材料力学

Mechanics of Materials

戴兆贺

北京大学工学院

2024-02-20

材力力学B：强基（能生材）/材机大三（选修）+双培1

- **讲授：** 戴兆贺，资源西楼2328，daizh@pku.edu.cn
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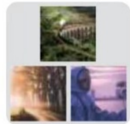
  - 陈尔腾，chen_et@stu.pku.edu.cn
  - 曾维嘉，2301111692@stu.pku.edu.cn
- **时间：** 二教402，周二1-2，周四3-4
- **教材：** 殷有泉，励争，《材料力学》（第三版），北京大学出版社，2017
- **参考书：**
  - 清华大学材料力学教研室，《材料力学解题指导与习题集》，高等教育出版社
  - Strength Of Materials 3Ed Part 1 Elementary Theory And Problems, 2002
  - Strength Of Materials 3Ed Part 2 Advanced Theory And Problems, 2002

课程介绍

- **先修课：** 微积分，高等代数，常微分方程，理论力学（静力学）
- **复习：** 理论力学绪言及第一章
- **成绩：** 平时作业（20%）＋期中考试（30%）＋期末考试（50%）
- **作业：** 每次2-4道，每周二提交，次周二返还
- **考试：** 闭卷，3-4道，难度与作业题相似，但难度略高。
- **模式：** 上课听讲、阅读讲义、阅读教材（根据情况记笔记）



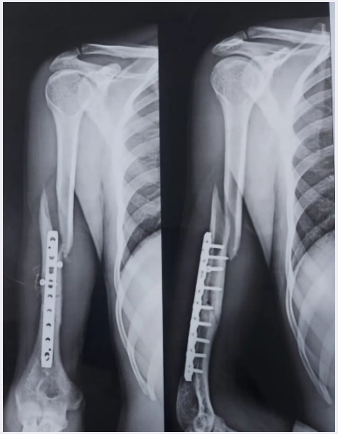
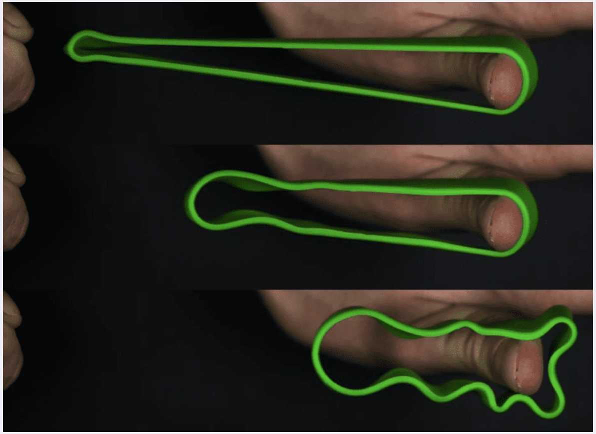
Group: 材料力学2024

Valid until 2/24 and will update upon joining group

材料力学

- 是固体力学的一个分支，研究构件承载能力的基础学科

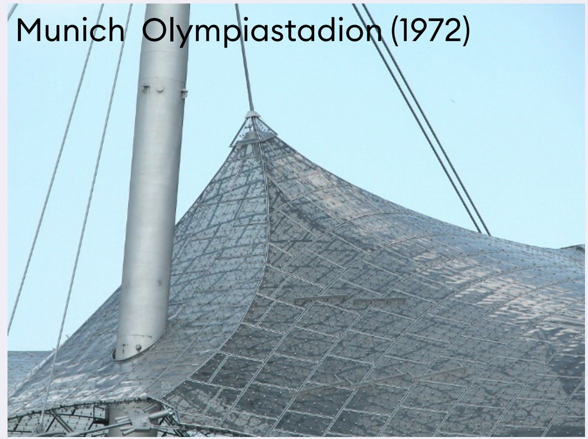
  - 构件：构成机械和工程结构的零部件，通常较为“细长”
  - 承载能力：强度（抵抗破坏能力）、刚度（抵抗变形的能力）、稳定性（保持原有平衡形式的能力）


From woods and stones to steels and glasses


Cathedral of Santa Maria del Fiore (1436)


赵州桥 (605)


Munich Olympiastadion (1972)

材料力学

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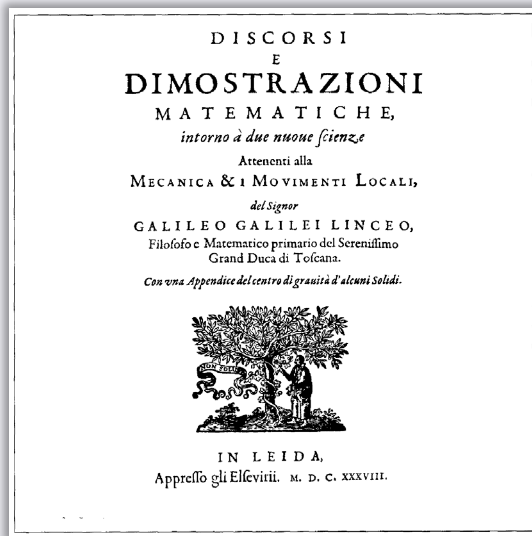
- 是学习高等力学甚至近现代科学的启蒙性质课程
  - Early version of solid mechanics (c.f. A. E. H. Love’s 1927 book)
  - **Dialogues Concerning Two New Sciences (Galileo Galilei，1638)**

课程哲学：培养新一代工程师和科学家

Generative AI is experimental. Info quality may vary.

A scientist is a professional who conducts research to further knowledge in a particular area.

- ❑ They make observations in nature and conduct experiments to test their observations.
- ❑ They use scientific methods to explain the natural world.
- ❑ They believe that there is a natural explanation for most things.



DISCORSI
E
DIMOSTRAZIONI
MATEMATICHE,
intorno à due nuoue ſcienze
Attenenti alla
MECANICA & I MOVIMENTI LOCALI,
del Signor
GALILEO GALILEI LINCEO,
Filoſofo e Matematico primario del Sereniſſimo
Grand Duca di Toſcana.
Con vna Appendice del centro di grauità d'alcuni Solidi.

IN LEIDA,
Appreſſo gli Elſevirii. M. D. C. XXXVIII.

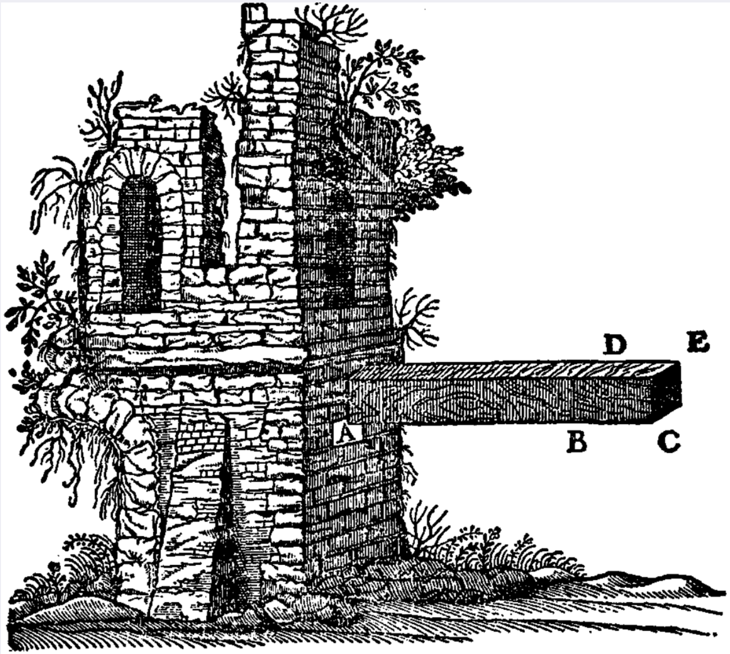
Galileo Galilei (1564/02/15-1642/01/08)
(1638)

Not only new knowledge but also the process by which it is created!

一个著名的“材料力学”例子

Dante Alighieri's vision of hell, which Galileo attempted to map.

伽利略早期的方法和结论



Dome: ~45 meters in diameter and ~3 meters in thickness

Hell: ~45 km in radius (from Jerusalem to Marseille) and thus **~6 km** in thickness

"On the Shape, Location, and Size of Dante's Inferno", Galileo Galilei (1588)

更为仔细的观察

SALV. For a while, Simplicio, I used to think, as you do, that the resistances of similar solids were similar; but a certain casual observation showed me that similar solids do not exhibit a strength which is proportional to their size, the larger ones being less fitted to undergo rough usage just as tall men are more apt than small children to be injured by a fall. And, as we remarked at the outset, a large beam or column falling from a

[165]

given height will go to pieces when under the same circumstances a small scantling or small marble cylinder will not break. It was this observation which led me to the investigation of the fact which I am about to demonstrate to you: it is a very remarkable thing that, among the infinite variety of solids which are similar one to another, there are no two of which the forces [*momenti*], and the resistances of these solids are related in the same ratio.

Galileo Galilei (1638): Proposition IV of Day 2

更为科学的推演

to be devoid of weight. But if the weight of the prism is to be taken account of in conjunction with the weight E, we must add to the weight E one half that of the prism BD: so that if, for example, the latter weighs two pounds and the weight E is ten pounds we must treat the weight E as if it were eleven pounds.

SIMP. Why not twelve?

SALV. The weight E, my dear Simplicio, hanging at the extreme end C acts upon the lever BC with its full moment of ten pounds: so also would the solid BD if sus-

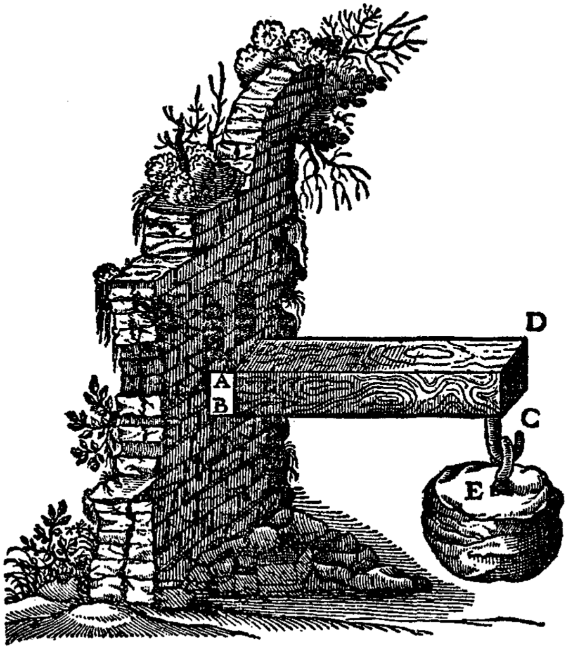


Fig. 17

Galileo Galilei (1638): Proposition IV-VIII of Day 2

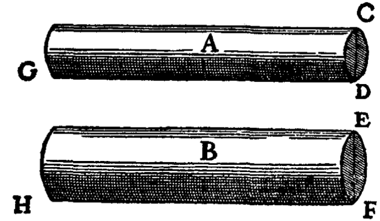


Fig. 20

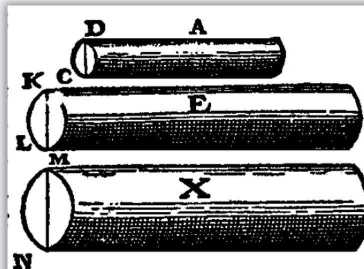


Fig. 26

- Galileo's square-cube Law
- CD:KL=KL:MN

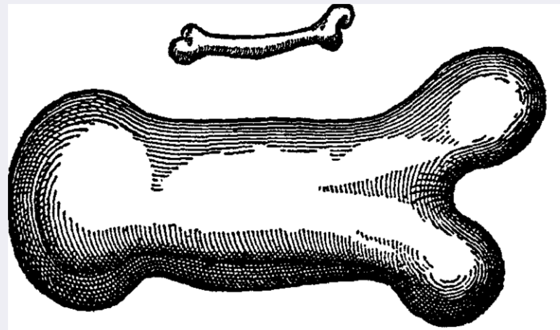
伽利略晚期的结论

Dome: ~45 meters in diameter and ~3 meters in thickness

Hell: ~ 45 km in radius (from Jerusalem to Marseille) and thus ~**6km*2000** in thickness

"The roof would have to be so thick that there would hardly be any room underneath to accommodate all those dead souls."

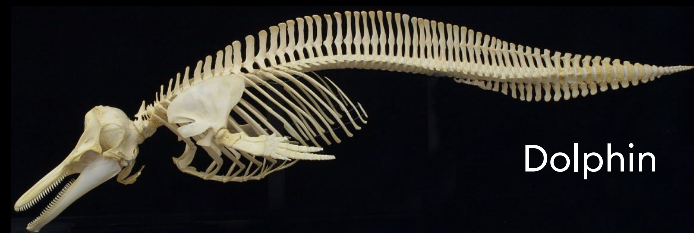
From what has already been demonstrated, you can plainly see the impossibility of increasing the size of structures to vast dimensions either in art or in nature; likewise the impossibility of building ships, palaces, or temples of enormous size in such a way that their oars, yards, beams, iron-bolts, and, in short, all their other parts will hold together; nor can nature produce trees of extraordinary size because the branches would break down under their own weight; so also it would be impossible to build up the bony structures of men, horses, or other animals so as to hold together and perform their normal functions if these animals were to be increased enormously in height; for this increase in height can be accomplished only by employing a material which is harder and stronger than usual, or by enlarging the size of the bones, thus changing their shape until the form and appearance of the animals suggest a monstrosity. This is



标度律

Elephant

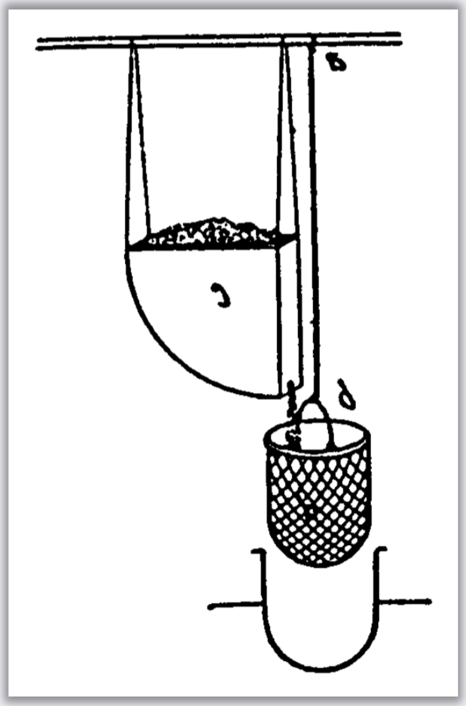
Rat



Leonardo da Vinci's fracture test (1452–1519)

The object of this test is to find the load an iron wire can carry.

- ❑ Attach an iron wire to a basket
- ❑ Feed into the basket some fine sand through a small hole placed at the end of a hopper.
- ❑ A spring will close the hole as soon as the wire breaks.
- ❑ The basket falls a short distance into a hole, so as not to upset the basket.
- ❑ The weight of the sand and the location of fracture of the wire are to be recorded.
- ❑ The test is repeated several times to check the results.
- ❑ Then a wire of one-half the previous length is tested and the additional weight it carries is recorded;
- ❑ the a wire of one fourth length is tested and so forth,



The strength of a metal wire increases with decreasing length.
This size effect is the result of the decreasing number of which were clearly visible in metal wires at that time.

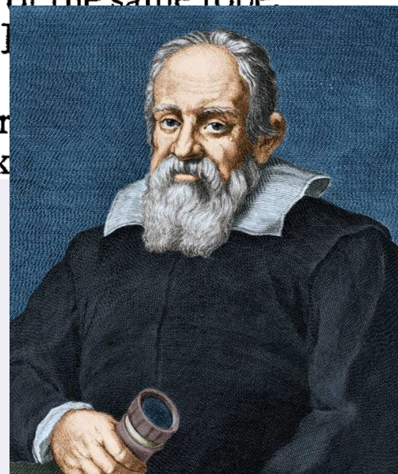
Galileo Galilei (1564–1642)

Day two

SALV. I fear, Simplicio, if I correctly catch your meaning, that in this particular you are making the same mistake as many others; that is if you mean to say that a long rope, one of perhaps 40 cubits, cannot hold up so great a weight as a shorter length, say one or two cubits, of the same rope.

SIMP. That is what I … ee the proposition is highly probable.

SALV. On the contr … erely improbable but false; and I think … ou of your error.



the short one? Give up then this erroneous view which you share with many very intelligent people, and let us proceed.

In 19th century, elasticity theory is developed, with some criteria for failure of materials

- ❑ Coulomb (1763–1806): Ultimate shear strength (stress/strain not clearly defined)
- ❑ Saint Venant (1797–1886): Maximum strain hypothesis (until the end of the 19th century)
- ❑ Lamé (1795–1870), Rankine (1820–1872): Maximum stress criterion (for brittle materials)
- ❑ Tresca (1814–1885): Maximum shear criterion ("for plastic materials")
- ❑ Mohr (1835–1913): General failure criterion using Mohr's circles (Mohr-Coulomb criterion, still in use in Geomechanics)

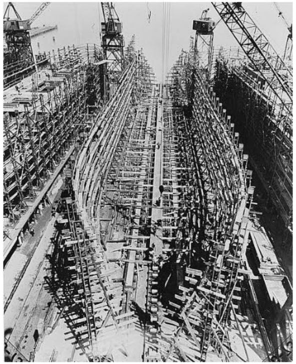
Until the end of the 19th century there was not yet a clear differentiation between failure by brittle fracture and failure by plastic flow

- ❑ Huber (1872–1950), von Mises (1883–1953), Hencky (1885–1951): Maximum distortion energy criterion

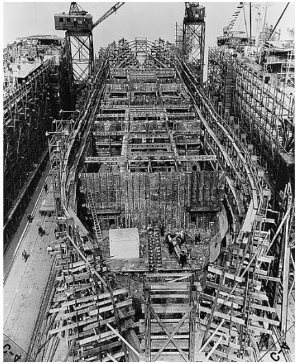
本课程基本涵盖了清朝时期左右人们对材料力学的认知。

无法解释在低于设计载荷下，钢结构发生突然断裂：1.波士顿糖蜜灾难1919；2. WWII自由号舰事件

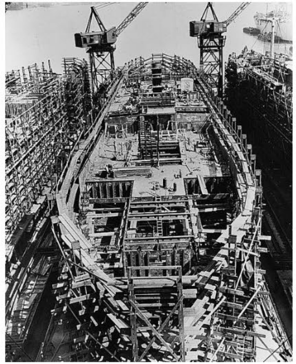
从构件到整体：The Liberty ships



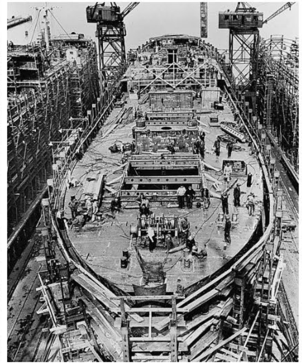
Day 2 : Laying of the keel plates



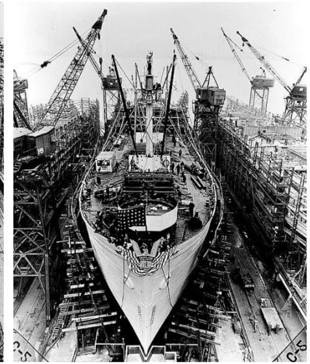
Day 6 : Bulkheads and girders below the second deck are in place.



Day 10 : Lower deck being completed and the upper deck amidship erected



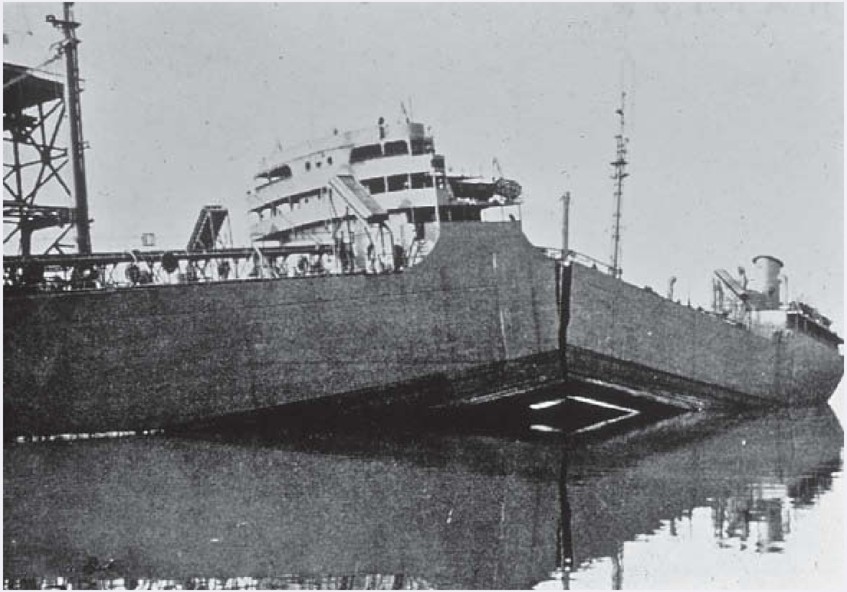
Day 14 : Upper deck erected and mast houses and the after-deck house in place



Day 24 : Ship ready for launching

- ❑ Replaced much riveting with welding
- ❑ 2,751 Liberties were built between 1941 and 1945 (an average of three ships every two days, symbolizing U.S. wartime industrial output)

更复杂的工程系统：弹性力学、塑性力学、断裂力学



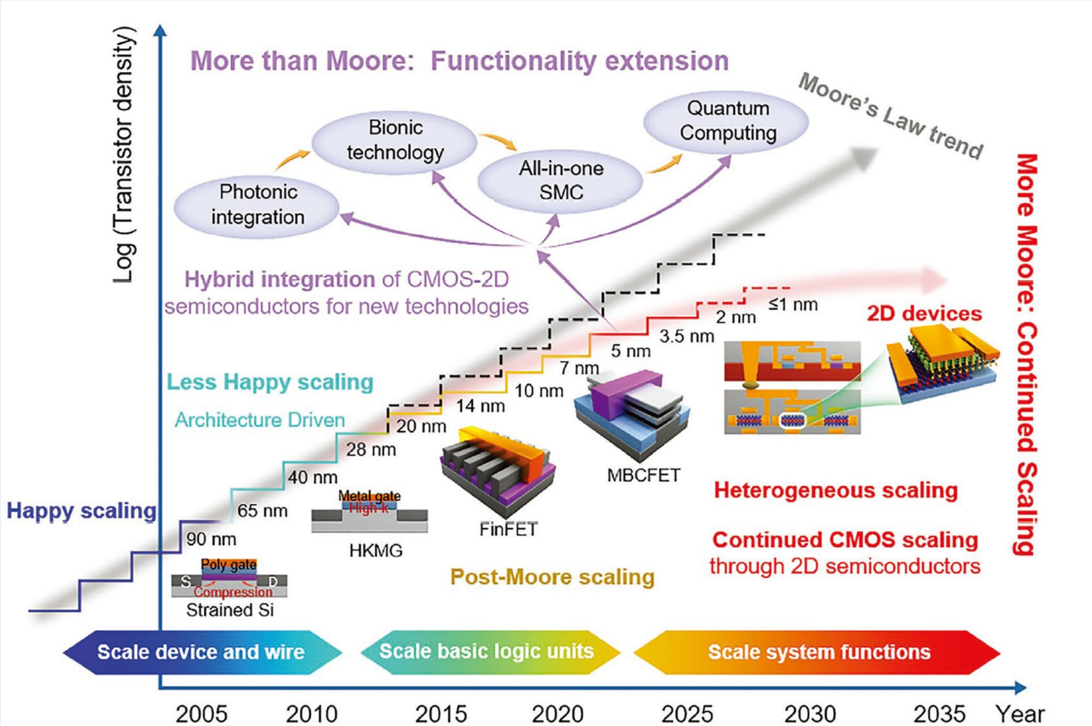
The Liberty ship that was fractured the day after it was launched in 1943

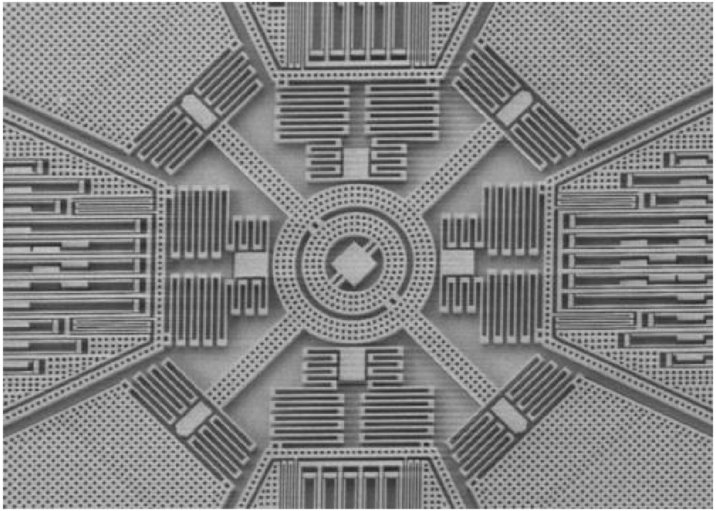
- ❑ As of 1946, 1,031 out of 2,751 damages or accidents due to brittle fractures had been reported. 19 ships breaking in half without warning (behaving like brittle, why?).

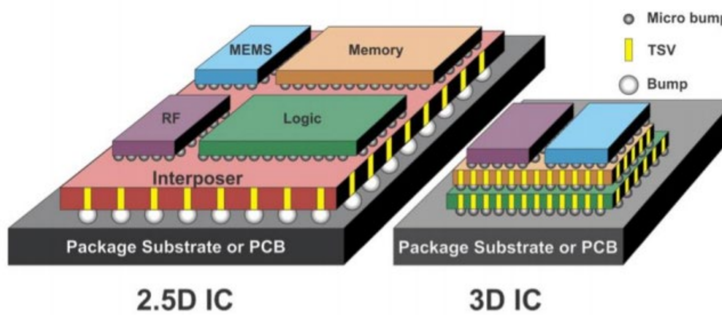
- ❑ Reasons: Stress concentrations at the hatch corners, weld defects and fatigue cracks

Semiconductors

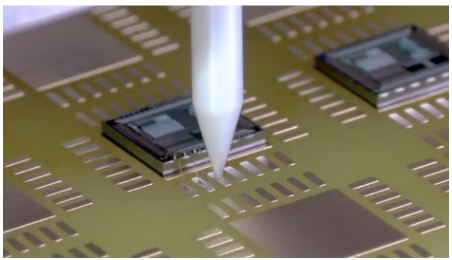
Number of components in electronic circuits has doubled every two years since the 1960s

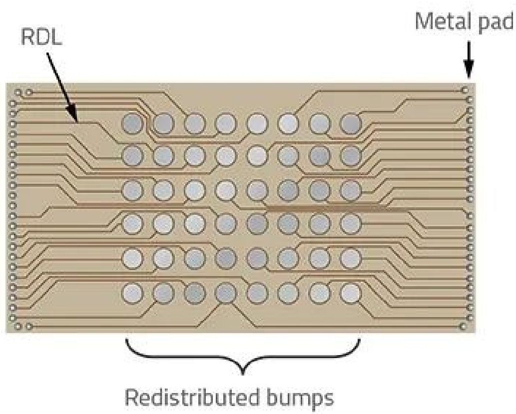





Micro bump
TSV
Bump
MEMS
Memory
RF
Logic
Interposer
Package Substrate or PCB
Package Substrate or PCB
2.5D IC
3D IC

开裂、分层、脱粘、翘曲…




RDL
Metal pad
Redistributed bumps


功率半导体封装技术
集成电路系统级封装
硅通孔三维封装技术
集成电路先进封装材料
集成电路
先进封装材料
Advanced Packaging Materials

Nowadays mechanics is an organic part of applied mathematics. An analogy of mechanics with the phoenix comes to mind. This legendary bird has appeared with practically identical magical features in the ancient legends of many cultures: Egyptian, Chinese, Hebrew, Greek, Roman, native North American, Russian. ...Death could never touch it... However, from time to time. when ii was weakened, the phoenix would carefully prepare a fire from aromatic herbs collected from throughout the world and burn itself. Everything superfluous is burnt in the fire and a new beautiful creative life opens to the phoenix.

So, what is the analogy? Mechanics now is living through a critical period. The community at large, particularly the scientific community, often considers mechanics to be a subject of secondary value...I am sure that a phoenix-type rebirth of mechanics is unavoidable... The reason for my confidence is the existence (not always generally recognized by society, nor political leaders) of fundamental problems of vital importance for humankind that cannot be solved without the leading participation of mechanics and applied mathematics as a whole. To mention a few of these: The prediction of earthquakes, the creation of a new branch of engineering based on nano-technology; earth's non-renewable resources... (AI, Semiconductors, Aerospace...) The surge of interest in mechanics during World War II and its aftermath demonstrated this clearly.

Flow, deformation and fracture by G. I. Barenblatt, 2014, Cambridge University Press

Thanks!