World-leading Elevator Research Tower and New Elevator Technology for Next Generation of Urban Vertical Mobility Infrastructure

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OVERVIEW: Large buildings around the world require the ability to transport significant numbers of people around inside them and this together with the need to make effective use of the space in the building means there is a strong demand for ultra-high-speed elevators with large capacity. To help satisfy this demand and allow for experimental testing during elevator development, Hitachi completed a new elevator research tower in April 2010 which, at 213.5 m, is the tallest in the world. The new tower utilizes a wide range of construction design techniques including being equipped with control devices and vents for reducing wind-induced vibration. The research tower will be put to use developing products such as the world's fastest elevator and elevators with speeds and capacities among the best in the world.*

INTRODUCTION

HITACHI'S involvement in the development of ultra-high-speed elevators with large capacity goes back to the construction of Japan's first ultra-high-rise buildings in the late 1960s such as the Kasumigaseki Building. These buildings required elevators with a rated speed of 5 m/s, twice which of the fastest domestically produced elevators of the time which had a rated speed of only 2.5 m/s. In response, Hitachi constructed an elevator research tower at its Mito Works which, at 90 m high, was the tallest of its type in the world at that time. The tower was used to develop and study technologies such as accurate speed control techniques, vibration and noise suppression techniques, and safety devices for high-speed elevators, leading to the completion of an ultra-high-speed elevator with a rated speed of 5 m/s[1]. This success was followed by the development of a series of even faster elevators including in 1993 a model with a rated speed of 13.5 m/s which was the world's fastest at that time[2]. During this time, Hitachi retained its role as one of the leading domestic elevator manufacturers in Japan.

Internationally, the arrival of the new century was marked by a rapid expansion in the Asian market, especially China which grew into a market of unprecedented size[3]. Hitachi faces fierce competition in this market where it is up against elevator manufacturers from around the world. There is also an international trend toward making buildings taller and larger, including in the Middle East, and the requirements of these buildings include ultra-high-speed elevators and elevators with large capacity.

Against this background, Hitachi constructed a new elevator research tower with the aim of developing technologies to further improve product safety, efficiency, and comfort and strengthen the competitiveness of its products in the global market based on the technologies it has built up over time in the field of ultra-high-speed and large-capacity elevators[4]. The tower was constructed at Mito Works, Hitachi's base for research, development, and production of elevators and other vertical transport equipment, and has a height of 213.5 m which makes it the tallest elevator research facility in the world (see Fig. 1).

This article describes the characteristics and other features of the new elevator research tower building together with a description of the elevator development work for which it is being used.

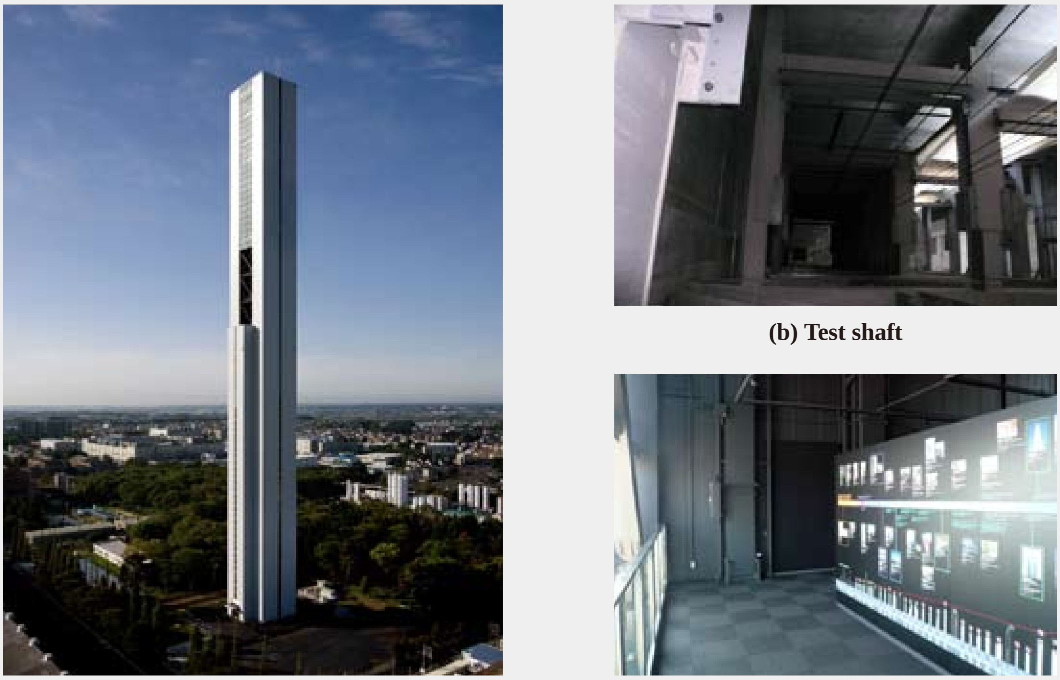
OVERVIEW OF CONSTRUCTION PLAN

The main elements of the plan for the construction of the new elevator research tower[5] were as follows.

(1) The high-rise section of the building is to have a rectangular cross section and the lower section will be in the form of a cross.

(2) The body of the building is in the form of a slender tower with a height of 203 m and an aspect ratio of 10.

* As of December 2010 (based on investigation by Hitachi)



(a) Exterior

(b) Test shaft

(c) Display space

Fig. 1—Interior and Exterior of New Elevator Research Tower.
The photographs show external and internal views of the new elevator research tower. Work commenced on the tower in March 2008 and it was completed in April 2010. The building, which is the world's tallest elevator research facility, has a volume of 388 m^2 and height of 213.5 m, extends 15 m below ground, and has nine above ground floors and one basement. The tower is intended to develop world-leading elevator technology and products.

(3) The influence of wind force is to be reduced by fitting vents in the mid part of the building at a height of 110 to 140 m.
(4) A vibration damping mechanism is to be fitted at the top of the tower to improve living conditions at times of high wind.
(5) A high-capacity winch with a high lifting height is to be fitted to assist with elevator testing and for general lifting.

STRUCTURAL PLAN

The central structure up to a height of 203 m consists of the main core wall with a rectangular cross section, and the lower section up to a height of 110 m is in the shape of a cross with test elevator shafts used as structural outriggers (stabilizers) located on either side. The main core wall is constructed of four L-shaped core walls joined by boundary braces and boundary beams. These structures (hybrid structures) and other elements reduce the tendency for resonant vibration to occur during strong winds and give the building a natural period that prevents the seismic load from becoming excessive.

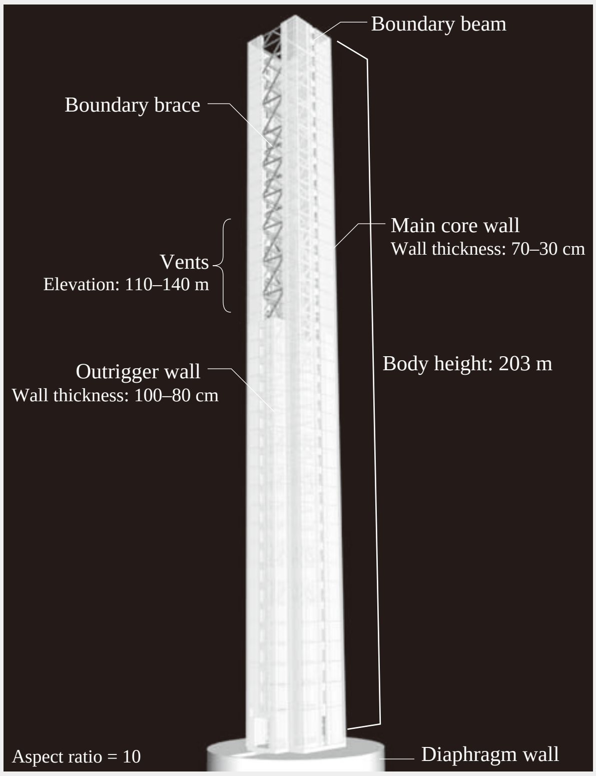


Fig. 2—Perspective Drawing of Tower Structure.
The tower body has a height of 203 m and the total height is 213.5 m.

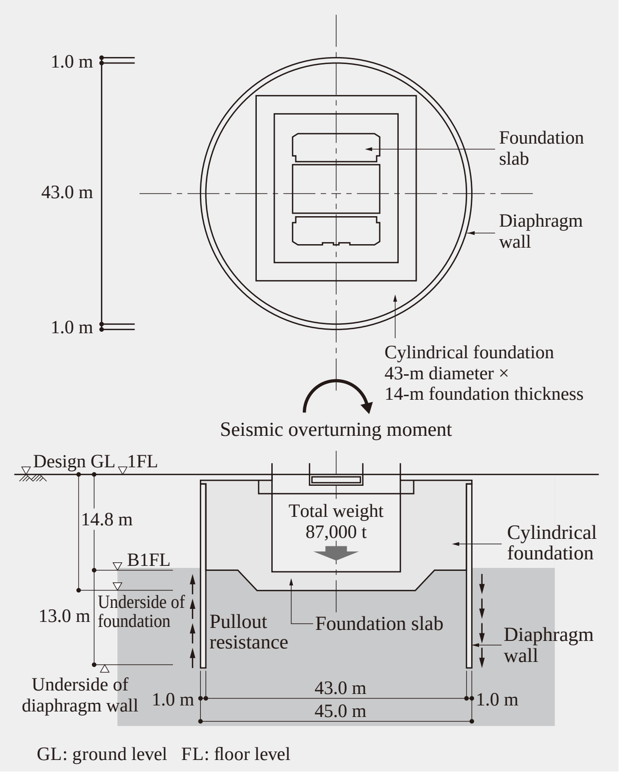


Fig. 3—Foundation Plan.
The foundations are designed to withstand earthquakes and strong winds.

To ensure that maximum use can be made of the new elevator research tower for its primary purpose of providing elevator test shafts, the cross section design of the tower does not have clipped corners. Although this is not ideal from an aerodynamic perspective, it is compensated for by using other methods to reduce the wind force. These include vents located from 110 to 140 m above ground which have the effect of keeping the wind load during strong winds (level 2 wind strength: strong wind that occurs very rarely with a return period of 500 years) to the equivalent of a level 2 seismic load (seismic ground motion that occurs very rarely and has a low probability of being experienced during the lifetime of the building) or less (see Fig. 2).

The foundations are made from cylindrical pieces of concrete which are directly supported by strong bedrock and are surrounded by diaphragm walls with a thickness of 1 m which also act to prevent collapse in an earthquake or strong winds (see Fig. 3).

DESIGN FOR EARTHQUAKE RESISTANCE AND ABILITY TO WITHSTAND WIND

Because the new elevator research tower is an ultra-high-rise building with a very slim aspect ratio

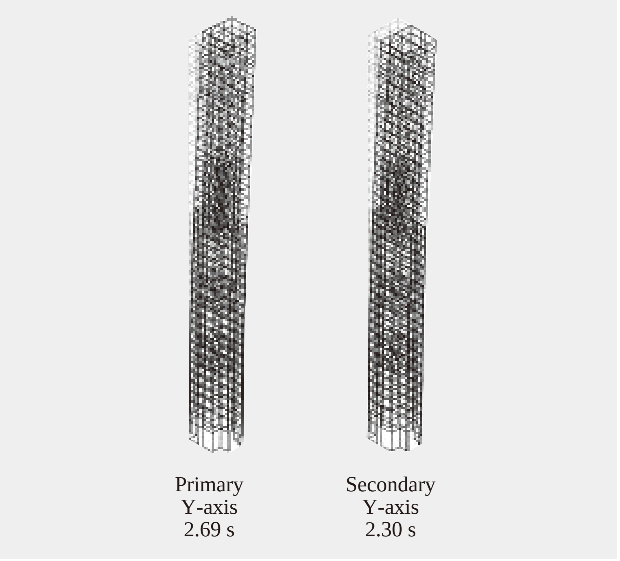


Fig. 4—Natural Mode.
The figure shows the results of eigenvalue analysis of an analytical model of the tower's vibration used for seismic response analysis.

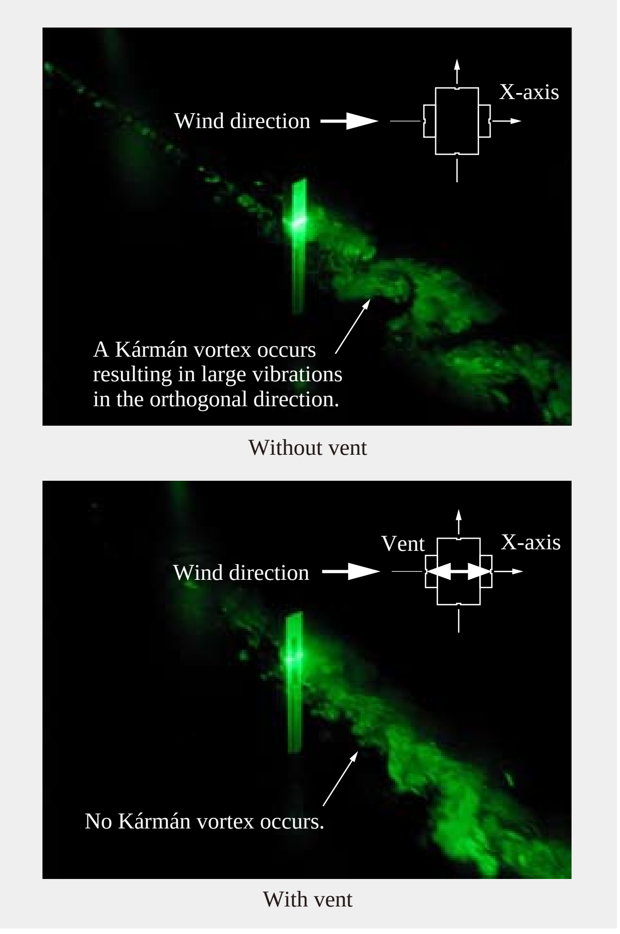


Fig. 5—Wind Tunnel Testing.
The alternating series of vortices that form downstream of an obstacle (building) placed in a flow are called Kármán vortices. The formation of Kármán vortices causes the building to sway.

of 10, it was subject to particularly stringent design criteria in terms of its ability to withstand earthquakes and wind.

Firstly, its earthquake resistance was evaluated in two stages consisting of level 1 (seismic ground motion that occurs rarely but has a high probability of being experienced at least once during the lifetime of the building) and level 2 seismic ground motion respectively. This determined, for example, that the forces to which the main structural elements would be subjected in a level 2 earthquake would not cause them to fail (less than proof strength at elastic limit). This is one of the benefits of the hybrid structure design described above and indicates that the tower has a high level of seismic safety (see Fig. 4).

Next, to improve the ability of the tower to withstand wind, preliminary wind tunnel testing was performed to evaluate the performance of models with and without wind vents and the results of this were incorporated in the structural design (see Fig. 5). This was followed by two further stages of wind tunnel testing using a model fitted with wind vents to evaluate the wind load for a level 1 wind strength (strong wind that occurs rarely with a return period of 100 years) and level 2 wind strength respectively. This determined, for example, that the load to which the foundations would be subjected in a level 2 wind is safely within the ultimate bearing capacity (level 2 seismic load). The wind tunnel testing was continued past the maximum anticipated wind strength (level 2 wind strength) to verify that the tower would not be subjected to any devastating effects even if the wind speed reached that of a 1,000-year wind event. This demonstrated that the new elevator research tower has a high level of safety with respect to its ability to withstand wind.

EQUIPMENT

A large-capacity winch was installed at the top of the new elevator research tower for lifting various different materials and equipment used in the tower (see Fig. 6). In addition to lifting, the winch is also used to support the test load frame when testing elevator safeties.

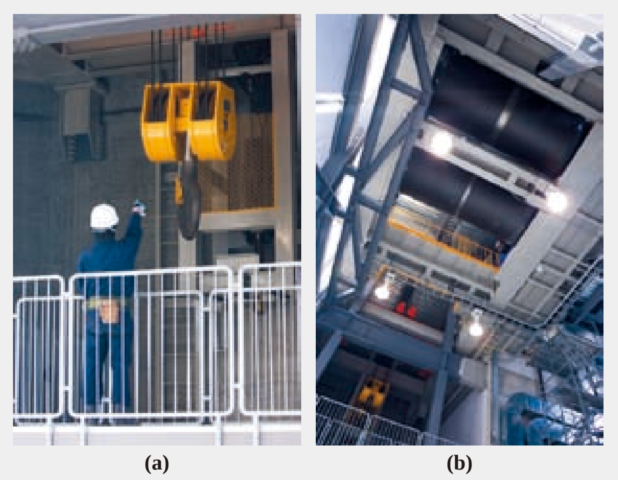


Fig. 6—Large-capacity Winch.
The winch has a lifting height of 210 m. Photograph (a) is a front view of the hook and photograph (b) is a view of the traction machine seen from below.

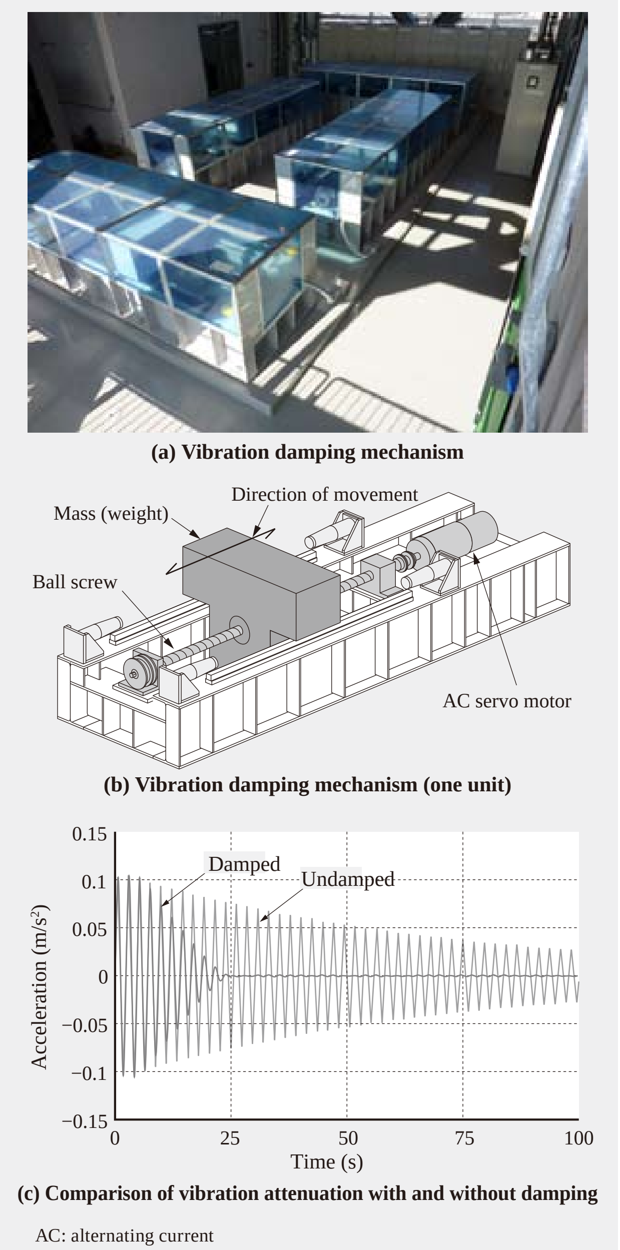


Fig. 7—Vibration Damping Mechanism.
The vibration damping mechanism consists of four units, two each in the X and Y directions. The system damps vibrations by using an electric motor to move a weight.

Also, although the wind-tolerance design of the tower described above ensures that it can safely withstand strong winds, there was a concern that the building would sway with a period equal to the tower's natural period (2- to 3-s long-period oscillation) shown in Fig. 4 and that this would detract from the level of comfort experienced by people inside. To suppress this tendency, a vibration damping mechanism was installed at the top of the tower (see Fig. 7).

The system uses three accelerometers installed at the base, mid-point, and top respectively of the tower to detect swaying of the building during an earthquake and strong wind and acts as an AMD (active mass damper) which damps the swaying by using an electric motor to move a mass (weight) in accordance with control rules based on the optimal control method. This improves the comfort level inside the building during earthquakes or strong winds and makes elevator installation, testing, and other work easier.

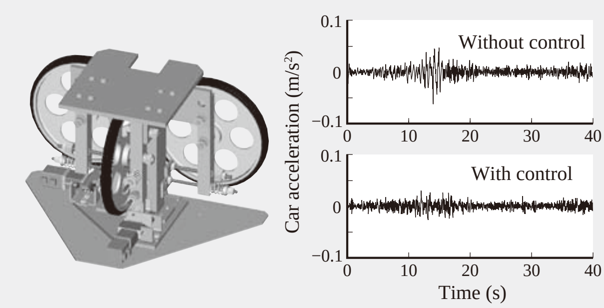
It is also possible to use the vibration damping mechanism as a vibration forcing system to reproduce the swaying of the building that occurs in situations such as during earthquakes or strong winds. This is done by forcibly operating the system in synchronization with the natural period of the tower, thereby causing it to sway. This function can be used for the testing of other equipment such as testing the earthquake resistance of elevators.

ELEVATOR DEVELOPMENT

The following section describes elevator development using the new elevator research tower.

As described earlier, the tower includes a number of shafts that can be used to test ultra-high-speed elevators with large capacities as well as other elevator models. Using these, the following two main types of development work are performed using the shaft designed for ultra-high-speed elevators with large capacities [see Fig. 1 (b)]. The first is the development of ultra-high-speed elevators with a rated speed of 16.7 m/s or more and the second is the development of large-capacity elevators capable of carrying 5 t or more and with rated speeds of 10 m/s or more.

Development of ultra-high-speed elevators utilizes existing technologies for large-capacity traction machines and heavy-duty motor drive control systems to test the operation of elevators at ultra-high speeds. Testing of safety devices called "safeties" (emergency stop), governors, and buffers is also performed. Because of the long distance traveled by these ultra-high-speed elevators, other concerns include poor ride quality caused by increased vibration of the elevator car due primarily to curvature of the guide rails used to guide the car and user discomfort due to the effect of pressure changes on their ears. Technologies being developed to solve these problems include an active guide unit that reduces elevator car vibration[6] (see Fig. 8) and an "air pressure adjustment device in cab" that adjusts the air pressure inside the car.



(a) System configuration (one unit)

(b) Example of vibration suppression on elevator car traveling at 8 m/s

Fig. 8—Configuration and Effects of Active Guide Unit.
The active guide unit (a) uses the acceleration inside the car as feedback to control the force applied to the guide rollers. The graph (b) shows an example of how the system reduces car vibration.

Meanwhile, development of elevators with high capacity includes work on further increasing the size and speed of double-deck elevators which are considered essential for increasing elevator capacity. Test elevators are installed in the new elevator research tower and used to conduct trials. An example of this is testing of the "distance adjustment device between decks" which adjusts the distance between the upper and lower cars of a double-deck elevator. This system is required if double-deck elevators are to be used in buildings with different inter-floor heights.

These examples show how the new elevator research tower is used in the research and development of leading-edge technologies and products. It is also to be used in the research and development of future technologies such as seismic force-resisting technology that allows elevators to be restored to operation quickly after an earthquake.

CONCLUSIONS

This article has described the characteristics and other features of the new elevator research tower building together with a description of the elevator development work for which it is being used.

Through their ongoing use, the new tower together with the existing 90-m elevator research tower are not only helping make elevators reassuring, comfortable,

Fig. 9—New and Old Elevator Research Towers.
The old 90-m high elevator research tower is on the left.

and convenient, they are also making a contribution to society by becoming symbols of the region in which they are located (see Fig. 9).

Finally, we would like to express our deep thanks to everyone involved including Mr. Keiichi Hirose of the Structural Design Department at Shimizu Corporation who was responsible for the building design, Mr. Takayuki Nagano of the Solution and Service Management Group of Hitachi Industrial Equipment Systems Co., Ltd. who was responsible for the winch, and Mr. Hiroyasu Komatsu of the Drive Control Systems Division of Hitachi Automotive Systems, Ltd. who was responsible for the vibration damping mechanism.

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