Inundation Analysis Simulation for Underground Spaces

Introduction

Given the clustering of the population, assets, and core functions in Japanese cities, land use—including underground spaces—is quite advanced.

Over the past several years, damage from inundation in underground shopping areas, along subway lines, and in other underground spaces has increased alongside the increase of flooding in cities prone to localized torrential rain. Flooding of underground spaces is highly likely to lead to severe and even life-threatening damage; accordingly, measures to combat underground flooding are important and urgent.

This technology makes it possible to simultaneously analyze inundation both above ground and in the complex web of underground spaces in major cities as well as the inflow, retention, movement (including movement through subway lines), and other properties of flood water from above ground in and through underground spaces.

Additionally, inundation analysis simulations envisioning various types of flooding (e.g. overflow from rivers; short, sudden, extremely localized downpours) make it possible to obtain useful information for examining appropriate flooding countermeasures and evacuation plans, considering business continuity plans (BCP), and more.

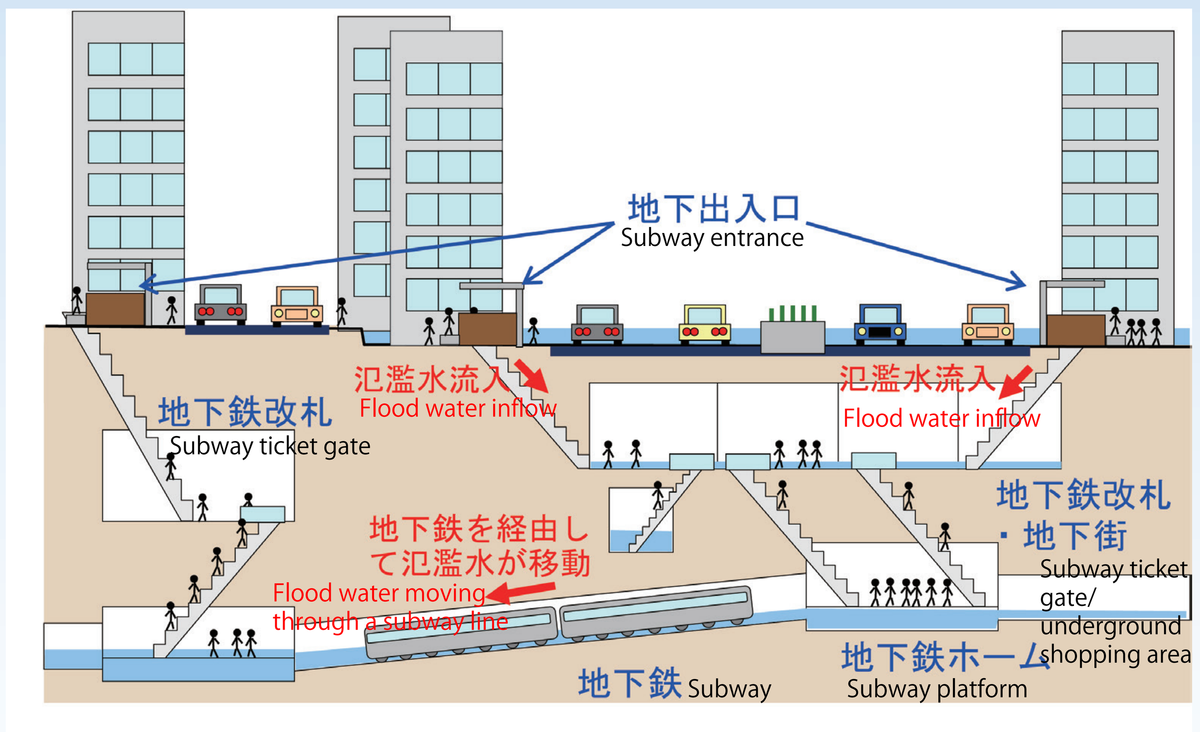

Image of flooding of underground spaces

Necessary background

In July 2015, the Flood Control Act was among legislation that was partially amended. The amendments made the following obligatory:

- Listing information such as means of conveying the names, locations, flood forecasting, and the like of underground shopping areas and other underground spaces prone to inundation in local disaster risk reduction plans in each area at risk of inundation under the maximum imaginable level of flooding, inland flooding, and storm surges.
- Creation of plans to ensure evacuation and prevent flooding by owners of underground shopping areas and other underground spaces

Tasks for ensuring safe, reliable evacuation and effective plans for preventing flooding

- Envision inundation in underground spaces under various forms of flooding (e.g. overflow from rivers, inland flooding,*1 storm surge/tsunami damage)
- Considerations for preventing the inundation of facilities in underground spaces (including proper water stop plates in consideration of evacuation, etc.)
- In addition to and separately from the above, it is necessary to consider business continuity plans (BCP)*2

*1Inundation resulting from the inability of sewer systems and other facilities to drain rainwater from short, sudden, extremely localized downpours or the like.
*2It is necessary to strategically examine business continuity (restorative measures that detail how to drain flood water and the like) in order to minimize risks associated with interruptions attributable to flooding

Inundation analysis simulations for underground spaces are an effective method of consideration

1. Project inundation under various types of flooding with good precision	• What is the area and depth of inundation under various types of flooding? • From which above-ground openings, underground shopping areas, and the like will flood water enter? • Where will water pool in underground shopping areas and other underground spaces? • How quickly will the area become inundated? When will the flood water arrive? • How long will the flooding continue?
2. Ascertain the effects of flood prevention measureres	• Consider effective placement of water stop plates • Delay the start of inundation/timing of total submersion of underground shopping areas and other underground spaces
3．Consider drainage from underground spaces	• Drainage methods, routes, times, and effects

Inundation Analysis Simulation for Underground Spaces

Inundation analysis model characteristics

Modeling subway lines and all the underground shopping areas and other underground spaces that connect to them is vital for developing an accurate understanding of inundation in underground spaces.
Additionally, simulations based on models that enable simultaneous analysis of inundation above ground and in underground spaces make it possible to develop an understanding of inundation in underground spaces from moment to moment, the effects of different flooding countermeasures, and more as well as to consider various scenarios of flooding.

【Above-ground model】
- Flooding analysis model based on flood hazard maps

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【Underground spaces model】
- Model for analyzing inundation in underground spaces (e.g. underground shopping areas, subway lines, basements, underground parking areas)

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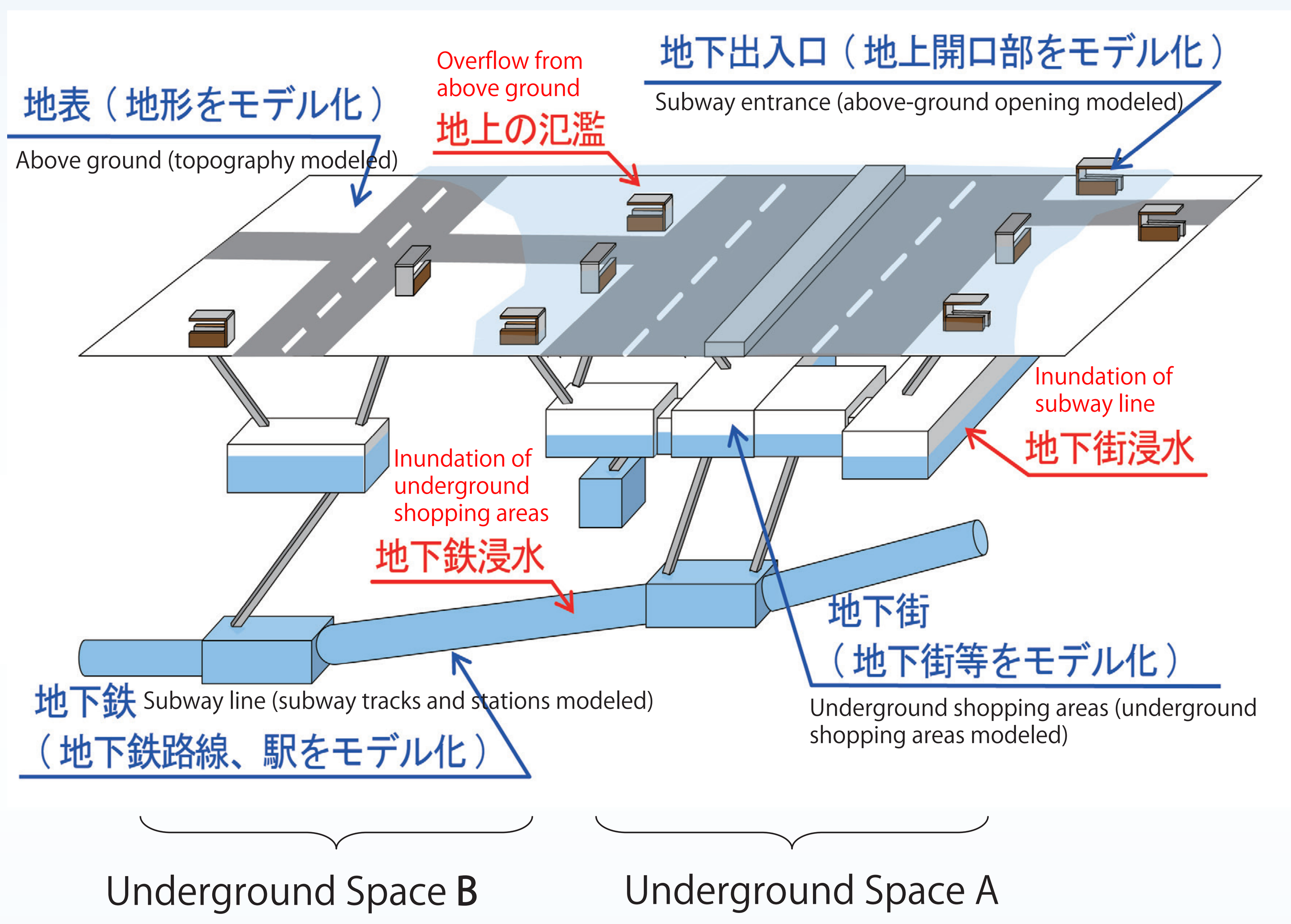
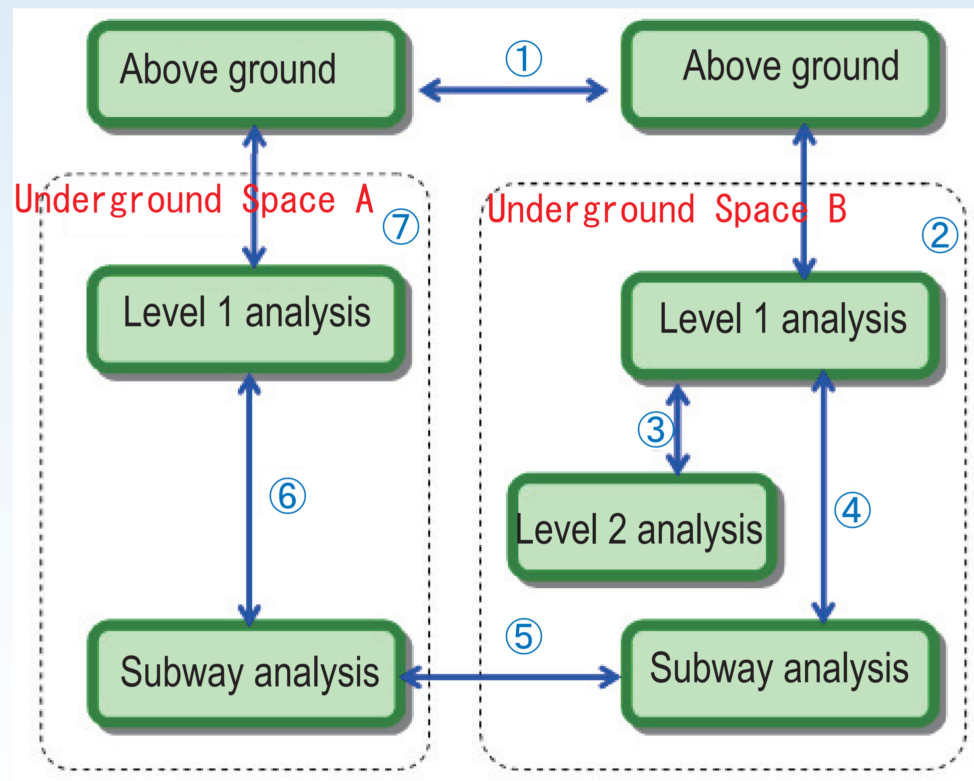
【Simultaneous analysis of above-ground and underground spaces】
- Makes it possible to develop an understanding of inundation in above-ground and underground spaces from moment to moment
- Makes it possible to envision inundation in various scenarios

Category	Method of analysis
Avobe ground	Use a planar, two-dimensional unsteady flow analysis model
Underground	Expressed as a relationship between H (water depth) and V (volume) with stores, corridors, and other components of underground shopping areas rendered as boxes
Subway	Use a Preissman slot, one-dimensional unsteady flow analysis model with the subway lines rendered as pipes



【Image of the analytical model】

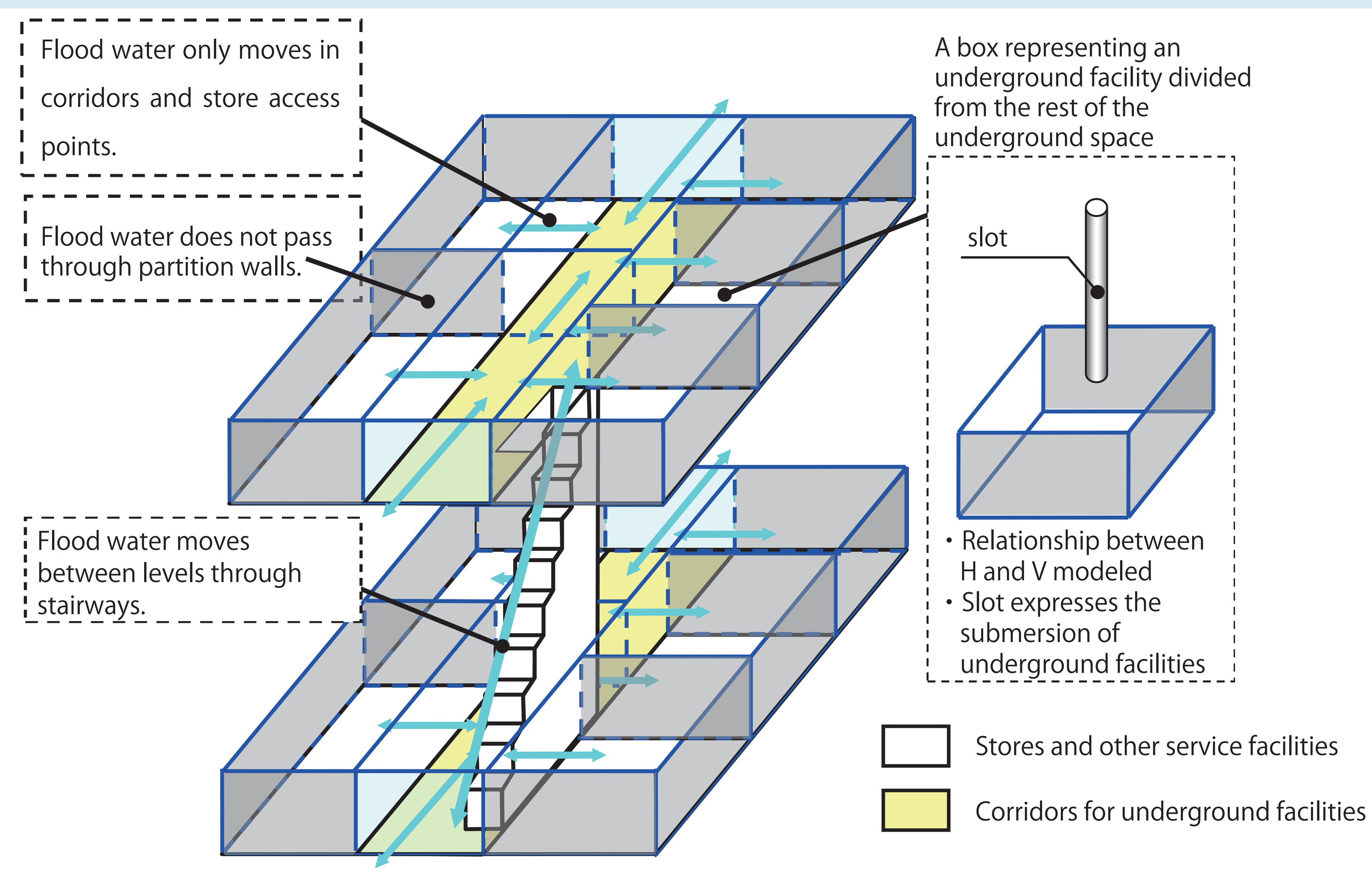


Item		Flow of analysis
Aobve ground	①	Movement of flood water above ground
Underground Space A	②	Inflow/outflow of flood water from above-ground entrances into the underground space
	③	InInflow/outflow of flood water from Level 1 to Level 2 of the underground space
	④	Inflow/outflow of flood water from Level 1 of the underground space to the subway
Subway tracks	⑤	Movement of flood water from Underground Space A to Underground Space B along subway tracks
Underground Space B	⑥	Inflow/outflow of flood water from Level 1 of the underground space to the subway
	⑦	Inflow/outflow of flood water from above-ground entrances into the underground space

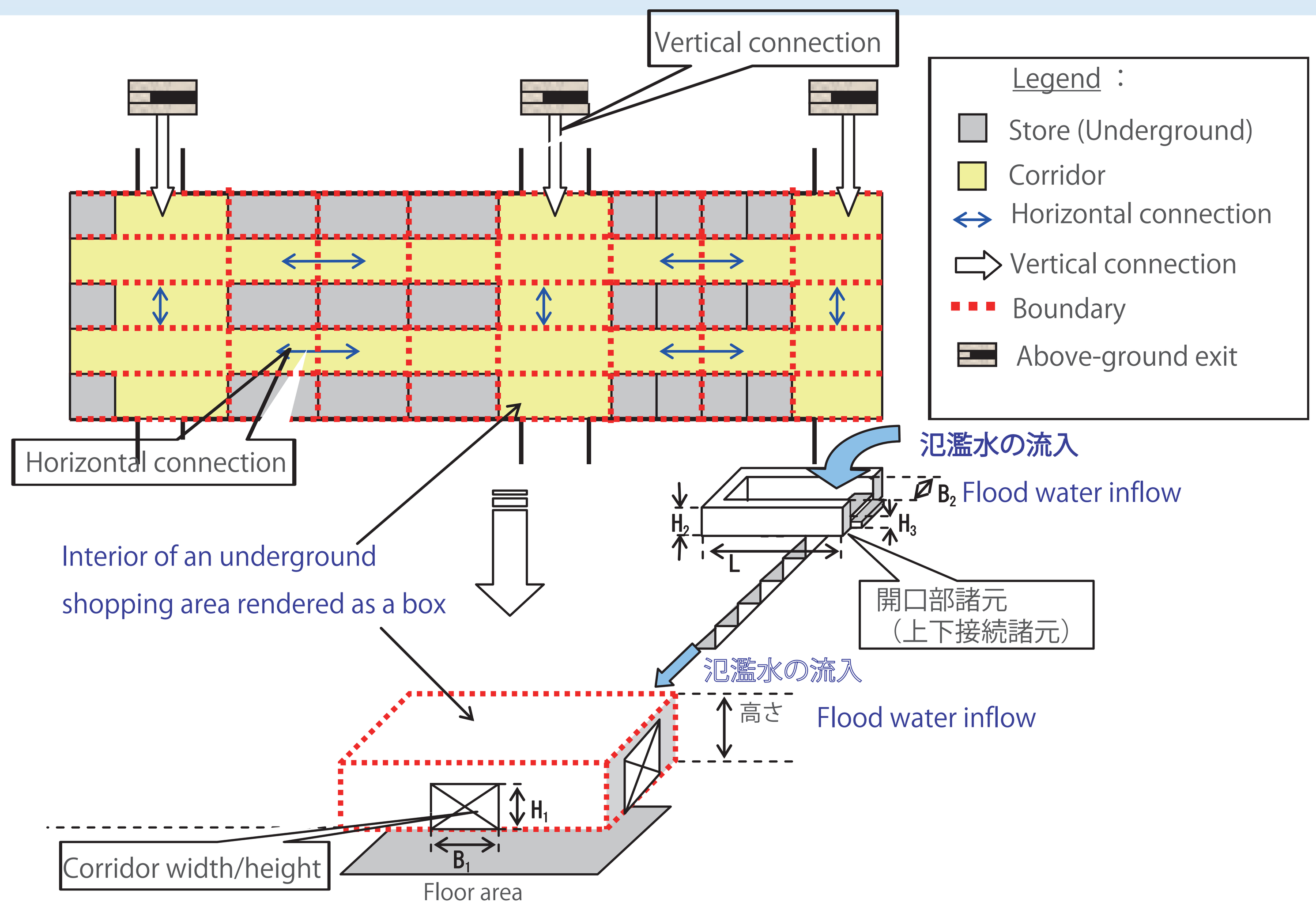
【Image of the flow of analysis】

Overview of the inundation analysis model (modeling an underground space containing underground shopping areas)

In order to properly express the flow of flood water in underground shopping areas and other underground spaces, the interiors of the areas and spaces are divided, rendered as boxes, and then modeled. The surfaces of walls and other structural components of stores are considered to simulate the flow of flood water corresponding to the actual shapes of the spaces. Additionally, slots are established between (upper and lower) levels to simulate the flow of flood water corresponding to the different water levels on each level of the underground shopping areas (outflow from the lower level to the upper level and from underground to above-ground spaces are also expressed).



【Image of multilayered structure of an underground space】

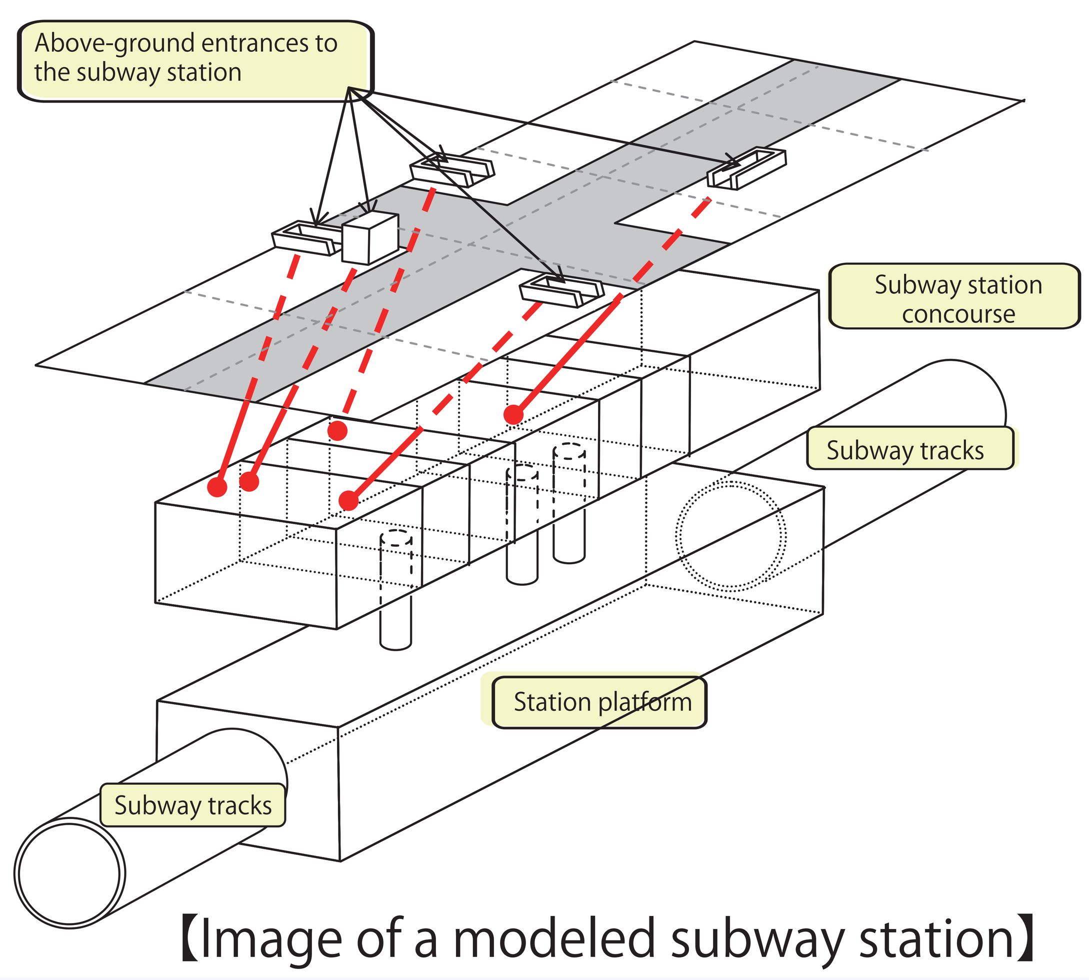


【Image of inlets from above ground and connections between underground spaces】

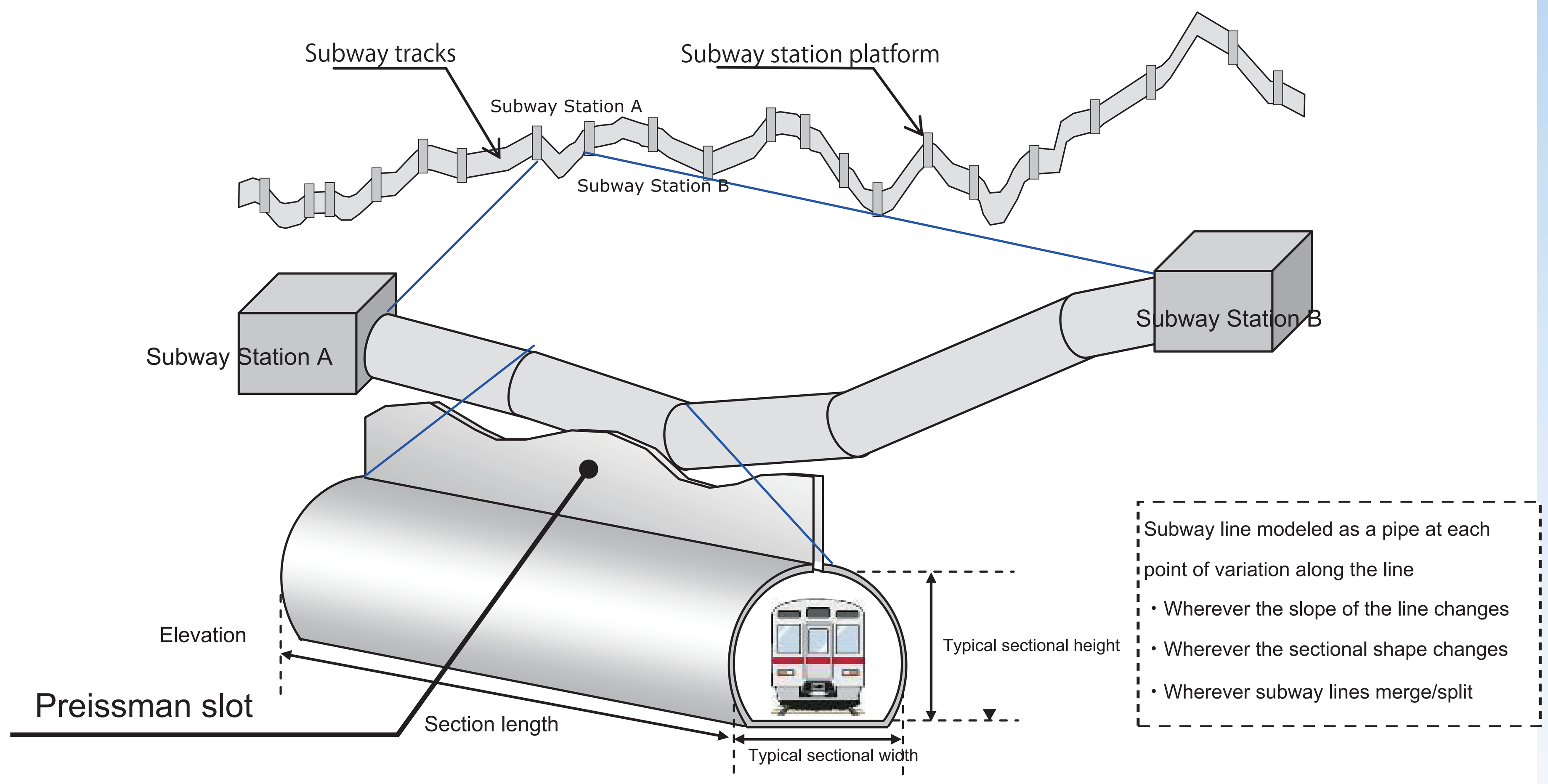
Inundation Analysis Simulation for Underground Spaces

Overview of the inundation analysis model (modeling a subway line)

Subway stations are modeled based on the same approach as for underground shopping areas. The subway line is rendered as a tube and then modeled. The level of flood water in subway lines determines how it flows; when tunnels are full, the water flows under pressure, and when tunnels are not full, the water flows as it would in an open channel. Other phenomena can also occur—for example, flood water can become backed up in subway tunnels and flow into underground shopping areas. Preissman slot, one-dimensional unsteady flow analysis is conducted to properly simulate these phenomena.



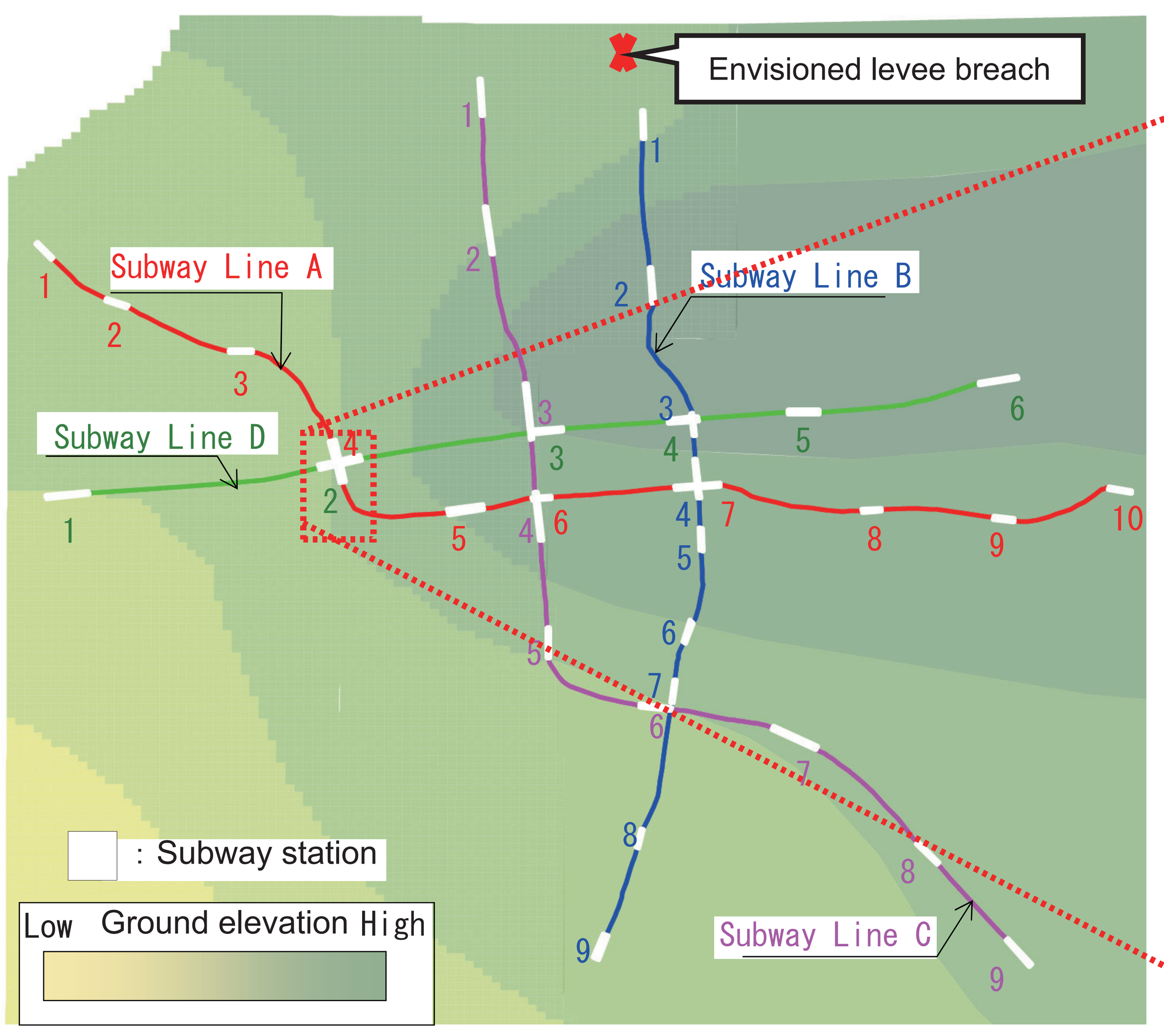
【Image of a modeled subway station】



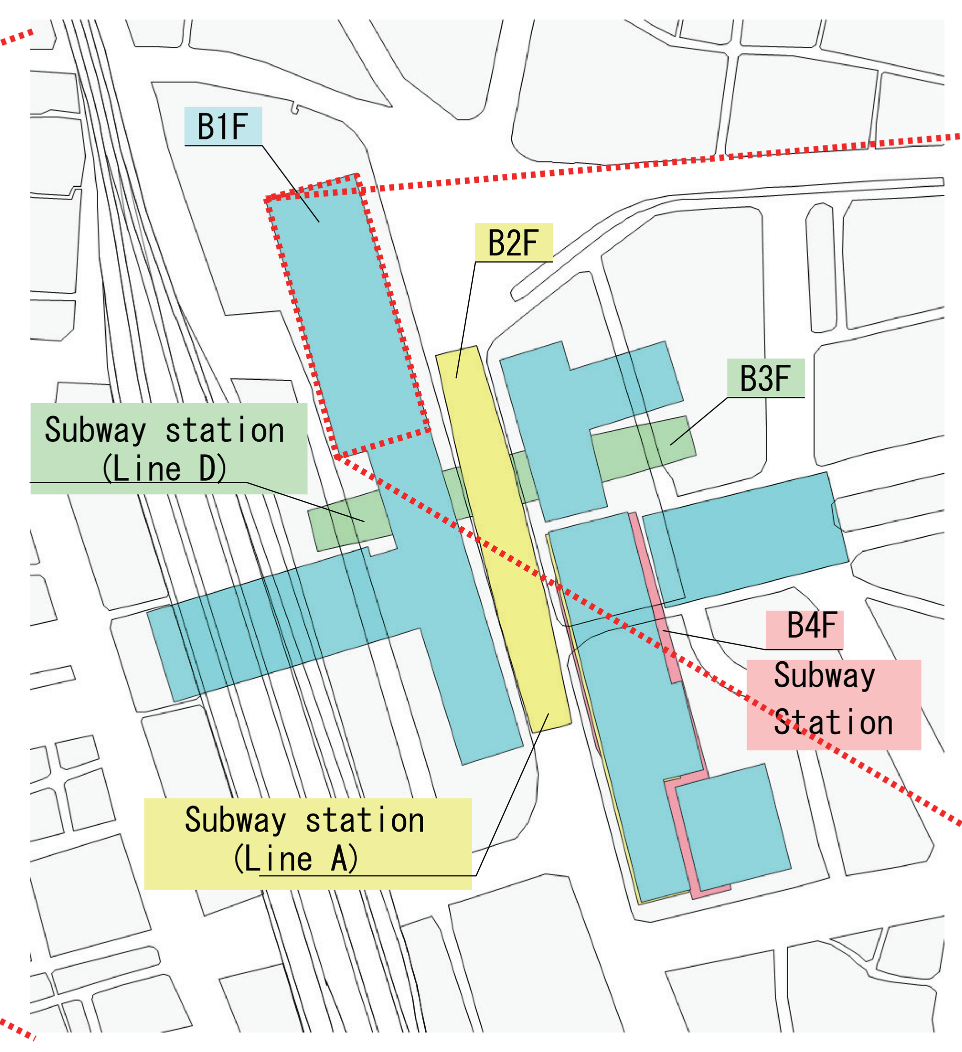
【Image of a modeled subway line】

Example inundation analysis simulation for underground spaces

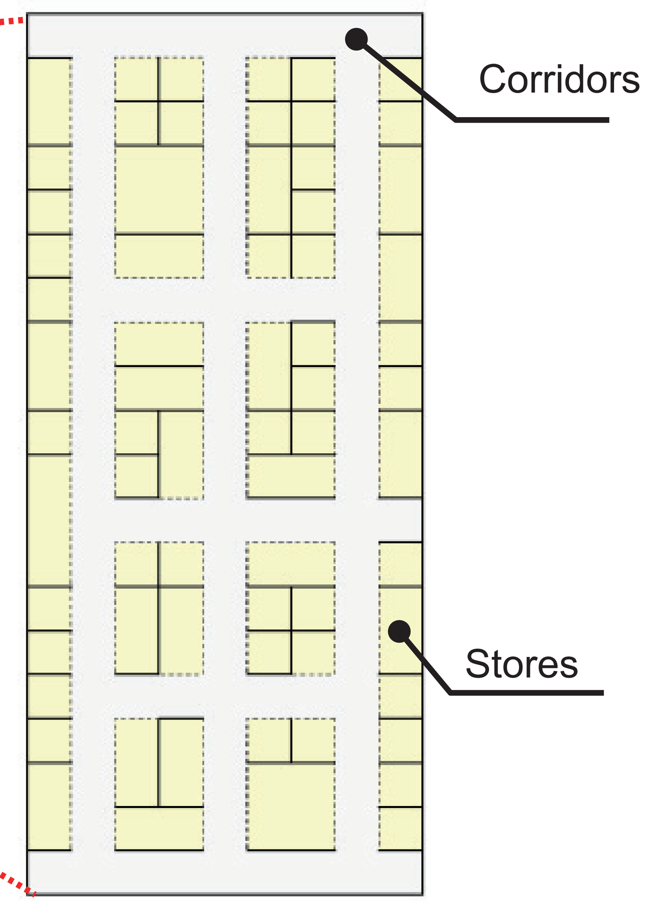
The following is an example of an inundation analysis simulation for underground spaces conducted for virtual models of above-ground and underground spaces (underground shopping areas, subway lines).



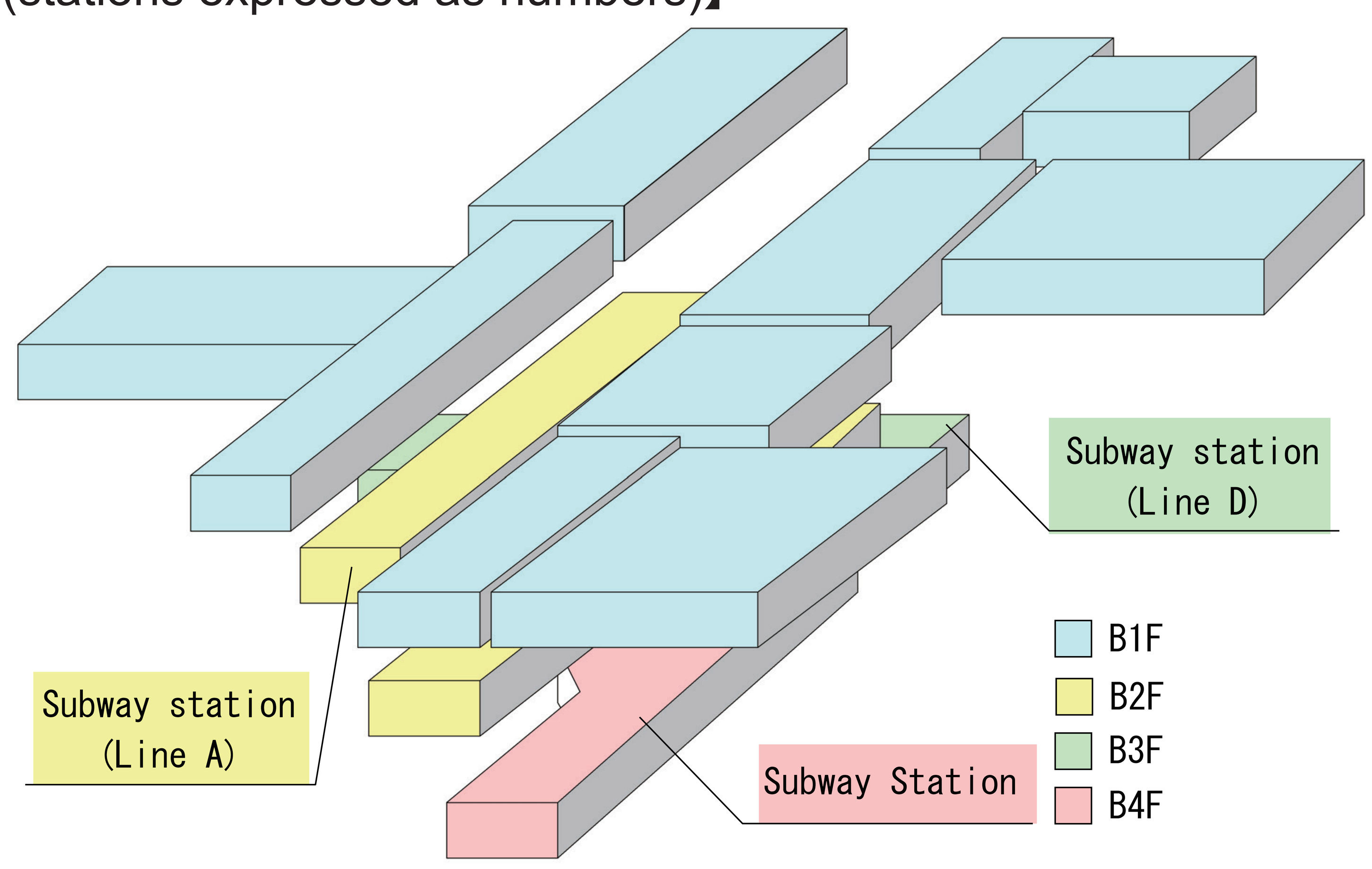
【State of above-ground topography and subway lines (stations expressed as numbers)】



【Planar layout of underground shopping area】

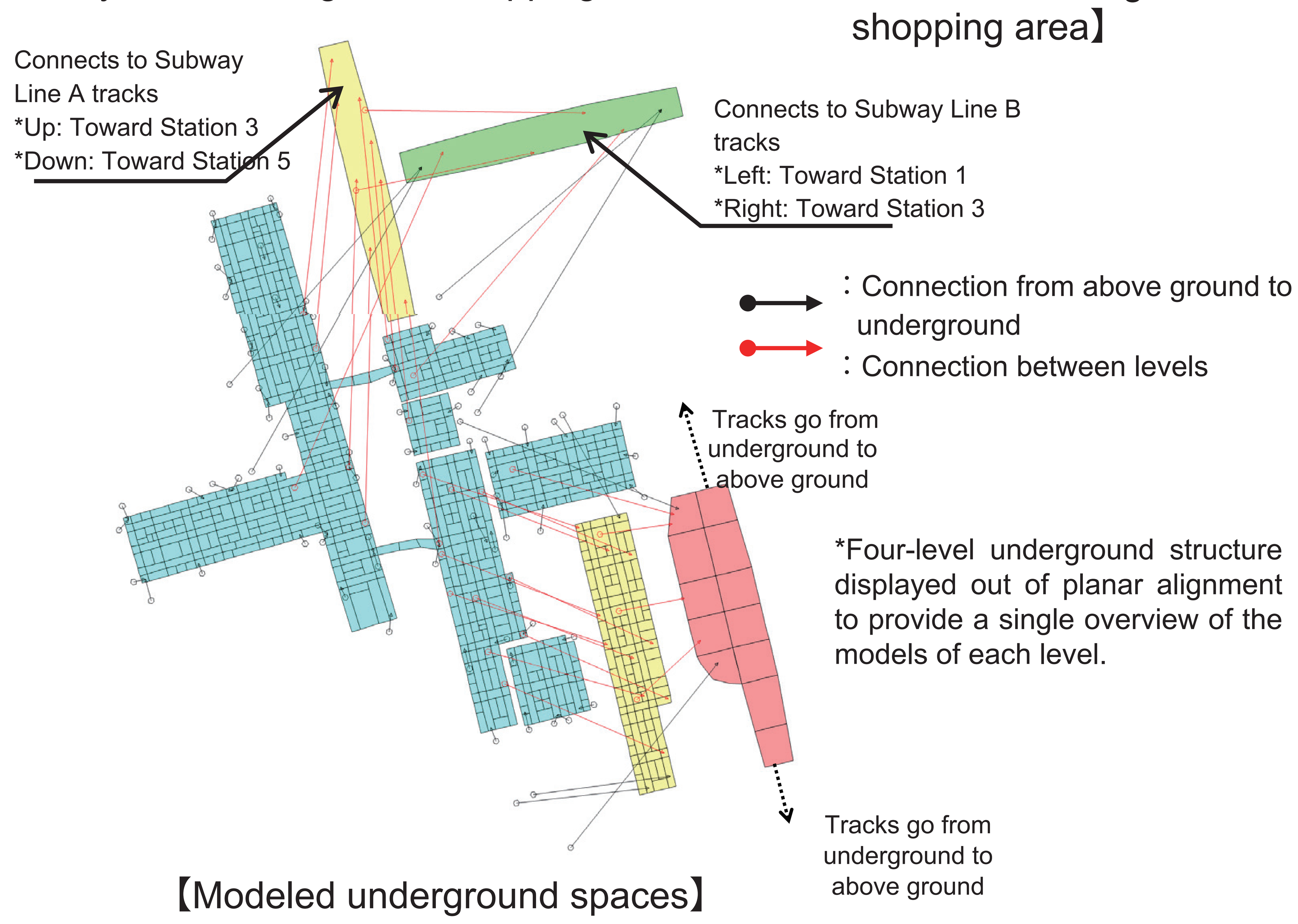


【Interior of underground shopping area】



*Assuming a four-level underground space comprising underground shopping areas and subway and railway lines (the railway tracks travel underground from above ground)

【State of multilayered structure of an underground space】



【Modeled underground spaces】

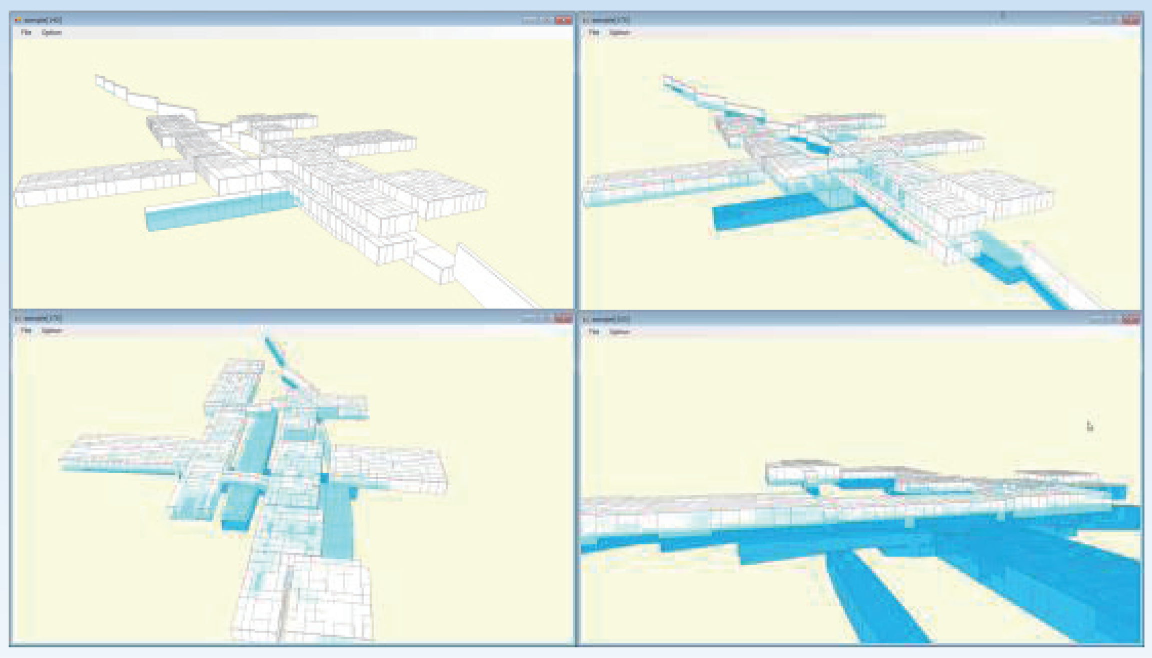
Inundation Analysis Simulation for Underground Spaces

Visualizing inundation in underground spaces

Inundation spreads differently in underground spaces than flood water above ground, and spreads differently depending on the complex shapes, usage patterns (e.g. underground shopping areas, underground parking areas, subway lines), and individual levels of underground spaces. Creative steps must be taken to visualize inundation from the results of inundation analysis simulations so that the results can be displayed straightforwardly and used when considering evacuation and flood prevention plans, restoration plans, and more.

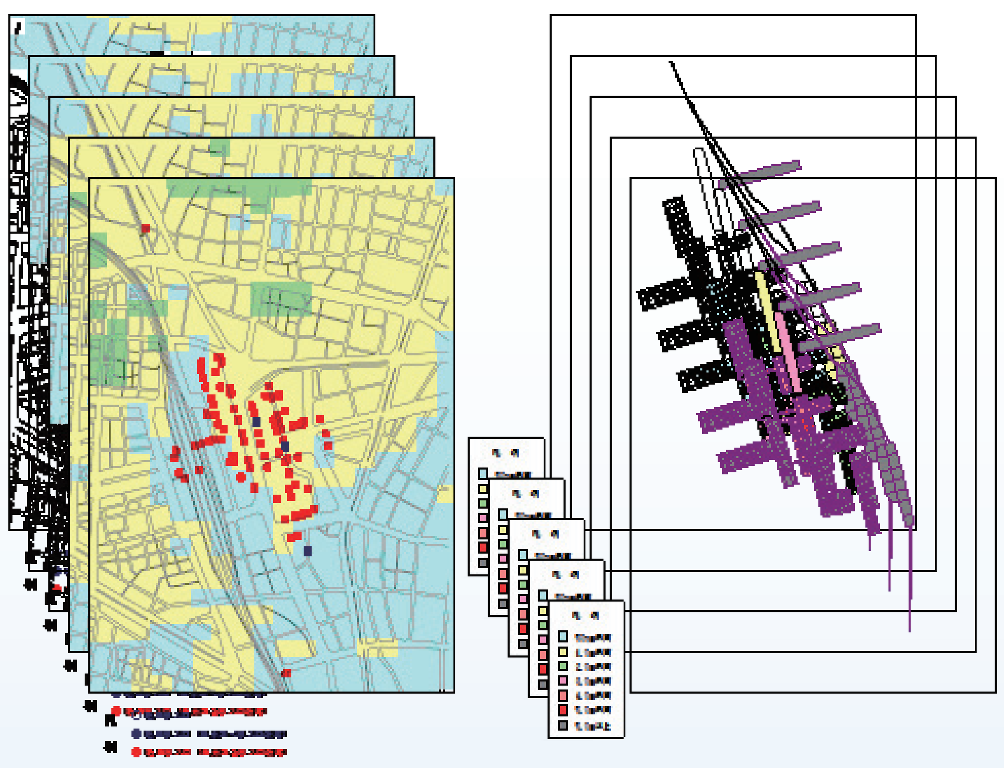
Three-dimensional displays

Rendering underground spaces in 3D and allowing users to change viewpoints, expand images, and watch animations makes it possible to develop a visual understanding of the multilayered structures of underground spaces, and their state of inundation.



Two-dimensional animations

Animations make it possible to develop a visual understanding of how flood water moves and the process by which inundation occurs.



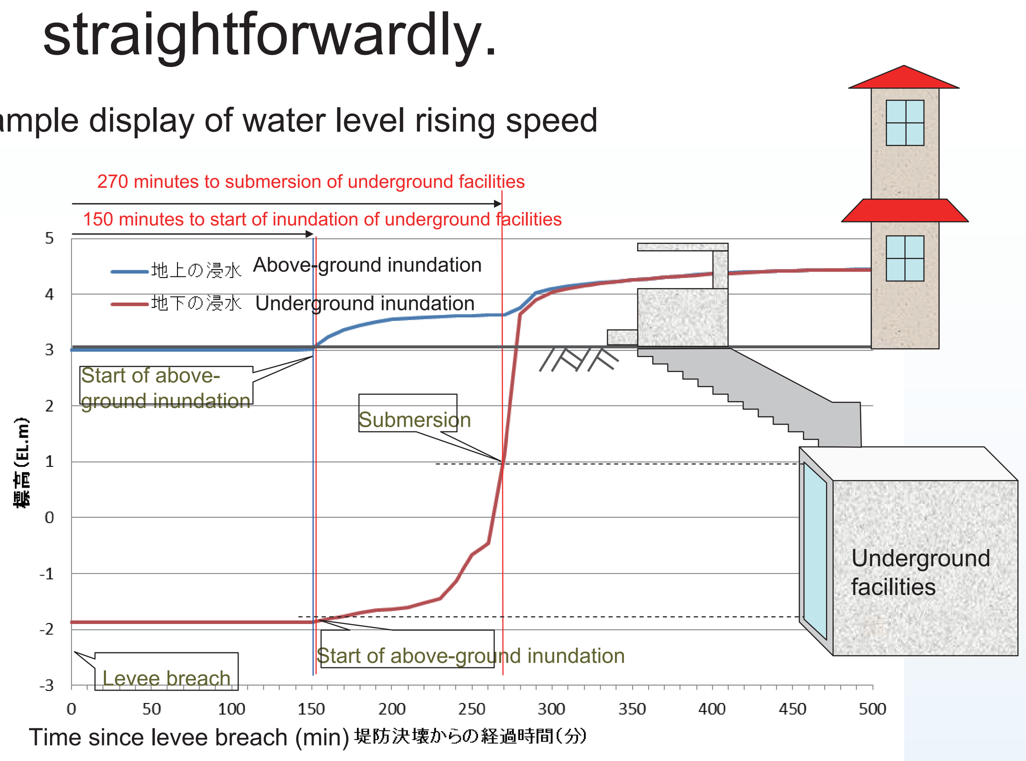
Displaying inundation in individual facilities

The state of inundation in individual facilities is displayed separately. (2D, 3D)

Displaying detailed inundation information in underground spaces

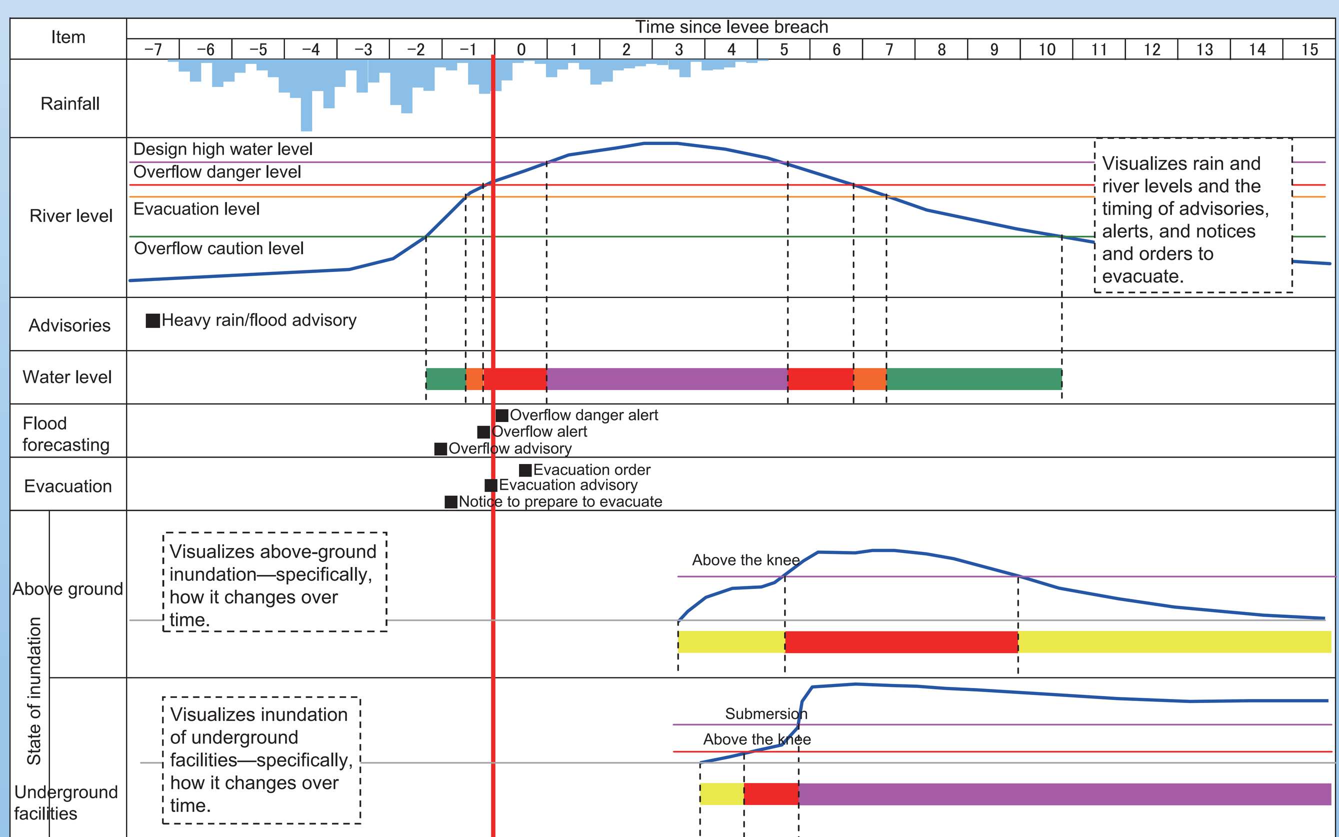
Information about inundation in underground spaces (e.g. water level rising speeds, flow speeds) needed for evacuation plans is displayed straightforwardly.

Example display of water level rising speed

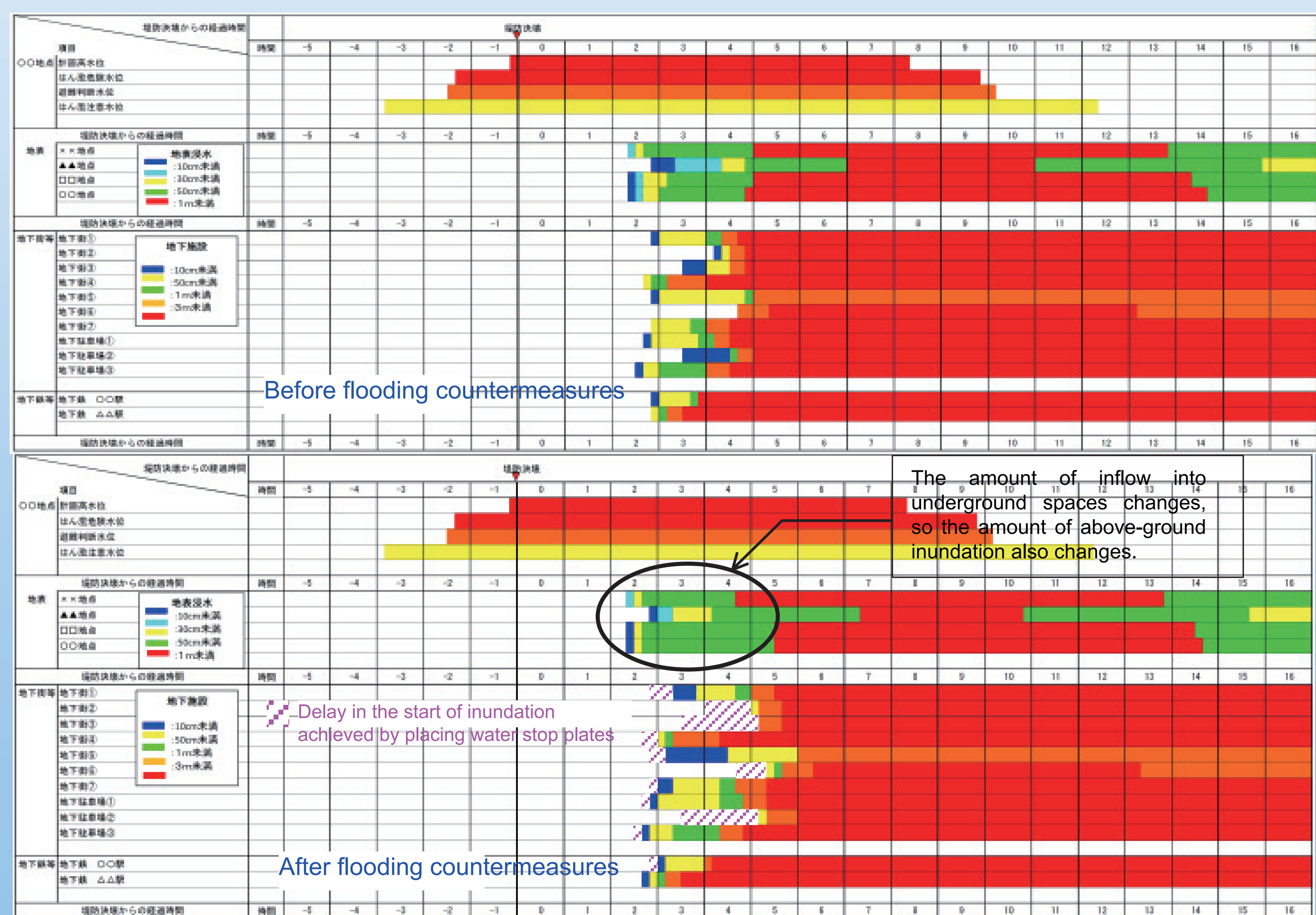


Organizing inundation information in time charts

It is crucial to develop an understanding of overall inundation in underground spaces, including facilities to which they are connected (e.g. other underground shopping areas, other subway lines). Accordingly, organizing inundation start times, inundation periods, and other data for each underground space and level in time charts makes it possible to provide overviews. The information can also be used in efforts such as timeline considerations.



Time charts can be used to straightforwardly display the effects of water stop plates and other flooding countermeasures (i.e. the effect of delaying the start of inundation), time required for restoration via drainage, and the like.



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Application in simulations of evacuation plans during inundation of underground spaces

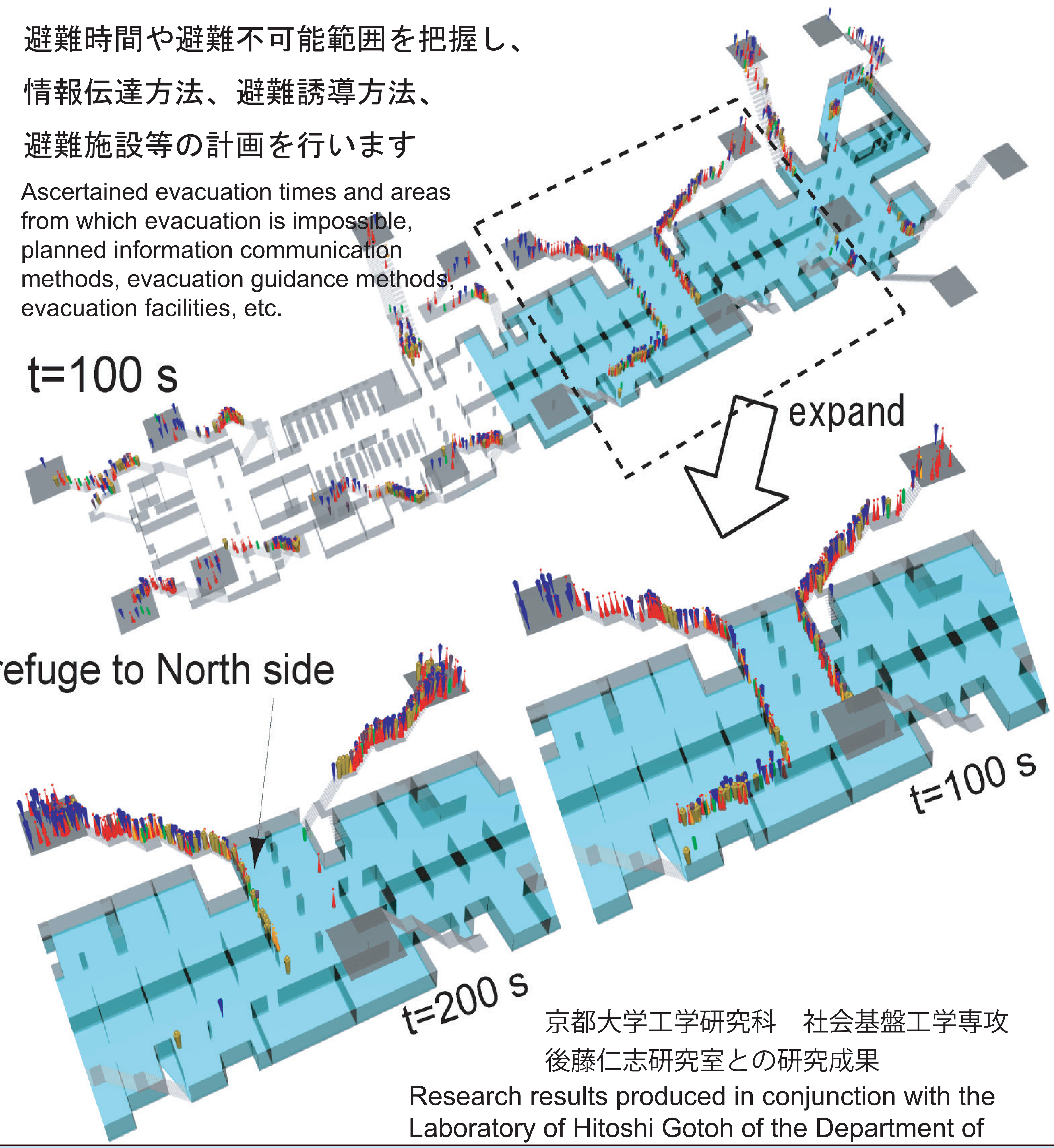
Swift, smooth evacuation is the key to saving lives when underground spaces are inundated. Therefore, it is extremely important to ensure proper evacuation routes and stairways as well as evacuation areas. Unfortunately, evacuation drills and other efforts taken during normal times rarely replicate the crowding and other conditions under which people must evacuate during disasters, and there are no decisive means of verifying the suitability of evacuation routes and stairways or evacuation areas.

Social experiments are one way to verify the suitability of efforts to respond to tunnel fires, tsunami, flooding, traffic accidents, and other disasters, but they are not easy to implement due to limitations of budget, labor, location, and time. To address this problem, we worked with the Laboratory of Hitoshi Gotoh of Kyoto University to develop a virtual social experiment based on a crowd behavior simulator, and used the results of inundation analysis simulations for underground spaces to provide helpful information for considerations for ensuring safe, reliable evacuation and effective plans for preventing flooding.

【 Simulation results 】

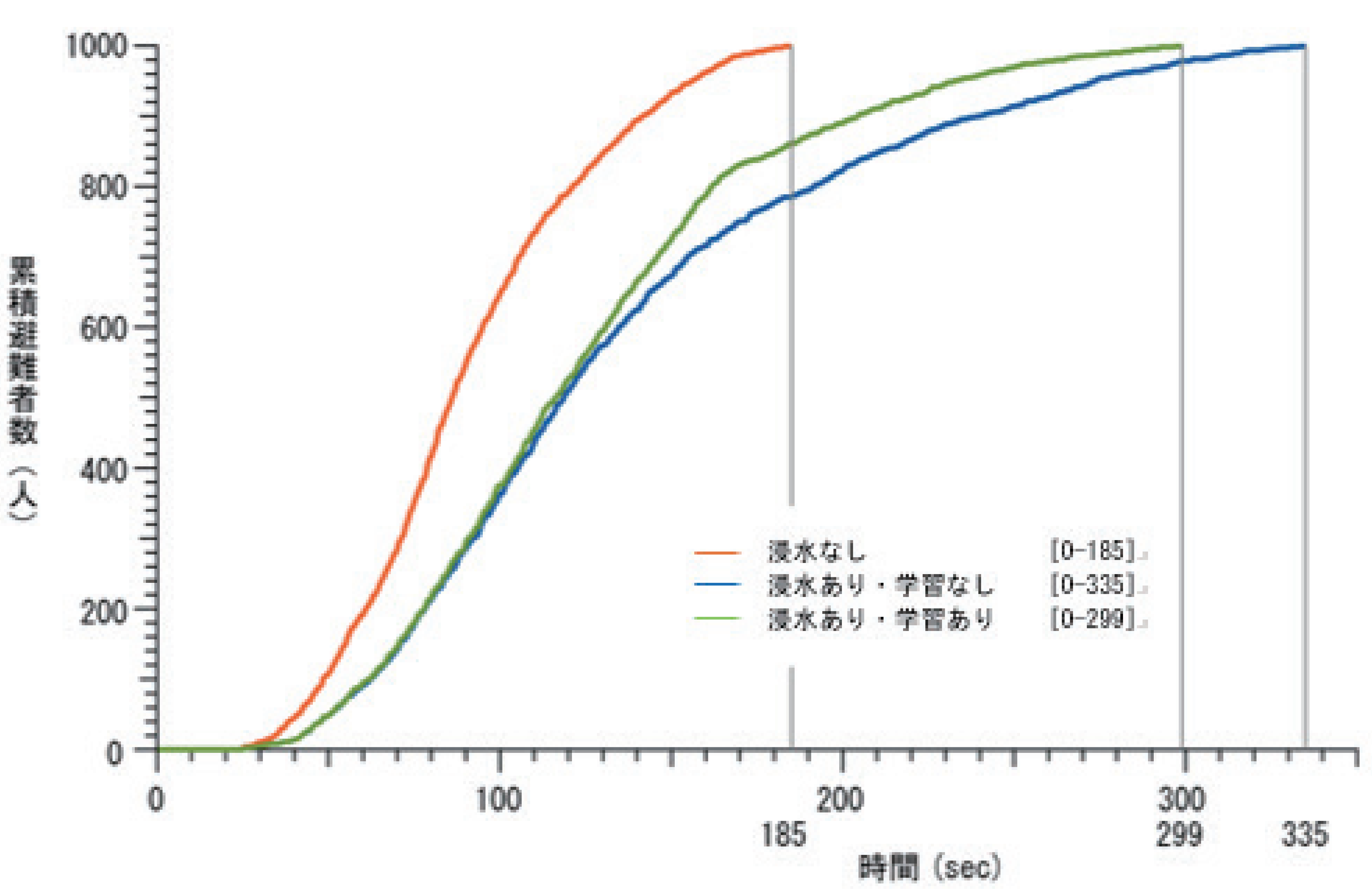
避難時間や避難不可能範囲を把握し、
情報伝達方法、避難誘導方法、
避難施設等の計画を行います

Ascertained evacuation times and areas from which evacuation is impossible, planned information communication methods, evacuation guidance methods, evacuation facilities, etc.



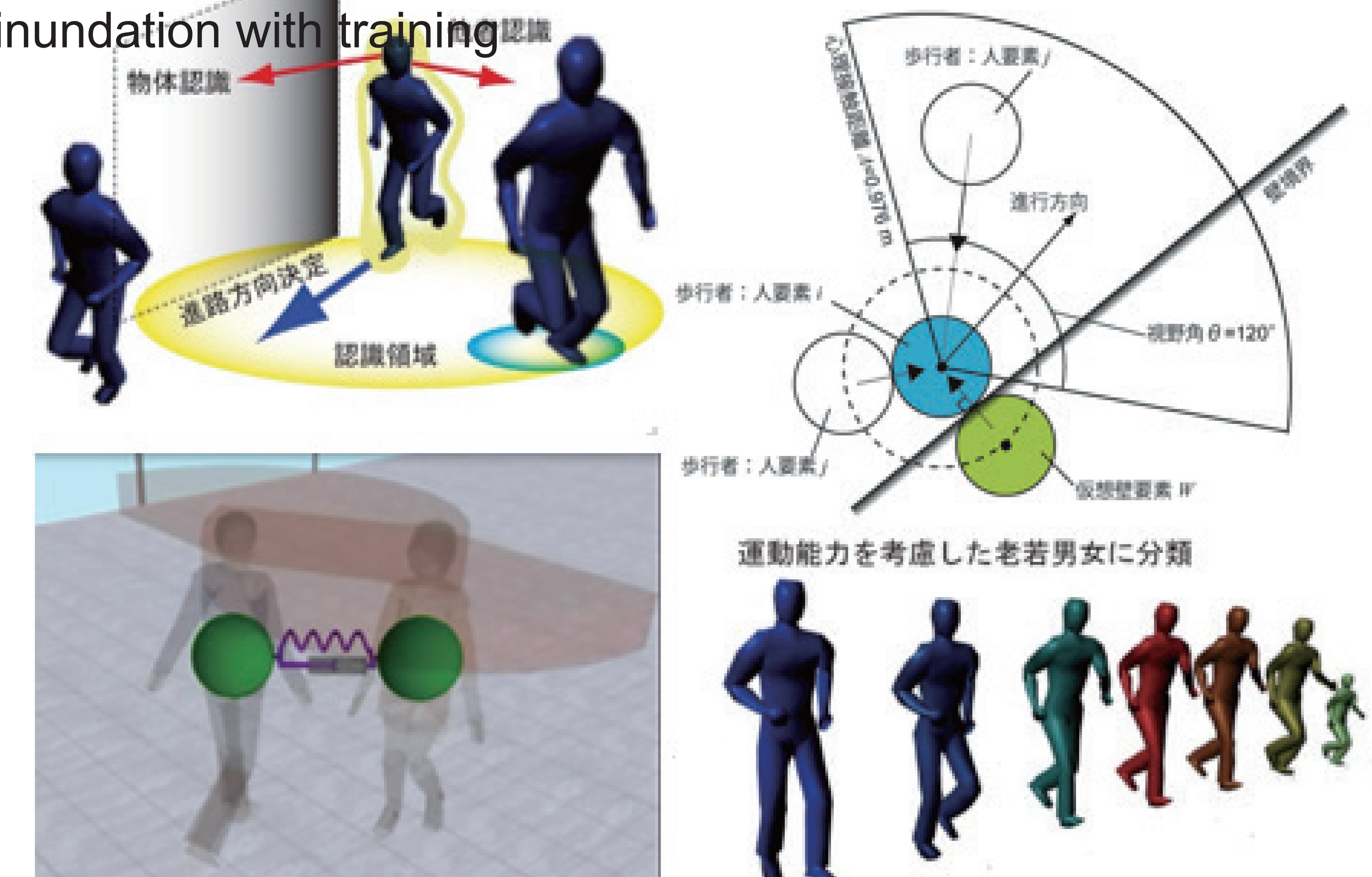
京都大学工学研究科 社会基盤工学専攻
後藤仁志研究室との研究成果

Research results produced in conjunction with the Laboratory of Hitoshi Gotoh of the Department of Civil and Earth Resources Engineering of the Kyoto University Graduate School of Engineering



［浸水なし］［浸水あり・学習なし］［浸水あり・学習あり］の避難完了時間の比較

Compared results after completion of evacuation in three scenarios: no inundation, inundation with no training, and inundation with training

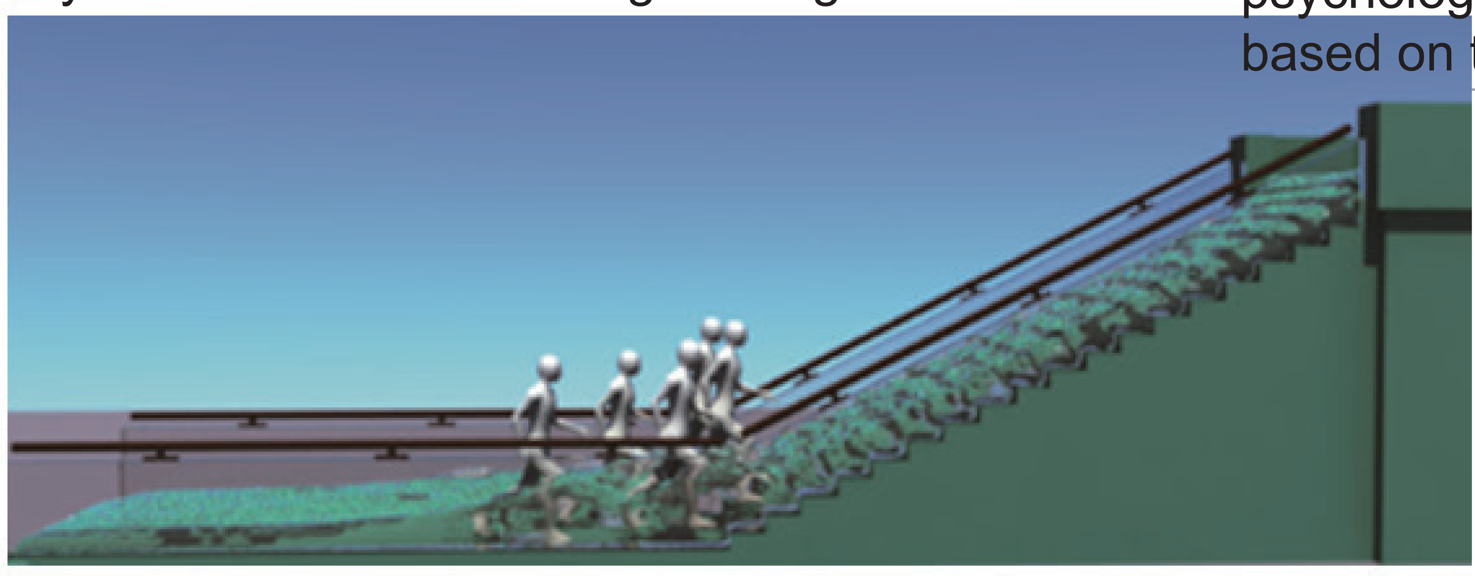


個別要素法（DEM 法）による避難者の物理的・心理的接触や身体特性を考慮した群集行動モデル

Crowd behavior model that accounts for the physical and psychological contact and physical attributes of evacuees based on the distinct element method (DEM)

水中歩行実験による歩行運動の観測・モデル化

Observation/modeling of pedestrian behavior from an experiment in which people walked through water



個別要素法（DEM 法）と粒子法（高精度 MPS 法）による避難者の群集行動と流体運動の相互作用を考慮したカップリングモデルの構築

Construction of a coupled model that accounts for the interaction of fluid dynamics and crowd behavior of evacuees based on the distinct element method (DEM) and particle method (high-precision MPS method)

福岡豪雨災害　1999.6　出典：国土交通省 HP

Fukuoka Heavy Rainfall Disaster, June 1999
Source: MLIT website