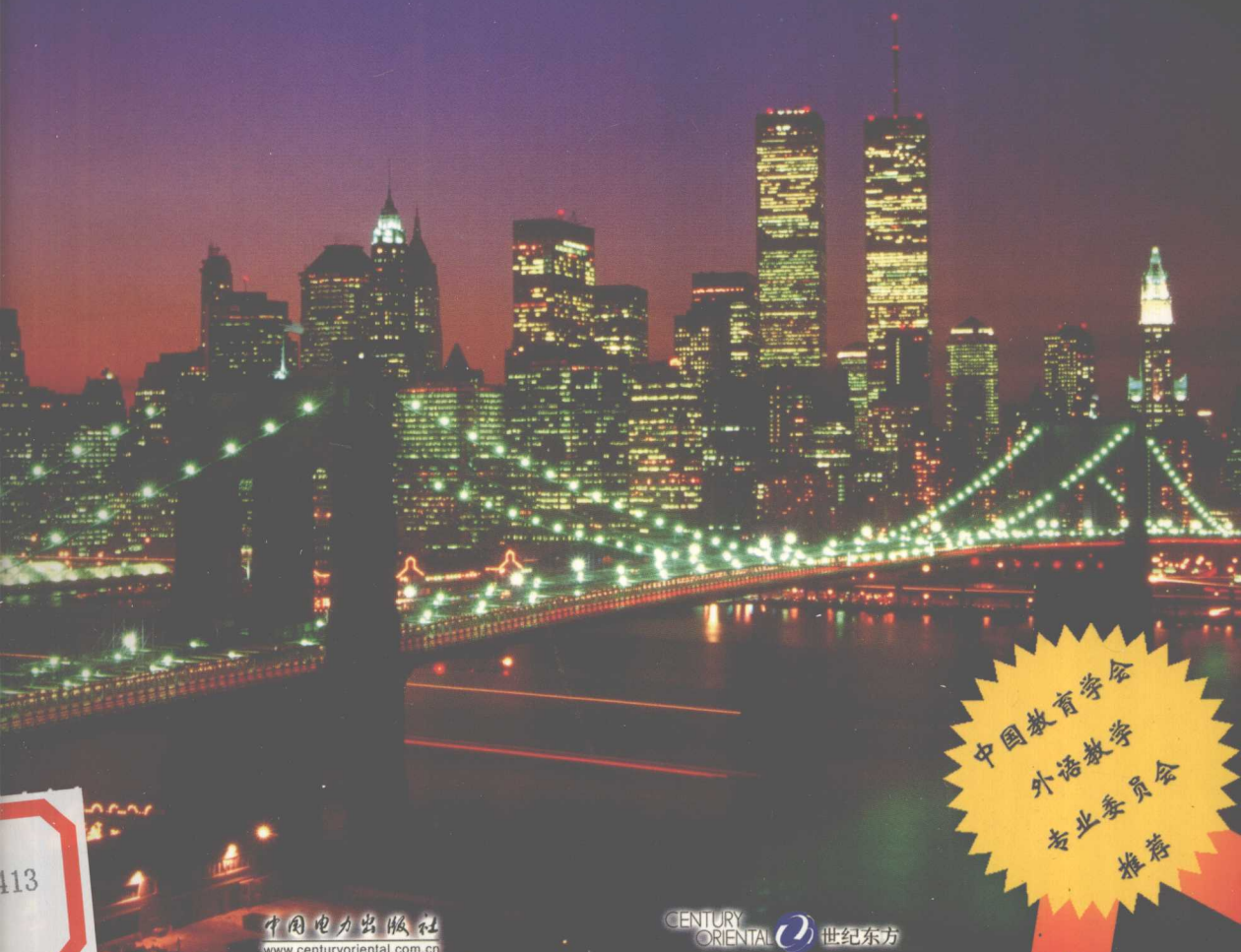
超大建筑

Super Structures



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阅读空间 · 英汉双语主题阅读

超大建筑

Super Structures

李莉 译

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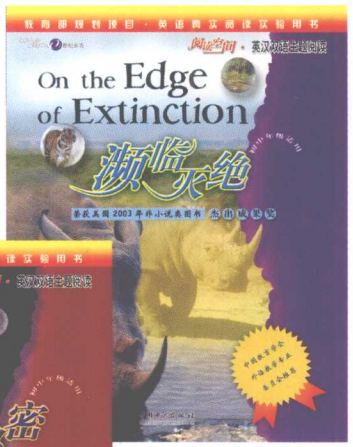

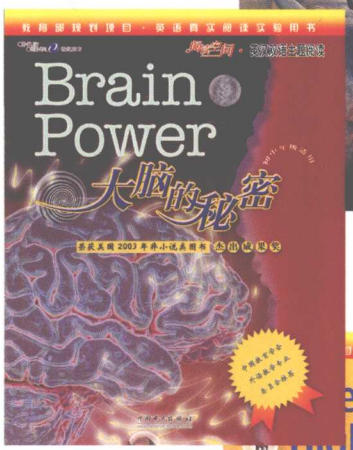

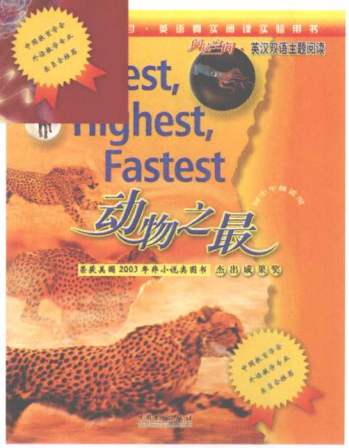

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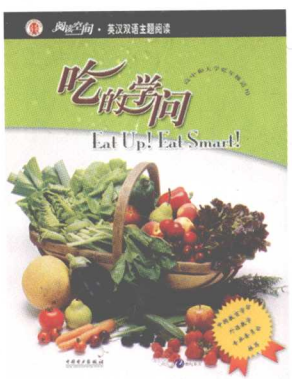

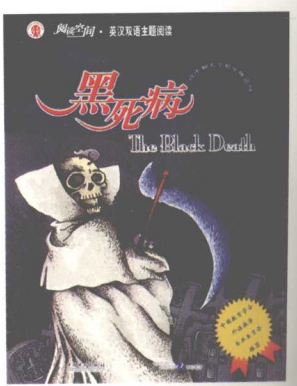

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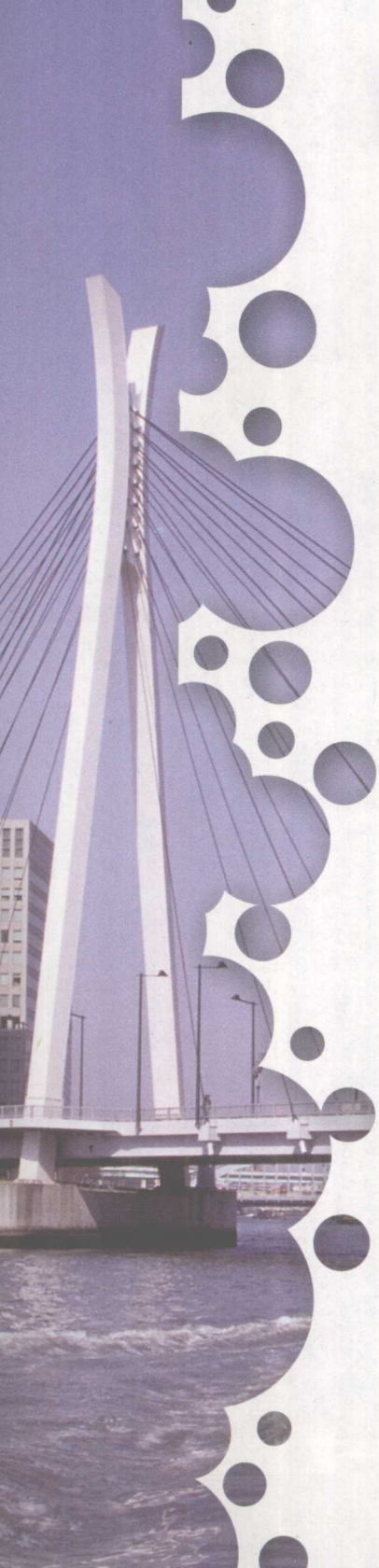

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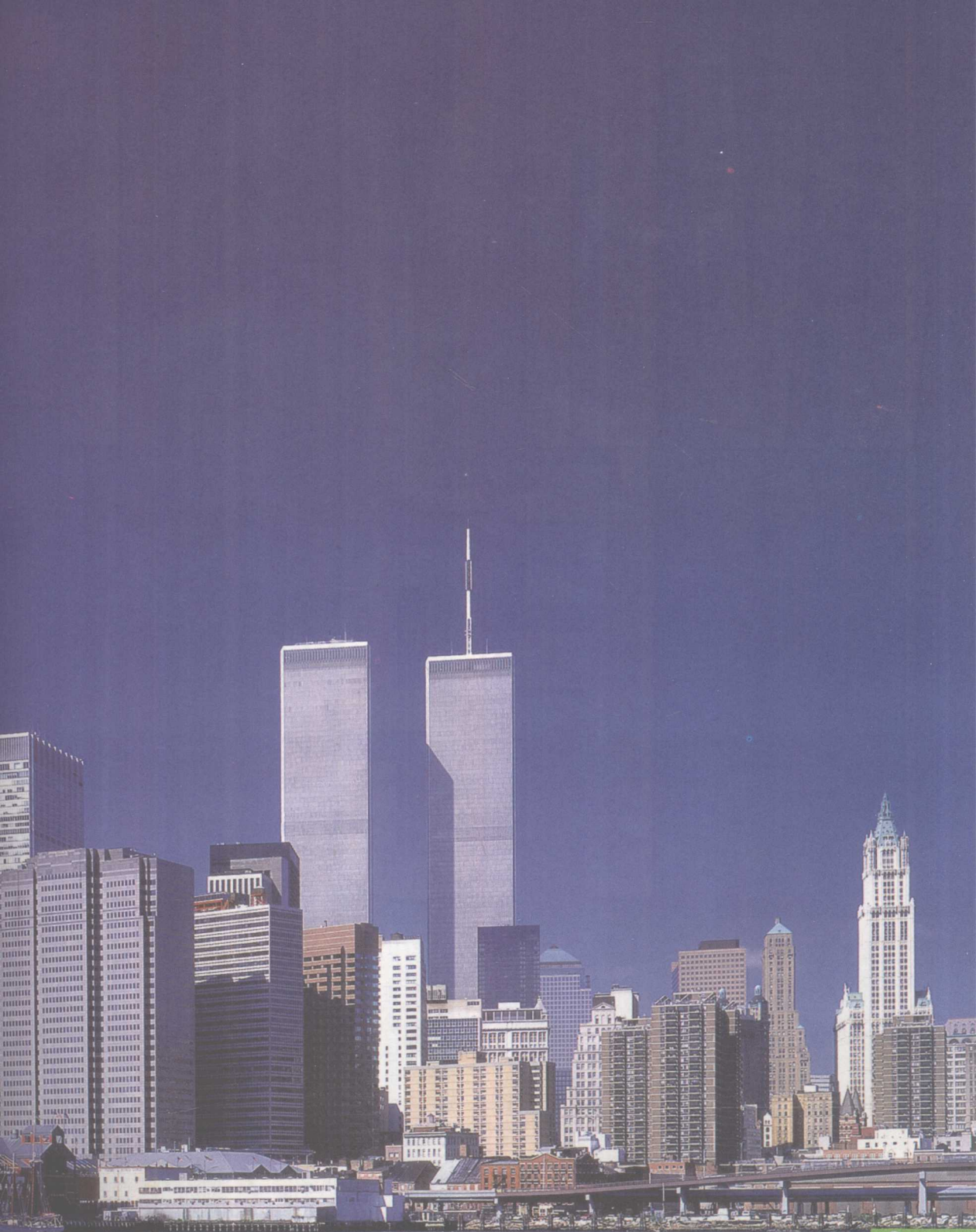
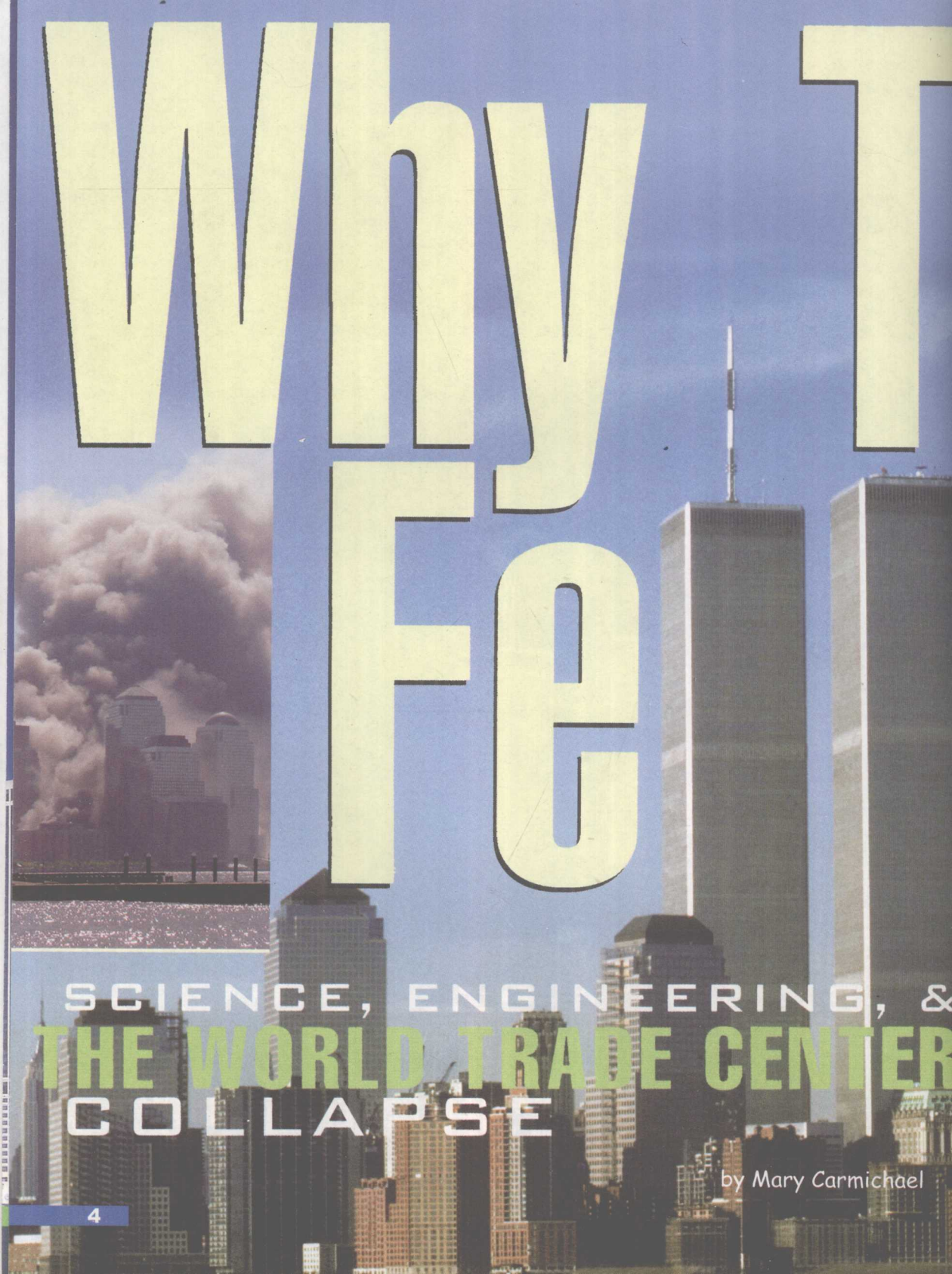
Editor's Message 编辑手记

2001年9月11日，纽约人心中的骄傲——世贸双子大楼永远地从这个城市的天际消失了。尽管这幢摩天大楼的倒塌给纽约城的天空留下了巨大的空洞，但这空洞仍然无法和它在人们心中留下的创伤相提并论。

结构工程师们为这座豪华双塔设计了可以屹立几百年的非凡结构，因此，即使是在恐怖主义分子的飞机猛烈撞击之后，它仍然可以坚挺一个多小时。那么，究竟是什么导致了它的倒塌呢？为此，结构工程师们在“9·11”当天就赶赴灾难现场勘察情况、探询原因。那么，未来的建筑会是怎样的呢？工程师们要如何使未来的建筑更加安全呢？请到本书中去寻找答案吧！





Why T Fe

SCIENCE, ENGINEERING, & THE WORLD TRADE CENTER COLLAPSE

by Mary Carmichael

hey

After watching the twin towers of the World Trade Center collapse last September, twice reducing 110 stories to five in less than a minute, it's hard to see how the buildings could have ever been considered safe. It's even harder to see how engineers can look at the events of September 11, 2001, as a relative success in terms of architectural strength. Consider this: The rubble at the site weighed a million tons. The site spanned a vast 16 acres (6 hectares). The nonstop cleanup, conducted day and night, still took the better part of a year. Even if the greatest loss – so many human lives – is excluded, there's no arguing: This was, in all senses, an enormous disaster.

在目睹了110层高的世贸双塔顷刻之间化为5层楼高的废墟的时候，人们不禁对高楼大厦的安全问题开始担心。甚至更难想象建筑工程师们怎样将2001年的“9·11”事件看成建筑史上的一个相对成功。考虑一下这个数据：废墟碎砖瓦砾重达100万吨，占地16英亩（6公顷）。夜以继日的清扫工作还在进行（指到2002年9月为止——编者注），再加上这么多人丧生，毫无争议，这绝对是一场巨大的灾难。

然而，尽管大楼倒塌了，尽管人们不敢相信他们的眼睛，工程师们却一致认为在经受恐怖分子用飞机撞击之后，双塔仍然表现出色，因为被撞后每幢都挺了约一个小时没有倒下，这给了救援人员以足够的时间去疏散楼里的人群。这样坚挺的韧度得归功于它的建筑设计师山崎实和结构工程师莱斯利·罗伯逊，他们的独创性的设计使得世贸大楼能承受住飞机的冲撞，而只在高温烈火把钢梁烧化后才坍塌下来。

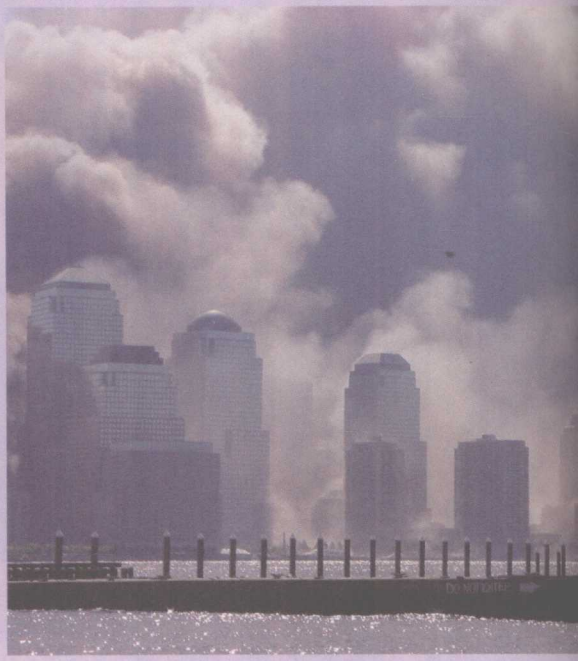
它们为什么倒塌：
科学、工程及世贸中心之坍塌

And yet, for all the destruction – and for all the disbelief Americans felt as they watched the towers collapse – engineers unanimously say that the buildings performed "magnificently" after terrorists crashed a plane into the side of each. Because the towers stayed standing for about an hour each, they gave rescue workers enough time to get tens of thousands of people out. The towers owed their resilience largely to their architect, Minoru Yamasaki, and structural engineer Leslie Robertson. The men's original design enabled the buildings to withstand the impact of the planes, crumpling only after jet-fuel fires weakened their steel beams.

AN EXTRAORDINARY DESIGN

Constructed with cheaper methods, many other buildings would have collapsed immediately. Today's most common skyscraper design places vertical support beams throughout a building. Others have diagonal beams as their main means of support. But the World Trade Center was built *before* those were the standards. Raised in the 1960s, the glass-and-steel towers were designed and built with innovation and special attention to safety and stability because of their extreme height. Engineers wanted to make sure the towers could withstand hurricane-force winds of up to 200 mph (320 kph) – on an especially windy day, the towers could sway up to several feet in either direction. With memories of a 1945 plane crash into the Empire State Building lurking in their minds, engineers and architects also designed the towers to withstand the force of a Boeing 707 (at the time, planes were much smaller than they are today and carried less fuel).

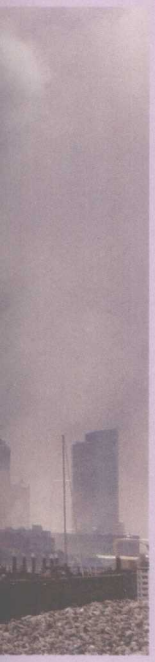
The engineers agreed that the secret to ensur-



非凡的设计

要是用较便宜的方法建造，许多别的大楼就会立刻倒塌了。现在大多数的摩天大楼中间都有一根垂直的承重柱贯穿到底，或者有对角交叉横梁来支撑，但是世贸大楼建在它们之前。它建于20世纪60年代初，由于它的极端高度，在设计和建造的时候都进行了一番革新，尤其注重它的安全性和稳固性。要确保它能经受得住每小时200英里的飓风，在这种天气下，塔楼往任何方向都能晃动几英尺。1945年飞机撞上帝国大厦的事件人们还记忆犹新，有了前车之鉴，这次的设计能承受一架波音707的冲撞（要知道现在的飞机可比以前大，而且装的燃油也多）。

工程师们都同意这种说法：使世贸大楼在极端环境中屹立不倒的关键是支撑它的钢柱，而这些钢柱的建造与其他大多数摩天大楼是不同的。大多数的钢梁都用来加固外墙，每211英尺（64米）就有61根钢梁相隔18英寸（46厘米）分布，从侧面来给予最好的保



ing the buildings would stand tall under extreme circumstances rested in their supporting steel columns, which were set up differently from most skyscrapers'. The majority of the beams framed the outside walls of the towers: 61 beams (placed only 18 inches [46 centimeters] apart) per 211-foot (64-meter) side provided maximum reinforcement. Engineers often refer to this as a solid "steel tube" design, and rightly so compared to most buildings, which may have vertical support columns spaced as far as 20 feet (6 meters) apart. The outer columns helped the buildings withstand a huge wind load, but another, smaller group of steel beams shot through the centers of the buildings and bore the main load of supporting the towers. This "core", which housed elevator shafts and stairwells, was connected to the outer steel columns by still more steel running through each concrete floor. The "double support" may have been what ultimately kept the buildings standing for so long.

GRAVITY AND TOO MUCH HEAT

All the same, no amount of reinforcement could have prevented the towers' eventual collapse. Immediately after September 11, most engineers thought the fires, and not the planes' impacts, were to blame. That theory has generally held up, with a little tweaking. A federal investigation was inconclusive, but it did conform with engineers' suspicions. The steel columns didn't actually melt. But as the fires inside the buildings consumed more and more jet fuel – about 24,000 gallons (90,000 liters) of it – they overwhelmed the buildings' sprin-

护。工程师们称之为“钢管”设计，而大多数建筑只有垂直的柱子，每隔20英尺（6米）分布着来支撑。这些外部的加固材料能有效地抵御强风的侵袭，而内部安置的小钢梁则承载大楼本身的重量。这个安装着电梯升降机通道的“核心”被更多的穿过每一层的混凝土楼板的钢梁紧紧地连接在大楼外侧的钢柱上。这种“双重保护”得以使世贸大楼在遭受袭击之后仍然坚持了那么久。

重力和灼热

然而，有些情况下无论怎么加固都不能阻止建筑物的倒塌。“9·11”之后，大多数工程师都认为倒塌的根本原因是飞机燃油燃烧的火而不是飞机的撞击。这种判断虽然有点绕弯子，但却站得住脚。联邦调查的结果与工程师们的猜测的确吻合。钢筋柱子实际上并没有熔化，但是随着大火烧掉了愈来愈多的喷气燃油，大约有24 000加仑（90 000升），大楼的消防系统已经不再管用，包裹在钢筋外面的隔热层也被破坏，因此灼烧到钢筋，而楼板钢架上的防火喷涂也由于飞机的猛烈冲撞而脱落下来。 火的温度窜到了

kler systems, started to weaken the concrete insulation around the steel, and then debilitated the steel itself. Most of the fluffy fireproofing material on the towers' steel columns was blasted off by the plane crashes. With flames reaching temperatures of 1,500 degrees Fahrenheit (800 degrees Celsius) and higher, the steel columns started to warp, and the top floors buckled. (It takes temperatures of 2,700 degrees F. [1,500 degrees C.] to *melt* steel.) From then on, the towers had no more chance of standing than a building targeted for demolition. Their collapse was the first known instance of steel buildings collapsing because of fire alone.

In fact, the collapse played out just like a controlled demolition would. To destroy a building, experts usually place explosives not just on the lowest three floors, but also on higher floors. (Damaging just the lower floors usually won't make a building collapse – a lesson terrorists must have learned in 1993, when a bomb exploded in the underground garage of the Trade Center but the buildings were left standing.) With the top floors exploding, demolition experts can create what they call a "pancake effect," which you might realize is the same as a downward domino effect. Unlike dominos, of course, the towers fell straight down rather than sideways (although some pictures do appear to show one of the towers leaning slightly to one side as it collapsed). But their downfall was caused by the same forces that knock a line of dominos on their faces: Floors on the top gave in, crashing through the floors below them. As each concrete floor fell, it added force to the collapse – making it harder for each floor to hold up against the increasing pressure.

1500°F（800℃）甚至更高，钢筋开始弯曲，顶上几层由于受热而开始变形（钢铁的熔点是2700°F，相当于1500℃）。这样一来，大楼就像人为拆除的建筑物一样，只有倒塌的份了。这是目前钢结构建筑物仅由大火而导致倒塌的首例。

实际上，这次的倒塌过程就像是有控制的爆破。为了拆毁一幢高楼，专家们在底下三层和上面的高层上都要放置炸药（仅仅破坏底下几层有时候并不能炸毁整幢大楼，1993年世贸中心的地下车库发生了大爆炸，但是对大楼的主体根本没有任何影响）。通过爆炸高层，能产生“煎饼效应”（各楼层的楼板像煎饼一样摞起来下落）而使大楼逐渐崩塌。这跟“多米诺骨牌效应”是一样的原理（像多米诺骨牌，一旦一个倒下去，会制造连锁反应）。当然，多米诺骨牌是往侧面倒下，而大楼是垂直倒下的（尽管从有些图片上看其中一幢的确是微微倾斜了一下再坍塌的），但是它们倒下的原理如出一辙，顶上的楼层塌陷下来，把下面一层压穿。每掉一层，重量就不断增加，直到越来越难以承受。所以一旦上面几层塌陷下来，灾难就不可避免了。

Once the top floors gave way, the rest of the catastrophe was inevitable.

MANY LIVES LOST, BUT MANY SAVED

So if the towers were never going to stay standing, why all the extra support? Was it futile after all? Suppose for a minute that the towers hadn't been built with all that reinforcement – that they'd collapsed a few minutes after being struck. The rubble at the site still would weigh a million tons. The site still would span a vast 16 acres. The cleanup still would have taken as long. But how many more people would have died? It's a figure no one wants to calculate.

Thankfully, because a team of engineers and architects made the Trade Center as safe as it could possibly be, no one has to.

许多人丧生，而许多人得救了

有人说既然反正要倒，为什么还要那么多的加固措施呢？那到底这些努力有没有用呢？让我们假设没有了这些加固，那么在被撞击几分钟之后它就会塌陷，废墟的碎片仍然会重达100万吨，仍然会占地16英亩，人们还会花同样的时间进行挖掘清扫。但是会多死多少人呢？我想没人愿意去计算这个数字。

得感谢工程师和建筑师们，他们提高了世贸中心的安全系数，使我们不必去计算这个数字了。

Gravity Takes An Astonishing Toll

by Mary Carmichael

重力使损失惊人

As the old saying goes, the bigger they are, the harder they fall. That lesson never became so painfully clear as in the aftermath of the collapse of the World Trade Center.

"The airplanes destroyed 20 stories of the building, and gravity did the rest," says Swarthmore College physics professor Frank Moscatelli, a native New Yorker. "Their splendor was their undoing."

The towers stood 1,353 feet (411 meters) tall and together weighed more than a million tons. As a result, they struck the ground at a furious 120 mph (192 kph) and released an enormous amount of potential energy – estimated by Moscatelli at 680 billion joules.

谚语云：分量越大，摔得越重。世贸大楼的倒塌所带来的重创给了这句话最好的验证。

“其实是飞机撞毁了这其中的20层，而重力使其余的都垮掉了。”斯沃斯摩学院的物理学教授弗兰克·莫斯凯特利如是说，它的壮观导致了它的毁灭。

世贸双塔高1353英尺（411米），加起来重达100多万吨，因此它们倒塌的时候撞击地面的速度为120英里/小时（192公里/小时）并释放出巨大的潜能——弗兰克·莫斯凯特利估计有6800亿焦耳。

HOW MUCH IS THAT?

Well, one *joule* (the basic unit of energy) is equal to the work done when a force of one *newton* acts over a distance of one meter. An estimated 680 billion of them is equal to just one percent of the energy packed into an atomic bomb, and a severe earthquake might unleash 147,600 times as much power. But 680 billion is still a lot – seismic recordings registered the towers' collapse as equal to a minor earthquake, such as the one that jostled New York City in January 2001. (A monitoring station near the city kept picking up smaller signals after the towers came down because debris was still falling around the ruins.)

Newton
The unit of force required to accelerate a mass of one kilogram one meter per second per second

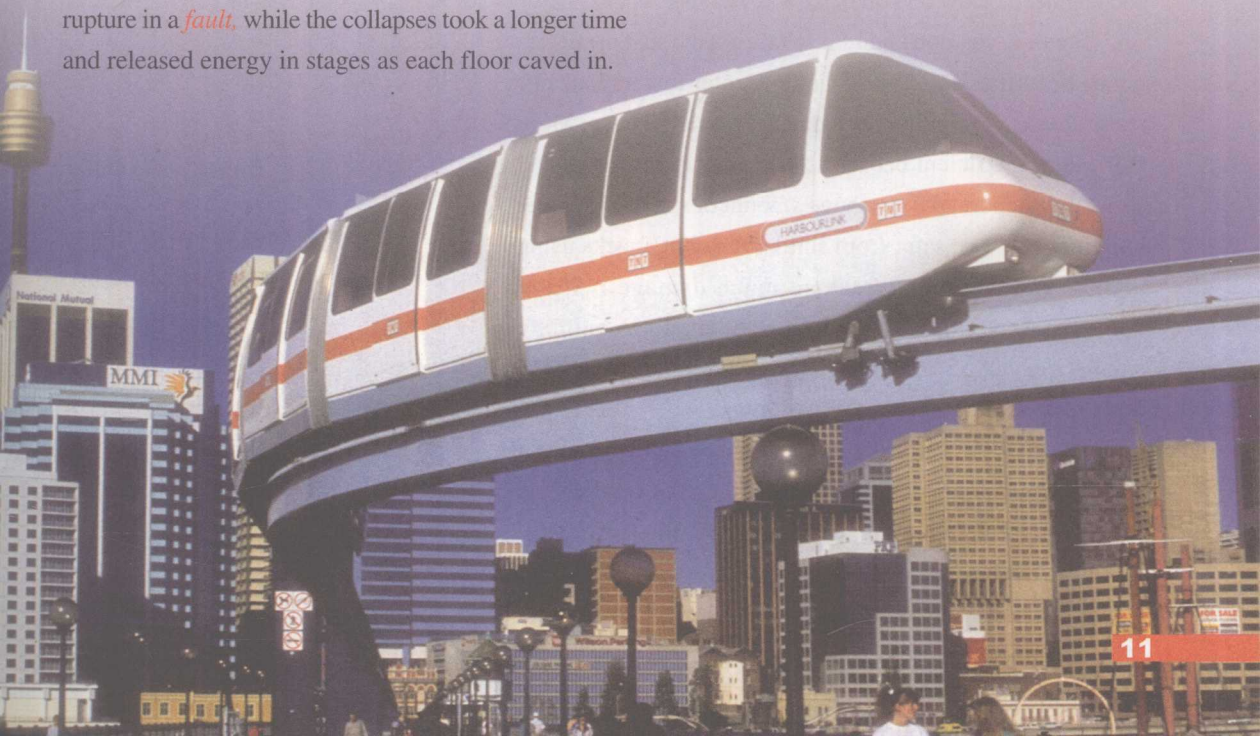
Fault
A fracture in a rock formation caused by the shifting of the Earth's crust

When the towers fell, people in New York didn't feel like they had been in an earthquake, possibly because the collapses gave off more low-frequency energy, and less high-frequency, than a quake would. Why? An earthquake is caused by a quick, intense rupture in a *fault*, while the collapses took a longer time and released energy in stages as each floor caved in.

那究竟是什么概念呢?

一焦耳（能量的基本单位）等于一牛顿的力作用于一米的距离上所做的功。6800亿焦耳仅等于塞进一个原子弹的能量的百分之一，而一次强烈的地震也许会释放147 600倍的这一能量。但是6800亿焦耳仍然是一个相当大的数字——这次倒塌相当于一次轻微地震，正如2001年1月发生在纽约的那次。（大楼倒塌之后，建在城郊的监控站不停地接收到信号，因为还是不断有碎片掉下来。）

当大楼倒塌的时候，纽约人并没有像地震时的感觉，可能是因为大楼倒塌比地震释放出较多的低频能量和较少的高频能量。为什么呢？ 因为地震是由地壳断层的突然破裂而引发的，而大楼是在每层楼倒塌的时候逐渐产生能量的。



The Future of Skyscrapers

摩天大楼的未来

by Mary Carmichael

Skyscrapers have always had their enemies among architects. Not all of the structures are elegant like the Chrysler Building or the Empire State Building. Even the World Trade Center, with its astounding height and subtle neo-Gothic flourishes, was panned by architects as a "milk carton" – boring, boxy, and plain.

But with the Trade Center in ruins, beauty is no longer the only concern about skyscrapers. They no longer appear safe, either. That is the challenge to the new generation of architects and engineers: How do you make a skyscraper secure?

For one, you don't build it so tall, even if that means it's not as beautiful. The World Trade Center towers had 110 stories each. Most buildings today have only 80 or so. More stories are inefficient because the necessary elevators and structural support take up a huge amount of space. A smaller building would be safer from similar terrorist attacks using planes, and wouldn't wreak so much damage if it did collapse. And there's a psychological benefit to building smaller: About 55 percent of New Yorkers now say they don't feel safe working in tall buildings.

Once architects and engineers agree on the size of a building, technology can be used to keep the smaller and safer skyscraper standing. Since most of the fluffy fire-proofing material on the towers' steel columns was blasted off by the plane crashes, engineers now are taking another

摩天大楼在建筑师当中一直有争议。不是所有的建筑都像克莱斯勒大厦或帝国大厦那样雄伟壮观的。即使像世贸大楼这样有着惊人的高度和新哥特式的外表的大楼，也被建筑师们呵责为“牛奶纸盒”，单调乏味，毫无特色。

但是随着世贸大楼成为一片废墟，美观不再是人们对摩天大楼的惟一关注， 人们也觉得它们不再安全了。这是对当今的建筑师和工程师们的挑战：摩天大楼的安全问题怎么解决？

一种办法是降低建筑物的高度，即使这意味着可能看上去不那么漂亮。世贸双塔每幢都有110层，而现在大多数楼房只有80层左右。其实过多的楼层完全没有必要，因为电梯和结构支撑材料会占去很多空间。在同样的飞机撞击之下，矮一点的建筑物会更安全，即使真的倒塌，也不会造成如此巨大的损失。而且现在还要考虑人们的心理，大约55%的纽约人觉得在高楼大厦里工作没有安全感。

建筑师和工程师一旦决定要降