金门大桥的幕后故事

- 庆祝金门大桥通车 80 周年

(普通版-初稿 2017 年 5 月 20 日；终稿 2017 年 6 月 1 日)，

段炼 （Lian Duan）

引言

作为一位桥梁工程师，从 1991 年第一次参观游览向往已久的金门大桥(Golden Gate Bridge，图 1）至今，每每到此，都会感到心灵的震撼！从 1937 年 5 月 27 日大桥建成 20 万民众漫步桥上庆祝，第二天 5 月 28 日，美国罗斯福总统华盛顿按下电钮，第一队汽车正式从桥上徐徐通过，至今，已整整 80 個春秋。值此庆祝金门大桥建成通车 80 周年（图 2）之际，谨以此文表达对所有当年参与建设金门大桥的工程技术人员，建造者以及管理者们，特别是对大桥的实际设计者（Designing Engineer）查尔斯•阿尔顿•埃利斯（Charles Alton Ellis）教授的崇高敬意！

图 1: 金门大桥西侧立面 （段炼摄于大桥西北角马连高地 Marin Highlands)

图 2： 金门大桥 80 周年花池 (段炼摄于大桥南桥头游客中心 Welcome Center）

金门大桥简介

金门大桥位于美国加州旧金山市区以北的美国 101 号公路和加州 1 号公路 （US Highway 101 and California Highway 1）上。大桥横跨旧金山海湾通向太平洋门户的金门海峡（图 3），是连接旧金山市和马连县（Marin County）的交通纽带,也是旅游胜地旧金山市的最著名地标之一。

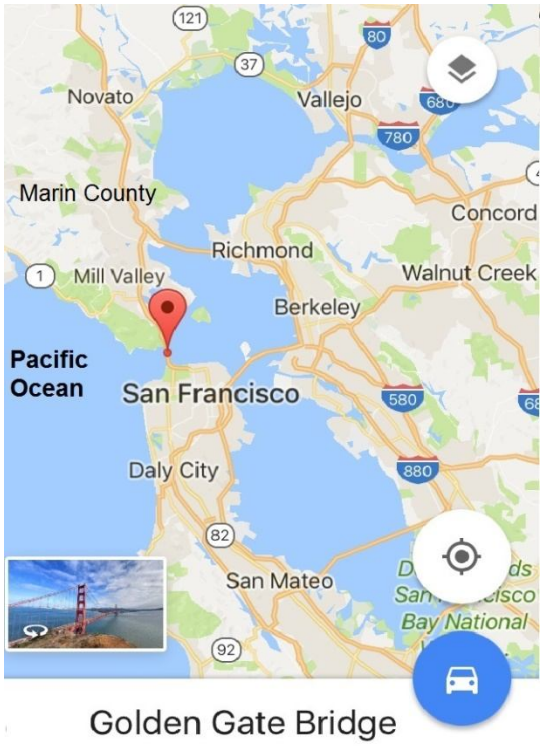


图 3：金门大桥地理位置图

金门大桥总长 2737.4 米（ 8981 ft），桥宽 27.4 米（90 ft）， 是一座六车道加两侧人行道的公路桥(图 4)。金门大桥主桥是一座悬索桥（Suspension Bridge）-- 桥面荷载通过加劲桁架（Stiffening Trusses）传递到由吊索（Hangers）和主缆 （Main Cables）组成的悬挂系统，再由悬挂系统传递到桥塔（Towers）和锚碇系统（Anchorage System）。其主跨（桥塔间距）为 1280.2 米（4,200 ft）， 边跨为 342.9 米（1125 ft），悬索桥三跨总长 1996.0 米（6450 ft）,涨潮时通航高度为 67.1 米（220 ft）， 桥塔塔顶高出海平面 227.4 米（746 ft）。

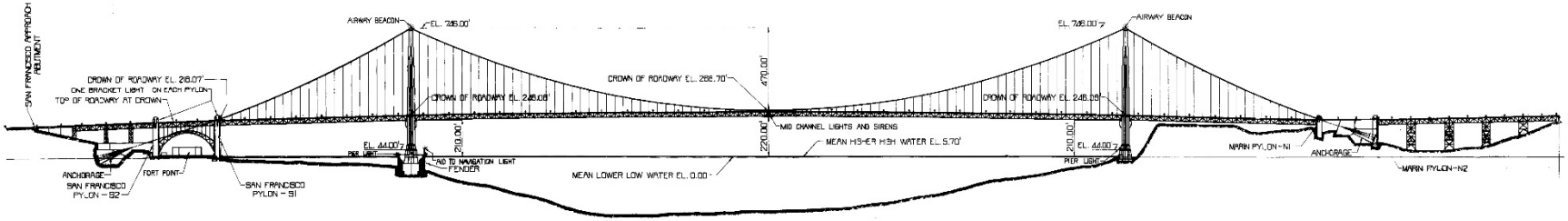


图 4： 金门大桥立面图 **(**金门大桥公路和交通局官网，**Golden Gate Bridge Highway and Transportation District Website, http://www.goldengatebridge.org/)**

悬索桥不仅和拱桥同为最古老的桥型，更是至今能跨越最宽天险的桥型。悬索桥又称为索桥或吊桥。汉朝时已有索桥，以索连接高崖横跨深谷，以滑桶交通。以后加悬板成人行桥。

金门大桥是人类桥梁史上的一座丰碑。从 **1937** 年到 **1964** 年，金门大桥以主跨 **1280.2** 米的长度一直雄踞世界跨度最长桥梁之首。 **1994** 年，为纪念二十世纪最伟大的土木工程成就，美国土木工程师协会**(American Society of Civil Engineers,** 简称 **ASCE)**选定金门大桥为现代世界七大奇迹（ **The Seven Wonders of the Modern World**）之一 （ **ASCE 1997**）。当今世界跨度最长的桥梁是 **1998** 年通车，主跨长 **1991** 米的日本明石海峡大桥 （**Akashi Kaikyo Bridge, Japan**）。

金门大桥是桥梁工程师的一件伟大艺术杰作。大桥的雄姿为世人拍摄绘画无以数计，被公认为是世界上曝光率最高的桥梁。

大桥不仅给人们带来交通便利，更给人们带来令人陶醉的美好享受。欣赏着图 **5** 至图 **12** 的美景，如身临其境。看着悬索结构与周围环境是那么美妙和谐， 只有无语的赞叹！以诗配景， 更以诗言志：

橘红桥碧海蓝天相映辉，耸双塔绿峰金山争雄魁。
钢桁架万吨巨轮互致意，雅缆索秀丽海峡依伴随。
黎云霞幽静湾区情真贵，夜雾灯金门大桥遐思醉。
主缆索加劲桁架柔克刚，重力锚框架桥塔坚不催。

（注：“橘红”-国际橙； “绿峰”-马连高地 Marin Highlands 冬春披绿装；夏秋穿金装成“金山”，与旧金山市区遥遥对望。 巨轮从 桥下“桁架”穿过。加劲桁架-刚性，钢丝缆索- 柔性，缆索悬吊支持桁架， 故有“柔克刚”之实。

而夜，雾，灯，黎明，朝霞，云彩，湾区全是图中景色。而主要结构构件-桁架，缆索，桥塔，锚碇则与景色容为一体，情真意切。八句诗，八張照片又喻意 80 年。以 8 副美照，和 80 个字的 8 句配诗歌来庆祝金门大桥通车 80 周年。）

图 **5:** 金门大桥东立面 （段炼摄于海湾渔船）

图 6：金门大桥东南侧立面（段炼摄于大桥南桥头游客中心，Welcome Center）

图 7: 巨轮过金门（段炼摄于大桥西北角马连高地 Marin Highlands)

图 **8:** 金门大桥塔入云霄（段炼摄于海湾渔船）

图 **9：** 金门大桥塔柱英姿（段炼驱车摄于桥上）

图 **10:** 金门黎明（沈建摄于大桥西北角马连高地 **Marin Highlands)**

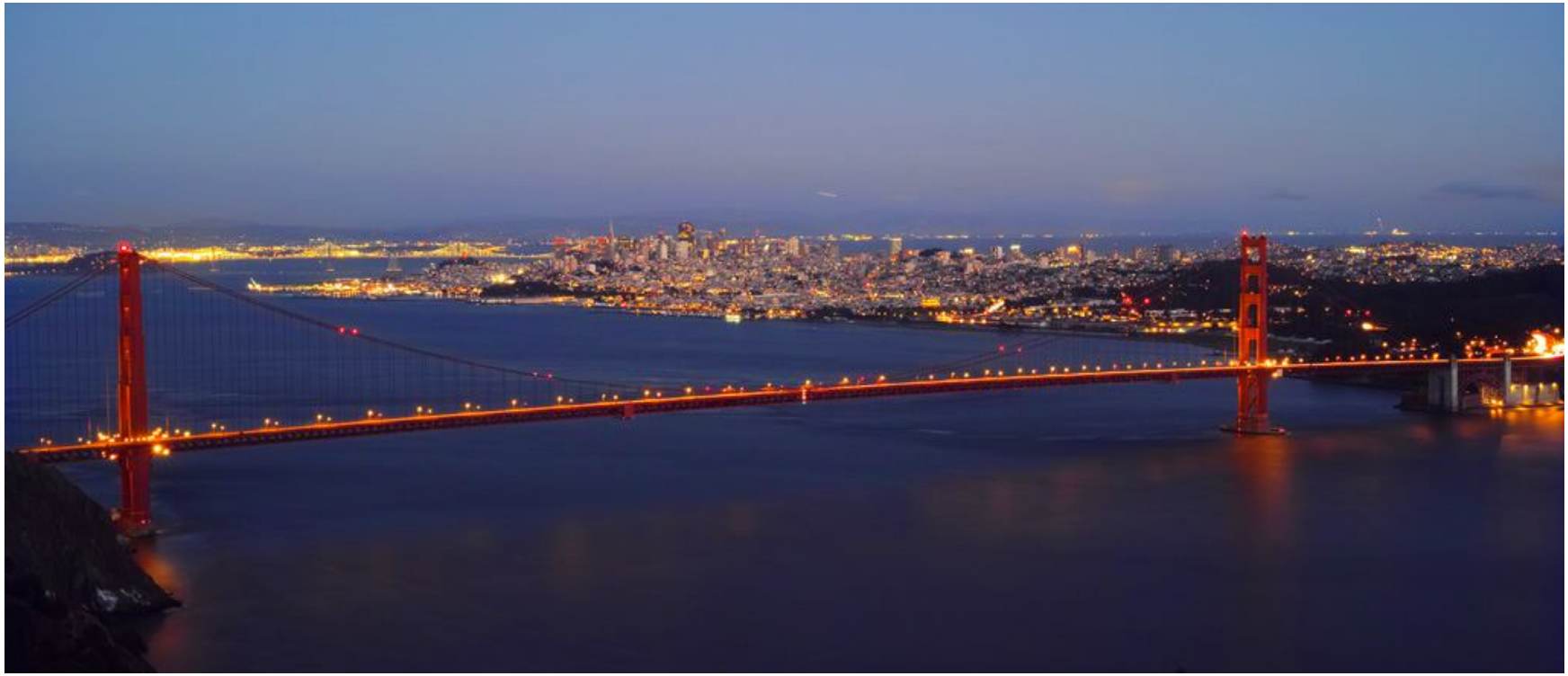


图 11: 金门灯火（沈健摄于大桥西北角马连高地 Marin Highlands)

图 **12:** 金门夜雾（沈健摄于大桥西北角马连高地 **Marin Highlands**）

金门大桥建设史

金门大桥是二十世纪最伟大的桥梁工程之一。大桥的可行性研究始于 1919 年；1928 年 12 月 8 日， 依据加州议会法案，由以旧金山湾区 6 个县（Six Counties in San Francisco Bay Area）为会员组成的金门大桥和公路局（Golden Gate Bridge and Highway District， GGBHD）正式成立，主管大桥的融资，设计，建造和运行。1929 年 8 月 15 日 GGBHD 董事会聘任约瑟夫·施特劳斯（Joseph Strauss）为金门大桥总工程师（Chief Engineer）；1930 年 8 月 GGBHD 董事会审核并接受了芝加哥施特劳斯工程公司（Strauss Engineering Corporation of Chicago）提交的金门大桥初步设计方案。1930 年 11 月 4 日六县选民投票通过发行大桥建设公债。1930 年 11 月至 1931 年 5 月施特劳斯工程公司完成了施工图设计和施工规范。

1931 年 7 月 8 日收到总施工投标 3500 万美元。1933 年 1 月 5 日大桥正式破土动工， 1937 年 5 月 27 日大桥建成 并开放行人， 翌日正式通车， 至今已整整 80 年。

金门大桥的总造价 2,384 万美元（$23,843,905），约合今天的 4 亿 5 百万美元（$405 million）。金门大桥的建设依靠发行公债没有得到联邦和州政府的资助。1971 年用过桥费收入已全部还清了公债本金 3500 万美元和利息 3900 万美元。

1969 年 11 月 10 日金门大桥和公路局增加管理大桥通道内的轮渡和公交的项目，更名为金门大桥公路和交通局（Golden Gate Bridge Highway and Transportation District， GGBHTD）。

1985 年 8 月 15 日完成了用现代正交异性钢桥面板更换因混凝土开裂导致钢筋严重腐蚀的钢筋混凝土桥面板（图 13）。从 1997 年起开始对大桥进行全面抗震加固（图 14），计划于 2018 年完工。

2015 年 1 月 10-12 日装备了可移动中间护栏（图 15），增加了 30%的高峰期的单向交通量。

2017 年 4 月 14 日动工在大桥人行道下方 6 米（20 ft）处安装不锈钢预防自杀网（图 16）。 或许因为金门大桥宛如天堂仙境，如此美丽动人，犹似自杀磁铁，使它成为世界上自杀者的首选圣地。据不完全统计，自大桥通车近 80 年来， 约有 1600 人从桥上跳海自杀身亡。但愿预防自杀网的安装能够给企图自杀者以警醒并得以挽救其生命。

图 13：金门大桥安装正交异性钢桥面板(Paul Hartbower 摄于大桥上)

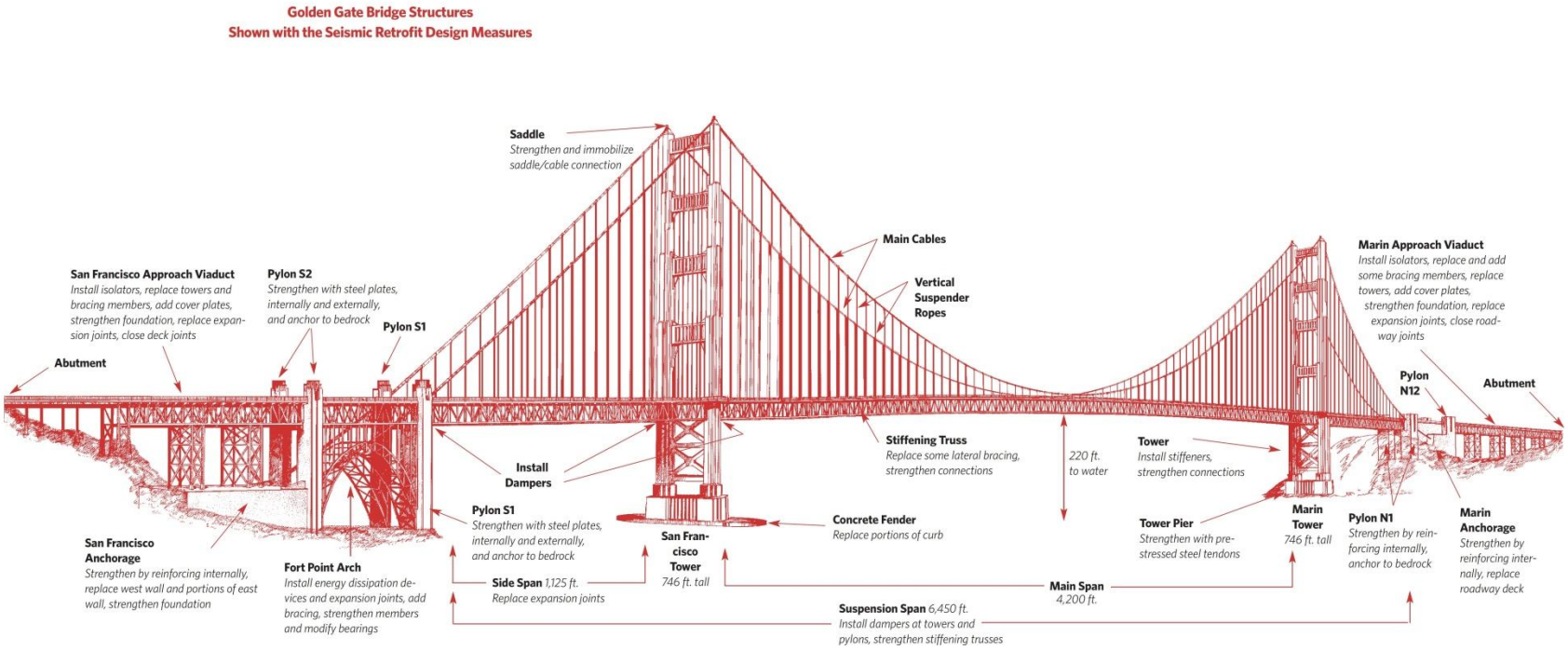


图 14: 金门大桥抗震加固图（金门大桥公路和交通局官网，**GGBHTD Website,** **http://www.goldengatebridge.org/**）

图 **15:** 金门大桥可移动中间护栏（金门大桥公路和交通局官网，**GGBHTD Website,** **http://www.goldengatebridge.org/**）

图 16：金门大桥不锈钢自杀预防网 （金门大桥公路和交通局官网，GGBHTD Website，http://www.goldengatebridge.org/）

八十年了，金门大桥依然容光焕发地向人们展示着迷人的风采。耸立在桥头的金门大桥第一任总工程师约瑟夫·施特劳斯铜像（图 17）和镶嵌在南桥塔的刻有当年金门大桥的管理者（Officers and Directors），工程技术人员 （Engineering Staff），建造者 （Contractors）的功德匾 (图 18) 受到来访者的关注和敬仰。

约瑟夫·施特劳斯（1870-1938）1870年出生于俄亥俄州辛辛那提(Cincinnati, Ohio)一个犹太裔艺术之家。1892年毕业于辛辛那提大学(University of Cincinnati)。大学期间，施特劳斯就显示出领导才能，成功竞选了学生会会长。他的有关在白令海峡 (Bering Strait)建造国际铁路的宏伟建议论文注定了他将献身于桥梁事业。

他是一位企业家， 1902年创建了芝加哥施特劳斯工程公司。他也是一位桥梁专家，设计了许多著名桥梁，特别是为“开启桥梁”（Movable Bridges）的设计做出了革命性的贡献。他更是一位具有远见卓识和战略眼光的社会活动家，1921-1928年积极游说推动了金门大桥的建设立项。他同时还是一位技术管理专家，1929-1937年担任金门大桥总工程师，领导了大桥的设计和建设。施特劳斯为大桥的建设奉献了17年（1921－1937）职业生涯，无愧为金门大桥的第一功臣。

他还是一位诗人， 在金门大桥完工后，他专注写诗，发表了著名诗篇《伟业已成》"The Mighty Task is Done"。

在金门大桥通车一周年前夕，施特劳斯于1938年5月16日在加州洛杉矶 (Los Angels, California)与世长辞，享年68岁。

图 17： 金门大桥第一任总工程师-约瑟夫·施特劳斯铜像 （段炼摄于大桥南桥头游客中心）

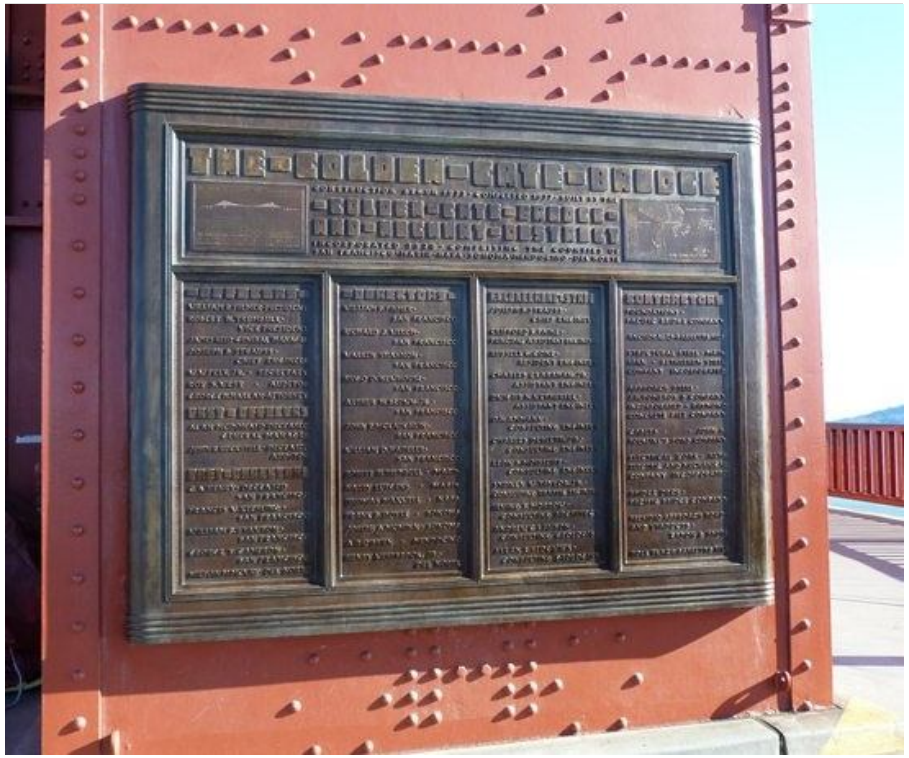


图 **18:** 金门大桥建设者功德匾 **(**段炼摄于大桥南塔南侧）

谁设计了金门大桥

作为一位桥梁工程师，我深感有必要为大家介绍一下这位为金门大桥的建设作出重要贡献的无名英雄。他就是大桥功德匾（图**18**）上被唯独漏， 世人大多都不知道的金门大桥的实际设计者查尔斯 • 阿尔顿 • 埃利斯 **(Charles Alton Ellis** 图**19)**的名字。

PBS / Mary Cone

图**19**： 查尔斯 • 阿尔顿 • 埃利斯 **Charles Alton Ellis**

（**SFGate** **http://www.sfgate.com/news/article/Golden-Gate-Bridge-corrects-history-2595242.php**）

一直以来（至2007年），金门大桥的设计一般都归功于约瑟夫• 施特劳斯。但证据显示：芝加哥施特劳斯工程公司副总裁 （Vice President）查尔斯•阿尔顿•埃利斯是1929年至1931年间真正的金门大桥的设计工程师 （Designing Engineer）(图20)。

从1929年8月至1930年2月，埃利斯在施特劳斯授权下完成了金门大桥地基基础勘探规范并在现场监理勘探（图21）。1930年3月至8月，埃利斯完成了金门大桥的初步设计图纸，期间得到了Leon S. Moisseiff，O.H. Amman 和 Charles Derleth 三位咨询工程师的审核帮助。8月，金门大桥和公路局董事会审核并热情地接受（enthusiastically accepted）了埃利斯的初步设计方案（图22-图23）。9月，埃利斯在加州伯克利市召开的美国国家科学院第一届西海岸会议上发表了主旨演讲，题目就是《金门大桥的设计理论》。

从1930年11月开始，埃利斯夜以继日不知疲倦地工作（worked tirelessly ）。他进行了数以万计的桥梁分析，绘制了全套施工图（had designed every stick of steel in the bridge, every stick），并编制了全部施工规范。

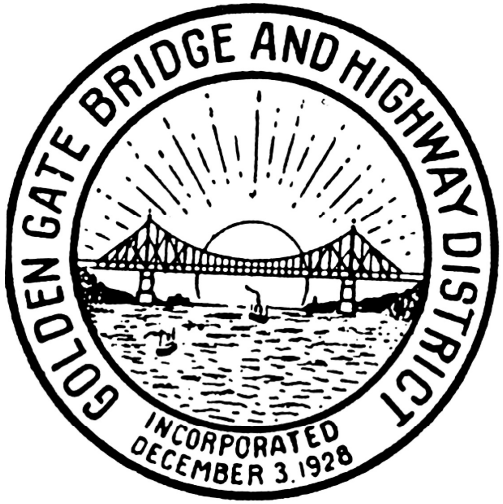
桥梁结构工程师们深知：金门大桥的结构分析需要求解上百甚至上千个联立方程，即便在现在，使用电子计算机求解联立方程只需分秒，但在建立力学模型过程中仍耗时费力。可是80多年前，这些方程的求解必须是手工完成，工作量之大难以想象。金门大桥的结构分析难度难于徒手攀登优胜美地半穹顶（Yosemite Half Dome，图24）。

但是就在埃利斯独自完成了金门大桥的初步设计，结构分析，施工图设计（图25 – 图27）和施工规范之后，1931年12月5日，施特劳斯要求埃利斯去休假两周。1931年末，施特劳斯在埃利斯的假期结束前三天解雇（take an indefinite vacation without pay）了他并要求他退还所有设计资料。

随后施特劳斯招聘了Clifford E. Paine（埃利斯的学生）取代了埃利斯的职位。

从1921年至1931年施特劳斯和埃利斯合作达10年之久。从在1929年施特劳斯写给金门大桥和公路管理局的公函中称“埃利斯”为“我亲爱的教授” （My Dear Professor）的亲密合作到施特劳斯解雇埃利斯而分道扬镳，原因至今未明（For reasons still not clear today）。

幸运的是， 在他们分手前，埃利斯就完成了金门大桥的施工图设计。 而后在施特劳斯的领导下，又把埃利斯的图纸变成了现实。



ENGINEERS
JOSEPH B. STRAUSS
CHIEF ENGINEER
CHARLES A. ELLIS
DESIGNING ENGINEER
O. H. AMMANN
CONSULTING ENGINEER
CHARLES DERLETH, JR.
CONSULTING ENGINEER
LEON S. MOISSEIFF
CONSULTING ENGINEER

OFFICE OF CHIEF ENGINEER
468 RUSS BUILDING
SAN FRANCISCO
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图 20：1929 年金门大桥总工程师办公室信笺抬头

(ASCE Library http://ascelibrary.org/cms/attachment/60698/1346645/6.jpg)

图 21：1930 年埃利斯在金门大桥现场监理地基勘探 （普渡大学图书馆）

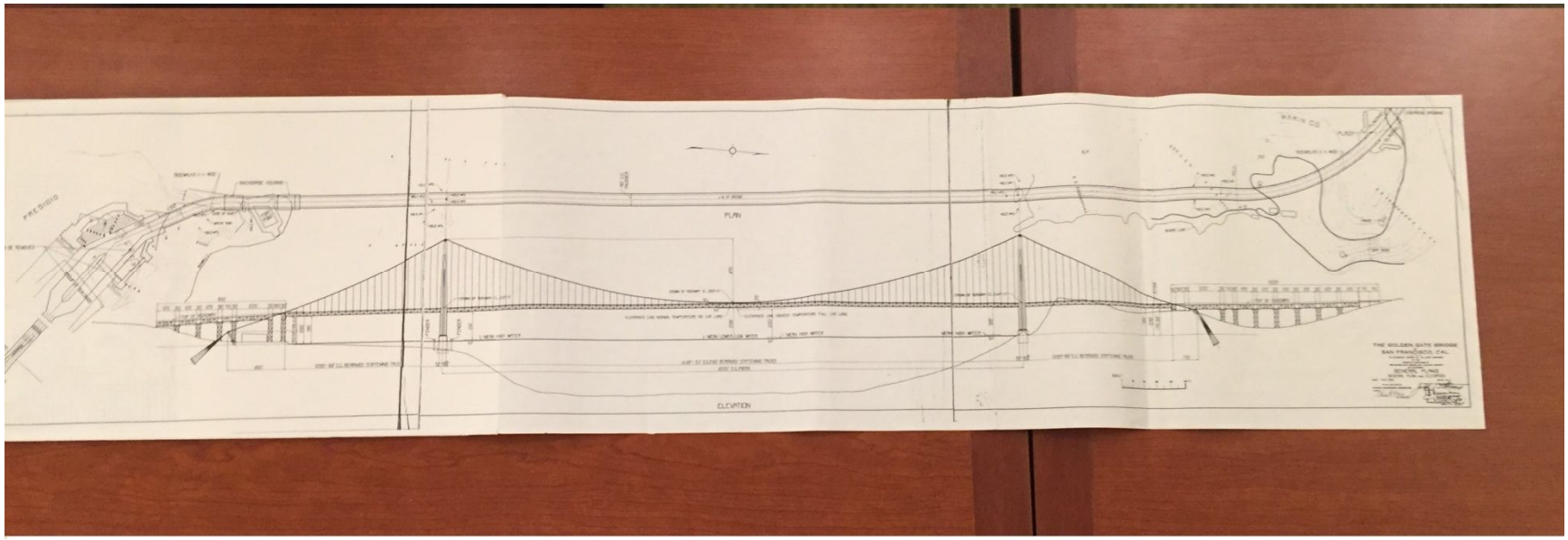


图 **22**： 埃利斯签名的 **1930** 年 **8** 月金门大桥初步设计总平面和立面图
（莫宗坚 摄于普渡大学图书馆）

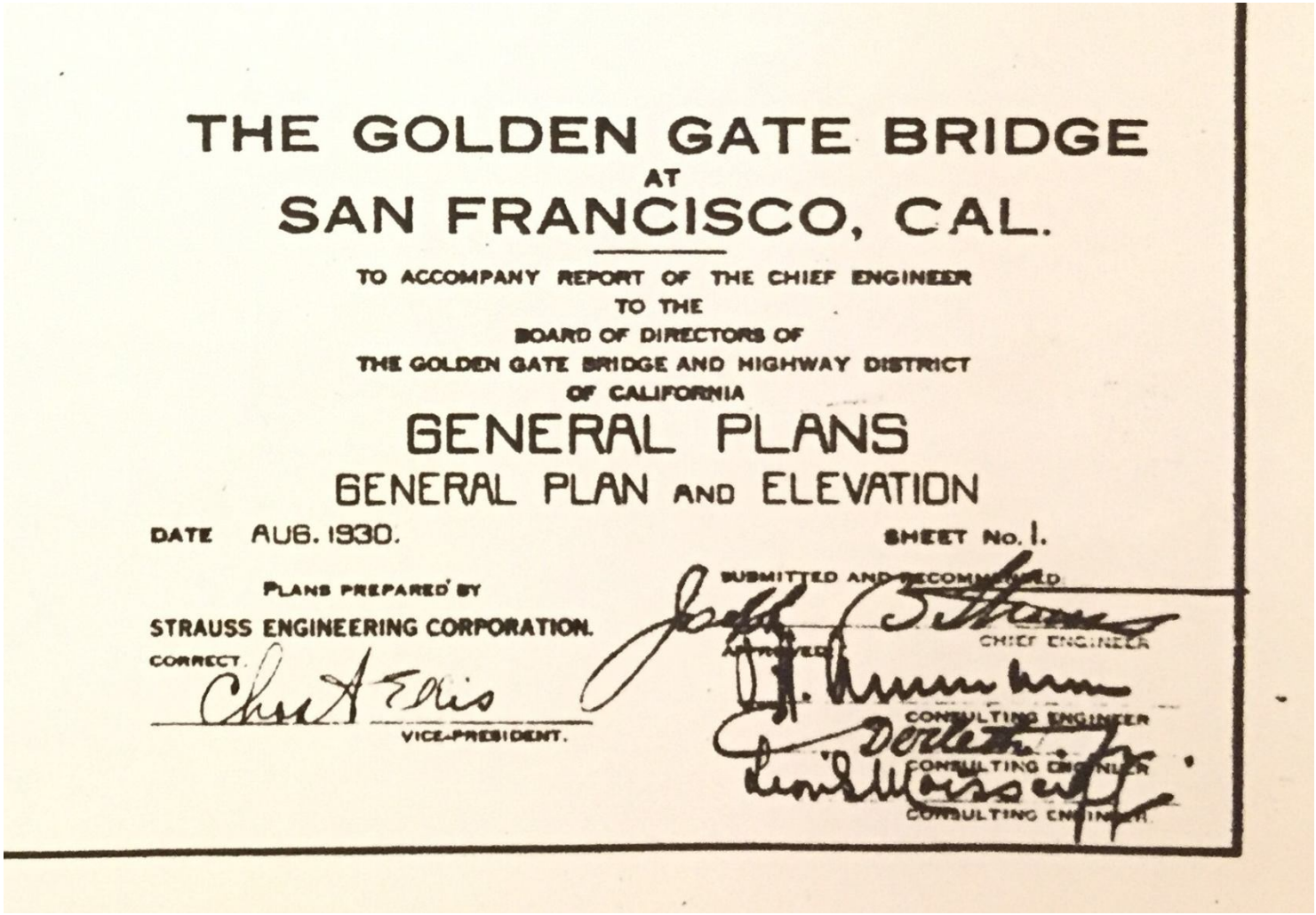
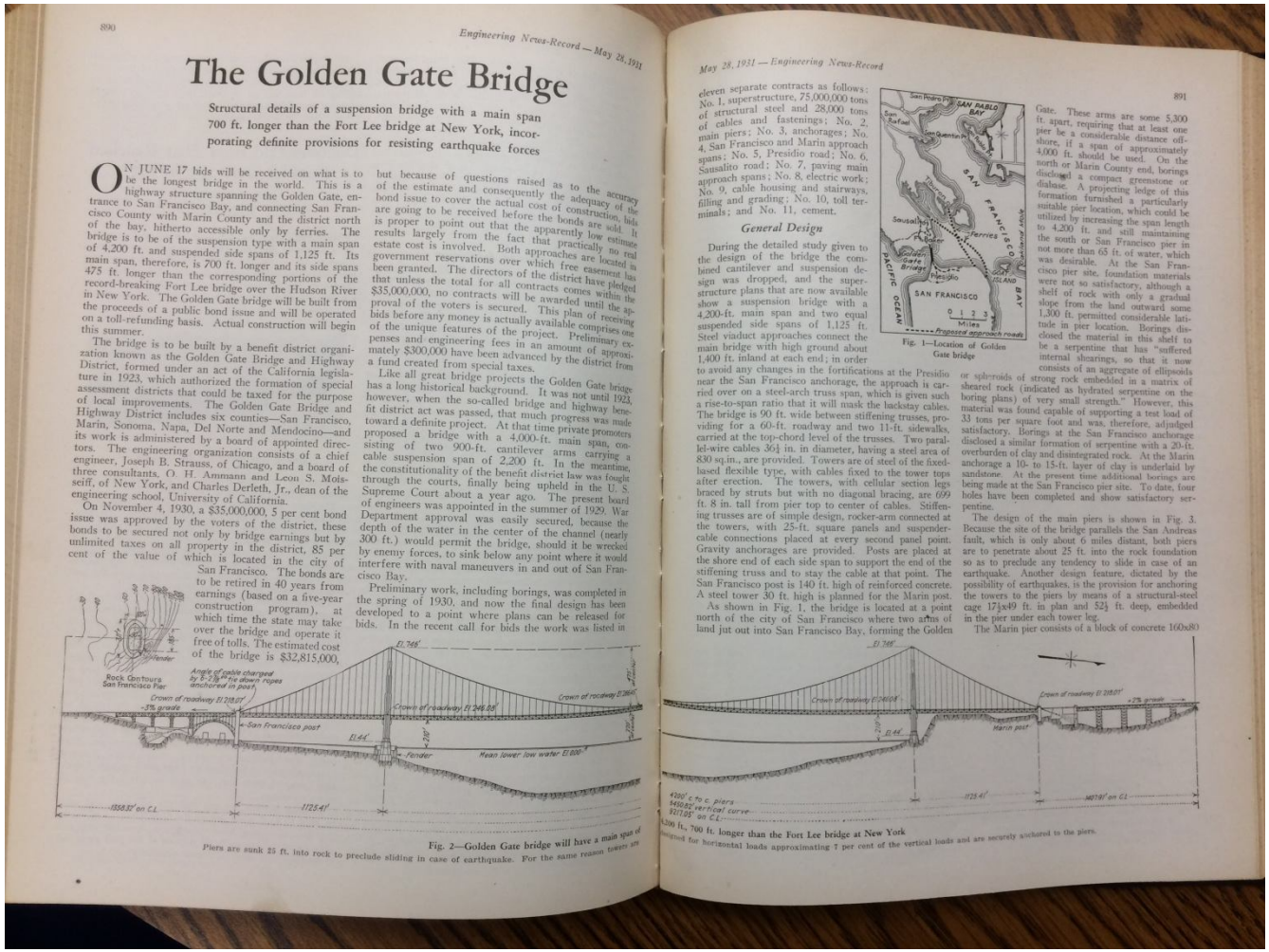


图 **23**： **1930** 年 **8** 月金门大桥初步设计总平面和立面图签字框
（莫宗坚 摄于普渡大学图书馆）

图24： 徒手攀登优胜美地半穹顶
（http://www.climbingyosemite.com/portfolio/half-dome-rockfall-2/）



890 Engineering News-Record — May 28, 1931

The Golden Gate Bridge

Structural details of a suspension bridge with a main span 700 ft. longer than the Fort Lee bridge at New York, incorporating definite provisions for resisting earthquake forces

ON JUNE 17 bids will be received on what is to be the longest bridge in the world. This is a highway structure spanning the Golden Gate, entrance to San Francisco Bay, and connecting San Francisco County with Marin County and the district north of the bay, hitherto accessible only by ferries. The bridge is to be of the suspension type with a main span of 4,200 ft. and suspended side spans of 1,125 ft. Its main span, therefore, is 700 ft. longer and its side spans 475 ft. longer than the corresponding portions of the record-breaking Fort Lee bridge over the Hudson River in New York. The Golden Gate bridge will be built from the proceeds of a public bond issue and will be operated on a toll-refunding basis. Actual construction will begin this summer.

The bridge is to be built by a benefit district organization known as the Golden Gate Bridge and Highway District, formed under an act of the California legislature in 1923, which authorized the formation of special assessment districts that could be taxed for the purpose of local improvements. The Golden Gate Bridge and Highway District includes six counties—San Francisco, Marin, Sonoma, Napa, Del Norte and Mendocino—and its work is administered by a board of appointed directors. The engineering organization consists of a chief engineer, Joseph B. Strauss, of Chicago, and a board of three consultants, O. H. Ammann and Leon S. Moisseiff, of New York, and Charles Derleth, Jr., dean of the engineering school, University of California.

On November 4, 1930, a $35,000,000, 5 per cent bond issue was approved by the voters of the district, these bonds to be secured not only by bridge earnings but by unlimited taxes on all property in the district, 85 per cent of the value of which is located in the city of San Francisco. The bonds are to be retired in 40 years from earnings (based on a five-year construction program), at which time the state may take over the bridge and operate it free of tolls. The estimated cost of the bridge is $32,815,000, but because of questions raised as to the accuracy of the estimate and consequently the adequacy of the bond issue to cover the actual cost of construction, bids are going to be received before the bonds are sold. It is proper to point out that the apparently low estimate results largely from the fact that practically no real estate cost is involved. Both approaches are located in government reservations over which free easement has been granted. The directors of the district have pledged that unless the total for all contracts comes within the $35,000,000, no contracts will be awarded until the approval of the voters is secured. This plan of receiving bids before any money is actually available comprises one of the unique features of the project. Preliminary expenses and engineering fees in an amount of approximately $300,000 have been advanced by the district from a fund created from special taxes.

Like all great bridge projects the Golden Gate bridge has a long historical background. It was not until 1923, however, when the so-called bridge and highway benefit district act was passed, that much progress was made toward a definite project. At that time private promoters proposed a bridge with a 4,000-ft. main span, consisting of two 900-ft. cantilever arms carrying a cable suspension span of 2,200 ft. In the meantime, the constitutionality of the benefit district law was fought through the courts, finally being upheld in the U. S. Supreme Court about a year ago. The present board of engineers was appointed in the summer of 1929. War Department approval was easily secured, because the depth of the water in the center of the channel (nearly 300 ft.) would permit the bridge, should it be wrecked by enemy forces, to sink below any point where it would interfere with naval maneuvers in and out of San Francisco Bay.

Preliminary work, including borings, was completed in the spring of 1930, and now the final design has been developed to a point where plans can be released for bids. In the recent call for bids the work was listed in eleven separate contracts as follows: No. 1, superstructure, 75,000,000 tons of structural steel and 28,000 tons of cables and fastenings; No. 2, main piers; No. 3, anchorages; No. 4, San Francisco and Marin approach spans; No. 5, Presidio road; No. 6, Sausalito road; No. 7, paving main approach spans; No. 8, electric work; No. 9, cable housing and stairways, filling and grading; No. 10, toll terminals; and No. 11, cement.

Fig. 2—Golden Gate bridge will have a main span of 700 ft. longer than the Fort Lee bridge at New York

Piers are sunk 25 ft. into rock to preclude sliding in case of earthquake. For the same reason towers are designed for horizontal loads approximating 7 per cent of the vertical loads and are securely anchored to the piers.

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Fig. 1—Location of Golden Gate bridge

General Design

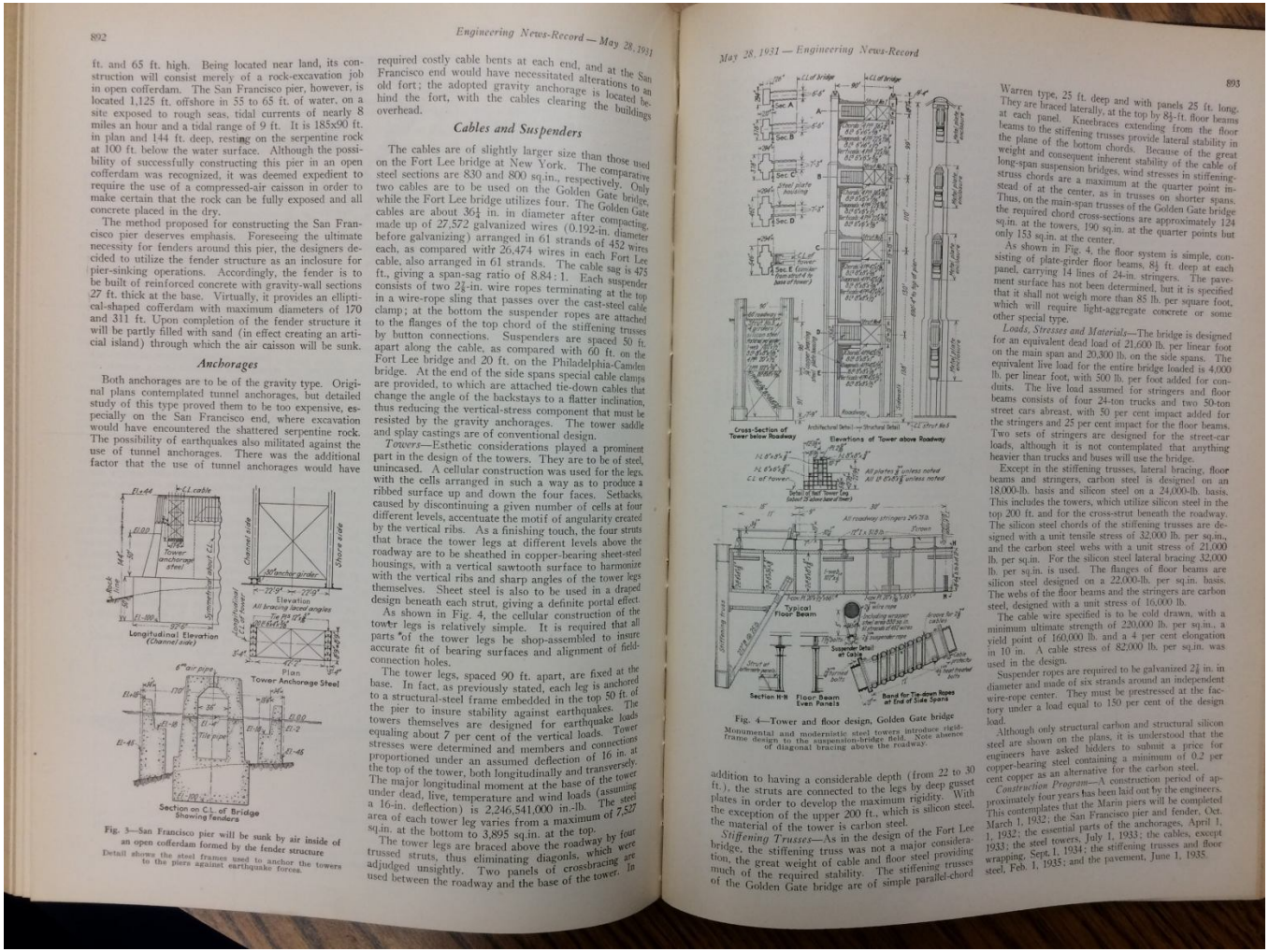
During the detailed study given to the design of the bridge the combined cantilever and suspension design was dropped, and the superstructure plans that are now available show a suspension bridge with a 4,200-ft. main span and two equal suspended side spans of 1,125 ft. Steel viaduct approaches connect the main bridge with high ground about 1,400 ft. inland at each end; in order to avoid any changes in the fortifications at the Presidio near the San Francisco anchorage, the approach is carried over on a steel-arch truss span, which is given such a rise-to-span ratio that it will mask the backstay cables. The bridge is 90 ft. wide between stiffening trusses, providing for a 60-ft. roadway and two 11-ft. sidewalks, carried at the top-chord level of the trusses. Two parallel-wire cables 36½ in. in diameter, having a steel area of 830 sq.in., are provided. Towers are of steel of the fixed-based flexible type, with cables fixed to the tower tops after erection. The towers, with cellular section legs braced by struts but with no diagonal bracing, are 699 ft. 8 in. tall from pier top to center of cables. Stiffening trusses are of simple design, rocker-arm connected at the towers, with 25-ft. square panels and suspender-cable connections placed at every second panel point. Gravity anchorages are provided. Posts are placed at the shore end of each side span to support the end of the stiffening truss and to stay the cable at that point. The San Francisco post is 140 ft. high of reinforced concrete. A steel tower 30 ft. high is planned for the Marin post.

As shown in Fig. 1, the bridge is located at a point north of the city of San Francisco where two arms of land jut out into San Francisco Bay, forming the Golden Gate. These arms are some 5,300 ft. apart, requiring that at least one pier be a considerable distance offshore, if a span of approximately 4,000 ft. should be used. On the north or Marin County end, borings disclosed a compact greenstone or diabase. A projecting ledge of this formation furnished a particularly suitable pier location, which could be utilized by increasing the span length to 4,200 ft. and still maintaining the south or San Francisco pier in not more than 65 ft. of water, which was desirable. At the San Francisco pier site, foundation materials were not so satisfactory, although a shelf of rock with only a gradual slope from the land outward some 1,300 ft. permitted considerable latitude in pier location. Borings disclosed the material in this shelf to be a serpentine that has "suffered internal shearings, so that it now consists of an aggregate of ellipsoids or spheroids of strong rock embedded in a matrix of sheared rock (indicated as hydrated serpentine on the boring plans) of very small strength." However, this material was found capable of supporting a test load of 33 tons per square foot and was, therefore, adjudged satisfactory. Borings at the San Francisco anchorage disclosed a similar formation of serpentine with a 20-ft. overburden of clay and disintegrated rock. At the Marin anchorage a 10- to 15-ft. layer of clay is underlaid by sandstone. At the present time additional borings are being made at the San Francisco pier site. To date, four holes have been completed and show satisfactory serpentine.

The design of the main piers is shown in Fig. 3. Because the site of the bridge parallels the San Andreas fault, which is only about 6 miles distant, both piers are to penetrate about 25 ft. into the rock foundation so as to preclude any tendency to slide in case of an earthquake. Another design feature, dictated by the possibility of earthquakes, is the provision for anchoring the towers to the piers by means of a structural-steel cage 17½x49 ft. in plan and 52½ ft. deep, embedded in the pier under each tower leg.

The Marin pier consists of a block of concrete 160x80

图25：埃利斯设计的金门大桥施工图-立面图 – ENR 05-28-1931 （段炼摄于加州交通厅图书馆）



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ft. and 65 ft. high. Being located near land, its construction will consist merely of a rock-excavation job in open cofferdam. The San Francisco pier, however, is located 1,125 ft. offshore in 55 to 65 ft. of water, on a site exposed to rough seas, tidal currents of nearly 8 miles an hour and a tidal range of 9 ft. It is 185x90 ft. in plan and 144 ft. deep, resting on the serpentine rock at 100 ft. below the water surface. Although the possibility of successfully constructing this pier in an open cofferdam was recognized, it was deemed expedient to require the use of a compressed-air caisson in order to make certain that the rock can be fully exposed and all concrete placed in the dry.

The method proposed for constructing the San Francisco pier deserves emphasis. Foreseeing the ultimate necessity for fenders around this pier, the designers decided to utilize the fender structure as an inclosure for pier-sinking operations. Accordingly, the fender is to be built of reinforced concrete with gravity-wall sections 27 ft. thick at the base. Virtually, it provides an elliptical-shaped cofferdam with maximum diameters of 170 and 311 ft. Upon completion of the fender structure it will be partly filled with sand (in effect creating an artificial island) through which the air caisson will be sunk.

Anchorages

Both anchorages are to be of the gravity type. Original plans contemplated tunnel anchorages, but detailed study of this type proved them to be too expensive, especially on the San Francisco end, where excavation would have encountered the shattered serpentine rock. The possibility of earthquakes also militated against the use of tunnel anchorages. There was the additional factor that the use of tunnel anchorages would have required costly cable bents at each end, and at the San Francisco end would have necessitated alterations to an old fort; the adopted gravity anchorage is located behind the fort, with the cables clearing the buildings overhead.

Fig. 3—San Francisco pier will be sunk by air inside of an open cofferdam formed by the fender structure

Detail shows the steel frames used to anchor the towers to the piers against earthquake forces.

Cables and Suspenders

The cables are of slightly larger size than those used on the Fort Lee bridge at New York. The comparative steel sections are 830 and 800 sq.in., respectively. Only two cables are to be used on the Golden Gate bridge, while the Fort Lee bridge utilizes four. The Golden Gate cables are about 36½ in. in diameter after compacting, made up of 27,572 galvanized wires (0.192-in. diameter before galvanizing) arranged in 61 strands of 452 wires each, as compared with 26,474 wires in each Fort Lee cable, also arranged in 61 strands. The cable sag is 475 ft., giving a span-sag ratio of 8.84 : 1. Each suspender consists of two 2⅜-in. wire ropes terminating at the top in a wire-rope sling that passes over the cast-steel cable clamp; at the bottom the suspender ropes are attached to the flanges of the top chord of the stiffening trusses by button connections. Suspenders are spaced 50 ft. apart along the cable, as compared with 60 ft. on the Fort Lee bridge and 20 ft. on the Philadelphia-Camden bridge. At the end of the side spans special cable clamps are provided, to which are attached tie-down cables that change the angle of the backstays to a flatter inclination, thus reducing the vertical-stress component that must be resisted by the gravity anchorages. The tower saddle and splay castings are of conventional design.

Towers—Esthetic considerations played a prominent part in the design of the towers. They are to be of steel, unincased. A cellular construction was used for the legs, with the cells arranged in such a way as to produce a ribbed surface up and down the four faces. Setbacks, caused by discontinuing a given number of cells at four different levels, accentuate the motif of angularity created by the vertical ribs. As a finishing touch, the four struts that brace the tower legs at different levels above the roadway are to be sheathed in copper-bearing sheet-steel housings, with a vertical sawtooth surface to harmonize with the vertical ribs and sharp angles of the tower legs themselves. Sheet steel is also to be used in a draped design beneath each strut, giving a definite portal effect.

As shown in Fig. 4, the cellular construction of the tower legs is relatively simple. It is required that all parts of the tower legs be shop-assembled to insure accurate fit of bearing surfaces and alignment of field-connection holes.

The tower legs, spaced 90 ft. apart, are fixed at the base. In fact, as previously stated, each leg is anchored to a structural-steel frame embedded in the top 50 ft. of the pier to insure stability against earthquakes. The towers themselves are designed for earthquake loads equaling about 7 per cent of the vertical loads. Tower stresses were determined and members and connections proportioned under an assumed deflection of 16 in. at the top of the tower, both longitudinally and transversely. The major longitudinal moment at the base of the tower under dead, live, temperature and wind loads (assuming a 16-in. deflection) is 2,246,541,000 in.-lb. The steel area of each tower leg varies from a maximum of 7,527 sq.in. at the bottom to 3,895 sq.in. at the top.

The tower legs are braced above the roadway by four trussed struts, thus eliminating diagonals, which were adjudged unsightly. Two panels of crossbracing are used between the roadway and the base of the tower. In addition to having a considerable depth (from 22 to 30 ft.), the struts are connected to the legs by deep gusset plates in order to develop the maximum rigidity. With the exception of the upper 200 ft., which is silicon steel, the material of the tower is carbon steel.

Fig. 4—Tower and floor design, Golden Gate bridge

Monumental and modernistic steel towers introduce rigid-frame design to the suspension-bridge field. Note absence of diagonal bracing above the roadway.

Stiffening Trusses—As in the design of the Fort Lee bridge, the stiffening truss was not a major consideration, the great weight of cable and floor steel providing much of the required stability. The stiffening trusses of the Golden Gate bridge are of simple parallel-chord Warren type, 25 ft. deep and with panels 25 ft. long. They are braced laterally, at the top by 8½-ft. floor beams at each panel. Kneebraces extending from the floor beams to the stiffening trusses provide lateral stability in the plane of the bottom chords. Because of the great weight and consequent inherent stability of the cable of long-span suspension bridges, wind stresses in stiffening-truss chords are a maximum at the quarter point instead of at the center, as in trusses on shorter spans. Thus, on the main-span trusses of the Golden Gate bridge the required chord cross-sections are approximately 124 sq.in. at the towers, 190 sq.in. at the quarter points but only 153 sq.in. at the center.

As shown in Fig. 4, the floor system is simple, consisting of plate-girder floor beams, 8½ ft. deep at each panel, carrying 14 lines of 24-in. stringers. The pavement surface has not been determined, but it is specified that it shall not weigh more than 85 lb. per square foot, which will require light-aggregate concrete or some other special type.

Loads, Stresses and Materials—The bridge is designed for an equivalent dead load of 21,600 lb. per linear foot on the main span and 20,300 lb. on the side spans. The equivalent live load for the entire bridge loaded is 4,000 lb. per linear foot, with 500 lb. per foot added for conduits. The live load assumed for stringers and floor beams consists of four 24-ton trucks and two 50-ton street cars abreast, with 50 per cent impact added for the stringers and 25 per cent impact for the floor beams. Two sets of stringers are designed for the street-car loads, although it is not contemplated that anything heavier than trucks and buses will use the bridge.

Except in the stiffening trusses, lateral bracing, floor beams and stringers, carbon steel is designed on an 18,000-lb. basis and silicon steel on a 24,000-lb. basis. This includes the towers, which utilize silicon steel in the top 200 ft. and for the cross-strut beneath the roadway. The silicon steel chords of the stiffening trusses are designed with a unit tensile stress of 32,000 lb. per sq.in., and the carbon steel webs with a unit stress of 21,000 lb. per sq.in. For the silicon steel lateral bracing 32,000 lb. per sq.in. is used. The flanges of floor beams are silicon steel designed on a 22,000-lb. per sq.in. basis. The webs of the floor beams and the stringers are carbon steel, designed with a unit stress of 16,000 lb.

The cable wire specified is to be cold drawn, with a minimum ultimate strength of 220,000 lb. per sq.in., a yield point of 160,000 lb. and a 4 per cent elongation in 10 in. A cable stress of 82,000 lb. per sq.in. was used in the design.

Suspender ropes are required to be galvanized 2⅜ in. in diameter and made of six strands around an independent wire-rope center. They must be prestressed at the factory under a load equal to 150 per cent of the design load.

Although only structural carbon and structural silicon steel are shown on the plans, it is understood that the engineers have asked bidders to submit a price for copper-bearing steel containing a minimum of 0.2 per cent copper as an alternative for the carbon steel.

Construction Program—A construction period of approximately four years has been laid out by the engineers. This contemplates that the Marin piers will be completed March 1, 1932; the San Francisco pier and fender, Oct. 1, 1932; the essential parts of the anchorages, April 1, 1933; the steel towers, July 1, 1933; the cables, except wrapping, Sept. 1, 1934; the stiffening trusses and floor steel, Feb. 1, 1935; and the pavement, June 1, 1935.

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图26： 埃利斯设计的金门大桥施工图-锚碇和桥塔 – ENR 05-28-1931（段炼摄于加州交通厅图书馆）

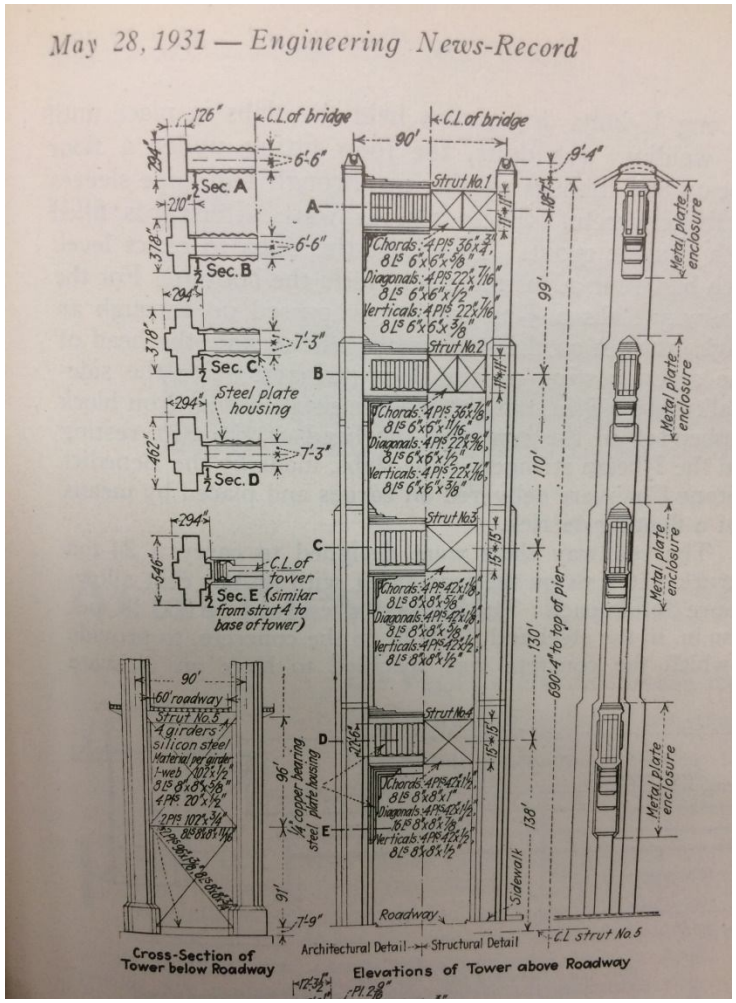

图27： 埃利斯设计的金门大桥施工图-桥塔 – ENR 05-28-1931（段炼摄于加州交通厅图书馆）

从1932年至1937年，大桥的三位顾问工程师， 著名桥梁大师 Moisseiff， Amman 和 Derleth， 大桥的监理工程师 Russell G. Cone多次向施特劳斯交涉有关埃利斯的贡献，但是施特劳斯在1937年9月30日提交的桥梁最终报告和竣工图中仍然系统地删除了埃利斯的名字。

1939年埃利斯的继任者Paine在伦敦出版的《工程 》（Engineering）刊物上发表了《旧金山金门大桥》的长篇报告。作为埃利斯的学生和曾经的同事，Paine有机会在报告中公正地评价埃利斯的贡献，但他却选择了施特劳斯的观点，报告中没有提到埃利斯的名字。从此，金门大桥的实际设计者埃利斯就消失在金门大桥的历史记载中。

直到1987 年，作家John van der Zee，出版了《门：金门大桥设计和施工的真实故事》 （van der Zee, J. 1987. *The Gate: The true story of the design and construction of the Golden Gate Bridge*, Simon and Schuster, New York.）一书（图28），查尔斯 • 阿尔顿 • 埃利斯才第一次出现在公众视野里。埃利斯的另一名学生 Lewis B. McCammon, Jr. （1920-2007）（普渡大学1940 年土木工程学士，1948 年硕士， 1951年博士)收藏了由埃利斯签字的最原始的金门大桥设计计算书，施工图，施工规范，及通讯记录(图29)。这些历史原件现存于普渡大学图书馆(Purdue University Library)。

McCammon对老师设计金门大桥的贡献充满敬仰，为老师的贡献未被世人知晓认可而鸣不平。经过 McCammon, John van der Zee，Russ Cone (金门大桥监理工程师Russell G. Cone之子，《旧金山主考官-San Francisco Examiner》记者) ，及其它多位桥梁专家，桥梁史学者和媒体，向金门大桥公路和交通局持续二十年（1987-2007）的执着申诉，并经过美国土木工程师协会历史遗产委员会（ASCE History and Heritage Committee）调查确认，这一段缺失的金门大桥建设史， 终于得以复原。

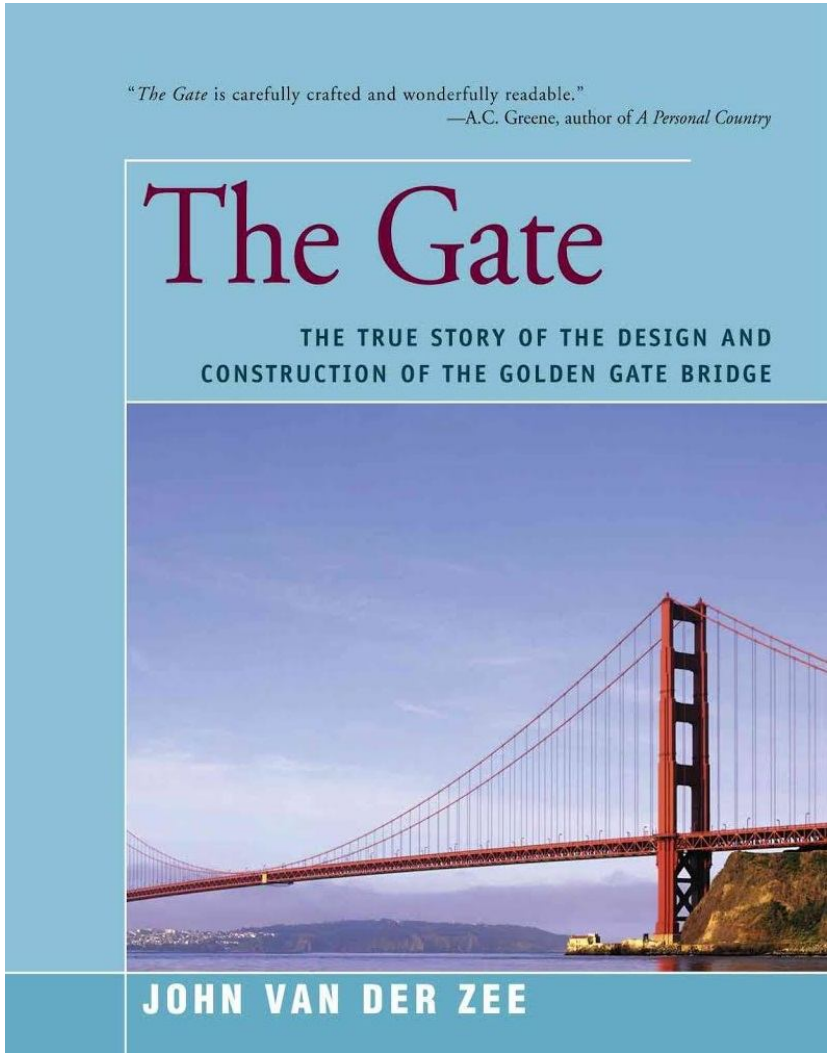

图28：《门：金门大桥设计和施工的真实故事》 封面

图 **29**：埃利斯原始设计图纸和资料
（莫宗坚 摄于普渡大学图书馆）

2007 年 5 月，金门大桥公路和交通局终于放弃了 20 年来（1987-2007）坚持的观点：“我们不计划试图重塑历史。施特劳斯是总工程师，其他人则是他的顾问或助理,单独把埃利斯列出是不公平的。”（We are not going to try to reinvent history. Strauss was the chief engineer, and the others were consultants or his assistants. It is not fair to single Ellis out.），勇敢地接受了这段二十年来都难以接受的缺失史实，在庆祝金门大桥建成 70 周年时发表报告正式承认埃利斯对金门大桥设计做出的重要贡献（He deserves significant credit for the suspension bridge design），并在其官网更正了大桥建设史。金门大桥公路和交通局纠正历史的做法受到了旧金山湾区新闻媒体专题报道称赞。

2010年4月，美国土木工程师协会杰出会员（distinguished member），Merrimack 学院荣休教授，著名土木工程历史学家 Francis E. Griggs Jr. 发表了学术论文 《“Joseph B. Strauss, Charles A. Ellis, and the Golden Gate， Bridge: Justice at Last”, ASCE, *Journal of Professional Issues in Engineering Education and Practice*, Vol. 136, No. 2, pp. 71-83》。他依据详实的史料，认为施特劳斯违背了基本职业道德规范之一: 功劳应归于应得者（Strauss violated one of the fundamental ethical canons—that of giving credit where credit is due.）。设计金门大桥的功劳应归于真正的设计者。

2012年5月和2013年11月，美国土木工程师协会先后给金门大桥公路和交通局和普渡大学分别颁发《查尔斯•阿尔顿•埃利斯功德匾 》-“值金门大桥通车75周年之际，美国土木工程师协会承认查尔斯• 阿尔顿•埃利斯在金门大桥的设计工作。特颁此匾， 2012 年5月”。埃利斯功德匾(图30)已分别镶嵌在金门大桥南桥头游客中心和普渡大学土木工程学院(School of Civil Engineering, Purdue University)。

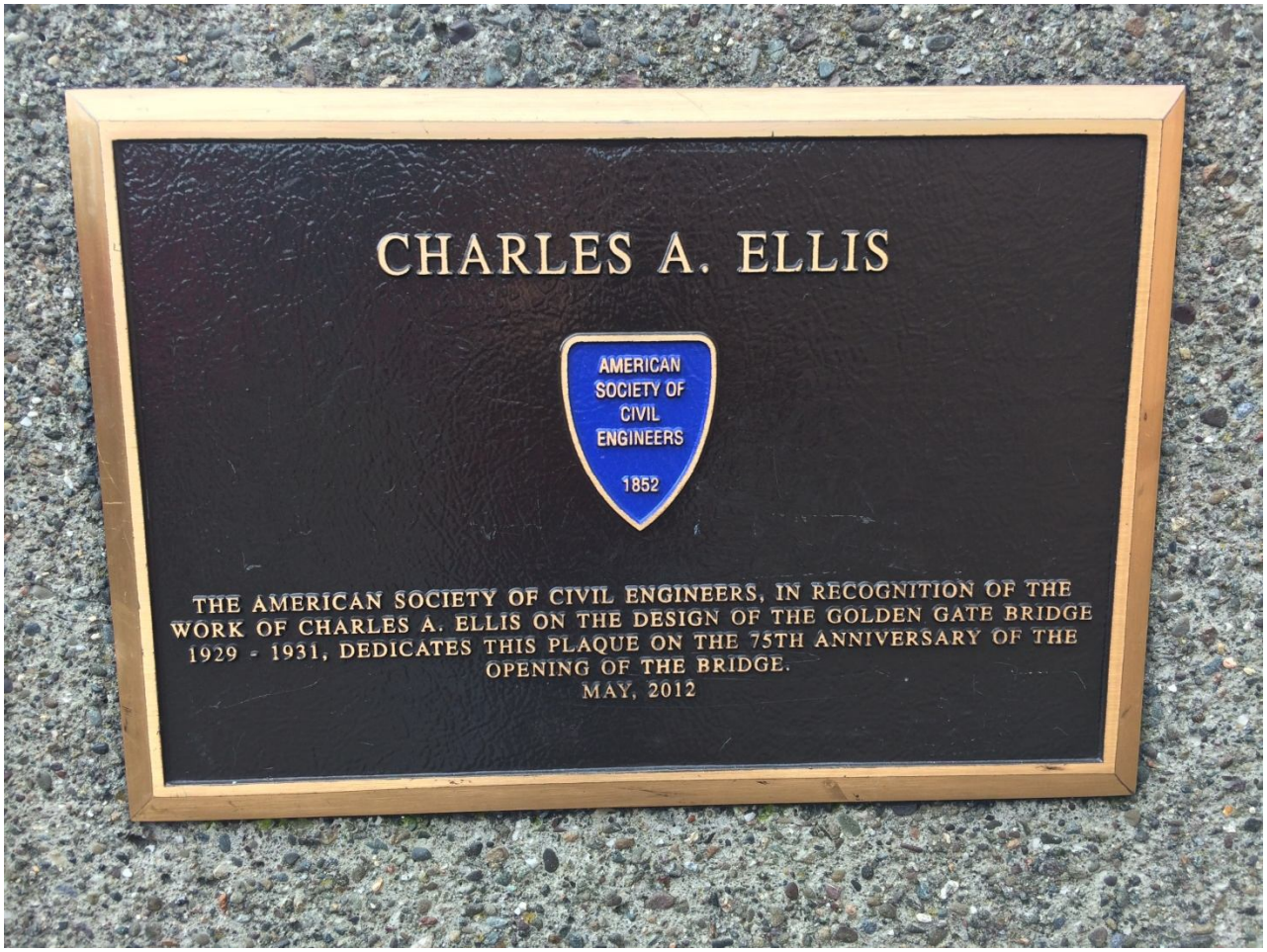

图30：2012年5月美国土木工程师协会颁发的埃利斯功德匾
（段炼摄于大桥南桥头游客中心**enter）**

查尔斯• 阿尔顿•埃利斯

查尔斯• 阿尔顿•埃利斯（1876-1949）1876年出生于缅因州帕克曼(Parkman, Maine)。1900 年获卫斯理大学（Wesleyan University）的数学力学学士学位。1922年获得伊利诺大学土木工程学位（Civil Engineering Degree）。

埃利斯是一位结构工程师和桥梁设计专家。从事结构和桥梁设计23年。先后任职于美国桥梁公司（American Bridge Company，1902-1908年，结构工程师，参与设计了蒙特利尔 海港大桥 Montreal Harbor Bridge），杜闵妮桥梁公司（Dominion Bridge Company，1913-1914年，设计工程师），芝加哥施特劳斯工程公司（Strauss Engineering Corporation of Chicago，1921年-1931年），此后曾从事私人工程咨询服务（1932-1934）。埃利斯在芝加哥施特劳斯工程公司曾担任副总裁，负责设计和施工监理及参加金门大桥设计工作。从1930年3月到1931年12月5日，埃利斯独自完成了金门大桥的初步设计，结构分析，施工图设计和施工规范。他是金门大桥当之无愧的设计者。

埃利斯也是一位教育家和学者，从事教育和科研工作23年。先后任教于密歇根大学 （University of Michigan, 1909-1912年，土木工程系助理教授），伊利诺大学(University of Illinois, 1914年，结构与桥梁工程助理教授；1915-1921年，结构与桥梁工程教授)和普渡大学（Purdue University, 1934-1946年，结构工程教授）。埃利斯著作等身，出版了标准教科书《框架结构理论》，发表了许多关于桥梁设计和结构工程领域的学术论文。

1949年8月22日，埃利斯在伊利诺州埃文斯顿（Evanston, Illinois）逝世， 享年73岁。

结语

金门大桥是二十世纪最伟大的桥梁工程和现代世界七大奇迹之一。

毫无疑问，约瑟夫 • 施特劳斯是一位杰出的桥梁大师和企业家。如果没有施特劳斯高瞻远瞩的极力游说和推动，当年就不会有金门大桥的建设立项。作为金门大桥第一任总工程师，施特劳斯领导了大桥的设计和建设，奉献了17年的职业生涯，无愧为金门大桥的第一功臣。

同样毋庸置疑，查尔斯 • 阿尔顿 • 埃利斯是一位杰出的桥梁大师，教育家和学者。如果没有埃利斯的工程研究理论和大桥设计技术，施特劳斯工程公司就不会设计出雄伟壮丽屹立至今的金门大桥。埃利斯是金门大桥的实际设计者。其功绩终能在大桥建成70年之后得到公认，使金门大桥建设史正本清源，实属幸事。

金门大桥的建设，约瑟夫•施特劳斯和查尔斯•阿尔顿•埃利斯缺一不可。他们之间的亲密合作，创造了人类史的光辉结晶。他们分道扬镳，导致了埃利斯的贡献被历史遗忘达70年之久。历史长河，大浪淘沙；深埋金子，终发光华。

后记

我第一次对金门大桥历史的初步了解是在 2001 年夏阅读了 William Meiners 刊登在普渡大学工程学院《*Extrapolations*》(图 31)的文章 《名归实者：1934 至-1946 年任教于普渡大学的土木工程教授查尔斯 • 埃利斯终于被公认为是金门大桥的实际设计者》（Credit Where Credit Was Due： Charles Ellis, a Purdue

Civil Engineering Professor from 1934-1946, is Finally Recognized as the True Designer of the Golden Gate Bridge）之后。

图 **31**：普渡大学工程《***Extrapolations***》**2001 Summer -** 名归实者 （**Credit Where Credit Was Due**）

而心中萌发了用中文写一篇关于金门大桥的设计故事于朋友们分享的想法则来自看到“美国土木工程师协会将于 2013 年 11 月 21 日向普渡大学颁发埃利斯设计金门大桥的功德匾”的新闻报道之时。后因忙它事迟未动笔。今年 4 月 18 日陪远道来访的普渡校友李军夫妇游览金门大桥，当亲眼看到埃利斯功德匾和金门大桥 80 周年花池时，心潮波涌， 感慨万千，就决定在庆祝金门大桥建成 80 周年之际，写此追忆以表达对所有当年参与金门大桥设计，施工和管理的桥梁界前辈的崇高敬意！

本文八易其稿，初稿完成于 2017 年 5 月 20 日；第 4 稿于 5 月 24 日送交《世界日报》；本文精缩版在金门大桥 80 周年情时，5 月 28 日首次发表于美国旧金山《世界日报》（图 32）(http://www.worldjournal.com/4993322/article-link/。

成文中，得到夏威夷大学陈惠发教授；林同炎国际公司邓文中董事长；上海交通大学刘西拉教授；加州交通厅同仁周科， 王立南， 王进荣，吴再光，韩立华， 龙文艺， 段明珠，郝友苏， 陈天顺， 沈壮 高级工程师， Sue Hida 主任工程师， Al Mangus 工程师；MGE 工程公司陈康付总裁； 加州教育厅李元庆研究员；加州物税局付继红计算机程序专家；普渡大学莫宗坚教授； 朝阳科技大学金文森教授，中国交通运输部公路科学研究院王克海研究员；美国摄影学会沈健国际代表等的审阅和帮助，吸取了他们许多宝贵建议。谨致谢意！

图 **32**： 《世界日报》**5** 月 **28** 日《庆祝金门大桥通车 **80** 周年》专刊