

G1) Performance evaluation and a design method for the horizontal fixture drain branch system comprising drain headers that can be adapted to long-life housing

Masayuki Otsuka (1)

(1) dmotsuka@kanto-gakuin.ac.jp

(1) Department of Architecture, College of Engineering, Kanto Gakuin University,
Dr. Eng

Abstract

Housing complexes in Japan used to be constructed using the “scrap & build” method, but the construction of long-life housing that lasts for as long as 200 years has been started in tackling global environmental issues with the aim of reducing environmental impact and controlling CO₂ which is emitted during the process of design, construction, demolition and disposal of housing.

The construction of long-life housing adopts the concept of providing a plumbing layout which can be flexibly adapted to a resident’s lifestyle, and in order to materialize this concept, much consideration is required in terms of construction planning while it is necessary to develop a horizontal fixture drain branch system which can be installed to a section (infill within a dwelling unit) available for the updating of the plumbing layout.

This study discusses the technique of plumbing planning for long-life SI (Support & Infill) housing complexes and the characteristics and advantages of the horizontal fixture drain branch system which uses drain headers and which is installed in the privately owned section (“horizontal fixture drain branch system with drain headers” hereafter). To be more specific, the study focuses particularly on the following four points:

- (1) The technique of plumbing planning for SI housing complexes and its characteristics
- (2) The length of the horizontal fixture drain branch and the drainage characteristics of sanitary fixtures in relation to the reduction of drainage load
- (3) The drainage characteristics of sanitary fixtures in relation to the carrying performance
- (4) The reduction of induced siphonage which is caused by combined drainage from multiple sanitary fixtures and the effect of backflow prevention

Keywords

Drain Headers, Support & Infill, Long-life Housing, The Horizontal Fixture Drain Branch System, Drain Headers

1. Introduction

The objectives of this study are as follows:

- (1) To clarify important points when constructing long-life SI housing complexes and planning drainage facilities for them
- (2) To identify design and planning advantages of the horizontal fixture drain branch system with drain headers for SI housing and to specify the points to bear in mind when implementing performance evaluation.

There are two advantages when designing and planning the horizontal fixture drain branch system with drain headers for SI housing. Firstly, the infill is much more adjustable depending on the plumbing planning by installing the drainage stack and the pipe shaft in the common use section instead of in the privately owned section as it often used to be, and the drainage pipes of the system have higher maintainability and updatability. Secondly, longer pipe distances, to connect sanitary fixtures to the drainage stack, help reduce the drainage load which is caused to the drainage stack while providing more options when selecting a drainage stack system.

There are two points to bear in mind when implementing performance evaluation. Firstly, because of the long pipe distance and the low pipe pitch, it is important to ensure that the carrying performance of the horizontal fixture drain branch is reasonably good. Secondly, it is also important to ensure that the trap seals do not break by induced siphonage created by combined drainage from multiple sanitary fixtures which are connected to the horizontal fixture drain branch in the privately owned section. Especially, backflows must be prevented from entering the traps that are installed close to the floors (in low positions), otherwise drained water could spill out of the drain outlets.

2. The characteristics of plumbing design and planning for SI housing

2.1 The concept of SI housing design

Fig.1 shows the image of a plumbing layout that is appropriate for SI housing. As shown in Fig.1, typical SI housing comprises a so-called “support” (or a “skeleton”), a collective term for a building frame and a common use section, which has a long useful life (100 years or longer). Also, the privately owned section adjustable for a plumbing layout that may need to be updated is called “infill” and has a short useful life (20 years max.). It is distinctive that the intended use of the support and the infill and their expected performance are taken into consideration when plumbing is designed and planned for SI housing. For this study, a pipe shaft and a drainage stack, which should be highly updatable and maintainable with a long useful life, are installed in the support

section. A horizontal fixture drain branch system with drain headers, which is flexible with the change of plumbing layout, is also installed in the infill.

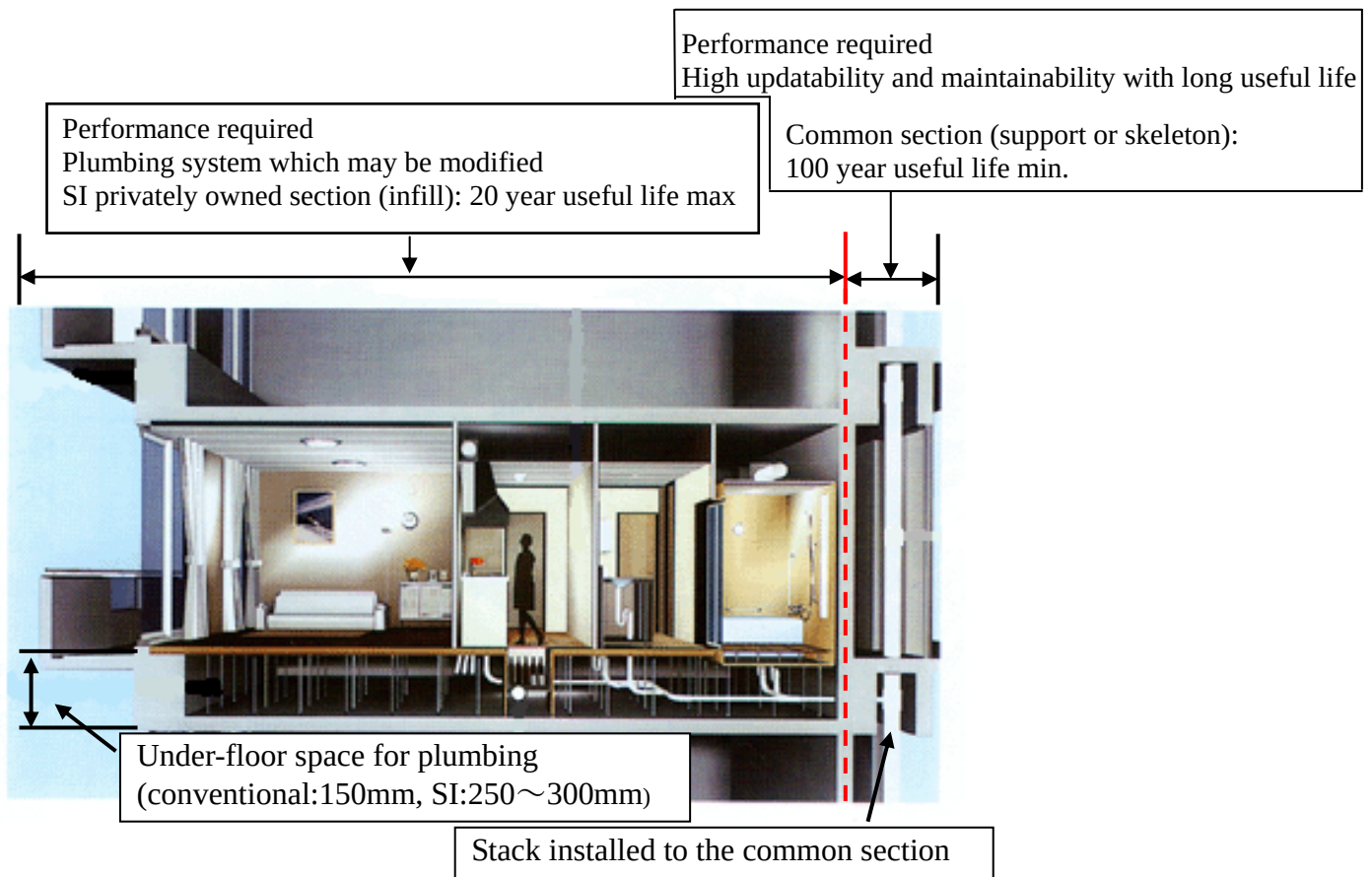


Fig.1 SI (Skeleton & Infill) plumbing layout and performance required

2.2 Pipe shaft and drainage stack planning

Fig.2 shows a horizontal fixture drain branch system installed in the infill of conventional housing. For conventional housing complexes, a pipe shaft is installed in the infill with a drainage stack running through the pipe shaft. Therefore, as shown in Photo 1, the maintenance and updating of the drainage stack requires a major operation including destroying the pipe shaft as well as the walls and floors around it. In addition, the residents of conventional housing complexes have no choice but to evacuate their homes and be relocated during such updating work. There have also been cases in which drainage systems were out of order for a long period of time, causing inconveniences to residents.

Meanwhile, Fig. 3 shows a horizontal fixture drain branch used on the horizontal fixture drain branch system with drain headers. As shown in Photo 2 (1) and (2), for SI housing, the pipe shaft is installed facing the common use corridor with the drainage stack

running through in the same place. This eliminates maintenance and updating work by entering the infill, thus not disturbing residents' daily life too much.

Fig.4 shows how a horizontal fixture drain branch can be housed in the under-floor space of SI housing. As shown in Fig.4, the under-floor space (a distance between the upper surface of concrete slab and the finished floor surface) of SI housing for accommodating a horizontal fixture drain branch used to be approximately 150mm but it has been expanded to 250 to 300mm, consequently enabling drainage along a comparatively long distance; approximately 10 to 15m, while securing a pipe pitch which is lower than the pitch specified by the standard.

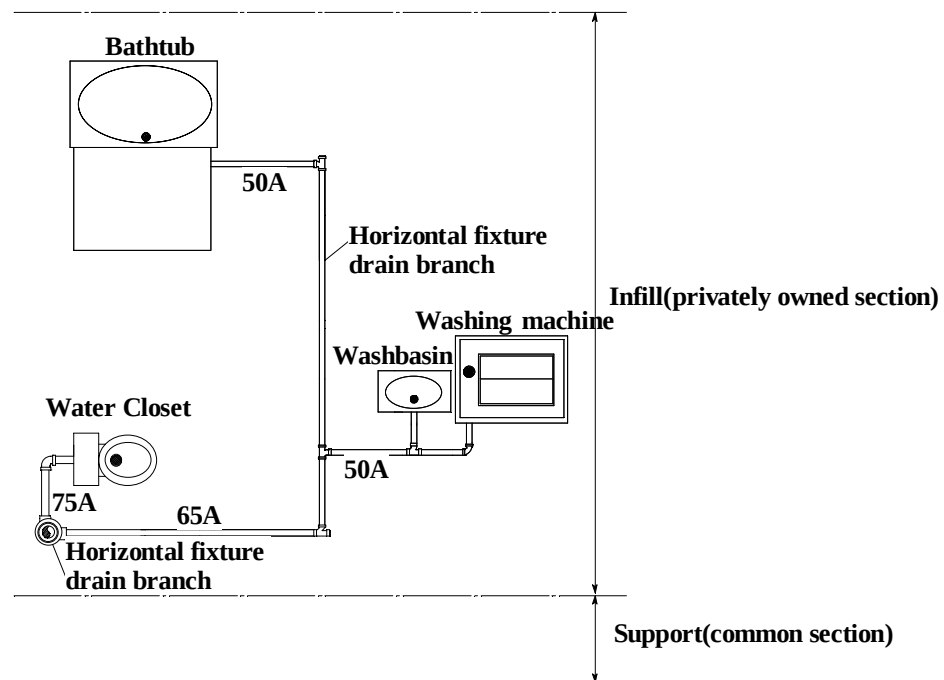
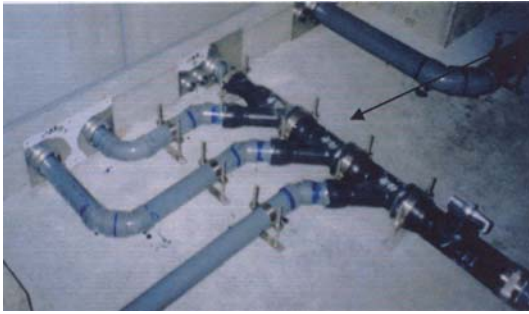


Fig.2 Conventional horizontal fixture drain branch system



Photo 1 Updating work on the drainage stack and horizontal fixture drain branch in the privately owned section



(1)Horizontal fixture drain branch with drain headers



(2) Pipe shaft installed in the common section

Photo2 Horizontal fixture drain branch with SI housing-compatible drain headers

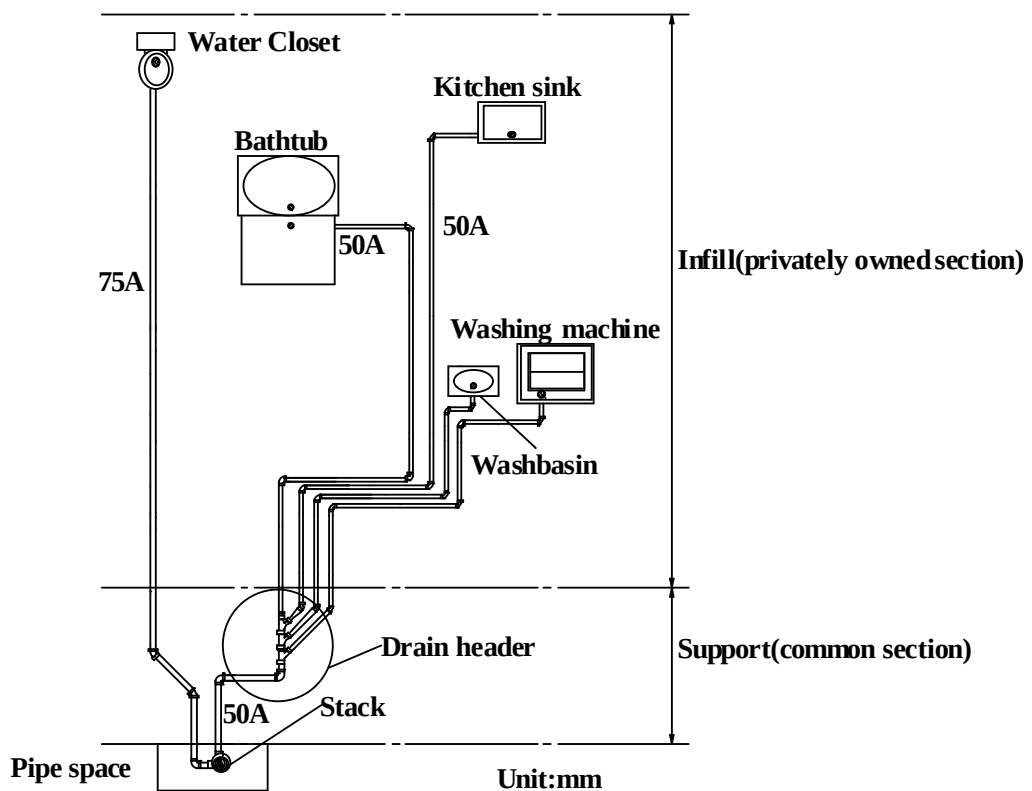


Fig.3 Horizontal fixture drain branch with drain headers for SI housing

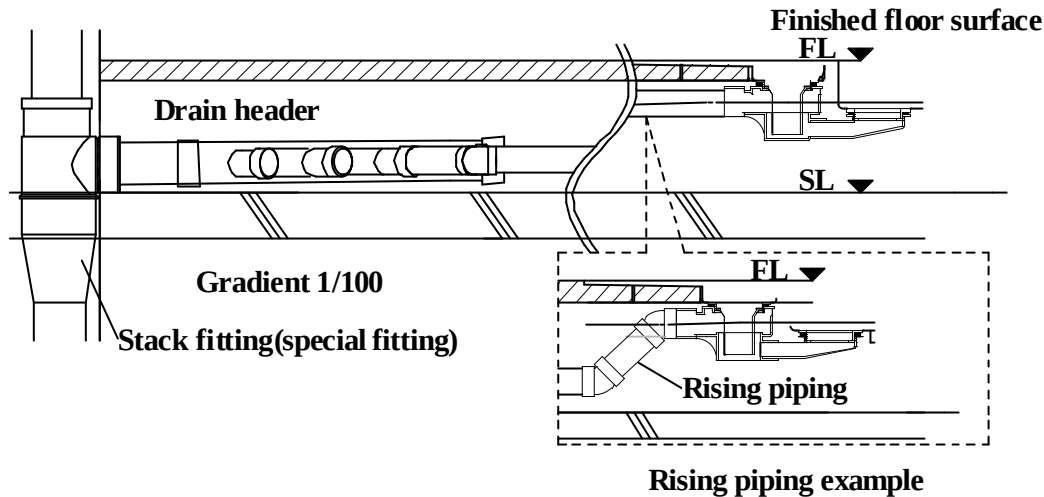
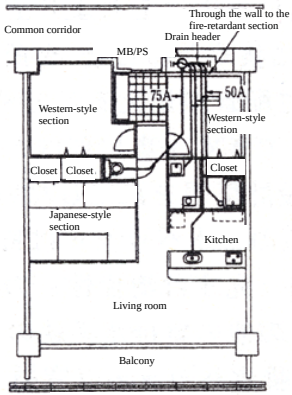
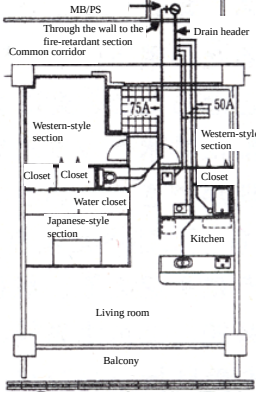
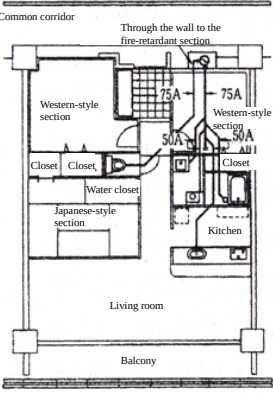


Fig.4 Under-floor space for installing a horizontal fixture drain branch for SI housing

2.3 The characteristics of the horizontal fixture drain branch system with drain headers that are compatible with different types of SI housing

The horizontal fixture drain branch system with drain headers is a drainage system by which the wastewater drained from various sanitary fixtures, which are connected to the miscellaneous drainage system in the infill, is combined at the drain header section and drained further to the drainage stack. As shown in Table 1, there are three different configurations which are actually used depending on how the drain headers and the drainage stack are connected as well as on where to install the drain headers. The characteristics of each configuration are also shown in Table 1. Types A and B are adopted by the Urban Renaissance Agency. They comprise drain headers which are housed in the common use section PS. A miscellaneous drainage system is connected to the drain headers whereas a sewage water system is installed separately and the wastewater from both systems is combined at the stack fitting section. These types each require five connecting points through the wall to the fire-retardant section, which is quite a few. Nonetheless, these types make it easy to clean the horizontal fixture drain branch from the drain headers which are housed in the common use section. Meanwhile, type C is configured with drain headers which are installed near the entrance of the privately owned section and the miscellaneous drainage water collected in this section is drained to the drainage stack using one horizontal fixture drain branch. A sewage water system is plumbed separately to provide a drainage route to the stack fitting section. Type C is a more sophisticated system than types A and B in the sense that it requires only two connecting points through the wall to the fire-retardant section, thus better constructability. It should be noted, however, that the horizontal fixture drain branch needs to be cleaned from the drain headers which are housed near the entrance of the privately owned section. This study focuses on type B.

Table 1 SI housing-compatible horizontal fixture drain branch systems and their characteristics

	Type A	Type B	Type C
Type			
Characteristics	○ Maintainable (cleaning) from the common section ○ Large pipe shaft space ○ Difficult connection through the wall to the fire-retardant section ○ Adjust the pipe shaft position to save frontage space	○ Maintainable (cleaning) from the common section ○ Stand-alone pipe shaft is required ○ Stand-alone pipe shaft is required ○ Finished floor is required above the corridor ○ Long pipe length to go along the corridor ○ Pipe shaft design	○ Maintainable from the privately owned section ○ Not quite maintainable from the common section ○ Access panel is required in the floor above the header ○ Small pipe shaft space ○ Easy drainage on the lowest floor ○ Easy connection through the wall to the fire-retardant section

2.4 The length of the horizontal fixture drain branch and the drainage characteristics of sanitary fixtures in relation to the reduction of drainage load

Fig.5 shows different pipe lengths in relation to different fixture drainage characteristics when the horizontal fixture drain branch system with drain headers for SI housing is used with a siphon-jet type Water closet. Compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing uses a longer horizontal fixture drain branch to connect a sanitary fixture to the drainage stack, and the fixture drainage characteristic curves, which represent the fixture drainage load, therefore change gradually from waveforms with sharp rises and drops to gentler forms as the pipe length increases. Based on this fact, when calculating the flow load in the drainage stack using a steady flow rate method under SHASE-S206, it is legitimate to think that the drainage load is less with the horizontal fixture drain branch system with drain headers for SI housing than with the conventional system. The advantage from the design perspective is that the diameters of the pipes used for the drainage stack system could possibly be reduced.

Similarly to Fig.5, Fig.6 presents fixture drainage characteristic curves showing different drainage pipe lengths in relation to different drainage flow rates, q_d values, of various sanitary fixtures. The definition of q_d value and how to calculate it were clarified at CIB-W062 Symposium⁴⁾ last year. The curves indicate that the q_d value of each Water closet decreases drastically as the pipe length increases. However, the q_d

values of the other sanitary fixtures, including the bathtub, are hardly affected by the pipe length as the Water closet are, and it is characteristic that these qd values remain more or less the same.

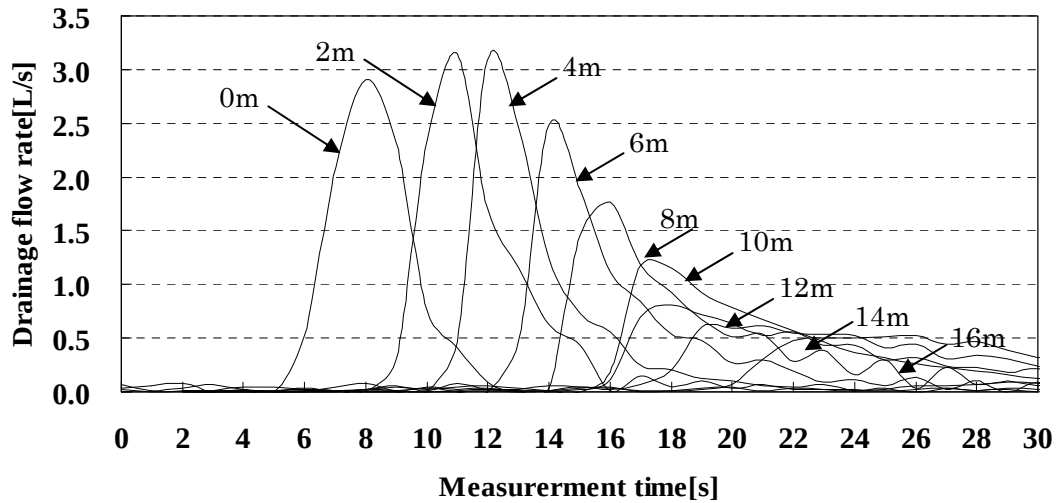


Fig.5 Transition of characteristics of fixture drainage (in the case of a siphon-jet water closet)

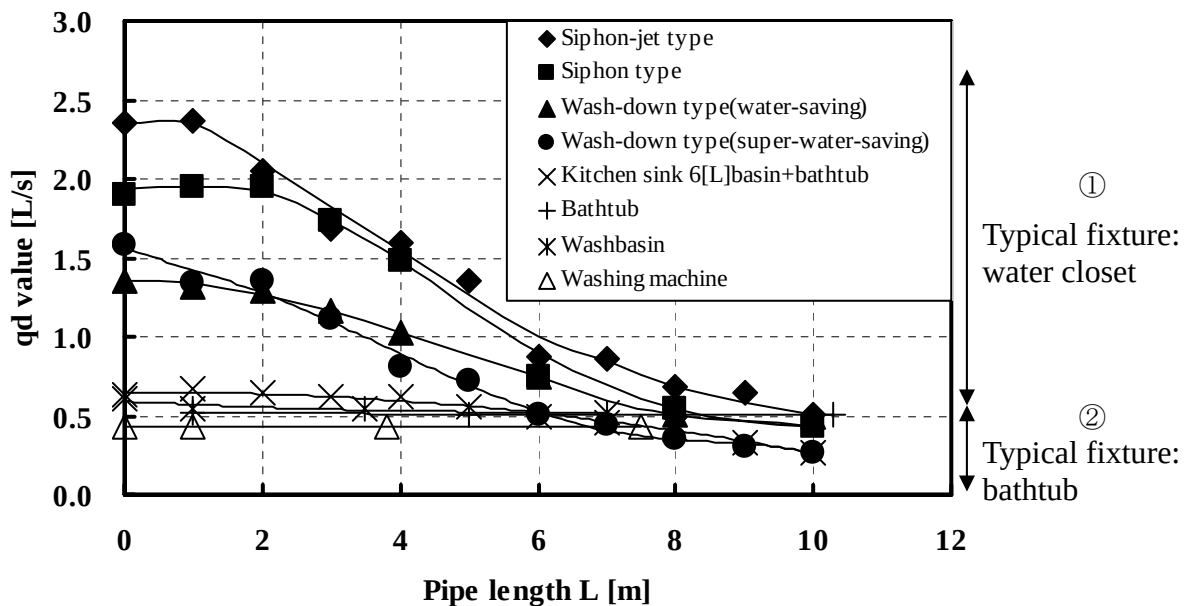


Fig.6 Change of the average fixture drainage flow, qd value, in relation to the pipe length

Next, Fig.7 shows the flow of how to calculate the drainage load and the pipe diameter using a steady flow rate method under SHASE-S 206 (plumbing code). Using the flow, the steady pipe flow, Q , is estimated and a sanitary fixture with the largest qd value is selected as a typical fixture. Using the qd value, the drainage load flow rate to the drainage stack is determined with reference to the pipe diameter curves in Fig.8. Toilet bowls are common nominees to be typical sanitary fixtures for these calculations but as shown in Fig.6, the qd values of the Water closet decrease as the pipe length increases and even become smaller than the qd value of the bathtub at a pipe length of 6 to 8m.

As it is clear from Fig.8, a longer pipe length is used with the horizontal fixture drain branch system with drain headers for SI housing than with the conventional system and

the q_d values of typical fixtures used for the drainage load calculation therefore become smaller, enabling the reduction of drainage load as a result. Fig.9 shows the drainage load curves along with different pipe lengths in relation to the drainage performance curves of a drainage stack system with special fittings when a siphon-jet type Water closet and a bathtub are used as typical sanitary fixtures. The drainage stack system comprises a stack with diameters of 100mm and 125mm and special fittings. Each height applied is also calculated to correspond to each pipe length. Based on the results shown in Fig.9, Fig.10 shows different heights and different numbers of floors applied that correspond to various lengths of the horizontal fixture drain branch when toilet bowls that apply different flush systems and a bathtub are used as typical sanitary fixtures.

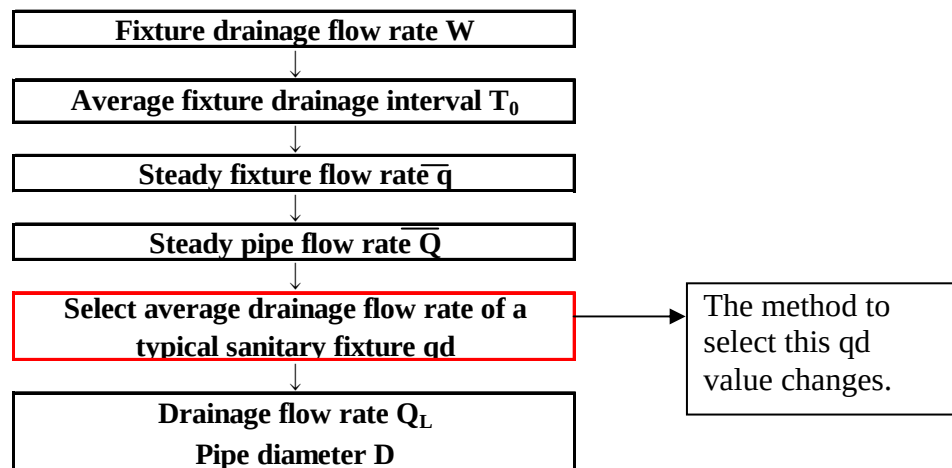


Fig.7 Flow of how to determine the pipe diameter using a steady flow rate method under SHASE-S 206 (plumbing code)

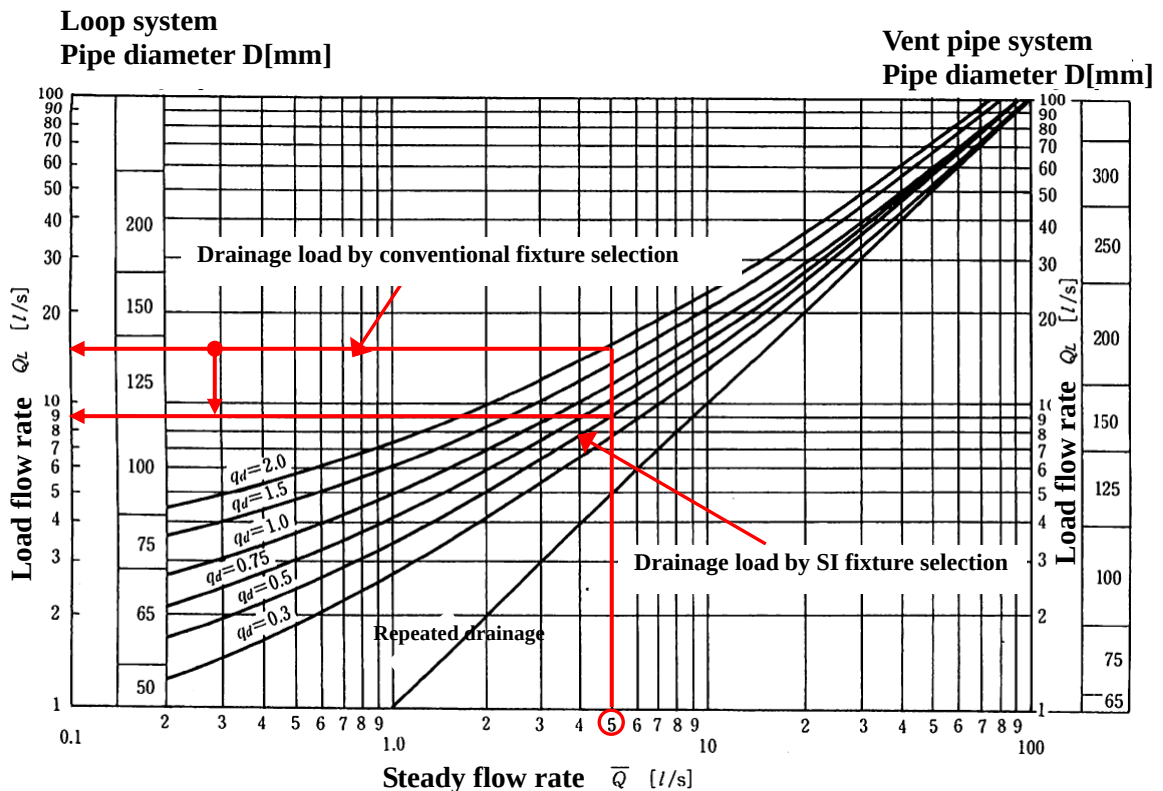
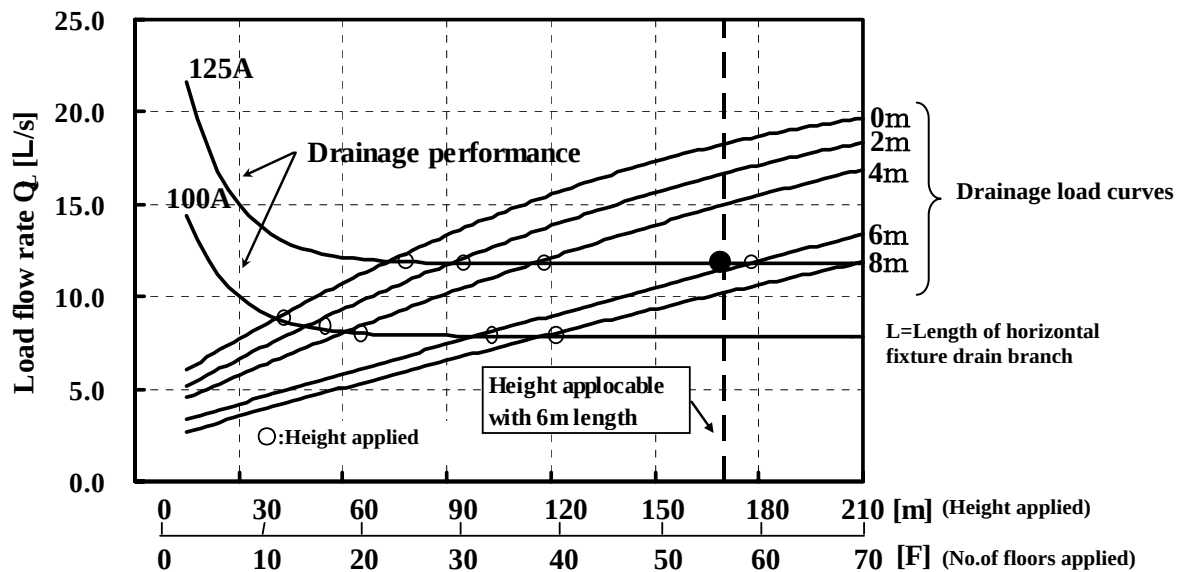
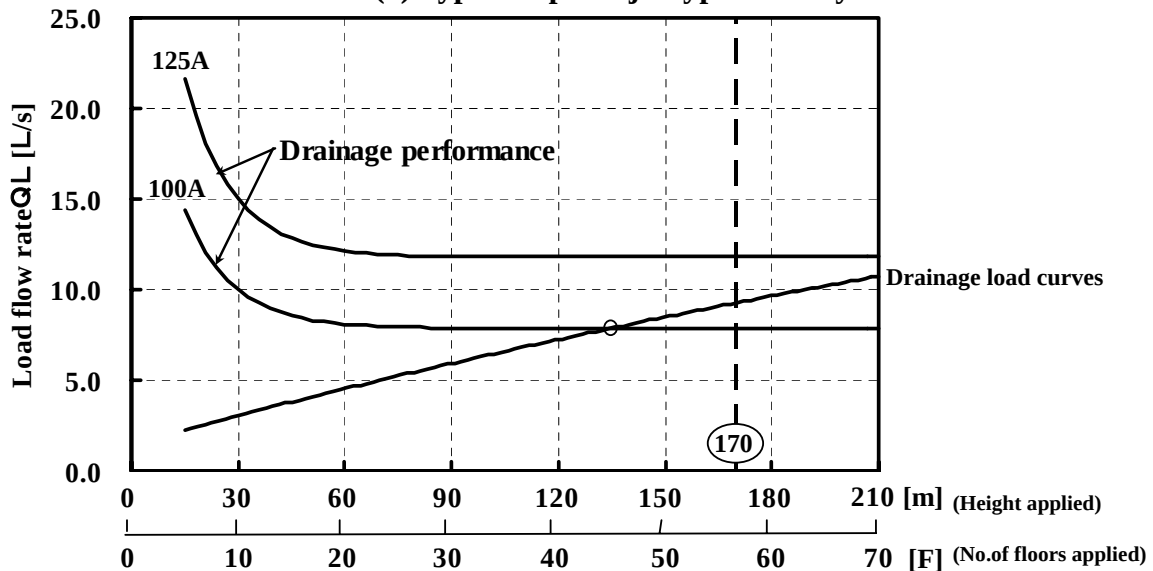


Fig.8 Calculation of drainage load in relation to pipe diameters (SHASE-S 206)



(1) Typical siphon-jet type sanitary fixture



(2) Typical bathtub

Fig.9 Drainage load curves and drainage performance curves of different sanitary fixtures

According to Fig.10, when using the siphon-jet type toilet bowl, for instance, if the pipe length is approximately between 4 and 6m, a drainage system with special fittings with a pipe diameter of 125A can be used, which also means that the horizontal fixture drain branch system with drain headers for SI housing can be applied to super high-rise housing complexes with a height of 170m. It is therefore right to say that compared to the conventional system with a short horizontal fixture drain branch generating large drainage load, the horizontal fixture drain branch system with drain headers for SI housing can reduce the drainage load to the drainage stack, which is a big advantage of the system.

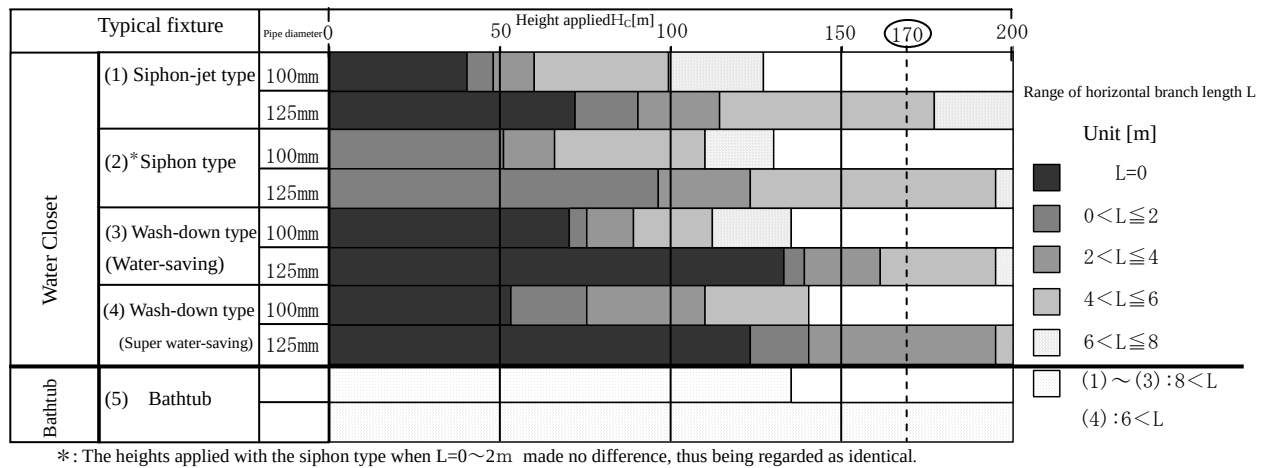


Fig.10 Heights applied with different types of sanitary fixtures and different pipe lengths

3. Point to bear in mind when implementing performance evaluation

3.1 Fixture drainage characteristics in relation to the ability to carry waste

Compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing allows more under-floor space (between the upper surface of the concrete slab and the finished floor surface) for housing the horizontal fixture drain branch, but as explained previously, the pipe pitch cannot be secured as to meet the specification. Hence, wastewater has to be drained along the horizontal fixture drain branch with a gentle pitch. This condition lowers the ability to carry waste especially from Water closet, possibly causing trouble, such as blockage, to the pipework. Therefore, performance evaluation needs to be implemented.

Shown in Fig.11 is an experimental horizontal fixture drain branch system used on the sewage water system and Fig.12 shows waste substitutes for the experiment. A carrying performance test was implemented using these items and the results are shown in Fig.13. The results clarified applicable carrying distances (pipe lengths) and the applicable number of pipe bends. For instance, using a super water-saving Water closet with a flush water volume of 6L, the applicable pipe length is approximately 6m, allowing the maximum of five bends created along the pipe. Fig. 14 shows the relationship of q_d values, which were measured at the end section of the horizontal fixture drain branch, with flow velocity V and water depth H . To set conditions to determine a carrying limit value, it is necessary to ensure that the decreased q_d value is 0.42L/s or above, water depth H is 15 to 20mm or above, and flow velocity V is 0.5m/s or above. These values are considered to be the requirements for maintaining good carrying performance.

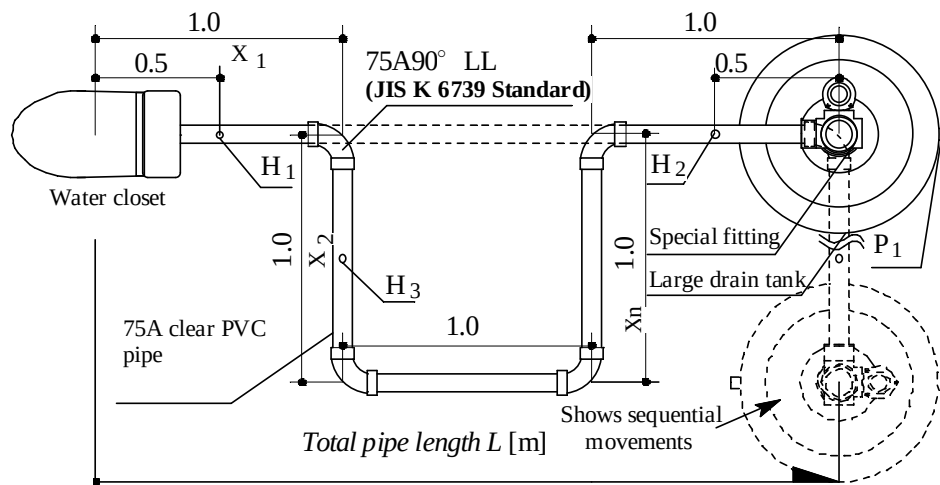


Fig.11 Experimental horizontal fixture drain branch system (sewage water system)

Substitute material for waste	BL Standard		BL Recommended		Standard by Fukuoka City
	A	A'	B	B'	C
Sponge	PVA Sponge:2 pieces	PVA Sponge:2 pieces	Toilet paper rolled:6m(1-ply)	Toilet paper rolled:6m(2-ply)	PVA Sponge:4 pieces
Paper	Toilet paper crumpled:4 pieces (1-ply)	Toilet paper crumpled:4 pieces (2-ply)			Toilet paper crumpled:7 pieces (1-ply)
Photo					
Waight [kg]	0.23	0.27	0.12	0.22	0.4
Volume $\times 10^{-5} [\text{m}^3]$	23.2	28.8	11.3	21.7	42.1
Density $[\text{kg}/\text{m}^3]$	996	931	1050	987	937
Acting force [N]	2.27	2.74	0.91	2.83	3.43

Fig.12 List of waste substitutes

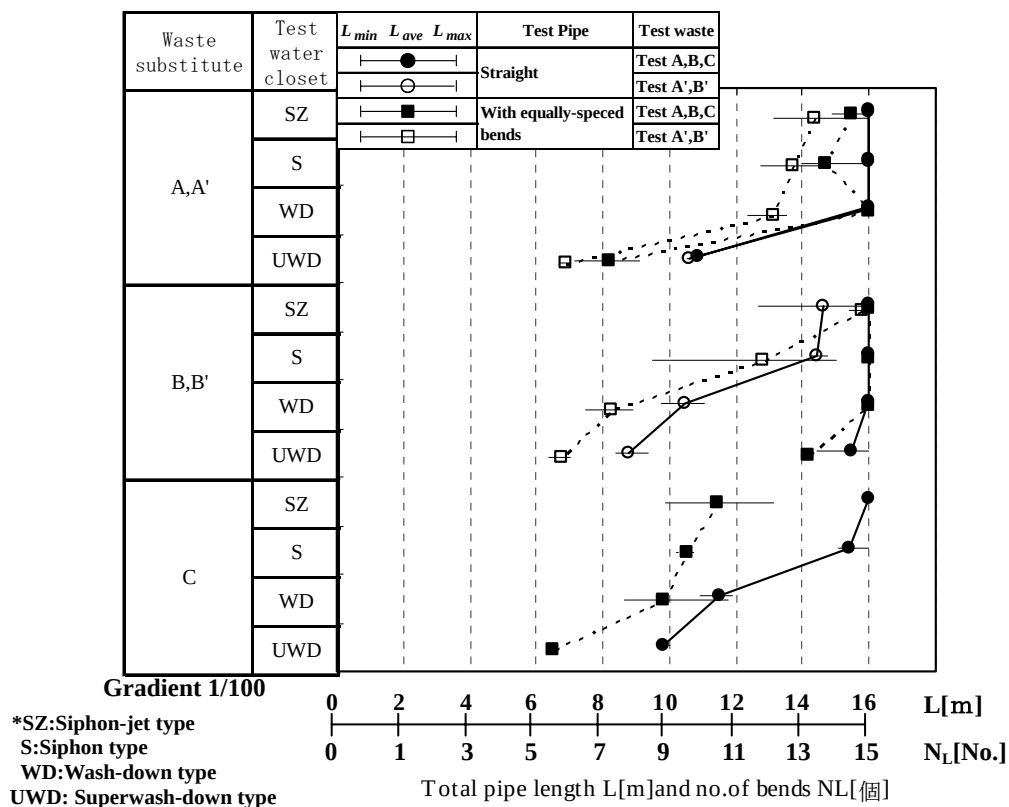


Fig.13 An example result of the carrying performance test on a sewage water system

*L: total length, N_L : no. of pipe bends

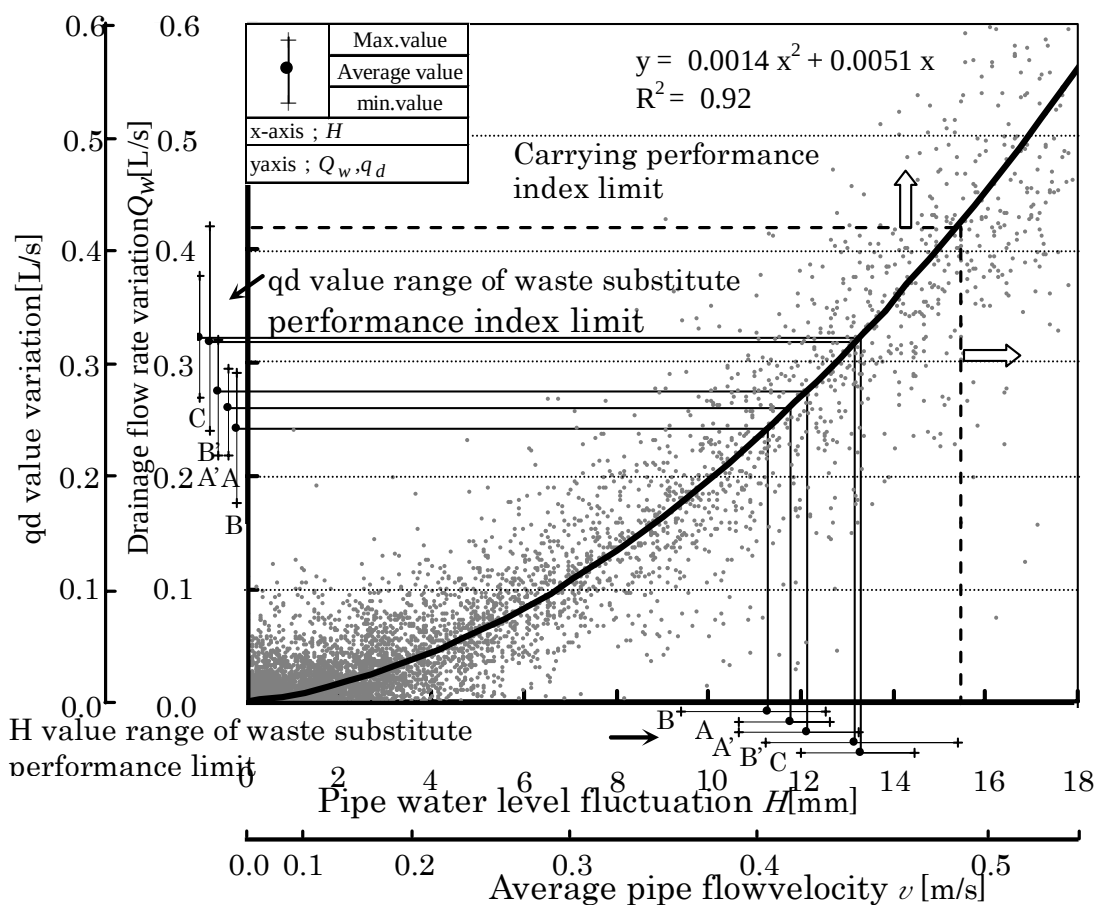


Fig.14 Relationship of water depth and flow velocity in the pipe with qd value variation

3.2 The reduction of induced siphonage by combined drainage from multiple sanitary fixtures and the effect of backflow prevention

Fig. 15 shows the maximum and minimum values of pressure in the horizontal fixture drain branch when wastewater from multiple sanitary fixtures, which are connected to the horizontal fixture drain branch, is combined and drained together. The results are shown in comparison between the conventional system and the system for SI housing. When combined drainage water is generated from two fixtures or from three fixtures, the pipe pressure variation exceeds -400Pa on the conventional system but it is kept within $\pm 100\text{Pa}$ on the system for SI housing. This suggests that the pressure variation is much likely to stay within $\pm 400\text{Pa}$, the limit specified by SHASE-S 218, ensuring that there is no risk of trap seals broken by induced siphonage created by combined drainage water. It has therefore been confirmed that the horizontal fixture drain branch system with drain headers for SI housing is much safer to adopt than the conventional system.

Furthermore, it is visibly clear that there is hardly any risk of combined drainage water backflowing to the floor drain traps which are installed in low positions near the floor surface. This is because, as shown in Fig.4, the horizontal fixture drain branch system with drain headers for SI housing allows more under-floor space (between the slab surface and the finished floor surface) which prevents backflows, if they occur, from reaching the floor traps.

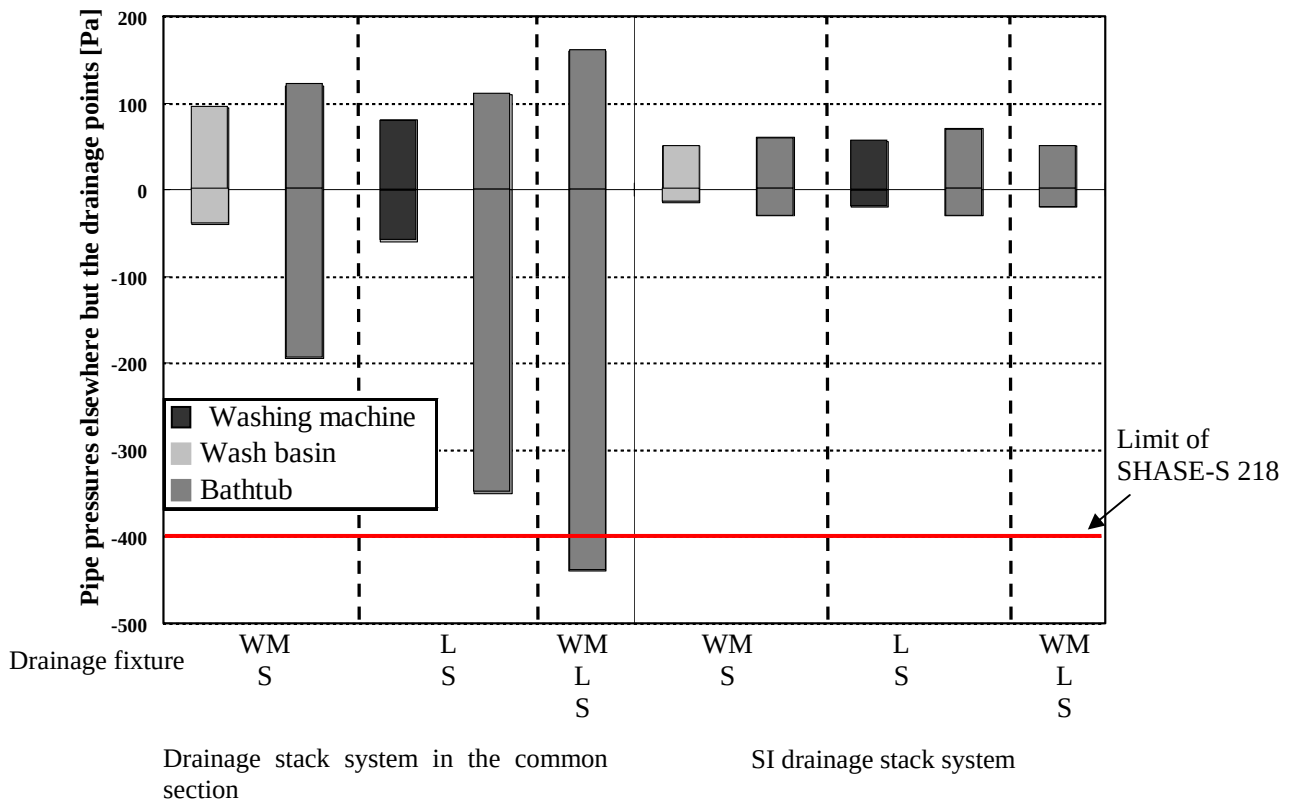


Fig.15 Comparison of drainage pipe pressure by combined drainage

4. Summary

This study examined the horizontal fixture drain branch system with drain headers for SI housing, which has improved updatability and maintainability for long-life housing complexes, and reached the following conclusions mainly in terms of design and planning advantages and points to bear in mind when implementing performance evaluation.

(1)The drainage stack was installed in the support section and under-floor space was secured sufficiently. This improved the updatability of pipework while confirming that this is a system design which enables the easy modification of plumbing layout in the infill.

(2)The relationship between the length of the horizontal fixture drain branch and the average fixture drainage flow rate, q_d value, was identified. The length variation and the q_d value variation were then used for the steady flow rate method under SHASE-S206 to calculate the drainage flow load to the drainage stack. The results indicate that compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing can reduce the drainage load to the drainage stack.

(3)Especially as for the horizontal fixture drain branch which is connected to the Water closet, the relationship between the variation of the average fixture drainage flow rate, in-pipe water level and in-pipe flow velocity was figured out to determine the level of ability to carry various types of waste substitutes. The conditions to limit these values were also clarified.

(4)It is certain that backflows are not caused to traps that are connected to the pipework even when wastewater from multiple sanitary fixtures is combined and drained together and that the pipe pressure variation, which is the cause of induced siphonage, remains below the reference value of $\pm 400\text{Pa}$. Therefore, the horizontal fixture drain branch system with drain headers for SI housing is superior to the conventional system from the performance point of view.

Acknowledgement

During this study, part of the Academic Frontier Promotion Project “Strategic Development Research of Symbiosis Technologies to Achieve Urban Building Stock Refurbishment”, which is supported by the Ministry of Education, Culture, Sports, Science and Technology, was kindly provided for reference.

5. References

- 1)Masayuki OTSUKA, et al. Study on the Drainage Performance Evaluation and the Design Method of Horizontal Drainage Pipe Systems for SI (Support & Infill) Housing Part1-Experimental Study on Drainage Performance of Model Piping System, July

2001, Paper No. 82, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan

2)Masayuki OTSUKA, et al. Study on the Drainage Performance Evaluation and the Design Method of Horizontal Drainage Pipe Systems for SI (Support & Infill) Housing Part2 - Declining Characteristic of the qd-Value and the Load on the Drainage Stack, January 2003, Paper No. 90, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan

3)Masayuki OTSUKA, et al. Study on the Drainage Performance Evaluation and the Design Method of Horizontal Drainage Pipe Systems for SI (Support & Infill) Housing Part5-Discussion Regarding the Calculation Method of the Decrease of the Average Flow Rate of Sanitary Fixtures and Carrying Performance, July 2006, Paper No. 111, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan

4)Takatoshi ISHII, et al. Experimental Study of Drainage Characteristics of Water-saving Toilet Bowls and Carrying Performance Evaluation, Sep 2008, 33rd CIB-W062 Symposium Book of Papers,pp.463~476,(Brno, Czech Republic)

5)SHASE-S206-2000 Plumbing Code

6)SHASE-S218-2008 Testing Methods of Flow Capacity for Drainage System in Apartment Houses.

6. Presentation of author

Masayuki Otsuka is a professor at the Department of Architecture, Kanto Gakuin University. He is a member of AIJ(Architectural Institute of Japan)and SHASE(Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, academic director). His current research interests are the performances of plumbing systems, drainage systems with drainage piping systems for SI(Support and Infill)housing.

