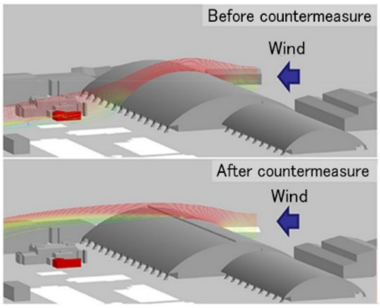
Typhoon Damage Simulation Technology for Improving Wind Disaster Resilience



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Natural disasters have been creating catastrophic damage because of climate change associated with global warming. On the other hand, the social infrastructure constructed in the period of rapid economic growth is aging. Therefore, damage risk analysis and new construction/repair planning for the infrastructure are becoming important. The Research & Innovation Center of Mitsubishi Heavy Industries, Ltd. (MHI) has its own simulation technologies for various types of disasters such as floods, tsunamis, earthquakes, typhoons, fires and leakage/explosions(1) *and has analyzed risks associated with climate change and developed countermeasure devices intended to improve infrastructure resilience (strength and recovery capability). In this report, focusing on typhoons, which are disasters familiar to us as they occur frequently, we introduce the outline of the typhoon damage simulation technology among MHI's simulation technologies, simulation examples including the risk analysis for roof uplift damage and strong wind damage, the development of damage reduction devices and the design wind velocity maps which visualize typhoon damage risk.*

1. Introduction

In recent years, there have been increasing cases where a typhoon formed in the south of Japan makes landfall on Japan while maintaining its strength. During typhoon No. 21 in 2018, the passenger terminal of Kansai International Airport was damaged by flooding due to the storm surge and it took over two weeks to fully recover from the damage(2). During typhoon No. 15 in 2019, major power outages occurred mainly in Chiba Prefecture due to the collapse of steel towers and electric poles, etc., and it took about three weeks to restore electric power(3). These disasters are still fresh in our memory. As seen from these cases, enhancement of resilience (strength and recovery capability) against typhoon damage is a critical issue.

On the other hand, facilities constructed in the period of rapid economic growth are aging. Therefore, from the viewpoint of resilience, it is important not just to conduct inspection and repair of defects on an as-needed basis but to make plans for new construction or repair.

As these social needs have grown, it is becoming more important to properly analyze increasingly catastrophic typhoon damage and thereby to make efficient investments in infrastructure. In order to analyze typhoon damage with high accuracy, it is necessary to assess the factors affecting the wind velocity over a wide area of the order of several hundred kilometers to an extremely narrow area of the order of several tens of meters using (1) the information of a passing typhoon, (2) the geographical information of the surroundings of the infrastructure and (3) the information on the shapes and arrangement of adjacent buildings. In order to satisfy these requirements, we believe that a numerical simulation that allows effects in a wide area to be applied to a narrow area is an assessment tool.

In this report, we first explain a risk assessment technology for typhoon damage, in which three simulation technologies required for assessment of typhoon damage are combined, and its accuracy, and then introduce examples of risk assessment for typhoon damage and developed

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damage reduction devices, focusing on roof uplift damage and strong wind damage around buildings in a model infrastructure. A visualization example for typhoon damage risk intended to clarify points with any risk in the whole infrastructure is also presented.

2. What is typhoon damage simulation technology?

2.1 Overview of typhoon damage simulation technology

The typhoon damage simulation technology is a tool for estimating the wind pressure acting on a building and the wind velocity around the building during the passage of a typhoon. At the infrastructure planning stage, it can be used for selecting a construction site and planning the arrangement of buildings resistant to typhoon damage. At the infrastructure operation stage, it can be used for conducting risk analysis for typhoon damage to the building, planning new construction/repair work and damage reduction devices, developing countermeasure scenarios in case of a typhoon, etc.

Figure 1 shows the flow of the typhoon damage simulation. The typhoon damage simulation, in which three simulations for different assessment fields are combined, has a feature so that it can quickly estimate the wind flow around the building in an extremely narrow area (up to 0.1 km) based on the information of a typhoon passing in a wide area (up to 1,000 km).

Firstly, (1) by the typhoon simulation, from the information of the typhoon (typhoon central location, central pressure, radius), the average wind velocity and direction over a flat terrain when hit by a typhoon are calculated. Next, (2) by the wind conditions simulation, based on the average wind velocity and direction over a flat terrain and the geographical information of the surroundings of the construction site, the average wind velocity and direction at the construction site are estimated with geographical effects taken into consideration. Finally, (3) by the wind pressure simulation, based on the average wind velocity and direction at the construction site and the data on the building shape and arrangement, the wind pressure acting on the buildings and the wind velocity around the buildings are assessed.

In addition, as for the data which is required for input in the simulation, the databases such as the Best Track Data by the Japan Meteorological Agency for the typhoon information and the Numerical Map of the Geospatial Information Authority of Japan for the geographical information can be used. When the shapes and arrangement of buildings to be assessed are input, assessment for any location and typhoon can be conducted.

As described above, with this simulation technology, the risk of typhoon damage reflecting the characteristics of a passing typhoon affected by the regional characteristics, surrounding terrain and buildings can be estimated with high accuracy and it becomes possible to make infrastructure investments aiming at satisfying both safety and economy.

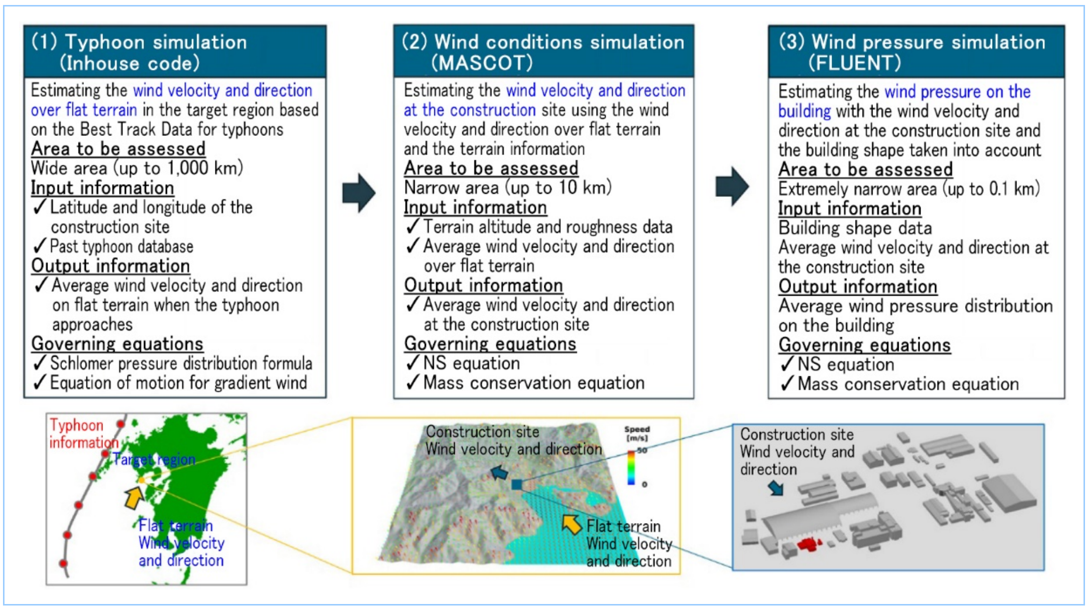

Figure 1 Typhoon damage simulation

2.2 Accuracy of each simulation

(1) Typhoon simulation, wind conditions simulation

Figure 2 shows the comparison of the observation result and the simulation result for the wind velocity and direction data at the Nagasaki Local Meteorological Observatory when typhoon No. 10 was passing in 2020. The average wind velocity over the flat terrain obtained by the typhoon simulation substantially exceeded the observation result. After the wind conditions simulation considering geographical effects was performed, the simulation result showed good agreement with the observation result and the maximum wind velocity when the typhoon was passing was reproduced with an error of about 10%. In addition, the geographical effects on the wind direction were not so marked as those on the wind velocity, and even only the typhoon simulation could reproduce the characteristics of the wind direction, which changed from the southeast to the southwest when the typhoon was passing.

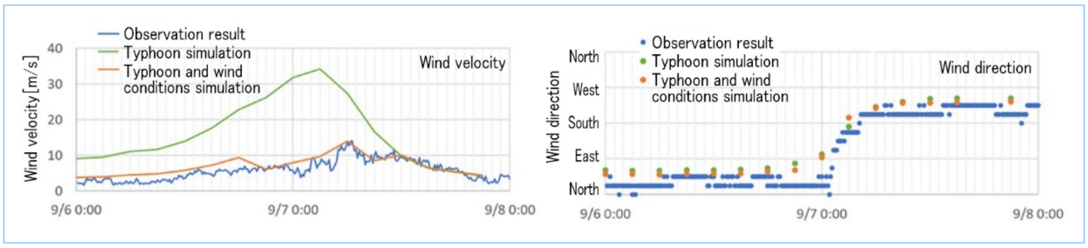

Figure 2 Validation result of typhoon simulation and wind conditions simulation

(2) Wind pressure simulation

Figure 3 shows the comparison of a past wind tunnel experiment result and the simulation result for the average wind pressure acting on the building wall surface which is a rectangular solid having the ratio of the height, width and depth = 1:0.5:0.5. It is known that when a wind flows from the direction of the corner of a building, the flow separating from the windward corner of the building entrains on the side face of the building, resulting in occurrence of conical vortices[(4)]. As shown in Figure 3(a), the wind pressure simulation also reproduced conical vortices. In addition, as shown in Figure 3(b), a wind pressure distribution in which a strong negative pressure arising from the conical vortices is generated along the corner of the roof face can be seen in both the wind tunnel experiment and the CFD. The comparison of the wind pressure distributions in the cross-section B-B' also showed that the local negative pressure obtained by the simulation was reproduced with about 10% error of the experimental result.

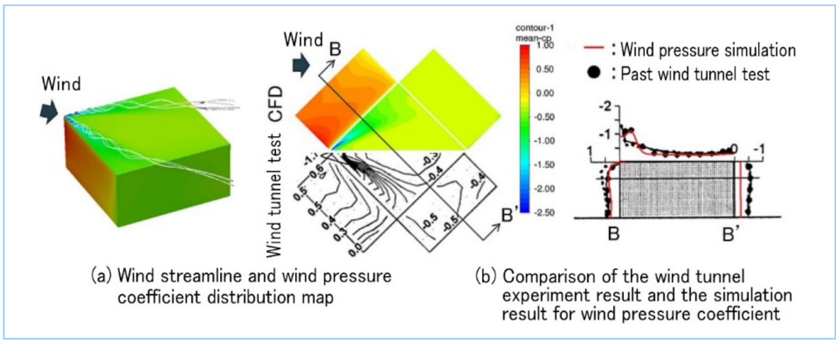

Figure 3 Validation result of wind pressure simulation[(5)]

3. Typhoon damage simulation examples

3.1 Buildings and typhoon damage to be assessed

In this chapter, with the model infrastructure shown in **Figure 4**, the risk analysis for typhoon damage, the planning of typhoon damage reduction devices and the design wind velocity map by wind direction are described. Since the sea is located in the southwest of the model infrastructure, there is a risk that typhoon damage may be caused by southwesterly wind. It was reported that in the target building group 1, the roofs were lifted off by the wind blowing down from the windward cylindrical roof and in the target building group 2, the wind passing through between the buildings increased wind velocity and damaged them.

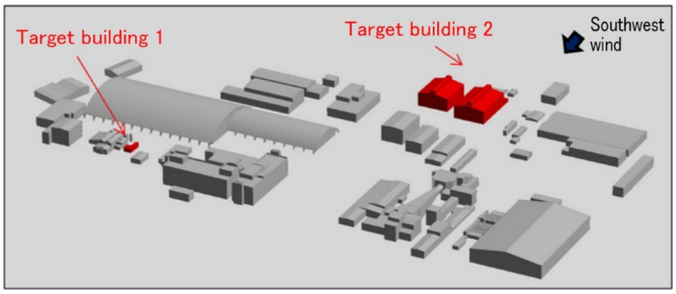

Figure 4 Arrangement plan of model infrastructure

3.2 Typhoon damage assessment examples

(1) Roof uplift damage

Figure 5 shows the result of a roof uplift damage simulation. As shown in the left figure, before taking countermeasures (in the existing conditions), the wind getting over and blowing down from the cylindrical roof of the building located on the windward side acts directly on the target building. In addition, since the target building is open at its southwest face, a positive pressure (pressing force) acts on the inside wall of the target building and a negative pressure (tensile force) acts on the roof surface, as shown in the right figure. As a result, it was revealed that the roof was subjected to an upward wind load about twice as large as the self-weight, which might cause the risk of roof uplift. It is conceivable that against this phenomenon, countermeasures can be taken such as closing of the southwest semi-open face and reinforcement of the connecting part of the roof and the structure. But around this building, other damage such as toppling of temporary constructions and breakage of exterior materials also occurred during the typhoon. Therefore, we considered countermeasures that could reduce typhoon damage over a wide area.

Figure 6 shows the simulation result after taking countermeasures. As shown in the left figure, when a countermeasure device (vertical panel) was set up on the cylindrical building top, the wind flow separated at the cylindrical building top and the wind was prevented from acting directly on the target building. As a result, the roof load was reduced by 84% compared to before taking countermeasures and we could confirm that it was effective as a roof uplift damage reduction device.

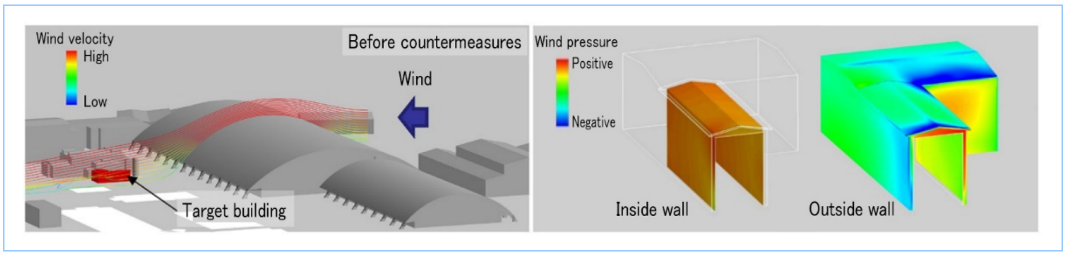

Figure 5 Roof uplift damage simulation (before countermeasures)

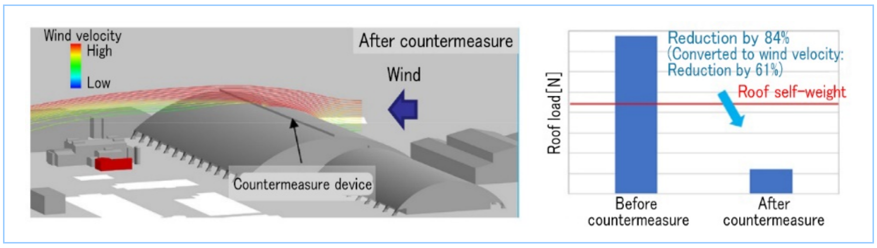

Figure 6 Roof uplift damage simulation (after countermeasures)

(2) Strong wind damage

Figure 7 shows the result of a strong wind damage simulation. Since the wind from the sea directly acts on the target buildings, a strong wind occurs in the area where the target buildings are located in the model infrastructure site. Furthermore, it is considered that the wind became stronger due to the increased velocity of the flow between the buildings.

Before countermeasure (in the existing conditions), the wind velocity between the buildings increases by about 15% compared to the upstream wind velocity. After a windbreak net with a solidity ratio of 50% was set up on the border of the site, the wind velocity became almost the same as the upstream wind velocity. It showed that such countermeasure could reduce the wind velocity by 16% compared to before the countermeasure.

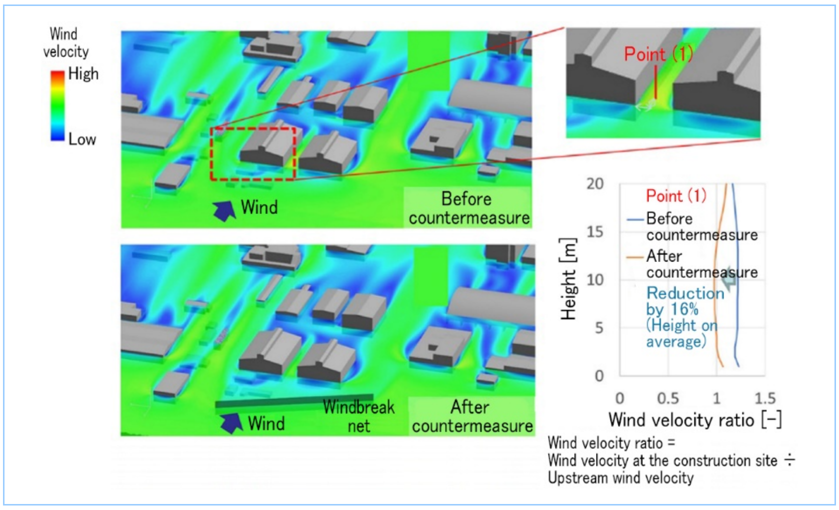

Figure 7 Strong wind damage simulation

3.3 Design wind velocity map

In a wind-resistance design, it is necessary to evaluate the integrity of the building by obtaining the design wind velocity for the typhoon that is experienced once on average within a certain recurrence interval. Therefore, in the typhoon simulation, the typhoon parameters were defined by the probability density function, virtual typhoons were formed over a long period (of about 1,000 years) based on random numbers and the design wind velocities were calculated. **Figure 8** shows the design wind velocity maps for different wind directions in a recurrence interval of 100 years. These maps showed that with the wind direction SE, the design wind velocity became low because the model infrastructure falls behind the mountain on its southeast side, while with the wind direction SW, the wind blew into the model infrastructure directly from the sea and the design wind velocity became high. By visualizing the design wind velocity for each wind direction like this, areas having a high risk of damage and target wind directions can be identified. Therefore, a repair plan, which was conventionally determined based on the years of use of the building or the like, can be prepared based on an appropriate assessment according to the risk.

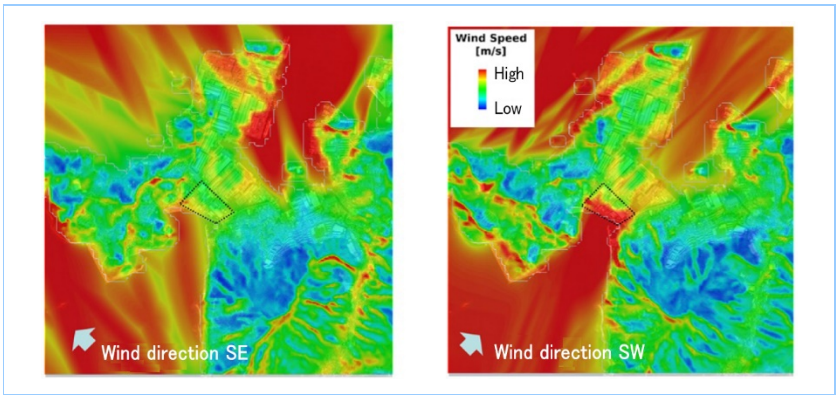

Figure 8 Design wind velocity map
* The dotted line shows the bordersite of the model infrastructure. Taken from aerial photographs on Google Map.

4. Conclusion

Using the typhoon damage simulation, we presented examples of risk analysis for roof uplift damage and strong wind damage, the development of damage reduction devices and the design wind velocity maps that visualize the typhoon damage risk.

It was confirmed that by combining three simulations for different assessment fields and reflecting in each simulation the information about the typhoon, the terrain around the infrastructure and the shapes and arrangement of adjacent buildings, which are influencing factors of typhoon damage, we could analyze typhoon risks precisely and develop effective devices for reducing typhoon damage.

Moving forward, we will make efforts to further improve resilience of infrastructure by predicting damage and planning evacuation scenarios before a typhoon strikes and developing technologies that can contribute to the prompt start of restoration work.

References

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