Development of new building systems using innovative structural materials
Part1: An approach and strategy to develop sustainable building systems to promote urban revitalization

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Summary

This paper presents findings in the studies that were pursued in New Building Structure Research and Development of the Association of the New Urban Housing Technology (ANUHT), in cooperation with the Japan Iron and Steel Federation (JISF) and the Japanese Society of Steel Construction (JSSC). Our target here is to develop new building systems using innovative structural materials by illustrating future visions of sustainable buildings in 21st century. Comprehensive researches have been performed based on investigations with typical models of urban revitalization to identify further research and development issues on new building systems using innovative structural. The paper aims to present current visions and strategies to develop sustainable building systems using innovative structural materials, which can promote urban revitalization. Firstly an approach to develop sustainable building systems using innovative structural materials is described. Secondary current processes to develop sustainable building systems are explained by illustrating future visions of society, lifestyle and supporting industry. Thirdly, a strategy to develop technical and organizational issues is proposed from a viewpoint of sustainable development. Finally, further research issues to develop sustainable building systems are presented.

1. Introduction

One of the current challenges in the field of urban revitalization is to integrate excellent innovation concept and innovative technologies. Many sophisticated concepts such as skeleton/infill, open building, two-stage supply system, and urban skeleton system have been carefully studied and practically implemented. When these concepts are integrated with current innovative technologies such as innovative material technology, ubiquitous network computer technology and distributed energy supply system, new concept of innovative building system will be realized. Our focus here is an integration of such sophisticated concept and innovative material technology to attain higher sophistication of sustainable buildings.

Reviewing past innovative technology developments in building construction, new building systems and structural systems have been realized by development and utilization of new structural materials, such as high-strength concrete, high-tension steel and lightweight materials. Current innovative structural materials to be used are super high-strength concrete, super high-tension steel are ultra fine-grained steel so called ultra steel, and innovative composite materials represented by carbon fiber reinforced plastics (CFRP).

Future sustainable buildings will also well depends on the development of new building systems in which innovative structural materials are optimally applied. These innovative structural materials have feature of not only high-strength as twice as ordinal concrete and steel, but high durability as twice as ordinal concrete and steel, high rigidity and high corrosion resistance.

Consequently new building systems are expected to make their lifetime longer and reduce amount of materials by developing non-welding joint between building components which allow them to be reused. The buildings designed by innovative structural systems can be viewed as sustainable buildings. The new building systems aim to reduce the time and cost of construction and greatly to extend facility performance, functionality, aesthetics, affordability, sustainability, and to increase responsiveness to changing business demands.
The Council for Science and Technology Policy, which was formed to develop Japan’s grand strategy in the field of science and technology under the leadership of Prime Minister Koizumi, recommended that relevant governmental agencies should work together to promote commercial exploitation of nanotechnology and materials science. The recommended materials science research is aimed at designing buildings with truly innovative structural properties, esthetics and characteristics.

A five-year interagency project started in 2004 with a goal of commercializing the new building structures in 2010. The concept of the innovative building structures includes buildings with (1) mixed use of residences, offices, and retail services, (2) easy modification of interior structures, including floor height, and (3) reduction of wastes by eliminating the need for connections among structural components. These building structures are expected to play a key role in urban revitalization that is being promoted by the commercial sector.

Association of New Urban Housing Technology was awarded grants from the Ministry of Land, Infrastructure and Transport, and invited the member companies to join the research activity on innovative building structures in 2003. 16 member companies formed the preparatory committee and working group in 2004. Finally, a total of 21 companies discussed deliberately and proposed a five-year development program starting from 2004.

2. Innovative Structural Materials in Urban Revitalization

The innovative structural designs are largely dependent on new structural materials. Among them, high-performance steel and advanced complex functional materials show particular promise because of their improved service performance, durability and maintainability. These features enable us to design and develop the following building structures.

(a) Due to their lightweight and high strength, new structural materials enable us to construct buildings with span twice wider and 1.5 times higher than conventional buildings.

(b) Combining high-strength main structure and high-flexible substructure meets demand for the use of open space flexibly.

(c) Few connections allow rapid assembly and disassembly of buildings, which reduces wastes of structural members and components.

Thin, high-performance steel sheets have emerged as the material of choice for modern automobile choice. However, construction industry still regards high-performance steel as an unproven material because of (1) high development cost, (2) uncertain demand, and (3) no clearly defined quality standard.

Conventional steel must satisfy the current severe requirements for plastic deformation region. Steel manufacturers argue that the requirements are not necessary for high-performance steel that has twice the strength of conventional steel. If the quality standard is established with consideration given to the unique characteristics of high-performance steel, the manufacturing process will be simplified to reduce the cost to 30%. The lower cost will increase demand substantially. Considering the virtuous circle, comprehensive approaches should be taken to expand use of innovative structural materials, such as high-performance steel and CFRP.

In addition to reduction of development cost, the demand side – Ministry of Land, Infrastructure and Transport and construction industry - has other requests for the supply side - Ministry of Economy, Trade and Industry and steel manufactures. The supply side must determine what they can do within the context of existing regulation and technology. Achieving the best balance between the demand and supply is inevitable to the development of innovative structural materials.

Association of New Urban Housing Technology undertakes research on the demand side, while the Japan Iron and Steel Federation and the Japanese Society of Steel Construction conduct research on the supply side. The first priority in the 2004 research activity is to measure the current position and future direction of the project against the research results.
3. 21st-century Urban Development Scenarios

Innovative structural materials are expected to improve urban landscape of long-term value in everything from resource efficiency to neighborhood amenities and services, safety and security, jobs and business opportunities, and improved education and transportation — in other words, social elements that are important to sustain, provide for and empower a better quality of living. On the other hand, an aging society with a decreasing birthrate is redefining the conventional perceptions of the way we live in the city. With very rapid changes in economic and social paradigm, the 21st urban development scenario should highlight the importance of “lifestyle vision”, “social vision”, and “industry vision”.

- Lifestyle vision: Green living to create a community that supports diverse lifestyles and interacts with a natural environment.
- Social vision: Community livability to create a city as a place attractive to live and work.
- Industry vision: Market appeal to create business opportunities to maintain and sustain social developments.

The following cities and building construction will meet the above requirements.

(a) Robust building structure capable of making the public feel safe and secure in the event of large-scale disasters.

(b) Adaptive building structure capable of making easy conversion of former use to new use in a resource-efficient manner.

(c) Structural design capable of providing a better quality of living, and in turn, leading to orderly urban development

(d) Resources recycling/reuse to reduce wastes generated from maintenance, repair, and alternation of buildings and civil infrastructure.

The development of innovative structural materials has two-fold objectives: to mitigate concerns for existing cities and building structures; and to develop sustainable cities and buildings based on the resources recycling concept.

(a) Mitigation of concerns for existing cities and building structures

Today, many cities and building structures share concerns for the earthquake resistance, real estate crisis, inflexibility to accommodate changing needs, destruction of serviceable buildings, inattention to cultural and historical value, and high cost of demolition. Innovative structural materials are expected to develop new urban living replaced with existing cities and buildings.

(b) Sustainable cities and buildings based on the resources recycling concept

The supply system of innovative materials should be established to develop the urban infrastructure inevitable for the creation of a safe, sustainable, resource-efficient city and building. Therefore, the government and relevant industries must work together to take comprehensive approaches toward this end.

Our project focuses on the development of structural systems to make a city or a building safe, sustainable, and resource-efficient by using innovative material-based building structures. The demand research is conducted to determine the requisites for the construction system.

4. Applicability of Innovative Building Structures

4.1 Urban redevelopment models

Innovative material-based building structures will provide a solution to urban revitalization in the 21st century. The applicability of the innovative building structures is examined for the following four areas.

(a) First priority urban redevelopment areas (City center redevelopment area)

17 districts (approx. 3,500 ha) in Tokyo, Yokohama city, Nagoya city, and Osaka designated as the first priority urban redevelopment area
(b) Third priority urban redevelopment areas (Crowded with wooden housings area)
Districts that are the most dangerous among those designated as the third priority urban redevelopment area (a total of 8,000 ha nationwide, including approx. 2,000 ha in Tokyo and Osaka)

(c) Other priority urban redevelopment areas (Waterfront development area)
Waterfront districts in Chiba, Tokyo, Yokohama, and Kawasaki, which comprise 4,400 ha

(d) Existing housing stocks area (Housing stocks renovation area)
 Improvement and reconstruction of 2.18 million public housing stocks and other dilapidated public housings through the utilization of PFI and private knowledge

Figure 2 Investigated urban redevelopment models
4.2 Investigation of innovative material-based building structures

Table 2 shows relationship of urban redevelopment models and issues that were studied with innovative building structures. Through the investigation, requirements for innovative materials and innovative material-based building structures, as well as organizational issues were identified.

These requirements for innovative material-based building structures are categorized into the following two urban structure models.

(a) Vertically mixed use

Businesses, housing, and civic uses are mixed “vertically” by constructing offices and residences above retail or parking space. This vertical architecture has two types: multi-story structure, where main structural frame is formed every three stories: and standard structure, where main structural frame is formed every story.

(b) Horizontally mixed use

Businesses, housing, and civic uses are mixed “horizontally” by connecting different uses adjacent to each other with public spaces above parking garage. This horizontal architecture has two types: long span urban structure, where main structural frame is formed twice as long as usual spans: and short span urban structure, where main structural frame is formed half as long again as usual spans.

With the combination of these mixed use zonings, we will be able to find solutions to problems with traditional zoning, such as relocation of subsidiary streets, integration of public open space, efficient use of energy, and reduction in waste of structural components.

4.3 Features of Innovative material-based building structures

Through the investigation, the following features with the innovative material-based building structures are identified:

(a) Multi-purpose

The proposed high-story building is comprised of residences, offices, tenants and the like. The interior can be divided according to the space functions, and electricity and water consumption is controlled at each block for energy savings.

(b) Stepwise development

Stepwise development approach can be taken to reflect the original heritage into the renovation.

(c) Integration of public open space

Commercial sector can promote the renovation with consideration given to the integration of public open spaces, such as green belt, plaza, and parking garage, with the building.

Table 2 Applicability of the innovative building structures to urban redevelopment models

<table>
<thead>
<tr>
<th>Innovative building structures</th>
<th>Urban redevelopment models</th>
<th>City center area redevelopment model</th>
<th>Crowded with wooden housing area redevelopment model</th>
<th>Waterfront business area redevelopment model</th>
<th>Existing public housing stocks redevelopment model</th>
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<tr>
<td>Vertically mixed use urban structure</td>
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<td>Super-high-rise building system</td>
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<td></td>
<td>Mid-rise and low-rise building system</td>
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<td>Horizontally mixed use urban structure</td>
<td>Multi-story urban structure system</td>
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<td>Standard story urban structure system</td>
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<td>Parking deck system</td>
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<td>Integration system with public open space</td>
<td>Parks</td>
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<td>Subways</td>
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5. Technical and Organizational Issues

We need to address both technical and organizational issues to implement the urban development scenario described above within a time frame of five years.

5.1 Technical Issue

Major technical issues to be developed is classified into the following three categories:

(a) Innovative material-based structural components and elements, that is reusable and recyclable as social infrastructures stocks
   - A production / processing / examination method of a super high strength structural materials, components and products.
   - A new JIS / ISO standard for innovative materials and innovative material-based building components.

(b) Multi-functional, flexible, and long-life building systems that support to maintain and to improve urban functions.
   - A design method with structure system corresponding to changes in building use.
   - A design method and performance validation method with a super quakeproof structure system against the Japanese earthquake intensity scale of 7.
   - Design method and performance evaluation method of Joint mechanism depending on characteristics of high strength and high performance materials.
   - Infill and cladding system corresponding to high performance structure systems.
   - Interface systems to incorporate a developed structure system in an existing building structure.
   - Construction methods for reusable building systems.

(c) Maintenance and revitalization technologies for urban functions that create a new urban building industry.
   - A performance and quality confirmation method in structural components when they are reused.
   - A disaster prevention planning method corresponding to the performance and design for plastic deformation against the Japanese intensity scale of 7.
   - A property management method for combined building structures.
   - Monitoring and inspection methods of structure performance, disaster prevention performance and environmental performance at city block level.
As described above, a new quality standard should be established for innovative materials developed by steel industry and other relevant industries. For this reason, national and industrial research institutes must work together to take a comprehensive approach to the development of new construction designs and methods, including connection techniques, as well as the development of performance assessment and verification methods. In addition, research must be conducted on the combined use of high-performance steel and existing concrete or advanced composite materials. These efforts would make it possible to develop a lightweight, smart reinforcement for the improvement in seismic resistance and hybrid reinforcement connecting multiple slender buildings.

Housing manufacturers also conduct their own research on infill and façade, given the fact that the urban development scenario needs interior functionality and exterior beauty that cannot be achieved through the development of new building structures.

5.2 Organizational Issue

One of innovative ideas is that public observers and commercial participants work together to develop techniques to promote the businesses to lease foundation structures and other equipment as follows:

(a) Building codes and regulations

Investigations of material criterion, performance criteria and design criteria with innovative building structure are required to establish new method for performance evaluation and verification in building codes. Stepwise authorization and examination methods of building construction should be established, when skeleton and infill or connection of existing buildings and new buildings is applied for authorization of an urban redevelopment project in multi-step processes. Investigations of measures to install and guarantee public spaces in an innovative building structure as special zones are also relevant.

(b) Law concerning the registration of real estate

Measures for ownership of skeleton and infill to be guaranteed and secured separately are carefully examined. Regulation of contract life to utilize an innovative building structure should also be studied.

(c) Supportive measure to establish a new housing market

Execution of leading urban redevelopment projects, applications of innovative building structures to public works, considerations of preferential tax treatment for long-lived building structures, and investigation of financing techniques for an infrastructure development are necessary to establish a new housing market.

Figure 4: An expected business model with innovative material-based building structures.
6. Approaches to the Commercial Application of Research Results

The five-year interagency project differs from traditional national projects in that an emphasis is placed on the development of the environment where research results can be smoothly commercialized.

The urban development scenario envisaged needs a new regulatory framework to promote the commercial application of research results. The regulatory changes include new standards on materials, performance and design for plastic deformation against the Japanese intensity scale of 7, analysis techniques for the integration of existing and new building structures, and streamlined procedures to file inspections and applications for tissue, skeleton and infill. Accordingly, the government must reexamine current real estate laws, as well as construction laws and standards.

In addition, future plan calls for pilot business projects and public works using new building structures to form a commercial market at the earliest stage.

According to the Council for Science and Technology Policy, innovative material-based building structures are to contribute to the construction of stronger disaster-resistant, better cost-effective social infrastructure because of its improved service performance, durability and maintainability. The government and industry are required to work together toward the development of relevant technologies.

Keeping recovery of economic vitality and creation of new markets in mind, Association of New Urban Housing Technology continues to promote research projects for applications of innovative materials in the urban development in cooperation with the governmental agencies and universities, as well as the Japan Iron and Steel Federation and the Japanese Society of Steel Construction.

7. Conclusion

An approach and a strategy to develop new building systems are briefly described through investigations in urban redevelopment models. The new building system is illustrated as combination of horizontal and vertical urban structures using innovative structural materials.

Features of innovative material-based structures are identified as to enable multi-purpose use, step-wise development and integration of public spaces. To implement new building systems, technical and organizational issues are to be solved with a clear scenario of research and development with innovative material-based structures. The scenario should be promoted as a national project with cooperation of government and industry.

Since the essential subject to develop new building systems using innovative materials is to solve environmental issues and human settlement in cities by introducing social infrastructures in high flexibility, performance and sustainability. The innovative materials and new building systems are to be applied in various types of urban redevelopment projects, to realize future sustainable buildings and urban structures with high economic ripple effect.

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