three late days to use over the quarter. a late day is charged for any fraction of a day past the due date. once you have used your allocation of late days, further late submissions will be corrected, but will receive a score of zero. the final homework may not be submitted late.

grades, grades, grades ...

e14 - applied mechanics: statics

midterm 1	wednesday, 04/20, in class
midterm 2	wednesday, 05/18, take home
final exam	to be announced

exams. your highest exam score will count for 30% of your final grade and your other two exams will count for 25% each. the first midterm and the final are closed book/closed notes exams. you may bring one handwritten, letter sized formula sheet to each exam but no photocopies or printouts. bring a calculator, but pre-programmed functions or programs may not be used. the second midterm is a take home exam. no internal or external communication is permitted during the exam. all exams must be taken at the scheduled time.

grades, grades, grades ...

structural failure

motivation

structural failure

when a structure fails, there is invariably an investigation to find out why it failed. apart from the legal and professional necessity to determine the cause of failure, there is also the **need to learn from it** lessons that would enable subsequent designers and builders to avoid the pitfalls of the failed structure and **develop safer alternatives**.

technological developments in recent decades have introduced **new configurations**, **materials**, and **methods of design and construction** that raise new and complex problems. failures are caused by many unprecedented causes singly or in combination. paradoxially, in the pursuit of innovation, even **basic principles of sound structural design and good construction practice are often violated**, leading to failure.

krishnamurthy [2007]

reasons for structural failure

• **structural analysis**	34%
• conceptual errors	34%
• drawings and specifications	19%
• work planning and preparation	9%
• combinations	4%
• **ignorance, carelessness, negligence**	35%
• **insufficent knowledge**	25%
• **underestimation of influences**	13%
• **forgetfulness, errors, mistakes**	9%
• reliance upon others without sufficient control	6%
• objectively unknown situation	4%
• others	8%

matousek & schneider [1976], krishnamurthy [2007]

reasons for structural failure

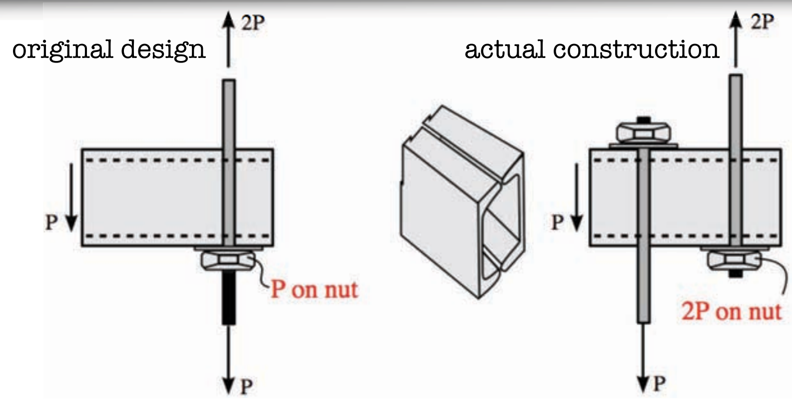
sudden failure, subtotal	**66%**
• loss of equilibrium	13%
• failure with collapse	29%
• failure without collapse	11%
• other types of failure	10%
unacceptable conditions, subtotal	**33%**
• excessive cracks	16%
• errors in dimensions and support conditions	8%
• deflections and change of shape	7%
• other unacceptable conditions	6%

krishnamurthy [2007]

hyatt regencey walkway collapse

the hyatt regency hotel walkway collapse occurred on july 17, 1981, in kansas city, missouri, killing 114 people and injuring 216 others. at the time, it was the deadliest structural collapse of u.s. history. one of the defining features of the hotel was its lobby, which featured a multistory atrium spanned by steel, glass and concrete walkways on the second, third and fourth levels suspended from the ceiling. the walkways were 37m long and weighed 29,000 kg. the fourth level walkway aligned directly above the second level walkway.

hyatt regencey walkway collapse



construction difficulties resulted in a subtle but flawed design change that doubled the load on the connection between the walkway support beams and the tie rods carrying the weight of the second and fourth floor walkways. this excessive load caused a lower bold to pull through the beam so that the upper walkway collapsed upon the one below.

hyatt regencey walkway collapse

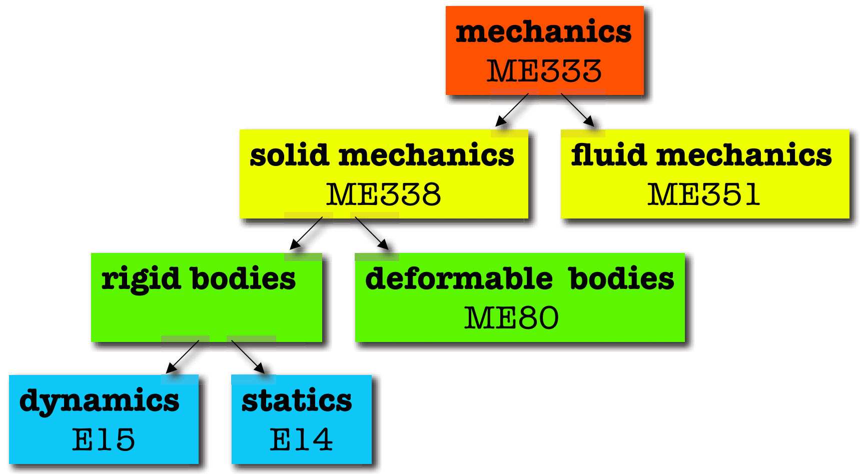
the engineers who had approved the final drawings were convicted by the missouri board of architects, profes-sional engineers, and land surveyors of gross negligence, misconduct, and unprofessional conduct in the prac-tice of engineering; they all lost their engineering licenses in the state of missouri and texas. while the design company was discharged of criminal negligence, it lost its license to be an engineering firm. at least $140 million was awarded to victims and their families in civil lawsuits.

ethics in engineering practise & research. whitbeck [1998]

hyatt regencey walkway collapse

the hyatt regency tragedy remains a classic model for the study of engineering ethics and errors. “investigation of the kansas city hyatt regency walkway collapse” us department of commerce [1982]

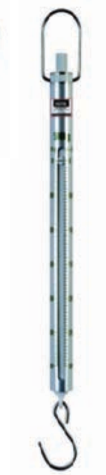
mechanics



basic quantities

- **length.** meter [m]
- **time.** second [s]
- **mass.** gram [g]
- **force.** newton [N]





idealizations

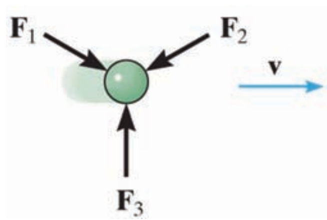
particle. a particle has a finite mass but a size that can be neglected. for example, the size of the earth is insignificant compare to the size of the orbit; therefore the earth can be modeled as a particle when studying planet motion.

rigid body. a rigid body is a combination of a large number of particles with all particles remaining at a fixed distance from one another.

concentrated force. a concentrated force is a representation of loading as a single point force. this is justified if the load is applied to an area which is small compared to the overall size of the body.

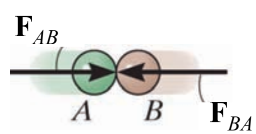
newton‘s three laws of motion

- first law
  equilibrium
  if □$\boldsymbol{F} = \boldsymbol{O}$ then $\boldsymbol{v} = \text{const.}$



- second law
  accelerated motion
  $\boldsymbol{F} = \boldsymbol{m} \cdot \boldsymbol{a}$

- third law
  actio = reactio
  $\boldsymbol{F}_{\text{AB}} = -\boldsymbol{F}_{\text{BA}}$

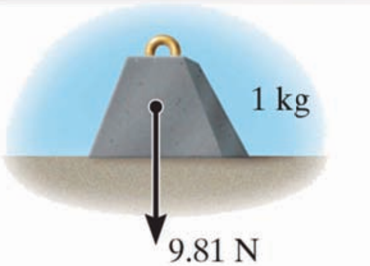


weight

SI system
$W = m \cdot g$
W … weight (derived quantity)
m … mass (basic quantity)
g … acceleration due to gravity
$g = 9.81$ m/s^2

FPS system
$m = W / g$
m … mass (derived quantity)
W … weight (basic quantity)
g … acceleration due to gravity
$g = 32.2$ ft/s^2

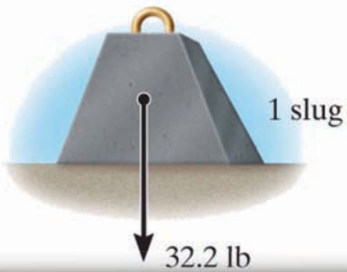
systems of units



SI system

basic units
- meters [m]
- seconds [s]
- kilogram [kg]

derived unit
- Newton [N = kg · m /s²]



FPS system

basic units
- feet [ft]
- seconds [s]
- pounds [lb]

derived unit
- slug [slug = lb · s²/ft]

systems of units

TABLE 1–1 Systems of Units

Name	Length	Time	Mass	Force
International System of Units SI	meter m	second s	kilogram kg	newton* N $\left(\frac{kg \cdot m}{s^2}\right)$
U.S. Customary FPS	foot ft	second s	slug* $\left(\frac{lb \cdot s^2}{ft}\right)$	pound lb

*Derived unit.

conversion of units

TABLE 1.2 Conversion Factors

Quantity	Unit of Measurement (FPS)	Equals	Unit of Measurement (SI)
Force	lb		4.448 N
Mass	slug		14.59 kg
Length	ft		0.304 8 m

prefixes

TABLE 1.3 Prefixes

	Exponential Form	Prefix	SI Symbol
Multiple			
1 000 000 000	10^9	giga	G
1 000 000	10^6	mega	M
1 000	10^3	kilo	k
Submultiple			
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n