An Integrated Floating Community Based upon a Hybrid Water System: Toward a Super-Sustainable Water City

Toshio Nakajima and Motohiko Umeyama

Abstract Over the next century or two, rising sea levels and the increased frequency of extensive natural disasters caused by global climate change will bring about serious problems. Such problems are especially foreseen in lower-lying coastal and riverside areas, located below sea level. The steel barge-type floating foundations were chosen for our research because of their outstanding performance in the Mega-float Project which had been conducted by the Mega-float Technological Research Association of Japan during the 1990s. A 1000 m-long floating structure was constructed under this project for siting an airport complex thereon, with many parts of the smaller floating modular units being welded together at sea using a newly-developed method. Now, our concept is of realizing a new waterfront—developed by excavating the soil in a low-lying ground to create an overall area few meters below the surface level, then flooded to produce an artificial reservoir. The foundations for an urban community are subsequently set afloat upon the artificial reservoir, with buildings and other facilities being constructed on these floating foundations, in a manner similar to the Mega-float Project idea. On the other hand, the construction of substantial sustainable cities not only capable of withstanding global environmental disasters but also simultaneously producing minimum burden on the environment is needed. And to realize a truly sustainable city, we should be mindful of the fact that a multi-water supply system will become more efficient, economical and safe for cities compared with the present status dependent upon a single water supply system. Our paper "a new concept for the safety of low-lying land areas from natural disasters" was therefore selected as one of the 100 top papers from among all papers published by springer-nature in 2015 as a ground-breaking paper that could help humanity while protecting and preserving our planet, under the theme of change the world, one article at a time.

Keywords Sea level rise · Multi-water supply · Natural hazard · Flooding · Lower-lying area · Floating structure

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1 Introduction

1.1 Natural Hazards Due to Global Warming

Numerous investigations confirm that the indirect effects may be more significant than the direct effects from global warming during the 21st Century: rising sea level inundating low-lying land areas and eroding beaches while increasing the salinity of rivers/estuaries [1, 2]. In order to establish a sustainable society, many countries have initiated strategies and regulations to reduce greenhouse gas emission in recent years. However, it seems almost impossible to halt the rising sea level brought about by global warming and the subsequent speed of land disappearing under the sea. Even if the global environment improves in the future as a result of regulations against greenhouse gas and other activities, it does not necessarily follow that there will be a reduction in the frequency of worldwide disasters. In fact, it appears that this phenomenon will accelerate further. Moreover, there are many who believe storm surges, abnormally high waves and localized heavy rain caused by powerful storms that continue to intensify in strength under the influence of global warming, will strike many cities throughout the world and bring about devastating flood damages.

However, many big cities such as Tokyo, New Orleans and so on are built on large areas of low ground below sea level known as “zero-meter sites at or below sea level”; these sites are potentially hazardous in that they carry a high risk of natural disasters due to their proximity to seas and/or rivers. Yet recently, because of global warming, lower-lying land areas in cities in particular have seen flooded streets many times as well. Precipitation amounts surpassing expected levels, as exemplified by sudden torrential showers, are pushing records beyond levels that can be handled by today’s sewerage system. Therefore, adaptation measures against these serious natural hazards are urgently required hereafter to preserve existing cities.

1.2 Water Shortage Problems

The water shortage issue has now become serious due to increasing population growth all over the world. This issue is especially crucial in big cities since people gather in such locations and an extraordinary amount of water is required for life in these heavily populated areas. Water conservation in cities is necessary not only for daily life but also during disaster situations. Currently, recognition is being renewed as to the fact that increased demand for water is leading to shortages in drinking water supply as part of emergency water supply, this being vital for firefighting; such situations are underscored by the lessons of the great 1995 earthquake in Kobe. If a modern water supply system were to collapse, people in cities will suffer from water shortage as a result. Under emergency conditions, experiences from the 1995 Kobe earthquake also shows that not only will drinking water becomes a necessity

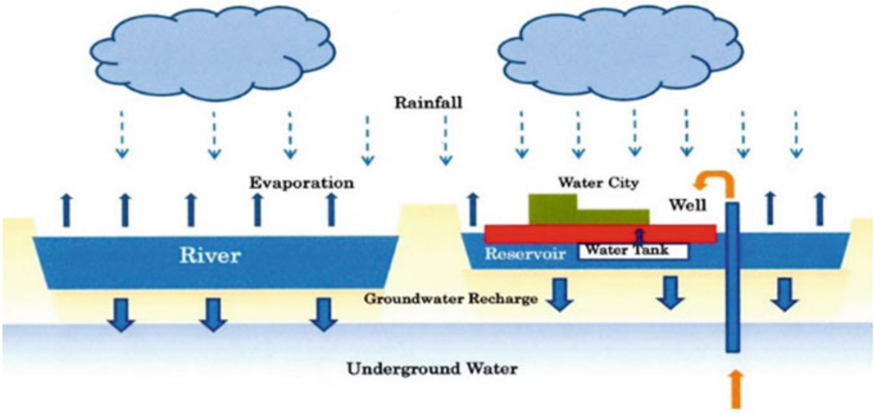

Fig. 1 Conceptual water circulation system in water city

for suffering people but water for other various uses will also become important for life such as for bathing, washing dishes and so forth.

Other serious problems recently are that the modern water supply system has aged and may require replacement, their construction on the average having taken place over half a century ago. Tremendous maintenance costs including repair costs, old piping refurbishments and water leakage detection in old pipes are required today with additional taxes becoming necessary due to increases thereof. This means that the centralized water supply system of modernity has become inefficient over the years to render it unsustainable, so we cannot rely on this water supply system any more. Conventionally, contemporary cities are supported by only this unitary water supply system comprising dams and/or reservoirs at long distance from cities and tremendous numbers of long water pipes carrying freshwater to cities. From the standpoint of cost performance, keeping water near and/or inside cities is much more reasonable; it is a low cost system for maintenance of water supply compared with the existing modern water supply system which already has many difficulties and problems upon sustaining it today, as transport of water is entailed. So we suggest holding large amounts of rainwater in the middle of cities as one of the water supply systems for use by cities while creating numerous reservoirs near urban areas as well (see Fig. 1).

1.3 Problems with Existing Old Civil Structures

Many big cities are built on large areas of low ground below sea level, areas that carry a high risk of natural disasters due to their hazard-prone locations close to seas and/or rivers. So far costly huge levees have been built to avoid water-related disasters such as tsunami and storm surge in cities. However, the levees are not sufficient in saving people from water-related natural hazards. Actually, powerful breakwaters constructed near the shores of northeastern Japan, believed then to be most reliable in the world, had been completely destroyed by huge tsunami in March 11, 2011 and resulted in a huge number of victims. When torrential rainfalls occur inside a city, the highest levees cannot save people from this kind of flooding. Furthermore, the tremendous loss not only in economic matters for cities but also in numbers of casualties once these huge civil structures collapse will be sizable.

To free people who live on lower-lying lands, considered prone to floodwater dangers, from the fear of natural hazards and to turn these areas into safer and comfortable places, we must apply lateral thinking. The weakness inherent in such locations can be converted to strength, offering protection against water disasters by rethinking the way people live in such areas, i.e. by constructing buildings on floating foundations in calm man-made reservoirs rather than on land near rivers and/or seas. Our idea emanates from the International Symposium on Sustainable Urban Environment 2007 (ISSUE2007) [3] which was held, with support from the Tokyo Metropolitan government and the Ministry of the Environment of Japan, at Tokyo Metropolitan University, under the theme of producing a sustainable urban environment. In order to offer a concrete image of our suggestions, we were then provided by our sponsoring organization, the Tokyo Metropolitan University Center for Academia/Industry/Public Collaboration, with funding for FY 2008 and continued to work on more detailed studies on this subject during FY 2009 and 2010.

2 Novel Floater-Based Solution Against Natural Hazards

2.1 Considerations and Objectives

Floating platform technology has become established in the ocean engineering field, thereby is now safe, trustworthy and reliable. In the 1980s, many offshore structures including floating platforms had been built for drilling offshore oil and oil production. During this era, the technology for floating structures was established and advanced drastically in such fields as ocean engineering or naval architecture. We should seriously consider an application of very large floating structure (VLFS) such as the Mega-float on land as a contribution for civil purposes to realize a new proposed countermeasure for extraordinary natural hazards. Between 1995 and 2000, the Mega-float Project was conducted by the Mega-float Technological Research Association established around a core of Japan's shipbuilding industry. In this project, a gigantic floating structure (VLFS) 1,000 m in length was constructed and floated in Tokyo Bay (see Fig. 2). We have since then proposed a novel concept for establishing an urban community exhibiting self-reliance during times of disasters, based on buildings atop the floating foundation situated in lower-lying lands.

We thus decided that, for water-related hazards as exemplified by floods, the answer lies not in dealing head-on with these problems using massive structures like

Fig. 2 Photograph of "Mega-float"

dams and/or dikes and seawalls but taking the indirect approach of simply taming the water, to keep to a minimum the effect of water-related hazards in a more economical manner. As an adaptation measure, the floating structure is therefore considered to be an excellent means of dealing with water-related hazards.

2.2 Conceptual Methodology for Water City

The concept is of a waterfront that is developed by excavating the soil in a low-lying land area down to a few meters below the surface and then flooding the area to produce man-made reservoir. The foundations for an urban community float on this man-made reservoir; buildings and other facilities are constructed atop these floating foundations.

Step 1: An area equivalent to approximately half of the total site's area is excavated up to a depth of several meters. Topsoil removed from the site is relocated in order to raise the urban site above sea level (see Fig. 3a).

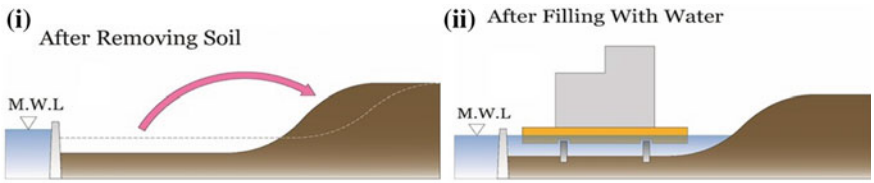

Fig. 3 Construction scheme for water city

Step 2: Concrete levees prevent erosion or destruction of the bank. The area inside the levees is then flooded until the water level inside the levees reaches that of surrounding seas and/or rivers, to produce a man-made inlet and/or reservoir.
Step 3: Floating modular units constructed at shipbuilding facilities are towed to their sites and are combined and welded to one another at their sites. Then the larger floating foundations for the water city are constructed.
Step 4: Finally, buildings are constructed on the floating foundations inside the man-made waterfront. Roads and bridges are constructed to allow passage between the floating foundations and the land, in addition to a water gate (see Fig. 3b).

In principle, these floating foundations stay afloat by themselves but the proposal calls for what is known as the "Soft-Landed System" for the purpose of positioning instead of using a mooring system. With this system, the floating foundations are partially propped by support piles found underneath. The buoyancy provided by the floating foundations serves to lighten the load on the supporting piles. Laterally-mounted piles located on sides of these floating foundations feature rubber fenders to help control their horizontal excursion. Since approximately a tenth of the total load is supported by several concrete piles, the remaining 90 percent for a floating foundation is supported by the buoyancy force of said floating foundation. When there is an unexpected increase in water level due to floodwater from heavy rains and so on, the floating foundation can easily change its position up from the Soft-Landed condition.

3 Water City Project for Koto Ward in Tokyo

3.1 Water City Proposal for Koto Ward Against Water-Related Natural Hazards

The Koto Ward area, which is selected as the project site used to be one of the most prosperous suburban industrial sites in Tokyo, and is one of the higher density urban area. The population in 1957 was 300,000, but by end of 2015 this had grown to more than 500,000. The total land area of Koto Ward is 39.9 km^2 and its population density is 125.3 persons/ha.

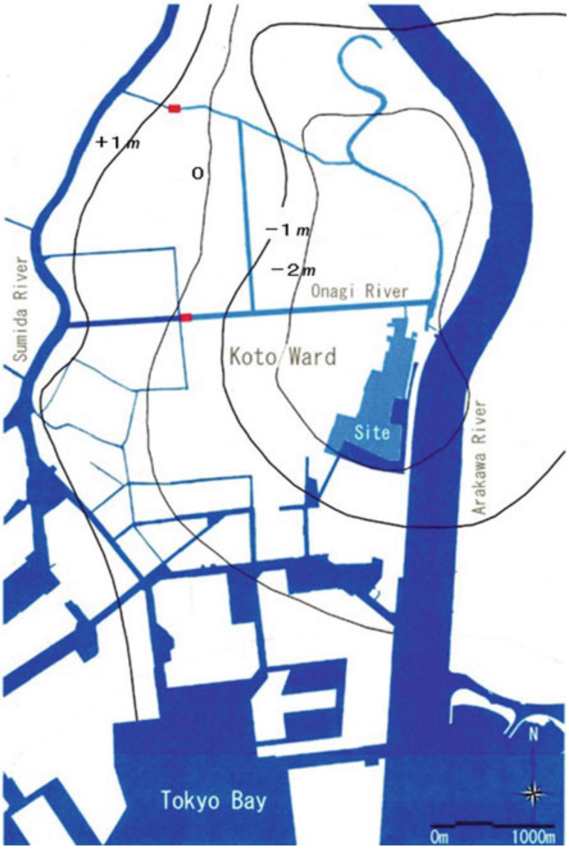

Fig. 4 Site for water city, Koto Ward

Today, as is show in Fig. 4, two-thirds of the total area of Koto Ward is lower than the average sea level of Tokyo Bay due to the fact that lots of underground water around this area had been pumped out during long time before. If a huge tsunami and/or fire due to a large earthquake were to occur, the status here would become highly critical as well. Since the Koto Ward in Tokyo is near the mouth of Arakawa River, there is the serious risk of a tidal bore from Tokyo Bay due to storm surges under typhoons and also tsunami. This levee could be destroyed by the flow, which may cause serious flooding around low-lying land areas of Koto Ward. The planned site in Koto Ward is protected by an old levee along Arakawa River, about 6 m high. This height seems sufficient to deal with storm surge level due to typhoon in Japan. The highest storm surge observed in Japan were recorded as 5.02 m including the astronomical tide under Isewan typhoon conditions in Sept. 26, 1958. Furthermore, even larger storm surges must be taken into account as long as the sea level continues to rise further and/or typhoons become larger due to future global warming.

Fig. 5 Various urban facilities in water city

The final stage of the planned entire water city project for Koto Ward, Tokyo covers an area of approximately 2 km from north to south and of between 0.5 and 1.0 km east to west, with a total land area of around 1.25 km^2 [4, 5]. The planned population is close to 27,500 people consisting of nearly 12,600 households, resulting in a population density of 223.6 persons/ha. This planned population, which is based on its current size between 27,000 and 30,000 people, is three times the neighboring communities' size (8000–10,000 people). In accordance with these demographic proportions, the project site constitutes a mid-sized city that will require three elementary schools and one junior high school. The plan includes the development of a mid- to high-rise housing area (about 560 persons/ha) and a waterfront as an open space that occupies some half of the total area being developed (625,000 m^2 or 22.7 m^2/person). In addition to its residential functions, under consideration is a variety of urban facilities to enliven the city. These include: (1) a shopping complex necessary for comfortable living, (2) an aggregated industrial site for small workshops, (3) an aquatic resort space along Arakawa River, and (4) an office complex (see Fig. 5).

Generally, since an entire variegated mega-city cannot be developed all at once, the area under development will be divided into several construction stages as is shown in Fig. 6 and handled on a step-by-step manner. For this adaptation planning for Koto Ward, the first development site involves an area approximately 400 m from east to west and about 600 m from north to south near Higashisuna 3-chome, in Tokyo's Koto Ward. Right to the east of this site, close to Tokyo Bay, is the bank of Arakawa River. The water surface level is designed to match those of Onagi River and the canals located near this site to enable boat movement between the man-made reservoir and the river system. Urban redevelopment at this site based upon our design concept is to be carried out as the first stage and the process outline is described as follows: To begin with, this area is excavated to a depth of 5 m from the existing crowded site shown in Fig. 7a and the topsoil removed. The total area for this region, which will be developed by excavating soil from lower-lying land areas, is approximately 185,000 m^2.

The topsoil removed from the site is to be relocated in order to raise the other sites above sea level and this excavated area is filled with water until a man-made inlet and/or reservoir is made. Secondly, as is shown in Fig. 7b, floating foundations consisting of many standard modular units will be built inside the man-made reservoir. The total number of floating modular units used for this water area is 44 modular units (total area: 11 ha) while those at the final construction stage is about 130 modular units. The steel barge-type floating foundations were chosen in this case because of their outstanding performance during the Mega-Float Project. In general, the floating foundation is to be constructed by welding many pieces of the standard modular units; 100 m in length, 25 m in width and 4.5 m in height (3 m in draft).

Next, residential housings are built on the floating foundation inside the man-made reservoir (see Fig. 7c). The population on the floating foundation will near 4300 people comprising some 1850 households, with a population density of 390 persons/ha (three times larger than the existing city) excluding the open water area at the first stage of the water city. As the next construction stage, the additional reservoir is constructed next to the original reservoir and then the residential floating platforms located in the first phase will relocate to different sites (see Fig. 8). In this way, the future enlargement of water city will proceed with the next stage of construction of additional reservoirs in a step-by-step manner. In addition to the construction of new floating platforms, almost all floating platforms placed at the original reservoir can be reused upon future construction in case of water city that is different from the conventional one on lands as is shown in same figure.

3.2 On Adaptation Measures of Water City by Arakawa River Against Flooding Hazards

Having a large river like Arakawa next to it, the levee could be destroyed should the river overflow. When the water level of Arakawa River reaches the levee's higher

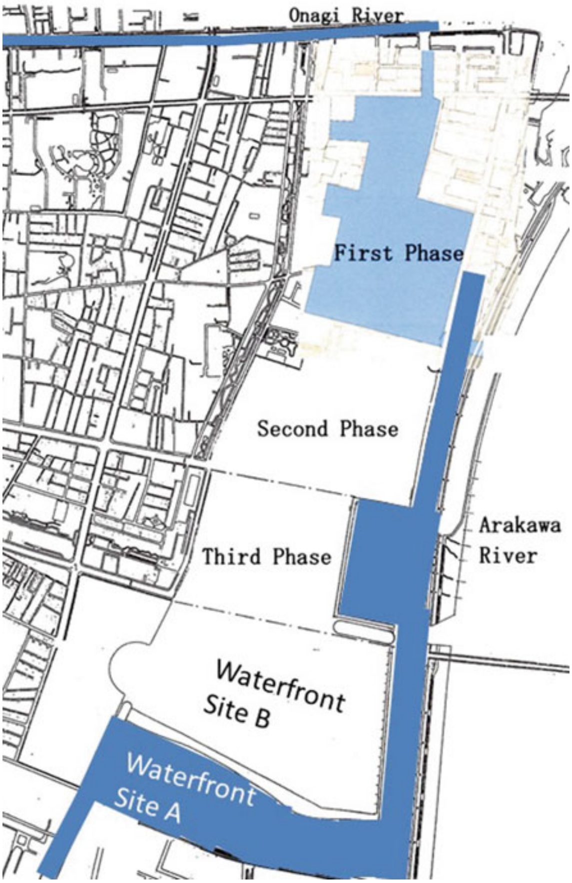

Fig. 6 Construction stages

portion, then the larger water pressure acts on only one side of levee and gradually water invades inside the levee and finally it could collapse at some location due to the water pressure. These levees will collapse cause serious harm to the surrounding low-lying areas in Koto Ward. To avoid such a dangerous situation, we had planned to construct another 3 m high sub-levee along the Arakawa levee paralleling the river (see Fig. 9). The advantage of this measure is that the main levee is seldom breached and safe conditions are maintained even when a high water level of Arakawa River has been reached since both sides of the main levee surface faces the water directly and the horizontal force on the main levee due to water pressure on obverse sides cancel out. Because waterfront Site B connects directly to Arakawa River and Tokyo Bay, the water level in waterfront Site B is almost at sea level and is therefore hardly affected by the discharged water.

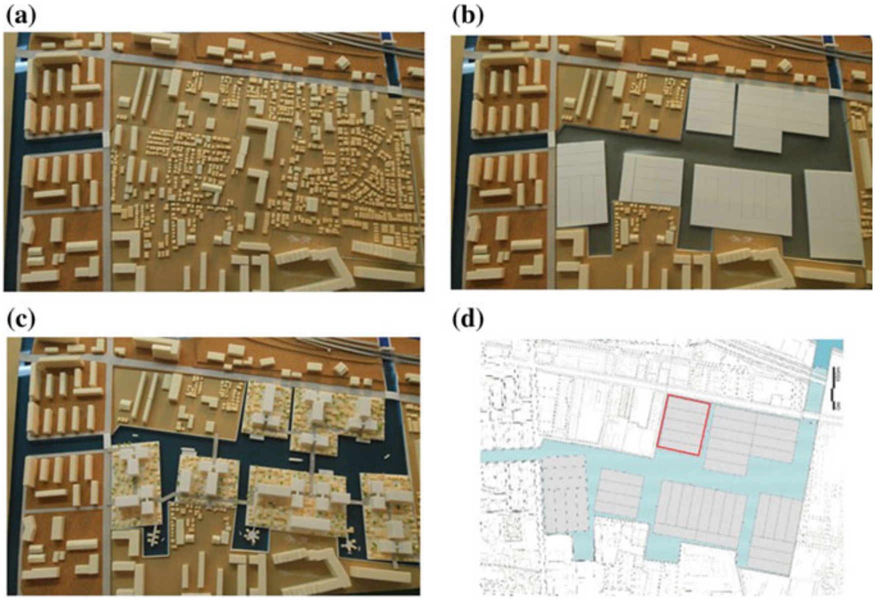

Fig. 7 Construction scheme and floating foundations for water city of Koto Ward

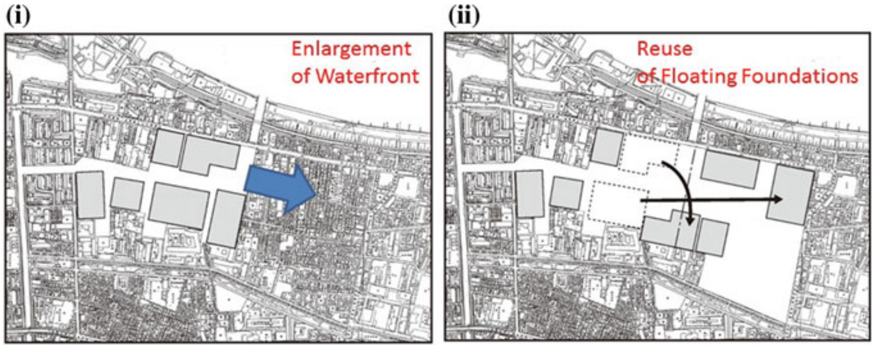

Fig. 8 Construction scheme for enlargement of waterfront area

These sub-levees are located between the water area of Site A and Site B as is shown in Fig. 10. The water level inside Site A is set as 2.344 m below the mean water level of Tokyo Bay, now found for rivers inside Koto Ward. Then the water-borne transport must use the Arakawa Lock Gate to ply between Onagi River and Arakawa River. On the other hand, the water level of Site B changes due to tidal conditions since the water is connected directly to Arakawa River, as long as the watergate is kept closed. In this way, the overall waterfront area to be developed in this Koto Ward Project is divided into two sections. Waterfront Site A (0.85 km^2) on the inland side is completely isolated from Arakawa River and Tokyo Bay. At

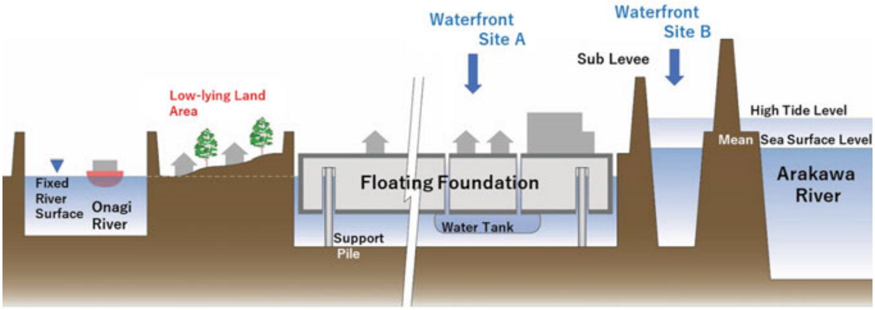

Fig. 9 Sectional view as to water city of Koto Ward, Tokyo

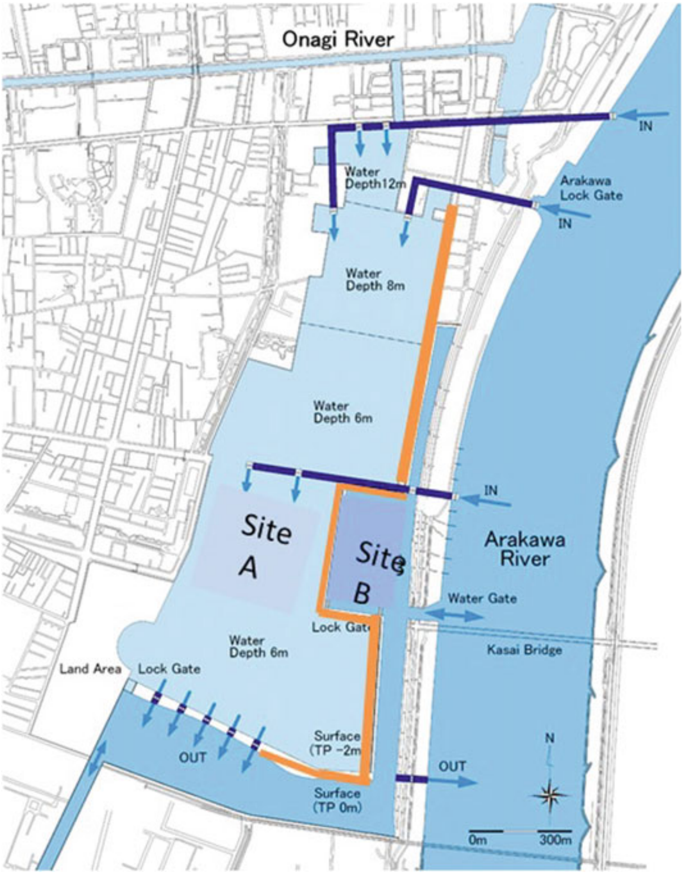

Fig. 10 Water circulation system for water city

present, in the eastern area of Koto Ward where the ground level is very low, the surface level of the water channels is adjusted to some 2 m below the average surface level of Arakawa River. Waterfront Site A is designed to link those channels, including Onagi River. The connection with Onagi River will enable free, extensive transportation of people and goods throughout the community regardless of tide levels. Waterfront Site B (0.34 km^2) is a narrow inverted L-shaped area. Boats travel back and forth between the site and Arakawa River by way of water gates that remain open except during emergencies, such as tsunami tidal bores and/or storm surges. Although the water level in waterfront Site B is altered directly by the tide, boats can move between Arakawa River and Tokyo Bay freely without passing through a lock gate. Consequently, the double levee system gives water city more safety against high water and becomes an excellent adaptation measure against flooding due to water-related hazards such as storm surge due to typhoon, tsunami and so on.

3.3 Multi-water System and Water Supply for a Sustainable Water City

The average precipitation in Tokyo amounts to about 1340 mm per year. We should consider using rainwater as much as possible for the water city of Koto Ward, Tokyo. In addition, by means of the groundwater recharge of rainwater that has once been stored, realization of a highly advanced society that circulates water by utilizing wells, etc. becomes possible. Moreover, with our proposal, we adopted the Grey Water Supply System which adds on an intermediate stage handling grey water to the existing drinking and sewage systems. As for the multi-water system of the water city, four water supply systems are prepared in this study; the freshwater one based on the existing water supply system, the rainwater-based one directly fall on the floating foundations, underground water system using wells and the grey water one made from water inside the reservoir. Rainwater gathered on the floating foundations are used as water for flushing the lavatory while the water inside the reservoir which mainly comes from Arakawa River is used as grey water for washing cars, sprinkling the gardens and so on. As is shown in Fig. 11a, there is a sewage facility near the reservoir and grey water is produced by purification of water inside the reservoir. Other water for living use is to be provided by the existing water supply and/or underground water system the latter primarily through wells.

The water surface area of the reservoir siting 44 floating modular units as a living space total is at approximately 110,000 m^2 (see Fig. 7d). The population for a single floating modular unit is about 90 people so the total water necessary becomes around 27 t assuming one person uses 300 l in a day. The total then for the 44 floating modular units becomes 433,620 t per year. It is said that in Japan general water usage upon living are categorized into five: flushing the lavatory (28%), washing hands (9%), bathing (24%), washing things (16%) and kitchen (23%). The population on five modular units (100 m $\times$ 125 m) which is used as a typical prototype of the residential

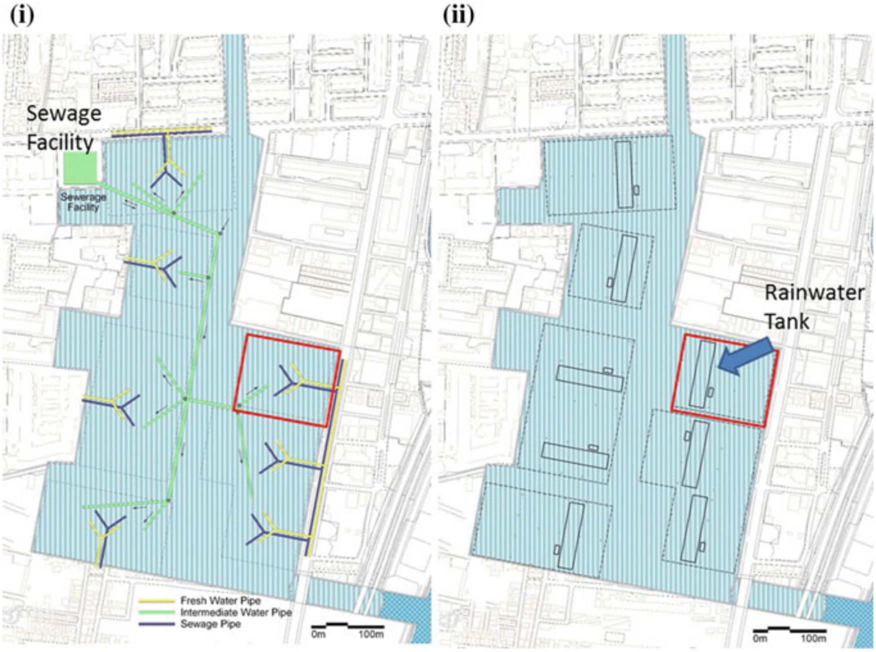

Fig. 11 Multi-water supply system for water city

floating unit showing as an enclosed rectangular line in Figs. 7d and 11 is some 441 people, the amount of water used by one unit's population per day is set at 132.3 t (or 48,290 t per year).

Rainwater falling on the five floating modular units are to be stored in rainwater tanks located underneath the modular units (see Fig. 11b). The rainwater is used to flush the lavatories within the water city. For a floating foundation consisting of five modular units with 12,500 m^2 surface area, a rainwater tank of 2800 m^2 is enough for maximum 250 mm/day precipitation, the heaviest precipitation recorded for the last 35 years, the tank being affixed underneath the floating foundation. Then, the volume of the tank below the floating foundation on the inner reservoir area is designed to cover the maximum precipitation (250 mm per day) of an entire year *in toto* because lots of space is available inside the man-made lagoon and/or reservoir. From this estimation, as is shown in Fig. 12, the tank size was designed to be 90 m in length, 20 m in width and 1.8 m in height while the water tank inside of the floating unit is set to be about 110 m^3 assuming use for flushing the lavatory as being 37 m^3 estimated in a day for 441 people over a 3-day period. In general, the rainwater tank made of quite flexible material such as rubber located underneath the floating foundation need not have a costly steel structure like ones on land. In addition, the largest space for rainwater are made available inside reservoirs.

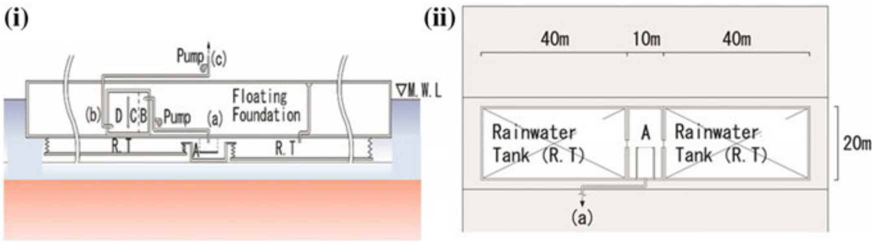

Fig. 12 Sectional plans for rainwater supply system

4 Application of Proposed Approach to Coastal Areas and/or Isolated Islands

In recent years, the "global warming trend" has, while contributing to the sea level rise, not only enabled the growth to inordinate size of hurricanes/typhoons and tornadoes but also led to expansive flooding. Especially, the adaptation measures for coastal areas becomes necessary to avoid the loss of coastal areas in these areas with beaches face the ocean directly and tend to be affected by the sea level rise. Although conventionally flood countermeasures implemented by countries like the Netherlands have been the construction of large-scale civil engineering structures such as dikes, it is impossible to avoid such extraordinary powers of nature using massive civil engineering structures such as seawalls and breakwaters.

We now suggest applying the present methodology to coastal areas by using the so-called "Coastal Aqua-Village System" (see Figs. 13 and 14) [6, 7]. The plan is to change the potential danger in this site to produce an area safeguarded against storm surge due to huge typhoons and massive tsunami. Under this concept, the dangerous coastal zone areas are excavated to a depth of some several meters and the topsoil removed as is shown in Fig. 15a, b. The topsoil removed from the site is to be relocated in order to construct banks in other areas of the seaside site in protecting against a run-up of seawater due to storm surge and/or high waves. Next, these are filled with water including saltwater until the water level reaches sea level, to construct a man-made lagoon and/or inlet. Finally, the floating platforms made of lower cost materials such as lightweight concrete are constructed with housings and even rice paddies/agricultural fields located on floating platforms inside the man-made lagoon and/or inlet (see Fig. 15c).

In principle, the Floaters float by itself also but the proposal calls for what is known as a "Soft-Landed System" (see Fig. 15d). When there is an unexpected increase in water level due to a high tide and/or floodwater from storm surge, tsunami and so on, the Floaters can easily change its position up from the Soft-Landed condition. In addition, tall concrete piles with guiderails are also erected and connected with the Floating Roads to deal with the unexpected extraordinary vertical excursion of floating structures due to a huge tsunami and so forth. For the purpose of keeping costs down and realizing functional flexibility as to change for the floating structure system,

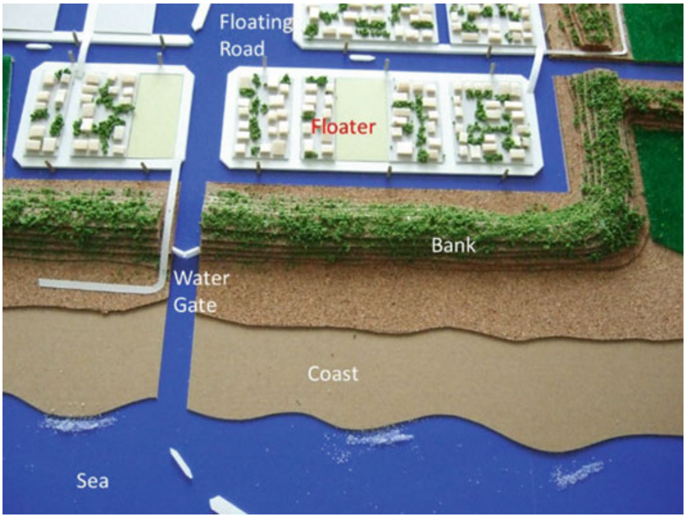

Fig. 13 Bird's-eye view of "Coastal Aqua-Village System"

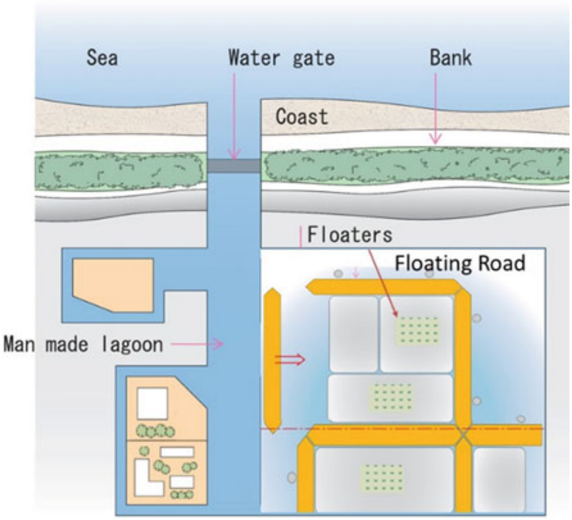

Fig. 14 Construction scheme

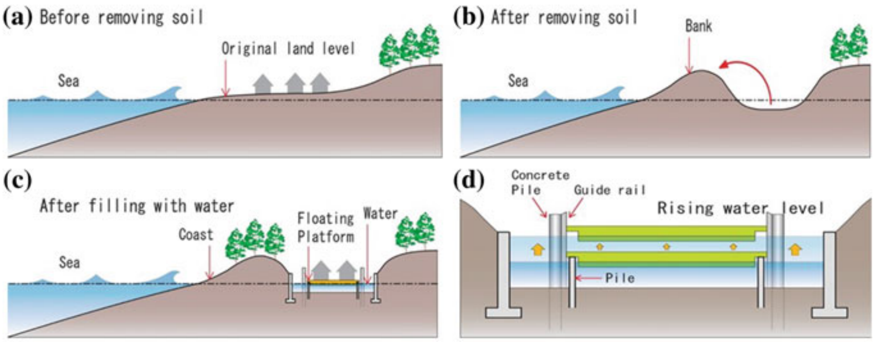

Fig. 15 Floating structure system for "Coastal Aqua-Village System"

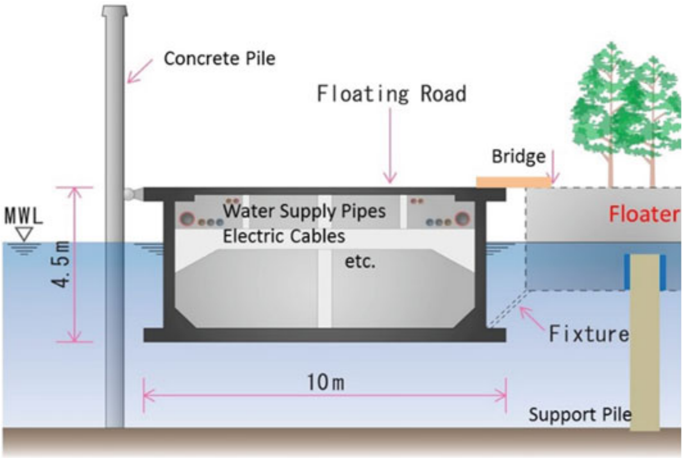

Fig. 16 Detailed sectional view as to floating infrastructural system

we recommend that the floating structure system inside the water area be divided into two components upon planning as is shown. One is the box-type Floating Roads which hold the infrastructures such as water supply pipes, electric cables and so on and the other is the functional Floaters where low-rise housings and/or agricultural fields are built on. Latter structures are bound with the Floating Roads using steel fixtures. Figure 16 shows the detailed sectional view of the Floating Road.

The proposed Coastal Aqua-Village System should stock up on rainwater as much as possible inside the man-made lagoon and/or inlet too, for use in agriculture and such applications since rain falling on the rural landscape is also an important natural resource (see Fig. 17). The precipitation is very precious such for Maldives, Singapore and so on and the proposed Multi-Water Supply System will become extremely useful for supporting water supplies at many places. As an example of isolated islands, there are many being adversely impacted by not only rising sea levels that threaten in

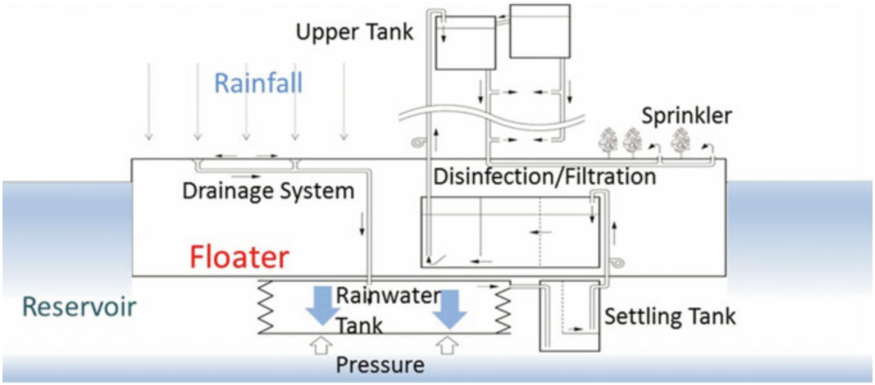

Fig. 17 Schematic sectional plan of rainwater supply system

addition to their shorelines the freshwater supply but other aspects of climatic changes as well like longer dry periods and extreme weather events increasing in frequency. This situation further increases the need to collect rainwater for use in supplementing their water supply. Even if a systematic layout and a link between supplies has been established as a backup system for areas in need of freshwater during dry seasons, there is a lot of rainwater that could be fully utilized through application of "in-water" tanks found underneath the floating foundations to realize an urban-use Multi-Water Supply System. By having water "tanks" filled with freshwater from rain and made from durable materials that could in fact be made elastic and thus expandable, floating in saltwater—of course having a cover on it to prevent contamination and even evaporation—a versatile source of freshwater such as drinking water or base thereof is made available for use by such island communities. As is shown in same figure, the water pressure difference between pressures inside the rainwater tank and outside of the man-made lagoon is almost in equilibrium, consequently, problematical air inside rainwater tank will be pushed out completely due to the water pressure in reservoir.

5 Discussion and Concluding Remarks

Our concept entails excavation of lower-lying land areas in the middle of cities, to produce large reservoirs for placing a semi-floating structure therein and to ready a man-made foundation for placing facilities atop it as is shown in Fig. 18 [8]. This allows for effective use of space above a body of water for realizing living space on the floating foundation. By promoting underground replenishment of water upon storage, a highly advanced society which circulates water by utilizing wells, etc. becomes possible, to turn disaster conditions like flooding into something advantageous. Excavating lower-lying land areas secures space for a large reservoir in the

Fig. 18 Bird's-eye view of sustainable water city "Waterpolis"

middle of cities where precipitation can then be used secondarily for human activities such as flushing the lavatory, sprinkling the garden with water and so forth, as an additional source of water to supplement the existing drinking water and sewage systems in a city. With abundant water resources inside cities, there are many merits. For example, it would be possible to improve the water cycle, to utilize this by directing water into the ground to produce an environment-friendly, sustainable urban community.

The magnitude of natural hazards is likely to keep growing annually along with future climatic changes and cannot be ignored. When considering the rise in sea levels to be unavoidable from the long-term perspective, the height of seawalls must keep increasing. What to do in developing the coastal and riverside areas to safeguard against water-related disasters over the long term? It is urgent that a reliable alternative solution which will ensure a higher degree of safety through mitigation of disasters be found. We believe that the water city concept with the Coastal Aqua-Village System presented here offers a new paradigm as to novel adaptation measures which matches next-generation standards and is applicable to isolated islands (e.g. Maldives and Tuvalu) suffering from sea level rises caused by global warming.

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