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The Comprehensive Structural Investigation Programme – A Green Initiative for Building Sustainability

Authors:

Ir. S.T. Chan, the Hong Kong Housing Authority, st.chan@housingauthority.gov.hk

Ir. Danny K.C. Chung, the Hong Kong Housing Authority, kc.chung@housingauthority.gov.hk

Ir. Bosco L.K. Au, the Hong Kong Housing Authority, lk.au@housingauthority.gov.hk

Ir. Stanley T.K. Ng, the Hong Kong Housing Authority, stanley.ng@housingauthority.gov.hk

Contact Point:

Stanley T.K. Ng

4/F, Block 1, Hong Kong Housing Authority Headquarters,

33 Fat Kwong Street, Ho Man Tin, Kowloon, Hong Kong

Tel: (852) 2761 7301

Mobile: (852) 6380 6802

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Ir. S.T. Chan, the Hong Kong Housing Authority, st.chan@housingauthority.gov.hk
Ir. Danny K.C. Chung, the Hong Kong Housing Authority, kc.chung@housingauthority.gov.hk
Ir. Bosco L.K. Au, the Hong Kong Housing Authority, lk.au@housingauthority.gov.hk
Ir. Stanley T.K. Ng, the Hong Kong Housing Authority, stanley.ng@housingauthority.gov.hk

ABSTRACT

The Hong Kong Housing Authority (HKHA) is currently managing a housing stock of around 730,000 flats with a population of over two million people. Driven by a policy evolution from mass redevelopment of aged buildings to optimizing use of public housing resources, the HKHA in 2005 rolled out the Comprehensive Structural Investigation Programme (CSIP) with the purpose of further sustaining its aged buildings. The CSIP is the first programme in Hong Kong which systematically and thoroughly probes into the in-depth structural conditions of aged buildings so as to ascertain root causes of defects, vulnerability to deterioration and long-term structural performance, based on which sustainable solutions are developed to maintain them in good conditions for at least 15 years. For such purpose, a number of innovative repair and maintenance solutions were established along with the CSIP over the years. The CSIP has proved to be a win-win-win solution enabling sustainable development of the HKHA buildings on environmental, economical and social fronts. The HKHA has been striving to share with the building industry its knowledge and experience accrued from the CSIP, including its established investigation methodology, findings as well as its innovation of repair and improvement schemes, with a vision of enhancing the long-term building sustainability in the territory.

Keywords: Building Sustainability, Building Deterioration, Comprehensive Structural Investigation, Innovative Solutions, Sustainable Development

1. BUILDING SUSTAINABILITY

1.1 Sustainability is the ability to meet today's needs without compromising those of subsequent generations. It is often described by the Venn diagram (Figure 1) with three overlapping aspects: Environmental, Economical and Social. For the past decade, a high level of research interest in green buildings has spawned notable environmental advances on all fronts including design philosophy, construction methodology, and energy efficiency. Many of the advances have been put into practice today by the building industry resulting in innovative buildings with lower carbon footprints and enhanced sustainability. While the industry is heading in the right direction for new construction, one cannot forget that new buildings in a highly developed city like Hong Kong only accounts for a fraction of the sustainability problem. In fact, the number of newly completed residential flats of all types in Hong Kong was only 27,000 units in 2011, which represents a mere 1% of the 2.6 million existing units [1]. In terms of public housing, the Hong Kong Housing Authority (HKHA) completed about 11,000 flats in Year 2011/2012, but the number still accounts for less than 2% of the existing public housing units. Hence, building sustainability for the territory at large cannot be upheld without a green strategy managing and maintaining the existing building inventory.

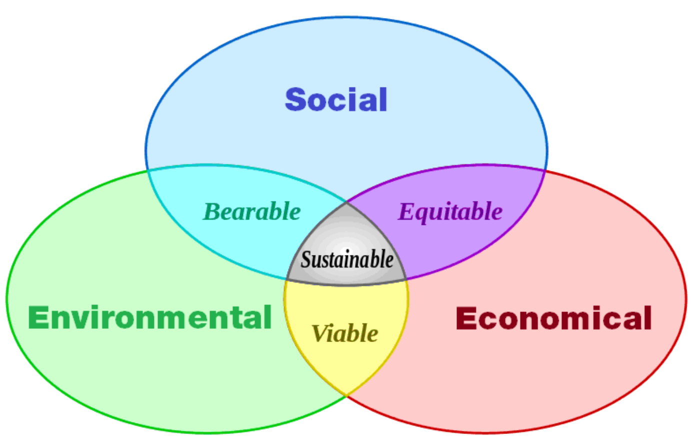

Figure 1: Overlapping Aspects of Sustainable Development

2. SUSTAINABILITY CHALLENGES FOR HKHA EXISTING BUILDINGS

Public Housing Development in Hong Kong

2.1 Public housing in Hong Kong has a long development history tracing back to the early 1950s. In the wake of the Shek Kip Mei fire on the Christmas Eve in 1953, the Hong Kong Government built the first resettlement estate to house the 53,000 homeless resulted from the tragedy. Building on the success of this initiative, a massive construction programme was established to provide affordable public housing for low-income families. In 1973, the HKHA was established to take charge of constructing and managing the public housing. The HKHA is currently maintaining more than 1,100 residential buildings accommodating over two million people. In the past, the main policy of the HKHA regarding old buildings was redevelopment, i.e. demolishing old ones and building new ones. Considering the heavy drain of land, manpower and financial resources resulting from the mass redevelopment and with the heightened environmental awareness in the late 1990s, the HKHA has switched to a sustainable strategy of maintaining buildings to optimize the use of housing resources. However, implementation of the sustainable strategy is met with three major challenges, namely, aging housing stock, aggressive environment, and old building design and construction technology.

Aging Public Housing Stock

2.2 In the HKHA's housing stock of 1,166 buildings, 216 (18.3%) buildings were constructed in or before the 1970s and 512 (44%) buildings in or before the 1980s (Table 1).

Table 1: Profile of the Public Housing Stock in 2012

Year of completion	Number of residential buildings	Percentage of total (%)
1950's	10	0.9
1960's	62	5.3
1970's	144	12.3
1980's	296	25.4
1990's	260	22.3
Since 2000	394	33.8
Total	1,166	100.0

Concrete is a durable material with good resistance against various attacks including fire, water, weather and chemicals. Despite its durability, the HKHA public housing stock, which mainly comprises reinforced concrete buildings, is deteriorating with time due to the interaction amongst various deterioration processes With the increasing number of the aging residential buildings, the conventional approach of reactive maintenance (i.e. provide a quick-fix repair after a visible defect appears) is not effective in slowing down the deterioration process. In fact, based on a study [2] by the CONREPNET team on the repair performance of 230 structures in 11 countries, only 50% of the repairs could be regarded as successful within the first 5 years. Failures of repairs could be attributable to inappropriate design, wrong diagnosis of causes, incompatible materials, and poor workmanship. As the responsive repairs obviously have their drawbacks, there is a clear need of having a proactive maintenance strategy that addresses the root causes of building deterioration and implements deterioration-arresting measures to further sustain the useful life of the aged public housing of the HKHA with minimum life cycle repair / maintenance cost.

Aggressive Environment

2.3 Hong Kong enjoys a subtropical climate free from major natural disasters. However, its coastal environment is hostile to reinforced concrete structures. Along the sea coasts, sprayed droplets of airborne chloride can be transported onto the surface of reinforced concrete structures by wind resulting in a higher risk of corrosion [3]. In addition, chloride attack may originate from toilet flushing with seawater causing the aerosol effect [4]. The steel corrosion rate under the chloride-laden environment can be 2.75 times higher than the chloride-free environment [5]. The resulting corrosion process causes concrete to crack, which in turn, induces further chloride ingress and accelerates the deterioration process.

2.4 Apart from chloride attack, the deterioration of reinforced concrete is also caused by the attack of acid rain and carbonation [4]. Rainwater becomes acidic in the atmosphere in the presence of pollutants, such as carbon dioxide and nitrogen dioxide. The rainwater pH values published by the Environmental Protection Department of Hong Kong from 1998 to 2011 vary between 4.27 and 4.73 [6]. When acidic rain is in contact with concrete, pollutants left behind penetrate through the cracks and diffuse through the porous concrete. Similar to carbonation, acid rain neutralizes the alkalinity of concrete leading to the breakdown of the steel alkalinity protective film. With adequate supply of oxygen and moisture, corrosion of rebars would be initiated resulting in cracking and spalling of concrete.

Old Building Design and Construction Technology

2.5 Early public housing in Hong Kong was designed to British standards which formed the basis of the Hong Kong Building Regulations. Though British Code CP110:1972[7] introduced four environmental exposure classes in the 70s, the concrete cover and concrete strength requirements in Hong Kong had not increased until the introduction of the 1990 version of the Building Regulations [8, 9]. As a result, domestic buildings in Hong Kong built before 1990 typically specified Grade 20 concrete and 15 to 20 mm concrete cover for internal elements. Due to the lower concrete grade and inadequate cover, the older public housing buildings are today subject to a higher deterioration rate because of the vulnerability to ingress of water and contaminants. Moreover, exposed elements such as open staircases, balconies and cantilever corridors (Figure 2) common in the older buildings are constantly subject to frequent wet-dry cycles and UV attack. In addition, numerous moisture ingress paths are possible in the design and construction of toilet-cum-bathrooms without bathtub (Figure 3). Under these outdated design and construction conditions, quick-fix repairs would not be able to slow down the deterioration process, and the ensuing disturbing repetitive repairs would neither be cost-effective nor environmentally-friendly.

Figure 2: Exposed Elements in Aged Public Housing

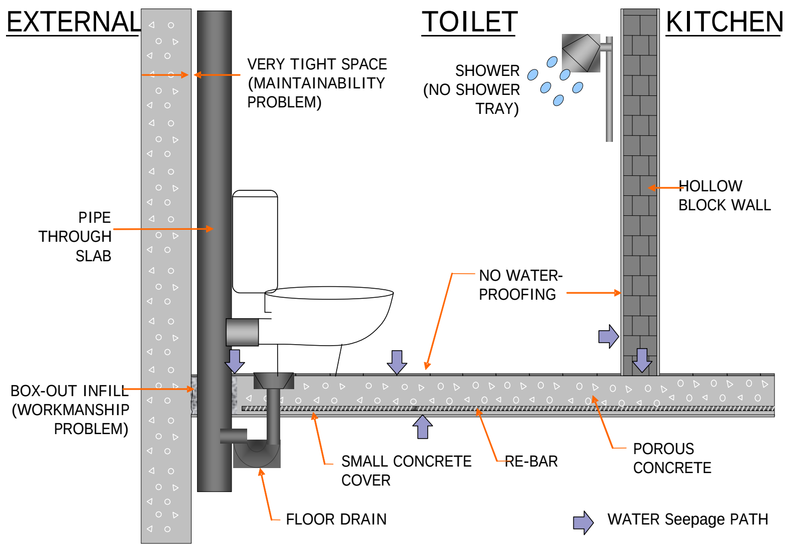

Figure 3: Possible Water Seepage Paths in Toilets

3. THE COMPREHENSIVE STRUCTURAL INVESTIGATION PROGRAMME

Background

3.1 Faced with the increasing rate of deterioration, one of the main strategies of the HKHA in the 1980s was to replace structurally obsolete estates with complete redevelopment. While numerous green initiatives can be adopted for a new estate resulting in possible lower energy consumption in operation, demolition and replacement of an existing estate is, nevertheless, an overwhelming energy intensive procedure. Owing to the premature loss of embodied energy[1] in good concrete of the existing structures, the redevelopment strategy cannot be considered as a sustainable way in meeting the housing needs of people. To meet the challenge of building sustainability,

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1 Embodied Energy - The energy used through the life cycle of a material or product to extract, refine, process, fabricate, transport, install, commission, utilize, maintain, remove, and ultimately recycle or dispose of the substances comprising the item" – ASTM committee E60

the HKHA has developed and launched the Comprehensive Structural Investigation Programme (CSIP) in 2005 with the following characteristics:

- Prioritization of resources in accordance with member sensitivity to deterioration
- Identification of root causes of defects
- Early intervention to slow down the deterioration process at its on-set
- Development of effective and durable solutions
- Monitoring of the performance for continual enhancement

Descriptions of CSIP

3.2 The CSIP serves to identify the in-depth structural conditions of the aged public housing buildings and develop solutions to further sustain them for at least 15 years in an environmentally responsible manner. The CSIP adopts a knowledge based approach using the concepts of ISO 15686-1:2000(E) “Buildings and Constructed Assets – Service Life Planning – Part 1: General Principles” [10]. Due to the fact that the public housing of the HKHA comprises mainly standard buildings constructed on a repetitive basis, experience and findings obtained from the investigation of one building may be extended to similar buildings after thorough consideration and statistical analysis. The knowledge database mainly provides information in three areas (Figure 4), namely, the categorization of elements with similar risk levels or defective patterns, the characteristics of vulnerable elements, and the correlation between defects and service conditions / symptoms. The knowledge gained from a new investigation would be reviewed and calibrated against those in the knowledge database. Where necessary, the knowledge database could be updated for subsequent applications.

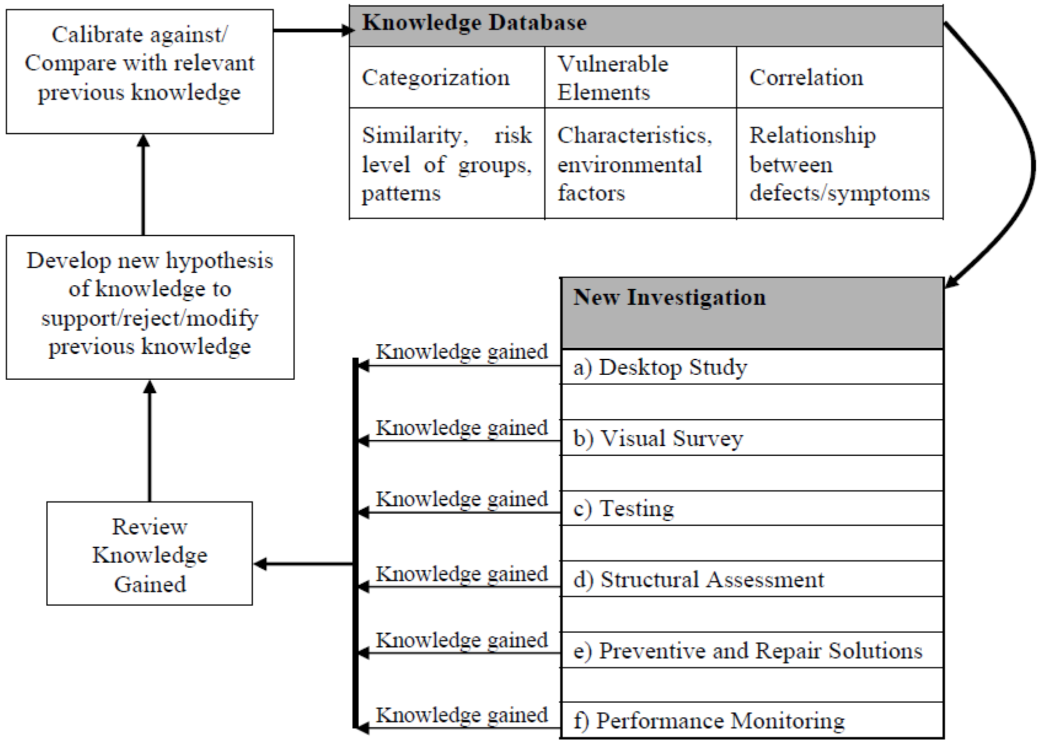

Figure 4: Knowledge Based Approach for the CSIP

A new CSIP investigation embraces 6 major activities, which are briefly described below:

a) Desktop Study

A desktop study for a new investigation involves the study of records including the repair history, record drawings, design calculations, past structural appraisals, and previous improvement/strengthening records. Elements that required substantial or repeated repairs as recorded from the repair history would be one of the focuses in this new investigation. Extra attention would also be paid to vulnerable structural elements as revealed by the knowledge database.

b) Visual Survey

A visual survey is conducted to cover all common and external areas. Based on the experience accrued from the CSIP, the in-flat inspection rate is set at 5%, which provides a good balance between minimizing the disturbance to the tenants and maximizing the representativeness of the surveys. The inspection rate would be increased whenever necessary for the purpose of identifying the root causes of defects. Besides documenting all visible defects on structural elements, the survey also identifies defects of non-structural elements which may pose structural concerns. Unauthorized structural alteration or addition works are also recorded for further actions to be taken. Tenants are interviewed in order to get a better picture on the causes of defects and for determining the associated repairs required.

c) Testing

Tests are carried out to determine the in-depth conditions of structural elements and identify the root causes of defects. Destructive tests are mainly conducted in selected common areas and vacant flats to minimize disturbance to the tenants. A destructive test is opening up of concrete for measurements of dimensions of corroded steel bars, concrete cover thicknesses, and carbonation depths. In-situ cores are also taken for compression tests and chloride content determination. Non-destructive tests are carried out at common areas, vacant flats, and occupied flats as well. These include concrete moisture content measurements to locate water leakage areas; concrete sounding examinations to detect delamination and spalling; half cell potential tests to assess corrosion risks; and corrosion current surveys to quantify reinforcement corrosion rates.

d) Structural Assessment

Based on the findings of the desktop study, visual surveys and testing results, a structural analysis is performed to evaluate the structural adequacy of all structurally critical members. A pathological assessment is also conducted to examine the root causes of defects and susceptibility of the structural elements to corrosion. Besides addressing the current structural safety concerns, information gathered would be used to project future structural conditions including the extent of steel corrosion for the next 15 years. The results would be used to formulate the preventive and repair solutions required for the buildings to be further sustained for at least 15 years.

e) Preventive and Repair Solutions

Contamination of concrete and corrosion of reinforcing bars in aged buildings are attributable to a variety of causes. Traditional concrete repair methods may not be designed to tackle the root causes of defects and cannot cope with some of the deterioration mechanisms. Since the inception of the CSIP in 2005, a number of new preventive and repair solutions have been developed and adopted to cater for particular situations of the public housing. Those state-of-the-art repair techniques and solutions developed/used under the CSIP are further described in Section 4.

f) Performance Monitoring

The CSIP is always about getting better based on the accumulated experience. In achieving this objective, long-term performance monitoring is required to improve the maintenance strategy. The monitoring may include visual surveys, moisture surveys, non-destructive tests, tenant interviews, and statistical analysis of the maintenance requirements before and after the repairs. Based on the monitoring results, adjustments and enhancements can be made to the formulated strategy with due considerations given to the environment, life-cycle cost, and disturbance to the tenants.

4. SUSTAINABLE REPAIR & MAINTENANCE STRATEGY & EXAMPLES

4.1 While there is an implicit idea of trade-offs amongst the environmental, economical, and social aspects of sustainability, the HKHA under the CSIP has formulated a number of repair and maintenance techniques that proved to be win-win-win solutions in all the aspects. The emphases (Figure 5) of the development and adaptation of repair solutions of the CSIP are to:

- Slow down deterioration in the first place
- Prolong the service life of existing elements
- Lower the life-cycle cost of maintenance
- Minimize the nuisance to tenants

Some examples of the structural repair and improvement schemes developed under the CSIP are depicted in the following sections.

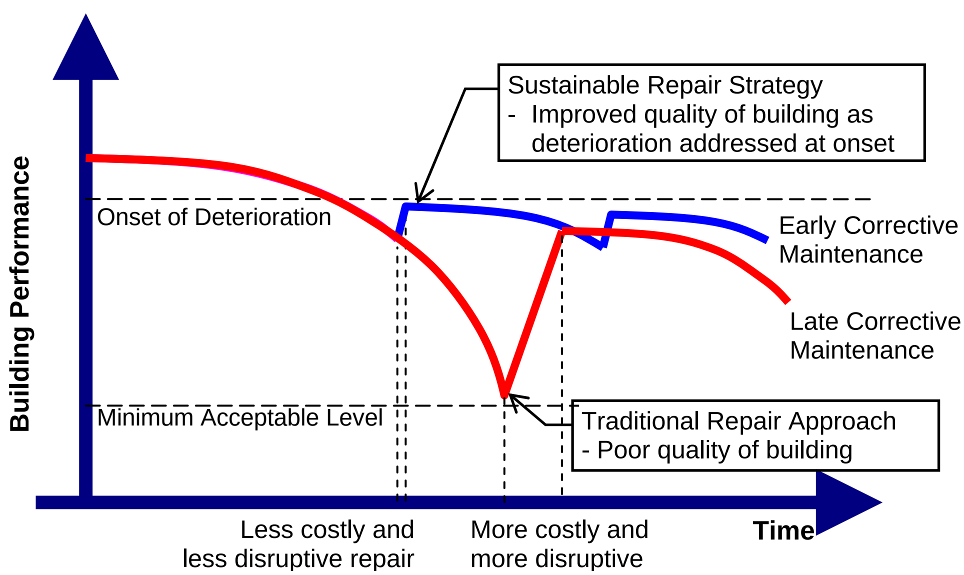

Figure 5: Sustainable Repair Strategy of CSIP vs Traditional Repair Approach

Structural Enhancement and Moisture Barrier for Empty Bays

4.2 In some older public housing buildings, open empty bays designed for recreational purposes were often built with external grille block façades (Figure 6, 7). The comprehensive structural investigation (CSI) revealed that rainwater would penetrate the external grille block walls leading to water ponding at some empty bays with improper fall of slabs (Figure 7). The frequent wet and dry cycles accelerated the corrosion process resulting in concrete cracking and spalling, which in turn, worsened the water seepage problem and became a major nuisance to the tenants living below the empty bays (Figure 8). Previous attempts in remedying the problem involved local concrete repair of visible defects and sealing the cracks with chemical injection. However, as the root causes of water penetration to the empty bays had not been addressed, corrosion continued resulting in repeated water seepage and concrete defects. In most severe cases, total recasting of the slab was necessary to restore the structural integrity of the concrete slabs. The required decantation of the units below the empty bays was obviously a major disturbance to the sitting tenants, and the construction noise and dust arising from the demolition and recasting works also caused tremendous nuisances to the nearby units.

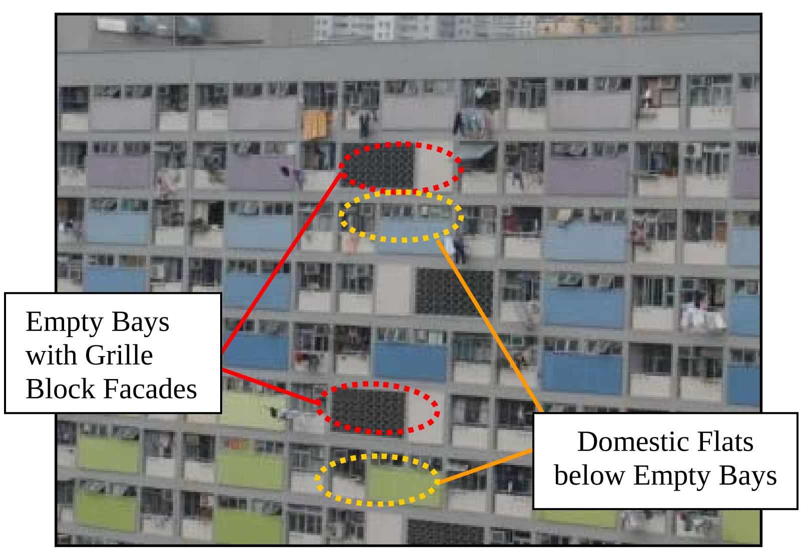

Figure 6: Empty Bays with Grille Block Façade above Domestic Flats

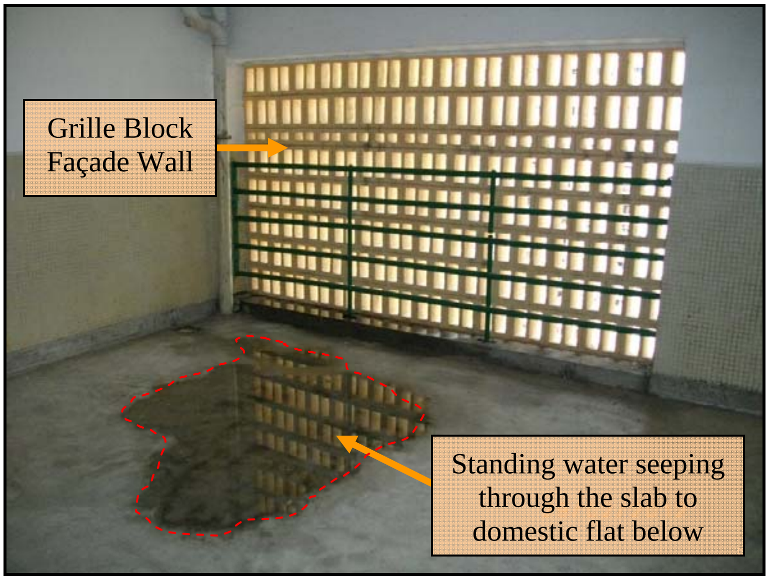

Figure 7: Poor Empty Bay Conditions (Conventional Repair Not Effective)

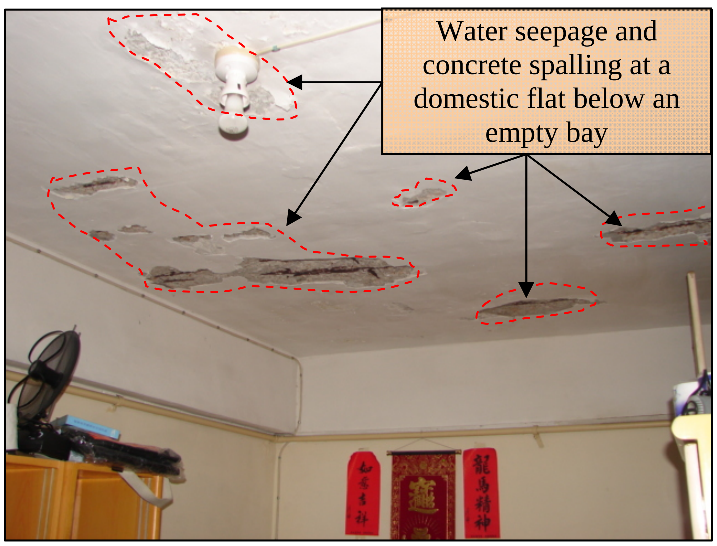

Figure 8: Poor Conditions of Domestic Flat below Empty Bay

To address the continual deterioration of some empty bays, a three-level repair solution was introduced under the CSIP. As the first line of defence, the existing grille block walls were converted to solid walls to minimize the original source of water ingress (Figure 9). As the second line of defence, a layer of trafficable waterproofing was applied on top of the slab to prevent water from seeping into the slab. Before applying the waterproofing layer, the top of the defective concrete slab was replaced with high performance concrete (HPC) developed under the CSIP as the third line of defence with the following characteristics (Figure 10):

- Excellent water barrier with its low water absorption quality
- Good compatibility with the existing concrete due to its comparable modulus of elasticity, good bonding characteristic and low shrinkage
- Ease of construction with its self-consolidating attribute
- Minimum disturbance to tenants with its quick setting property

Apart from serving as the third line of defence against water seepage, the HPC overlay also plays a role to enhance the structural capacity and durability of the deteriorated slabs. Based on the performance monitoring results of this three-level repair solution, no water leakage has been found after the repair and the concrete moisture content inside the repaired concrete slab was generally low, resulting in a slow rate of corrosion. The tailor-made solution for the empty bays is able to extend the service life of the existing reinforced concrete elements and eliminate the needs of repeated patch repairs and decantation for concrete recasting.

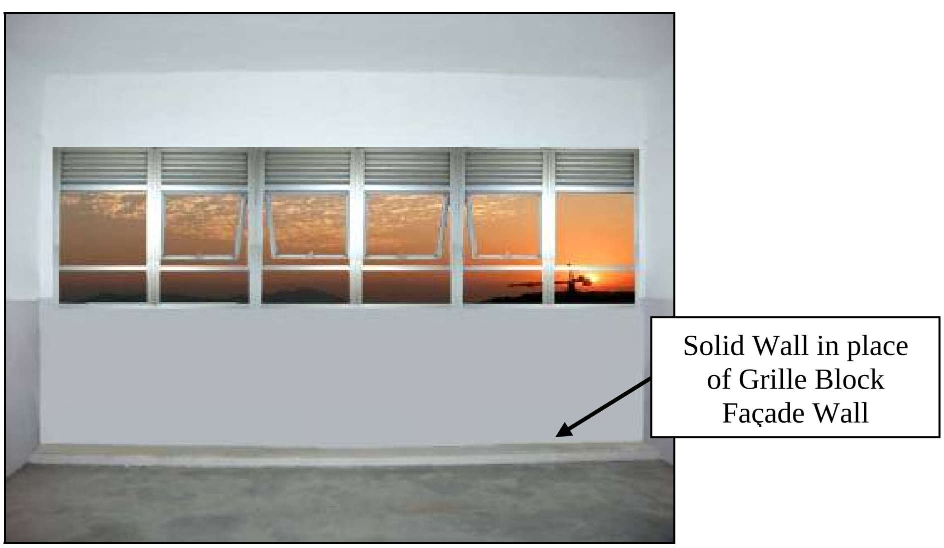

Figure 9: Good Empty Bay Conditions after the implementation
of the Three-level Repair Solution

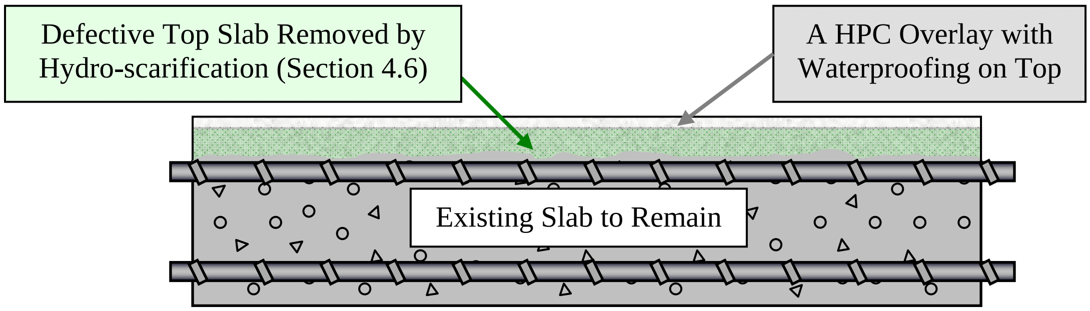

Figure 10: Durable Remedial Measure for Concrete Slab of Empty Bay

Multi-pulse Sequencing System (MPS) for Basements

4.3 Severe ground water seepage and corrosion were found at basements of some public housing buildings due to deterioration of the existing basement waterproofing and high levels of water pressure. For this type of exposure conditions, external waterproofing is considered by the International Building Code [11] as the only effective method to prevent structural damage caused by water intrusion. Unfortunately, this would involve very major excavation in the public housing cases where the basements can be at a few floors below ground. The associated cost, nuisance and technical difficulties are prohibitively high. As a result, previous attempts in addressing the issue was either to provide chemical injection from inside of the basements to stop the seepage or provide a proper drainage path for the infiltrated water to limit the damage. However, as no re-waterproofing had been done to stop water infiltration at the source, water leakage together with reinforcement corrosion and structural deterioration continued. Faced with the shortcomings of these conventional measures, a multi-pulse sequencing (MPS) system was introduced under the CSIP to stop water seepage and the resulting structural deterioration without the need of major excavation. The MPS system includes a series of low voltage, low current and pulsating charges passing through the anode and cathode strategically placed within the basement (Figure 11). The pulsating charges create an electro-osmotic force which repels water from concrete [12]. Indeed, the MPS system used in the CSIP (Figure 12) is successful in keeping water away from the basement without the need of an external waterproofing system. The adoption of the MPS system eliminates the safety risk, substantial expenditure and social disturbance to the tenants caused by major excavation. The service life of the structure is also extended with a minimal impact on the environment.

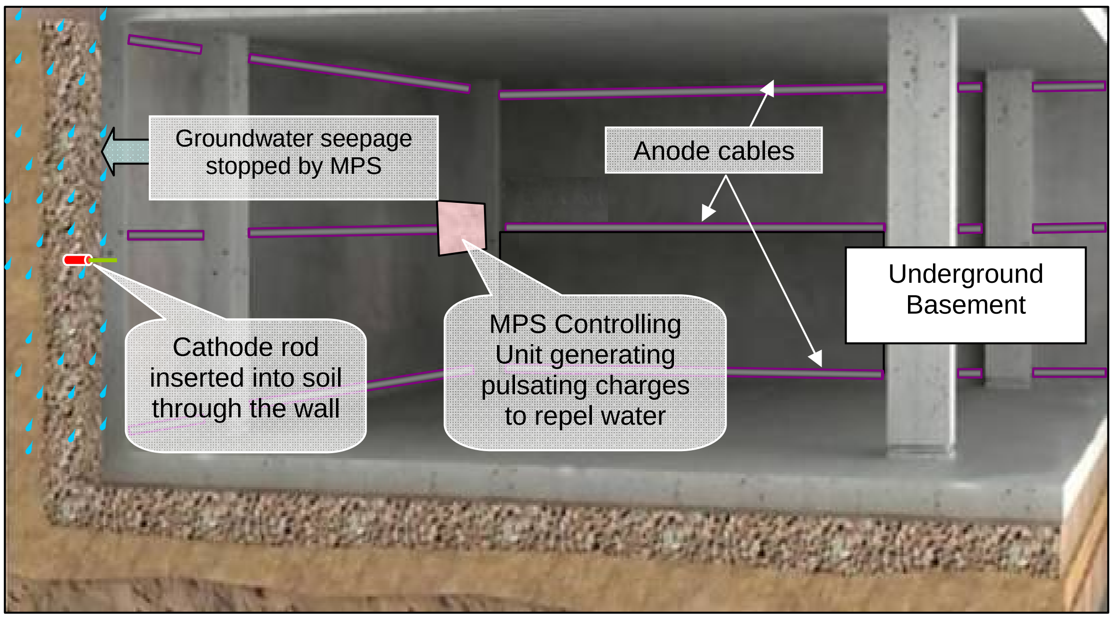

Figure 11: MPS System Preventing Water Seepage at Basement

Figure 12: Basement Conditions before and after the Installation of the MPS system

Electrochemical Protection for Chloride-contaminated Concrete

4.4 There is a paradox about patch repair for chloride contaminated concrete. Due to an electrical potential difference between the new (i.e. chloride-free) and existing (i.e. chloride-contaminated) concrete, corrosion of steel bars in the existing concrete adjacent to the new repair would accelerate (Figure 13). This corrosion, known as the ‘patch-accelerated corrosion’ [13, 14], worsens the condition of the surrounding existing concrete and is the major reason why residents are often unsatisfied with the repair performance. To minimize the electrical potential difference between the chloride-free and chloride-contaminated concrete, one feasible method is to enlarge the extent of concrete removal so that most chloride-contaminated concrete is removed. However, this method is neither cost effective, customer-oriented, nor environmentally friendly. The premature loss of embodied energy in the structurally sound concrete and the additional embodied energy required in the replacement would have a large impact on the environment. As a result, an alternative method has been put forward under the CSIP to address the patch-accelerated corrosion. The new method involves placing sacrificial anodes systematically (Figure 14) to the exposed reinforcement in order to provide galvanic electrochemical protection for the existing reinforcement surrounded by the chloride-contaminated concrete [15]. The sacrificial anodes are made of zinc alloy with a higher electrical potential for corrosion than steel; hence, the zinc alloy would corrode preferentially in the galvanic cell. Although the initial cost of a patch repair with this galvanic protection system is higher than a normal patch repair, the life-cycle cost of providing this system is highly favourable as the existing surrounding reinforced concrete can be effectively protected from corrosion for 15 years. In addition, the social and environmental gains from the prevention of repetitive repairs are invaluable to building sustainability.

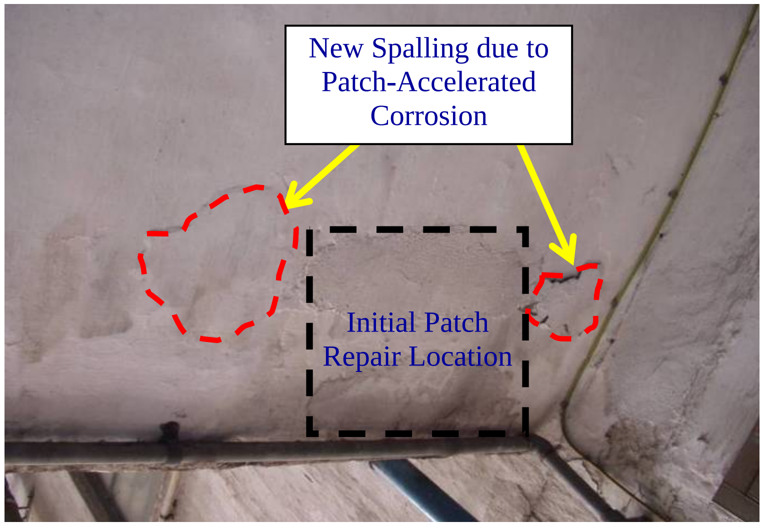

Figure 13: New Spalling due to Patch-Accelerated Corrosion

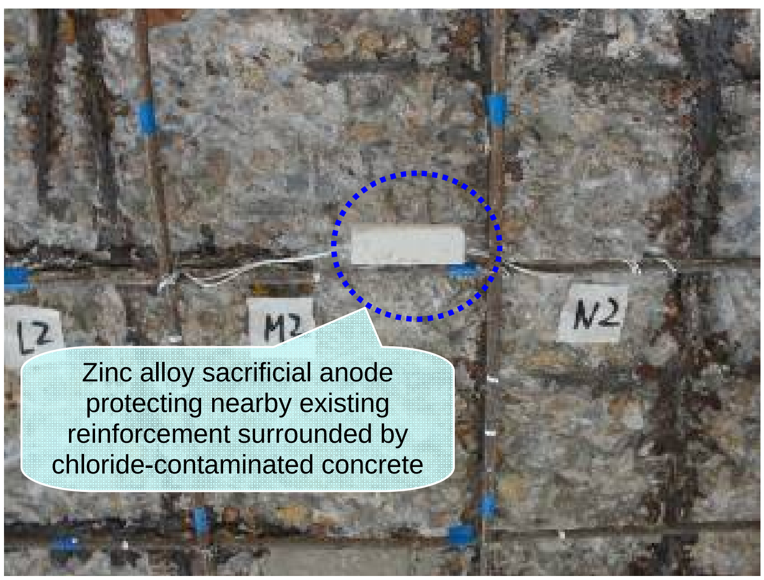

Figure 14: Electrochemical Protection System with Sacrificial Anodes

Carbonation Barrier for Concrete

4.5 The major cause of corrosion in reinforced concrete is carbonation. Based on the investigation results of the CSIP, carbonation rates vary considerably depending on the concrete quality and the surrounding environment. Lower grade concrete is typically associated with a higher rate of carbonation probably because of the higher permeability for carbon dioxide diffusion. As a result, a higher concrete grade with lower permeability can be specified for a new construction to delay the carbonation process. However, for existing reinforced concrete structures, an alternative method is needed to delay the carbonation process in order to prolong their service life. One of the possible methods is the utilization of anti-carbonation paint as a carbon dioxide barrier for concrete when carbonation front has not yet reached the reinforcement. Under the CSIP, a study [16] developed the test specifications for evaluating the anti-carbonation performance of existing paint coatings available in Hong Kong. Besides using the specifications for existing product evaluations, the newly developed specification would also encourage further advance in the carbonation suppression performance of future paint products used in public housing. In addition, the study provides an engineering basis for programming the façade re-painting schedule in a systematic manner to suppress carbonation during the service life of a building. Based on the cost modeling analysis of the same study, a saving of 64% from spalling repair cost could be achieved if paint is properly selected and used. In addition to economical incentive, the reduction of spalling repair would benefit the environment because of the reduction in construction waste and energy. The tenants would also be freed from the nuisance of constant spalling repair and the risk of falling concrete.

Hydro-scarification for Concrete Removal

4.6 For repair to buildings, mechanical concrete breaking with hand-held jack hammers is common because of the flexibility it offers. However, jack hammering

(Figure 15) may cause micro cracks in concrete and damage existing reinforcement in the process [17, 18]. Moreover, the dust, noise, and vibration generated by jack hammering would be a major nuisance to the tenants of the entire building. As a result, hydro-scarification machines, which achieve the concrete destructive action by means of water pressurisation of cracks and cavitations in an automatic manner (Figure 16), were developed under the CSIP. The major advantages of the hydro-scarification machine in concrete removal are:

- No micro crack induced in concrete
- No damage to reinforcement
- Resulting in a sound exposed concrete surface with a good mechanical key
- Reduction in structural-borne sound and vibration
- Reduction in dust during concrete breaking
- Flexibility in concrete removal depth by adjusting the water pressure

To suit the site constraints in the public housing buildings, the original hydro-scarification machine developed under the CSIP was enhanced to facilitate transportation, access, and application. Further green initiatives in reusing wastewater and recycling aggregates arising from the hydro-scarification work are being undertaken. The concrete removal technique was successfully employed in several existing public housing estates with encouraging feedback from the tenants and stakeholders. Besides being widely used in the HKHA projects, the HKHA has been striving to introduce the hydro-scarification technique to the building industry including both public and private sectors, with a view of turning the hazardous and disturbing concrete removal task to a safe and environmentally-friendly operation.

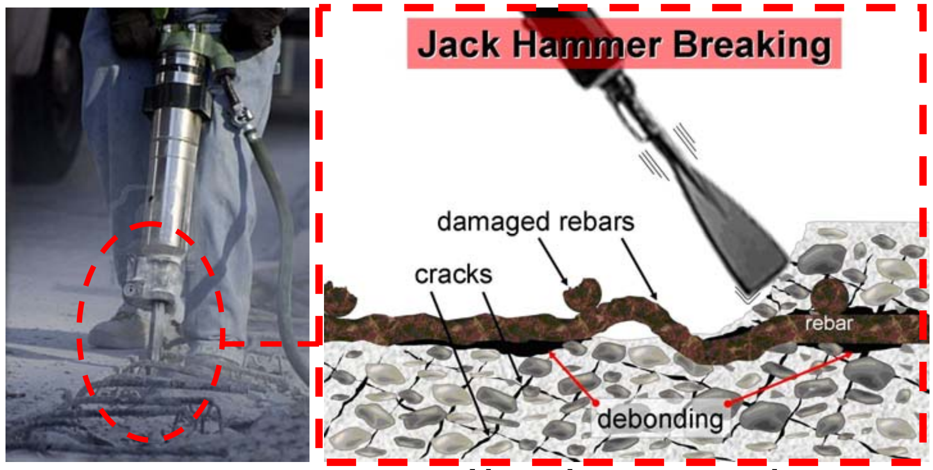

Figure 15: Concrete Removal by Jack Hammer Breaking

Figure 16: Concrete Removal by Automatic Hydro-Scarification Machine

Polyurea Waterproofing System (PWS) for Domestic Areas

4.7 The toilets in the older estates of the HKHA are often wet because no bathtubs were provided in the early design of toilet-cum-bathroom in the balcony. Water seepage from drainage and plumbing pipes penetrating through the toilet slab also increased the concrete moisture level. In addition, the CSI revealed that the aerosol effect from toilet flushing would result in major chloride contamination of concrete. Indeed, repeated water seepages despite repetitive repairs of the same toilet are commonly reported. The conventional method of re-waterproofing a toilet involves the breaking up of the entire existing floor finishing, re-waterproofing and subsequent reinstatement (Figure 17). Not only does this 3-day repair work represent a major nuisance to the tenants, the work is detrimental to the environment as the entire existing floor finishing is turned into construction waste. Another drawback is that the work can only be done properly at difficult areas with particular attention (Figure 18), such as the areas near congested pipes and floor drains, resulting in less satisfactory long-term performance. In addition, the demolition work in conventional re-waterproofing systems may cause possible damage to the existing structure. In view of the drawbacks and difficulties, an alternative approach of using the polyurea waterproofing system (PWS) was introduced under the CSIP to solve the current difficulties. The PWS possesses the properties of rapid setting, high hardness, high flexibility, high tear strength, high tensile strength, and good resistance to chemicals, weathering and abrasion. The attributes of polyurea together with its spray-on application enable it to become a seamless, effective and durable waterproofing system (Figure 19). Based on the positive results (Table 2) from a comprehensive study on the environmental, social and economical performance of the PWS, the HKHA is considering applying this environmentally friendly solution to its existing buildings from 2013.

Figure 17: Time Consuming and Disturbing Conventional Re-waterproofing

Figure 18: Problematic Areas for Conventional Waterproofing System

Figure 19: Spray-on PWS to Cope with Congested Areas

Table 2: Merits of the PWS over Conventional Waterproofing Systems

Environmentally Friendly	✓ ✓	No need to remove existing tiles, screeding Minimal noise, dust, vibration
Tenant Oriented	✓	1 day of work for PWS vs 3 days of work for conventional method
More Durable	✓ ✓ ✓ ✓ ✓ ✓	High water resistance High abrasion resistance High flexibility High chemical resistance Excellent adhesion to different substrate Seamless system covering difficult areas effectively

Twin Water Tank System for Water Supply

4.8 Water supply interruption during tank cleansing often causes water wastage and inconvenience to the tenants. According to the Hong Kong Waterworks Standard Requirements, all fresh and flush water tanks need to be thoroughly cleaned at least once every three and six months respectively. Normally, water supply is suspended for about four hours during the cleansing process. The affected tenants may need to store fresh water for temporary use or use fresh water to flush toilets during those periods. Considerable wastage occurs when water remaining in the tanks has to be drained away for tank cleansing or repair. Due to the high moisture level and wet-and-dry condition, the deterioration rate of a conventional reinforced concrete water tank is typically high (Figure 20). However, repair work on a deteriorated water tank could be a major nuisance to the tenants because of the long period of water suspension required.

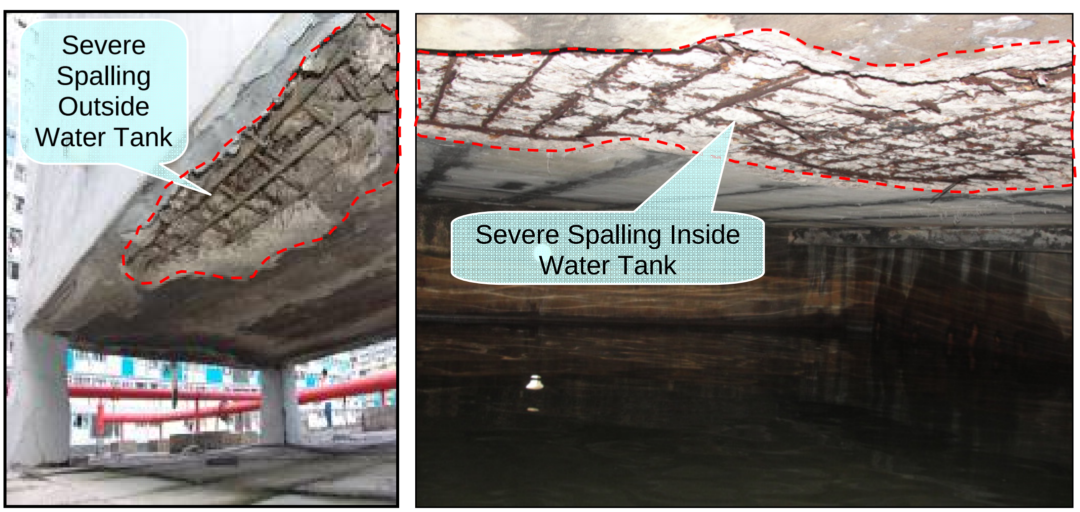

Figure 20: Poor Structural Conditions of Conventional Water Tank

For water conservation and better service quality to the tenants, a twin water tank system, the first of its kind for high-rise residential buildings, was proposed under the CSIP. The design divides each water tank into two compartments and adopts an "alternate operating" approach (Figure 21). When one compartment is shut down for cleansing, the other compartment remains in operation to ensure continual water supply to the tenants. Besides eliminating the disturbance to tenants during regular cleansing, the twin-tank system would facilitate major repair work without water suspension. Furthermore, a higher grade waterproof concrete is also specified for the new water tank to enhance its durability under the severe exposure conditions. Indeed, the new system is able to achieve a win-win-win solution for building sustainability. Water is conserved through the design of the twin-tank system and quality of the tenants' life is enhanced through continuous water supply.

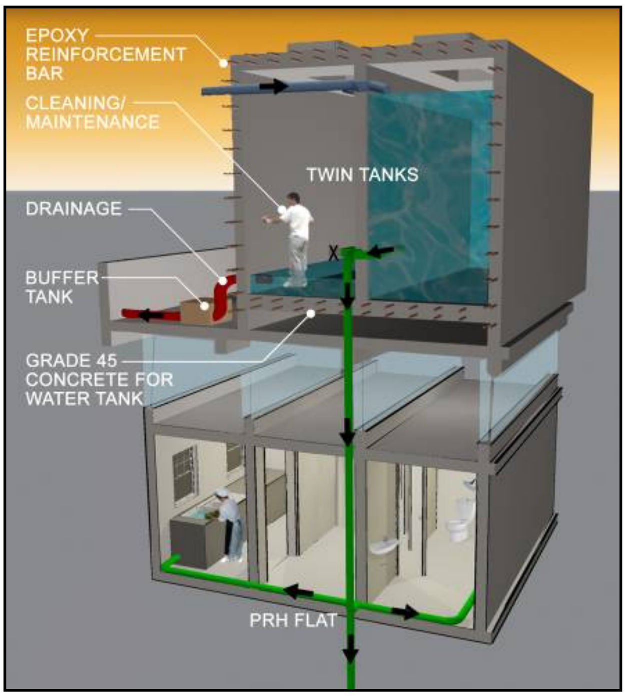

Figure 21: Design of Twin Tanks for Public Housing

5. CONTRIBUTION TO THE INDUSTRY AND RECOGNITION

5.1 The CSIP has proved to be an effective tool in enhancing sustainability for the HKHA buildings. The wealth of experience accumulated since the launch of the CSIP in 2005 has formed a knowledge pool for the continual structural health management of the 730,000 public housing units maintained by the HKHA. As a committed organization to building sustainability, the experience accrued from the CSIP is not bounded to the public housing only. Through publications, conferences, meetings, seminars and media reports, the HKHA has been sharing its CSIP experience with the industry with a vision of enhancing the long-term building sustainability of Hong Kong. In recognition of its contributions, the HKHA was granted a number of awards including the awards for Excellence in "Innovative Repairs" and "Sustainable Repairs" from the Hong Kong Concrete Repair Association in 2011, the meritorious award for the "Civil Service Outstanding Service Award Scheme 2011", and the merit award for the Green Building Award 2010 for the project "To Better Sustain Choi Hung Estate – A People-Oriented Approach". The new CSIP repair techniques and solutions have earned appreciations from the tenants, council members, as well as the building industry. The success stories have also been positively and widely reported by the media (Figure 22).

Figure 22: Media Reports on the Green Initiatives of the CSIP

6. CONCLUSIONS

6.1 Faced with the challenges of an aging housing stock, aggressive environment and obsolete design of older buildings, the CSIP was launched in 2005 as part of a green initiative for sustainability of public housing. The CSIP has proved through its work since 2005 to be a win-win-win solution in environmental, economical and social aspects of sustainability of public housing: it enables HKHA to optimize the use of land, manpower and financial resources instead of mass redevelopment as did in the past; and it develops effective solutions to enhance the tenants' living conditions and to prolong the service life of the aged buildings. The comprehensive structural investigation has been undergoing continual enhancement with ongoing reviews on the works implementation, performance monitoring and feedback from stakeholders. In addition to benefiting the quality of life of the tenants residing in public housing, the HKHA has been sharing its CSIP experience with the industry aiming to enhance the long term building sustainability of the territory.

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