Micro-house Utilizing Fully Recyclable Shirasu Concrete
— R·torso·C —

完全リサイクル可能なシラスコンクリートを用いた狭小住宅
— R・トルソ・C —

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Synopsis

This house, named R·torso·C, is located in the center of Tokyo on a site with an area of a mere 66m^2. At the request of the clients, a fully recyclable concrete was developed for this project. Instead of sand, this concrete uses shirasu, the deposit of pyroclastic flows of volcanic ash found in the southern Kyushu region of Japan. Apart from its recyclability, the advantages of this concrete are its strength, durability, and humidity- and odor-controlling qualities. Shirasu concrete (SC) has been used previously in the field of civil engineering but not in the field of architecture. After numerous experiments and procedures, the world's first piece of architecture utilizing SC was realized.

Structural Data

Structure: Rigid frame
Building Type: Private residence
Designer: Yasuhiro Yamashita of Atelier Tekuto Co., Ltd.
Structural Engineer: Assoc. Prof. Jun Sato of the University of Tokyo
Material Advisor: Prof. Takafumi Noguchi of the University of Tokyo
Contractor: Home Builder Co., Ltd.
Site Area: 66.67m^2
Building Area: 31.21m^2
Total Floor Area: 103.74m^2
Number of Stories: B1, 3F
Building Height: 9.715m
Construction Period: Aug. 2013 – Apr. 2015
Location: Shibuya ward, Tokyo, Japan

Fig.1 Exterior view

1. Introduction

The clients of this house are a married couple who both work in the field of chemistry and share a passion for architecture and art. Their initial request was that they wanted “to see exposed concrete finish inside and out. A challenging piece of architecture that is at the same time environmentally friendly”. With those words as a starting point, the architect assembled an interdisciplinary team with Prof. Takafumi Noguchi, Assoc. Prof. Jun Sato, shirasu supplier Principal Co., Ltd., and concrete manufacturer Tokyo SOC Co., Ltd., resulting in the development of an environmentally friendly concrete using shirasu.

2. Design

(1) An Urban House Open Toward the Sky

In high-density residential districts such as this site, it is difficult to create space with a sense of openness and oneness with nature. One way to build architecture that respects nature and the environment in this situation is to build toward the sky, which is the only direction that conveys the feeling of the vastness of nature.

The architect has repeatedly studied this approach toward the sky as an element of nature. This time, the corner of a rectangular volume was pruned away to achieve this. Paradoxically, cutting away the internal volume creates a sense of spaciousness in the continuous four-story interior space. The chamfered corners provide not only a view of the sky from inside but also a wider view of the sky from outside (**Fig.1**).

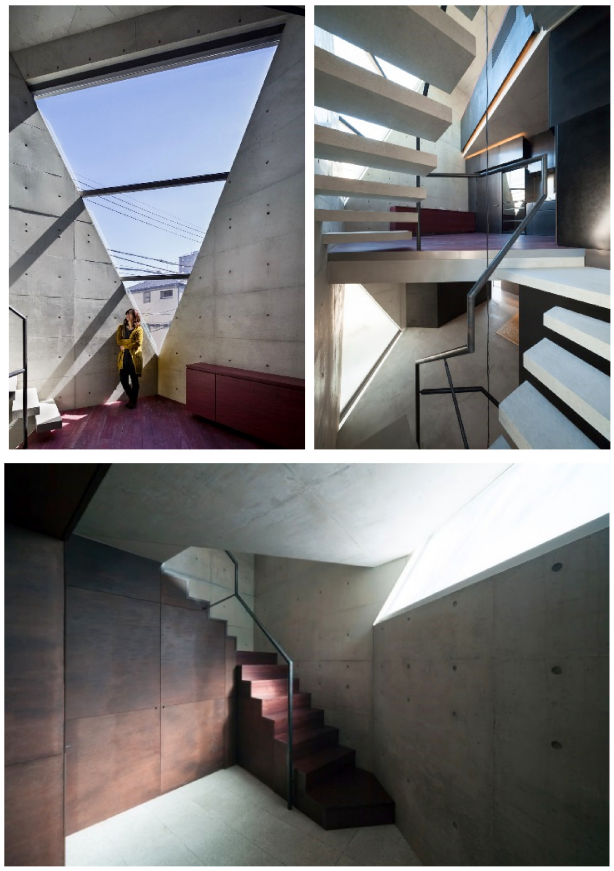

Fig.2 Interior views

(2) Designing Three-dimensionally

For architecture on a small site, sectional and volumetric design becomes very important. Therefore, at Atelier Tekuto, plans and sections are always considered simultaneously, and numerous study models are made to create a multi-layered space with enhanced spaciousness. The layering of concrete steps from the basement, the living space extending to the bedroom above, the toilet and high window leading to the sky and the bedroom, the bathroom leading to the exterior via a skylight: these interconnections produce spatial richness that cannot be measured by area alone. The living room is a very small space, but a 5-m ceiling and a large oblique triangular window drawing in an abundance of external light results in a sense of space that is far greater than reality (**Figs.2–4**).

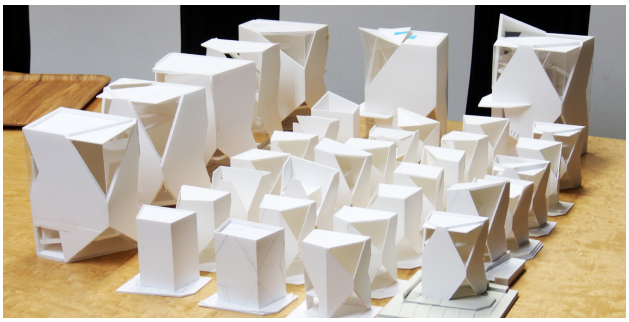

Fig.3 Study models

Fig.4 Floor plans

3. Material Development

(1) Material Planning

In view of previous studies by Prof. Takewaka at Kagoshima University, Prof. Noguchi proposed using shirasu as fine aggregate because its pozzolanic reaction is expected to increase the strength and durability of the concrete over a long period of time. Blended cement in which 40–45% of the Portland cement is replaced with ground granulated blast-furnace slag helps to establish a low-carbon society. To achieve completely recyclable concrete and to reduce cracking due to drying shrinkage, crushed limestone was chosen as the aggregate. Furthermore, the concrete mixture was designed to be self-compacting to reduce noise and vibration on the construction site, thereby also reducing energy consumption.

(2) Development Process

1) Complying with Regulations

Currently, shirasu does not meet the criteria for concrete aggregates stipulated in the Japanese Industrial Standards (**Fig.5**). Therefore, the safety and strength of SC had to be proven through experiments so that it could be used in this project. After multiple experiments, an Individual Ministry Approval was granted for this particular piece of architecture.

2) Quality Control

New guidelines for the manufacturing, transportation, and storage of shirasu were developed and verified to guarantee the quality of SC.

3) Testing Architectural Applicability

Buildings tend to be much smaller than those civil engineering structures in which SC has been used previously. To test the applicability of SC to architecture, a full-architectural-scale mock-up was constructed that resulted in high-quality concrete with a beautiful smooth surface (**Fig.6**).

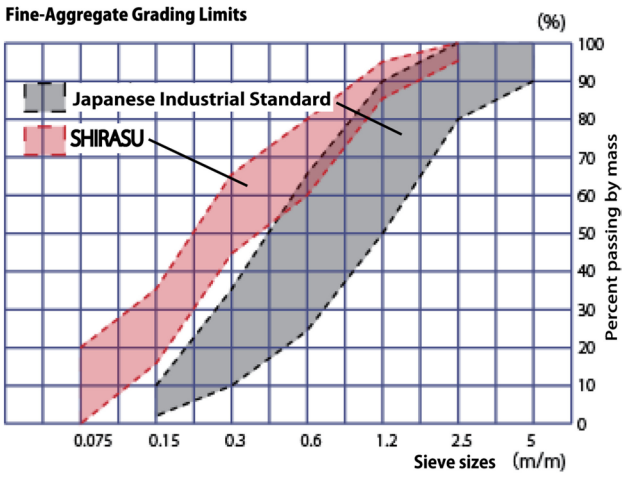

Fig.5 Fine-aggregate grading limits

(3) Benefits of Shirasu Concrete

1) Preservation of Natural Resources

The depletion of natural concrete aggregate is a longstanding and serious problem in Japan. River sand is becoming scarce and is being replaced by gravel scraped from the ocean floor. However, most local governments have banned the use of sea gravel for environmental reasons. An alternative is to use crushed recycled concrete, but here again huge amounts of energy are required for production, resulting in a problematic mass emission of CO_2. In SC, 60–70% of the sand can be replaced by shirasu, and it incorporates cement made from industrial waste.

2) Environmentally Friendly

The pozzolanic reaction caused by shirasu enhances the strength and durability of the concrete and reduces sulfate attack and efflorescence. Therefore, a building constructed with SC is expected to have a longer lifespan. Moreover, if a building built with SC is demolished, the concrete can be reused completely as cement raw material (**Fig.7**).

3) Other Beneficial Features

The fineness of shirasu granules gives the concrete surface a fine, smooth texture. Also, SC has enhanced humidity control and deodorizing ability due to the porosity of shirasu.

Fig.6 Full-scale mock-up

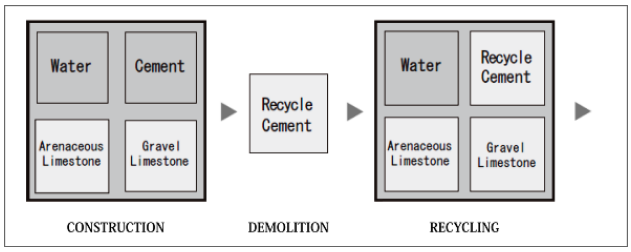

Fig.7 Fully recyclable concrete

4. Structural Design

Assoc. Prof. Jun Sato suggested adopting a rigid-frame structure in which the columns and walls are of the same thickness. The minimum thickness that satisfies the anchorage length and the bending of the reinforcement bars is 220mm. Because the structure is essentially a frame structure, it need not meet the specifications for box-frame construction and therefore becomes more flexible as to where and where not to have openings.

With these features in mind, the team was faced with the delicate process of arranging all structural members and components within the 220mm thickness limit while keeping a polyhedral form. Because reinforcement bars can become congested in a rigid-frame structure wall, it was necessary to ensure a smooth flow of concrete within the formwork. The flow was tested using a full-scale mock-up of part of the structure with as many reinforcement bars as there would be in reality. The smooth flow of SC was confirmed both in the mock-up and on site. Through experiments and the actual construction on site, the high efficiency of SC for use in rigid-frame wall structures was demonstrated (**Figs.8**, **9**).

5. Conclusions

It took two and a half years to complete this small private house, but it was worth the effort because SC was shown to have various benefits and be definitely applicable to architecture.

Currently, shirasu is regarded as something of a nuisance because of its lack of water-holding capacity for agriculture and bearing capacity for construction. However, if shirasu could be substituted for sand, it would provide over 2,900 years' worth of concrete production for the whole of Japan.

Furthermore, if shirasu was used widely, a completely new industry could emerge. Currently, 100m^2 of land resting on shirasu is worth 100,000 JPY (ca. 935 USD) as real estate; that piece of land is estimated to hold 600m^3 of shirasu. Meanwhile, sand is traded for 2,500–3,000 JPY (about 23–28 USD) per cubic meter. Therefore, if shirasu was used widely and sold at the price at which sand is traded today, the same plot of land could yield 1,500–1,800 million JPY (about 14–17 million USD). Hence, SC will contribute to not only the sustainability of concrete construction but also the region from which it is sourced (**Fig.10**).

This project received the JCI Best Work Award 2016.

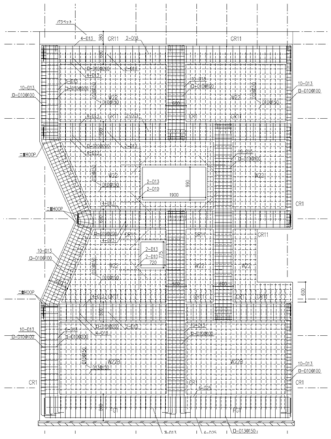

Fig.8 Northwest elevation structural detail

Fig.9 Bar arrangement

Fig.10 Shirasu excavation site

概　要

この住宅は東京の中心にあり敷地面積66㎡と小さい。クライアントの最初のリクエストは「コンクリートで内外部を包み込んでほしい。そして，そのコンクリートが挑戦的であり，環境的であってほしい」であった。その要望に応えるため，東京大学の野口貴文教授と佐藤淳准教授，シラス製造会社，コンクリート製造会社とチームを組み，砂の代わりに日本の南側で多く採取できる火砕流堆積物「シラス」を用いた，完全リサイクル可能なコンクリートを開発した。その特徴は，ポゾラン反応という化学反応があるために強度が増し続けること，シラスの粒度が細かいことから密実で中性化しにくいこと、シラスに独立気泡があるため調湿効果があることである。この開発はサステナブルなコンクリート産業への貢献のみならず，採取地に莫大な資産を生み出すプロジェクトとも成り得る。狭小住宅ながら計画から竣工まで 2 年半の年月を要したが，シラスコンクリートが土木のみならず建築にも適する優れた素材であることが実証できた。