Why pagodas don't fall down

In a land swept( ) by typhoons( ) and shaken by earthquakes, how have Japan's tallest and seemingly flimsiest( ) old buildings - 500 or so wooden( ) pagodas - ( )remained standing for centuries? Records show that only two have collapsed( ) during the past 1400 years. Those that have disappeared were destroyed by fire as a result of lightning( ) or civil war( ). The disastrous ( )Hanshin earthquake in 1995 killed 6,400 people, toppled( ) elevated ( )highways, flattened ( )office blocks and devastated( ) the port area of Kobe. Yet it left the magnificent( ) five-storey( ) pagoda at the Toji temple in nearby Kyoto unscathed( ), though it levelled( ) a number of buildings in the neighbourhood.

Japanese scholars have been mystified( ) for ages about why these tall, slender ( )buildings are so stable( ). It was only thirty years ago that the building industry felt confident( ) enough to erect( ) office blocks of steel( ) and reinforced( ) concrete( ) that had more than a dozen ( )floors. With its special shock absorbers( ) to dampen ( )the effect of sudden sideways ( )movements from an earthquake, the thirty-six-storey Kasumigaseki building in central Tokyo - Japan's first skyscraper( ) - was considered a masterpiece ( )of modern engineering when it was built in 1968.

Yet in 826, with only pegs( ) and wedges( ) to keep his wooden structure upright( ), the master builder Kobodaishi had no hesitation( ) in sending his majestic( ) Toji pagoda soaring fifty-five metres into the sky - nearly half as high as the Kasumigaseki skyscraper built some eleven centuries later. Clearly, Japanese carpenters( ) of the day knew a few tricks( ) about allowing a building to sway ( )and settle( ) itself rather than fight nature's forces. But what sort( ) of tricks?

The multi-storey pagoda came to Japan from China in the sixth century. As in China, they were first introduced with Buddhism( ) and were attached to ( )important temples. The Chinese built their pagodas in brick or stone, with inner staircases( ), and used them in later centuries mainly as watchtowers.( ) When the pagoda reached Japan, however, its architecture was freely adapted to local conditions - they were built less high, typically five rather than nine storeys, made mainly of wood and the staircase was dispensed with ( )because the Japanese pagoda did not have any practical use but became more of an art object. Because of the typhoons that batter( ) Japan in the summer, Japanese builders learned to extend ( )the eaves( ) of buildings further beyond the walls. This prevents rainwater gushing( ) down the walls. Pagodas in China and Korea have nothing like the overhang( ) that is found on pagodas in Japan.

The roof of a Japanese temple building can be made to overhang the sides of the structure by fifty per cent or more of the building's overall width.( ) For the same reason, the builders of Japanese pagodas seem to have further increased their weight by choosing to cover these extended eaves not with the porcelain( ) tiles( ) of many Chinese pagodas but with much heavier earthenware( ) tiles.

But this does not totally explain the great resilience( ) of Japanese pagodas. Is the answer that, like a tall pine tree, the Japanese pagoda - with its massive trunk-like( ) central pillar( ) known as shinbashira - simply flexes ( )and sways during a typhoon or earthquake? For centuries, many thought so. But the answer is not so simple because the startling( ) thing is that the shinbashira actually carries no load at all. In fact, in some pagoda designs, it does not even rest on the ground, but is suspended( ) from the top of the pagoda - hanging loosely down through the middle of the building. The weight of the building is supported entirely by twelve outer and four inner columns.( )

And what is the role of the shinbashira, the central pillar? The best way to understand the shinbashira's role is to watch a video made by Shuzo Ishida, a structural ( )engineer at Kyoto Institute of Technology. Mr Ishida, known to his students as 'Professor Pagoda' because of his passion to understand the pagoda, has built a series of models and tested them on a 'shake- table' in his laboratory. In short, the shinbashira was acting like an enormous stationary( ) pendulum( ). The ancient craftsmen( ), apparently without the assistance( ) of very advanced mathematics, seemed to grasp ( )the principles( ) that were, more than a thousand years later, applied in the construction of Japan's first skyscraper. What those early craftsmen had found by trial( ) and error was that under pressure a pagoda's loose stack ( )of floors could be made to slither ( )to( ) and fro( ) independent of one another. Viewed from the side, the pagoda seemed to be doing a snake( ) dance - with each consecutive( ) floor moving in the opposite direction( ) to its neighbours above and below. The shinbashira, running up through a hole in the centre of the building, constrained( ) individual stories from moving too far because, after moving a certain distance, they banged( ) into it, transmitting energy away along the column.

Another strange feature of the Japanese pagoda is that, because the building tapers,( ),with each successive ( )floor plan being smaller than the one below, none of the vertical ( )pillars that carry the weight of the building is connected to its corresponding( ) pillar above. In other words, a five-storey pagoda contains not even one pillar that travels right up( ) through the building to carry the structural loads from the top to the bottom. More surprising is the fact that the individual stories of a Japanese pagoda, unlike their counterparts( ) elsewhere, are not actually connected to each other. They are simply stacked ( )one on top of another like a pile of( ) hats. Interestingly, such a design would not be permitted under current Japanese building regulations.( )

And the extra-wide ( )eaves? Think of them as a tightrope walker's ( )balancing pole. The bigger the mass at each end of the pole, the easier it is for the tightrope walker to maintain his or her balance. The same holds true for a pagoda. 'With the eaves extending out on all sides like balancing poles,' says Mr Ishida, 'the building responds to even the most powerful jolt( ) of an earthquake with a graceful ( )swaying, never an abrupt ( )shaking.' Here again, Japanese master builders of a thousand years ago anticipated( ) concepts ( )of modern structural engineering.

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