NEW CONSTRUCTION MATERIALS PROLIFERATE IN JAPAN

Victor C. Li

Self-placing concrete is just one new construction material developed and being used in Japan. This and other materials are the result of research aimed at automation as well as creating a better environment for fewer workers and giving the major Japanese firms a competitive edge.

Many young people in Japan think construction sites are dirty and difficult places to work. This attitude contributes to the current construction labor shortage, one factor that drives research in that country. The goal is to develop new methods and materials that reduce manpower needs, reduce human error and improve that perception of the workplace. In the long run, these new methods should also lower construction costs in Japan, now about 30% higher than those in the U.S.

Japan's major construction firms invest heavily in research, looking for something special to offer their clients. Among the new developments are advanced concretes and fiber-reinforced composites. Self-placing concrete is one new category of materials, and Biocrete, NEFMAC and Hi-Silics are among brand names not widely known in the U.S. Before describing these materials, it is important to understand a few differences between construction-sector research in the U.S. and Japan.

Twenty years ago most Japanese construction research was led by the Ministry of Construction and other government groups. Today, Japan's "big five" construction companies dominate research and operate the country's major laboratories. Those corporations, Shimizu, Taisei, Kajima, Takenaka and Obayashi, all in Tokyo, aim at product differentiation to keep competitive. Each firm might be developing its own particular variation of a product or method. In Japan, quality is more important than price, especially in public construction work, so this differentiation will continue to be a research focus for these firms.

Another notable difference in research practice between Japan and the U.S. is that most academics are funded directly by the government and have had little incentive to seek private funds. This is changing, and cooperation between industry and academia is increasing. For example, H. Okamura, professor at the University of Tokyo, heads the High Performance Concrete Project, which attracts about 100 engineers from all the major construction companies to work at transferring laboratory-research results to the field.

The big five construction firms also collaborate with Japanese materials companies to develop construction materials. One result is the carbon-fiber–reinforced concrete (CFRC) building panel developed by Kajima with Kureha, a company that manufactures the carbon fibers. Such collaborations often result in spinoff or subsidiary companies that market the fruits of these joint efforts. Simultaneously, the vertical integration of Japanese construction companies enhances internal interaction between research labs and design and construction engineers. The big five firms are also now conducting research with universities outside of Japan and with public agencies such as Caltrans in the U.S.

The Japanese research environment accepts duplication among the participating firms and universities. There may be fewer major breakthroughs with everyone moving in the same direction, but there is steady progress.

The recent recession has affected research budgets among the big five companies. Most of these budgets have remained flat or have been reduced by 10–20%, except for Taisei, which has increased their research and development budget by 30%. There have been staff reductions at the research arm of Kajima, and a shift from long-range basic research to "project-driven" research. At Shimizu, the mix of 70% basic to 30% applied research has shifted to about a 50/50 mix in recent years. While the recession, which will probably continue until about 1998, has affected research budgets and policies, it has also eased the labor

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THE CENTER SPAN OF THE RIRENT CABLE-STAYED BRIDGE WAS CONSTRUCTED BY SHIMIZU USING LIGHTWEIGHT, SELF-PLACEABLE CONCRETE.

shortage problem and reduced the contract backlog in Japan.

The cost of construction is much higher than that in other nations, as much as 30% to 40% than that in the U.S. In spite of this, the Japanese have investigated and applied expensive materials such as advanced fibers. In Japan, construction efficiency and quality is very important, and this could be one explanation. However, the driving force behind R&D in construction materials is the effort of construction companies to maintain or enlarge market share by enhancing product differentiation. By contrast, U.S. construction firms put cost control above all other factors.

On the government side, historically Japan has favored industrial R&D over basic research. However, there are indications of a shift toward more emphasis on basic research in the academic sector. Many in Japan feel that basic research will lead to technological breakthroughs in the future, and the government may increase spending for such research.

Finally, attracting bright young people to the construction industry is important in Japan, where the big five companies recruit university graduates. Students do not apply for jobs directly. Instead, professors are the power brokers, and determine how many top graduates will go to which firm. The idea is to avoid overcrowding, or internal competition to ensure career opportunities for these graduates within each of the big five companies. Much of the research activity is aimed at making the industry more attractive to young people who will work there.

KEY MATERIALS

In the last decade, advanced concretes and fiber-reinforced composites have led the list of new materials. This article does not cover the developments in steel, where R&D is carried out by steel manufacturers with less involvement by the construction industry and the Building Research Institute, an arm of the Ministry of Construction. Some of the advances in the first two categories are highlighted here.

Self-placing concrete is an important new material and is also known as self-compactible concrete, self-consolidating concrete, flowable concrete and nonvibration concrete. These products are aimed at reducing site labor needs and shortening construction time, especially where congestion of steel reinforcing bars make the consolidation of concrete difficult. These products do not require vibration and thus reduce site noise and placement defects. Various types of self-placeable concrete are being worked on in Okamura's laboratory at the University of Tokyo. All the big five companies have developed their own version. Kajima has NV concrete with a segregation resistance agent called polysaccharide. Taisei has developed Biocrete 21, which gets its name from its viscosity agent—a fermented biopolymer.

The viscosity agent seems to be the differentiating characteristic in the several types of self-placing concrete, and each company wants to have its own version in order to compete in the market.

Self-placing concrete has been used since 1993. Taisei used its Biocrete 21 on the main tower of the Kiba-Park Large Bridge, a 151 m cable-stayed prestressed concrete bridge. Only two workers were needed to place 650 m^3 in nine months. The driving force was the difficulty and high labor cost of placing normal concrete in the heavily reinforced concrete structures due to the close spacing of rebar. The Landmark tower is another application. The 70-story building, the tallest high-rise building in Japan, was completed in 1993. A total of 885 m^3 was pumped into steel tubular columns. Biocrete 21, with high flowability and segregation resistance, was chosen to fill the steel tubular columns, with a maximum filling height up to 40 m. The self-placing concrete was pumped from the bottom, and passed through a number of diaphragms without any occurrence of cavitation. Shimizu's self-placing concrete was used for the center span of a cable-stayed bridge to reduce the unbalanced bending moment in a 1993 application.

The cost for these concretes is about 20% higher than for normal concrete, but as more workers are trained in the proper handling of the material, applications will increase.

A low-heat high-strength concrete and a low-shrinkage CFRC that uses a super-low contractile admixture are two other products developed by Kajima. Shimizu's ADLITH 12 admixture for nondispersible underwater concrete prevents washout in underwater applications and is used in a concrete called Joiluc, also marketed by Shimizu. Joiluc was used in the substructure of the recently opened Kansai airport connecting bridge. Yet another product is a high-strength lightweight concrete that uses biotite rhyolite from lava as an artificial aggregate, has closed pores and has extremely low water absorption. This concrete, developed by Shimizu and Chichibu Onoda Co., Ltd., was used in the Super CIDS Arctic offshore platform in the Beaufort Sea.

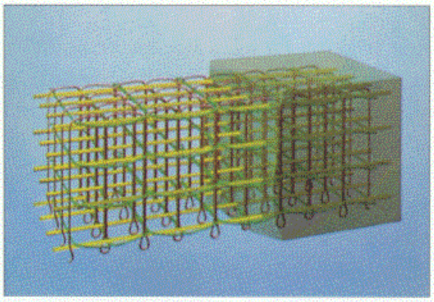
Permanent formwork is another innovation. Polymer-impregnated concrete developed by Taisei is used as formwork that becomes part of a structure after the concrete is cast. The board is made by impregnating a short fiber-reinforced concrete board with polymer. The porosity of the concrete is reduced to 85% of the original by filling airpores and microcracks with polymeric material. This material has excellent performance regarding water-tightness and freeze-thaw durability as well as corrosion resistance in salt water. Because the formwork does not need to be stripped, the product reduces labor costs, and is economical and safe. Taisei's product is limited to thicknesses of 25–30 mm, but can be used in dam spillways, tunnel linings, pavements and building shells. The material was used in the main tower and stayed-cable anchorages for the Kiba-Park Large Bridge.

Taisei also has a heat melamine composite, which can be used as "Earth-friendly" permanent formwork that reduces wood waste and saves labor. The product is a high-strength cement mortar (compressive strength 800–1,200 kgf/cm^2) and is being used as a thin-walled in-situ formwork for columns and beams. Similarly, Acelite ceramic wood products from Chichibu Onoda are designed to work like wood but do not burn, rot or warp.

Hi-Silics is a powder concrete additive developed by Taisei that includes regular silica fume and activated natural amorphous silica. The product can reduce water permeability to as much as one-fifth of that of ordinary concrete.

FIBER-REINFORCED COMPOSITES

There is no question that both the private sector (particularly the big five) and the Japanese government see fiber-reinforced composites as a significant enabling technology in the construction industry. Cooperation between construction companies and fiber manufacturers is likely to result in further advancement, especially involving intelligence embedments.



CARBON 3-D FABRIC, DEVELOPED BY KAJIMA (ABOVE), WAS USED IN THE CURTAIN-WALL PANELS OF THE SEA FORT SQUARE BUILDING IN JAPAN'S DEMANDING COASTAL ENVIRONMENT.

There are two major types of these composites: fiber-reinforced concrete (FRC) and fiber-reinforced plastic (FRP). FRC can incorporate either short or continuous fibers in a cement, mortar or concrete matrix. Perhaps the most notable achievement in the area is the carbon-fiber-reinforced building panels developed jointly by Kajima and Kureha. These panels have good strength and durability, light weight, and high fire resistance. Curtain walls for high-rises are one application. When the panels were used at the Ark Mori building in 1986, the external wall load was reduced by 60%, and structural steel was reduced by 4,000–20,000 t.

Another material developed jointly by Taisei and Toho Rayon Co. is applied to tall columns in the form of a layered tube. These are made of polyacrylonitrile-based carbon continuous monofilaments stacked in the circumferential (inner tube) and the longitudinal direction (outer tube) in a cement matrix. The tube serves as an external confining reinforcement layer as part of a permanent formwork and as finishing materials for tall columns. Concrete (greater than 50 MPa compressive strength) reinforced with steel bars is used in the tube interior. Compared to normal reinforced columns, the layered columns show no surface spalling under extreme compression load due to the external confinement effect.

It would be interesting to compare this jacketing technology in performance and cost with that of carbon FRP recently used by Caltrans in the retrofitting of bridge columns in California. A clear advantage of the CFRC tube is its fire resistance. However, because of the tube's high cost, there have been no field applications. In addition, the Taisei CFRC-layered columns may be more suitable for new construction than for retrofitting existing columns.

Extruded FRC products are another emerging technology, and include plates, beams and columns with or without continuous reinforcements. Claims of bending strength of 35–50 MPa have been made, but data are not clear. More than 10 Japanese companies are working on these extruded products, as is the Building Research Institute.

FRPs are another kind of composite. Most are in the form of strands, cables or 2-D grids and are made with glass, aramid, or carbon fibers embedded inside a polymer resin. Besides being corrosion-resistant, they have unique nonmagnetic properties and good mechanical properties. Many Japanese companies are working in this area, but FRPs are currently two to 20 times more expensive compared to conventional steel reinforcements.

At present, concrete elements reinforced with FRP unidirectional strands, 2-D grids or 3-D preforms are applied only to structures not controlled by building or construction codes. A builder who wants to

CERF SPARKS U.S. MATERIALS RESEARCH

The U.S. construction industry undoubtedly spends far less on research, as a percentage of earnings, than does its Japanese counterpart. The Civil Engineering Research Foundation (CERF) is working hard to change that. The centerpiece of that effort is their report *Materials for Tomorrow's Infrastructure*, subtitled, *A Ten-Year Plan for Deploying High-Performance Construction Materials and Systems*. The report was overseen by experts from companies and associations in ten areas: aluminum; coatings; fiber-reinforced polymer composites; concrete; hot mix asphalt; masonry; roofing materials; smart material devices and monitoring systems; steel; and wood. Some areas overlap with research being done in Japan and covered in the accompanying article, notably that on composites and smart materials.

The CERF reports also sets forth specific research programs and budgets; for example, suggesting a 10-year $882 million program for composites research that would aim at a "new generation" of bridges, marine and utility structures that could be constructed faster and have reduced life-cycle costs. One key proposal for all materials is for a clearinghouse for reliable data on the properties and performance of high-performance construction materials to users. Another is to reduce the barriers to transferring technology to practice. CERF, an affiliate of ASCE, already supports this idea through new product evaluation, and established the Highway Innovative Technology Evaluation Center (HITEC) in 1992 to evaluate new highway construction products.

Harvey Bernstein, president of CERF, says his organization has set up a coordinating council of industry representatives to implement the material report recommendations. Many of those industries have committed to support the effort financially on an annual basis, a major and gratifying step toward realizing the report goals, says Bernstein. CERF also plans to set up a national conceptual design competition for applications of new construction materials, possibly by early 1996, to draw attention to new technologies. Smart materials are an important subset of these new products and CERF held a late June meeting of industry, academic and public-sector individuals from the U.S. and Europe to identify advanced materials projects for possible collaboration. Finally, he says, CERF is considering expanding the HITEC concept to evaluate new construction materials and hasten the transition from the lab to the field.

The executive report of *Materials for Tomorrow's Infrastructure* is available for $40 and the full technical report for $75, through ASCE at 800/548-2723.

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use them in public facilities is required to get special approval from the Ministry of Construction. Even so, there are some instances of FRP use in civil engineering or in buildings in Japan. One is the concrete subbeams of the ground floor of a three-story apartment house on a foundation with an earthquake base-isolation system, built by Mitsui for their staff in 1992.

New fiber composite material for reinforcing concrete (NEFMAC), a 2-D FRP grid, is marketed through a subsidiary of Shimizu. The product is a noncorrosive lightweight grid containing aramid, carbon and glass fibers, and is being used in reinforcing elements for tunnel linings to overcome corrosion problems. More than 500,000 m^2 were used as reinforcing grids for shotcrete in an underground rock cavern at a petroleum plant in March 1991. A thinner version of NEFMAC is made as a much more flexible grid for earthwork reinforcement.

NEFMAC is being evaluated for use in the U.S. and in Canada, and the Ontario Ministry of Transportation is also investigating the use of planar carbon-fiber NEFMAC grids for concrete bridge deck slabs and cast-in-place barrier walls. In the U.S., the University of New Hampshire has a joint research program with the U.S. Federal Highway Administration for the use of NEFMAC in bridge decks.

Kajima has manufactured a 3-D FRP fabric in which fibers of carbon or aramid are dipped into an epoxy after weaving to provide the stiffness necessary for the 3-D shape. The fibers and the weaving process make this product very expensive, and its use is justified only for construction in demanding conditions. Tokyo's coastal region is one example, and the 3-D fabric has been used in two structures, the BCT/UBE building and the Sea Fort Square Building, within the last few years.

Over the last decade, there has been rapid development of FRP reinforcement for construction, and, according to H. Yamanouchi at the Building Research Institute, this development should continue in two stages. One stage would be for use of FRP reinforcement directly as a replacement for steel to take advantage of the material's corrosion-resistant properties. The second stage should explore all the unique properties of FRP reinforcement. For example, the material could be used in electrical facilities such as powerplants where electric corrosion is generated by a magnetic field. FRP reinforcement can also be used for concrete column confinements and used together with strain-hardening fiber-reinforced concrete.

In addition to the high cost of frp technology, there are other obstacles to its widespread use at this point. frp reinforcement deforms linearly and is subject to brittle failure. There are also difficulties in connecting frp and reinforced concrete components. Other potential problems are long-term creep, poor bonding performance to concrete, poor fire resistance and low rigidity after concrete cracking.

This material demands new structural design concepts to boost its performance/cost ratio, and Japan appears poised to abandon conventional structural design and take this next step.

A new three-year national research project, known as the New Structural Design System begins this year. A U.S./Japan Cooperative Earthquake Research Program will focus on composite-hybrid materials to enhance the efficiency of resisting seismic forces in structures. Several committees on intelligent construction materials have been created, and a new KEN–Materials Consortium at the University of Tokyo is supported by Shimizu. Shimizu has already developed a hybrid FRP with self-monitoring capability. This material, combining carbon and glass fibers, is being used in building slabs and bank vaults, and was used in the Republic Plaza, a high-rise building in Singapore completed this year.

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