Japanese Construction R&D: Entrée into U.S. Market

By Peter J. Sherman,[1] Associate Member, ASCE

Abstract: The research and development (R&D) laboratory and several of the most recently developed and successfully used construction technologies of Japan's "Big Five" general contractors are described. These technologies include the seismic or dynamic floor system that neutralizes the effects of earthquakes, robotic steel beam and column erectors, and a robotic concrete distributor. The system mechanics, performance record, and cost and/or maintenance of each innovation have been described. The paper identifies the direct benefits being derived from such intensive R&D efforts: revenues generated by private consulting, licensing arrangements, and increased contract awards—both domestic and overseas. There appears to be a direct correlation between such intensive R&D expenditures and increased overseas market share as evidenced by the recent emergence of Japanese contractors in the U.S. market, where they have parlayed their technical expertise in tunneling (shield-pressure tunneling technology) and dams (deep diaphragm cut-off walls, roller-compacted concrete dams) to underbid their American counterparts.

Introduction

While it is well-known that all of Japan's large general contractors and most middle-sized contractors perform their own "in-house" research and development (Paulson 1980a), it is not so clearly realized just what direct benefits are being derived from such R&D expenditures. Construction R&D spending by Japanese contractors is generating income through increased contract awards, licensing arrangements, and private consulting. But, perhaps most importantly, it is enabling Japanese firms to increase their overseas market share, particularly in the U.S.

The writer (the first American construction graduate to spend a one-year internship with a major Japanese construction firm) was privileged to spend the past year working in Japan with the Ohbayashi Corporation, one of the "Big Five" Japanese general contractors. During this training, considerable time was spent in the R&D lab. What follows is a description of Ohbayashi's lab and an account of several of the latest and most successful technologies developed in the labs of Ohbayashi and Takenaka Komuten, another "Big Five" firm.

As an update to perhaps the first detailed account describing Japanese construction research by Professor Boyd C. Paulson, Jr. (1980a), this paper reflects today's greater emphasis on construction robotics and earthquake neutralizing systems by Japanese contractors. Clearly, the shift toward construction automation has begun in Japan, and this in turn

[1]Vice Pres., Sherman and Son Development Corp., 9801 Collins Ave., Bal Harbour, FL, 33154.

Note. Discussion open until August 1, 1988. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 11, 1987. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 114, No. 1, March, 1988. ©ASCE, ISSN 0733-9364/88/0001-0133/$1.00 + $.15 per page. Paper No. 22304.

J. Constr. Eng. Manage., 1988, 114(1): 133-143

is enabling Japanese contractors to create new markets and to gain a keener competitive edge over their overseas counterparts.

LAB

Nestled in the middle of a farming community outside Tokyo on 16 acres of land, the Ohbayashi Technical Research Institute (see Fig. 1) engages in the research of every kind of construction technology, including urban development, pollution prevention, energy conservation, development of nuclear power facilities, energy storage, offshore structures, and biotechnology-related matters. In all there are 16 departments within the laboratory. They include:

1. Civil engineering (five departments): soils, tunneling, offshore structure technologies, etc.
2. Architectural engineering (three departments): new materials and methods, robotization, etc.
3. Structural engineering (three departments): high-rise design, nuclear power structures, base isolation structures, LNG tanks, etc. (see Fig. 2).
4. Soil and foundations (one department): earth-retaining structures, deep foundations, etc.
5. Seismology and vibration (one department): vibration hazard prevention, design of machinery foundations, etc.
6. Environmental technology (one department): solar energy, heat storage, clean air technologies, etc.
7. Acoustic engineering (one department): acoustical designs for studios, music halls, chapels; sound insulation, etc.
8. Chemical engineering (one department): properties of slurries used in excavation, soil stabilization, waste treatment, etc.

Established in 1948, the laboratory presently houses a staff of 300 members including 148 research engineers and 81 lab technicians who are supported by a healthy \$30,000,000 annual budget (140 yen/\$1.00). Realizing the importance of research for enhancing its competitiveness in domestic and overseas construction markets, Ohbayashi has increased the staff and budget of the lab by 11% and 23% respectively over the past five

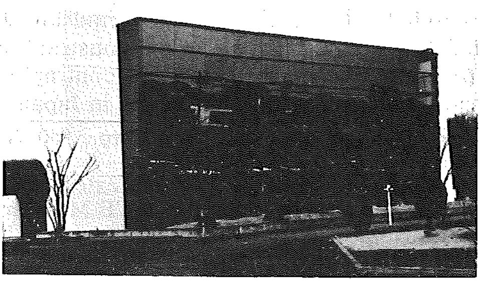

FIG. 1. Ohbayashi Corporation Technical R&D Institute

J. Constr. Eng. Manage., 1988, 114(1): 133-143

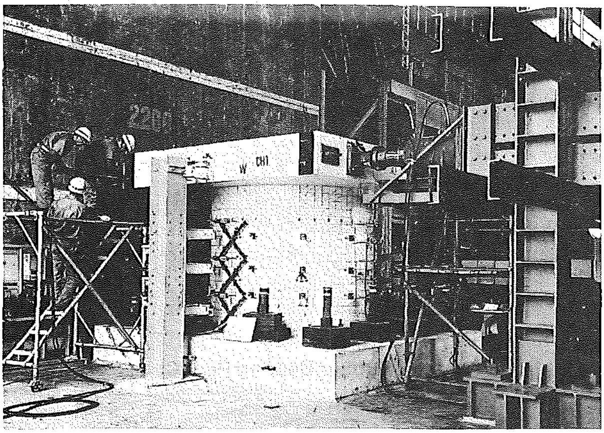

FIG. 2. Large-Scale Structural Testing Facility (Courtesy of Ohbayashi Corp.)

TABLE 1. Innovation Data Sheet (Ohbayashi Corp.)

Innovation (1)	Number of projects used (2)	Number of licensing agreements (3)
Base isolation system (Figs. 3 and 4)	3	5
Foam injection shield tunneling method	34	15
Aqua concrete (a nonsegregating underwater concrete)	40	10

years. Approximately 20% of the revenues for the lab are generated by outside consulting contracts.

As mentioned previously, the technologies developed in the labs are generating steady income streams through increased contracts awarded and licensing arrangements. Some of the proven and successfully licensed technologies developed within Ohbayashi's lab are described in Table 1.

The following are descriptions of just four of the more recent construction technologies enabling Japanese contractors to increase their contracts domestically and overseas.

Innovation 1: Dynamic Floor System

The seismic or dynamic floor is a system that permits sliding of floors to protect computers and other sensitive office equipment during earthquakes. Developed by Ohbayashi, the system has now been installed in more than 50 buildings throughout Japan totaling nearly 500,000 ft^2 of office space ("Dynamic floor system" 1986). The most recently completed project to date has been the Sumitomo Bank, located in Kawasaki, which used the system for its third, fourth, and fifth floor computers. Seven new projects are scheduled for this year.

The patented dynamic floor system required two years and approximately $300,000 to develop, a modest time and capital expenditure considering the success of the system since it was introduced. The

J. Constr. Eng. Manage., 1988, 114(1): 133-143

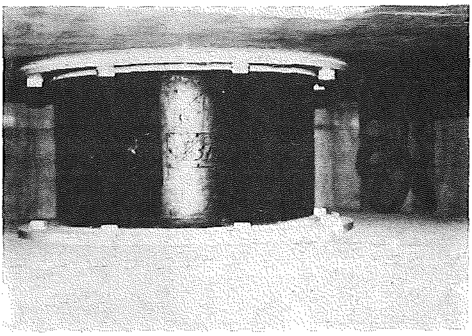

FIG. 3. Base Isolation System: Rubber Bearing Pad (Courtesy of Ohbayashi Corp.)

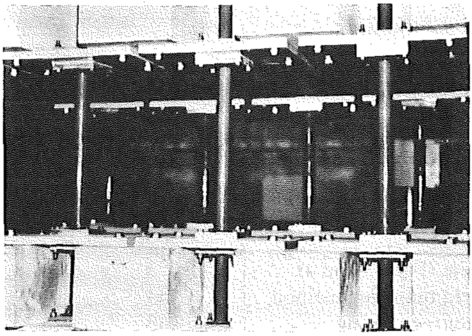

FIG. 4. Base Isolation System: Steel Dampers (Courtesy of Ohbayashi Corp.)

dynamic floor system provides an attractive economic alternative for the protection of computer office equipment in comparison to the more costly base isolation system (another earthquake-neutralizing system which requires the entire structure's foundation to be specially fitted with rubber pads and steel dampers) which is shown in Figs. 3 and 4. The dynamic floor

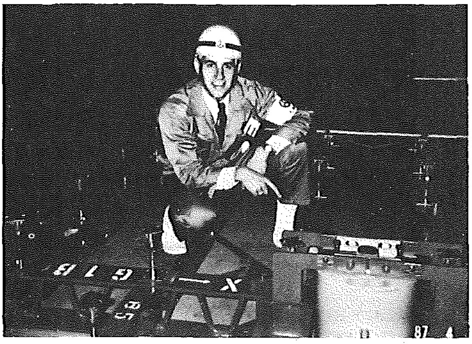

FIG. 5. Writer Shown with Dynamic Floor System at Sumitomo Bank Project (Courtesy of Ohbayashi Corp.)

J. Constr. Eng. Manage., 1988, 114(1): 133-143

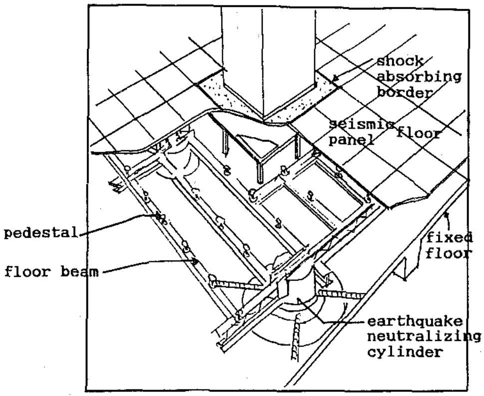

FIG. 6. View of Dynamic Floor System Layout (Courtesy of Ohbayashi Corp.)

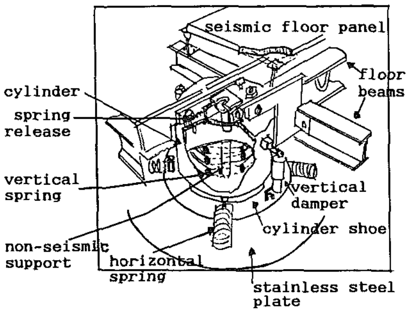

FIG. 7. Detail View of Dynamic Floor System (Courtesy of Ohbayashi Corp.)

system, on the other hand, can be installed for any particular floor desired and can even be retrofitted into existing buildings. In fact, 25% of the dynamic floors installed by Ohbayashi to date have been retrofitted.

System Mechanics

Essentially, the system consists of a double floor, with a movable or dynamic floor built 18 in. (457.2 mm) above a fixed floor. The dynamic floor bears down on vertical springs encased in 14-in. (355.6 mm) diameter steel cylinders. Two oil dampers located on either side of the cylinder absorb and neutralize most of the vertical seismic shock (see Fig. 5).

To counteract horizontal movements, each cylinder has a mechanism that allows it to slide. This consists of a Teflon-coated steel shoe under the cylinder that can slide eight in. (203.2 mm) in all directions on the 40-in. (1.016 mm) stainless-steel plate attached to the fixed floor (''Seismic floor floats during quakes'' 1978).

To prevent sliding when an earthquake is not occurring, the steel plate is fastened by four horizontal springs which are in turn anchored to the fixed floor. Steel rods inside the cylinders support the dynamic floor and prevent the floor from responding with spring action to persons walking in the computer room and other loads. Under the impact of a vertical shock, the dynamic floor is released from these rods by a spring latch. Since its development, the system has undergone only minor design changes primarily in the spring-latch mechanism (see Figs. 6 and 7).

Performance Record

Japan (like California) is a country prone to earthquakes. In the five months spent in Tokyo, the writer experienced no fewer than three earthquakes, the last one causing cracks in the concrete walls of the company dormitory room where he lived.

In 1976, an earthquake registering 6.4 on the Richter scale was recorded at the All Nippon Airways Computer Center located at Haneda Airport. Although the acceleration caused by the earthquake reached 300 m/s^2 at the sixth-floor's fixed floor, the dynamic floor 18 in. (457.2 mm) above reduced the acceleration to only 120 m/s^2. No computer damage was reported at the sixth floor.

Cost/Maintenance

The present cost (1987) for the system ranges from \$50–\$60/ft^2. Even after adjusting for the sharp appreciation of the yen, the current cost is approximately 50% lower than when the system was first introduced in 1976. According to Mr. Okuda, chief engineer for the system, the dynamic floor is designed to last the life of the building. The only maintenance required is the resetting of the spring latches after an earthquake occurs.

Innovations 2 and 3: Auto-Claw and Auto-Clamp

These two robotic devices are used for steel beam and column erecting on construction sites. The auto-claw (beam erector) was developed in 1987

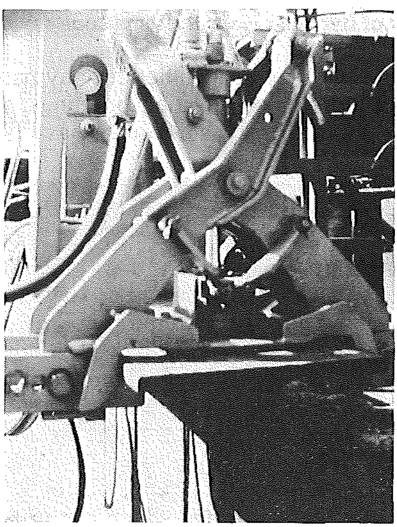

FIG. 8. Detail View of Auto-Claw Clamp (Courtesy of Ohbayashi Corp.)

J. Constr. Eng. Manage., 1988, 114(1): 133-143

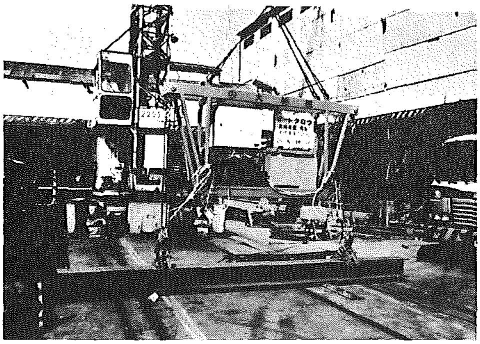

FIG. 9. Auto-Claw Shown with Steel Frame Housing Power Source (Courtesy of Ohbayashi Corp.)

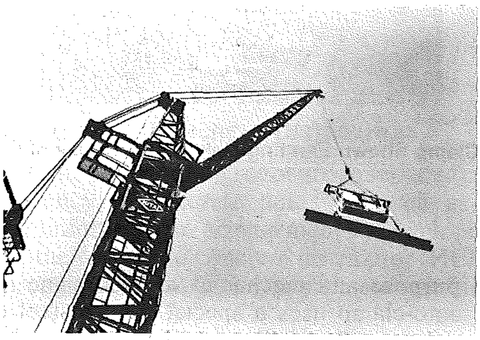

FIG. 10. Auto-Claw Hoisting Steel Beam with Crane (Courtesy of Ohbayashi Corp.)

and has been used on one project thus far (Kawasaki Steel Factory in Chiba Prefecture). Meanwhile, the auto-clamp (column erector) was developed in 1986 and has been used on three projects so far. Both construction robots have been developed to speed up erection time and to minimize the risks incurred by steel workers.

System Mechanics

Auto-Claw

Two steel clamps extend from a steel-encased unit containing a DC battery pack, electrical panel, and microprocessor unit, which is in turn suspended from a standard crane. The two clamps have a rated capacity of two tons (1,816 kg) each and can be adjusted to fit beam flanges from 8– (203.2 mm) 12 in. (304.8 mm). The clamps are automatically released by remote radio control once the beam is securely in place. Fail-safe electronic circuitry prevents the accidental release of the clamps during erection by keeping the circuit broken at such times. The steel beams require no special preparation when using this robot (see Figs. 8–10).

J. Constr. Eng. Manage., 1988, 114(1): 133-143

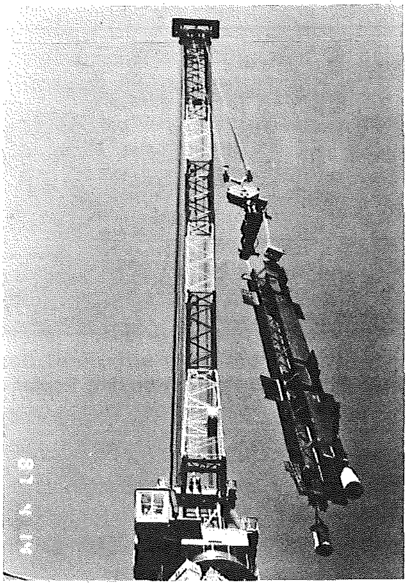

FIG. 11. Auto-Clamp Shown Erecting Column (Courtesy of Ohbayashi Corp.)

Auto-Clamp

The essential purpose and mechanics are the same as the auto-claw except that the auto-clamp uses a special electro-steel cylinder tube to secure and erect columns. Basically, a steel appendage plate with a hole in the center must be welded to one end of the column. The steel cylinder is electrically inserted and locked into the hole by remote control, whereupon the column can be erected. The auto-clamp has a rated lifting capacity of 15 tons (13,620 kg). The appendage plates must be removed after the columns are erected. Like the auto-claw, the auto-clamp has a fail-safe system preventing the cylinder from retracting from the hole during erection (see Fig. 11).

Performance Record

On the four projects using these robots, safety records indicated no accidents were sustained by steel workers. With the remote-control securing and releasing feature, workers do not endanger their lives by having to climb the tops of columns or center-spans of beams to release cables. While this feature undoubtedly reduces the time involved in the erection process, precise data have not yet been quantified.

MAINTENANCE

In addition to periodic checks to ensure proper oil levels, electrical cables, and hydraulic hoses, the only major servicing is the daily or weekly charging of the battery. If the robots are used 1–2 hr/day, weekly charging

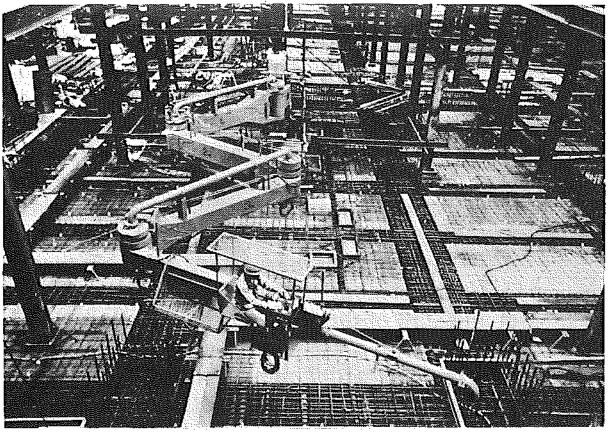

FIG. 12. Horizontal Concrete Distributor (Courtesy of Takenaka Komuten)

is required. However, if used continuously, the battery must be charged every day.

INNOVATION 4: HORIZONTAL CONCRETE DISTRIBUTOR

The purposes of this construction robot are to reduce the manpower and improve the efficiency of concrete pours, as well as minimizing the deterioration of reinforcing-bar arrangements. Developed by Takenaka Komuten in 1984, the horizontal concrete distributor (HCD) has been used on 17 projects throughout Japan (''Horizontal concrete distributor'' 1986).

System Mechanics

The HCD is a hydraulically driven three-boom telescopic arm that cantilevers from a steel column. The boom can extend 66 ft (20 m) in all directions over a 11,000 ft^2 (1,000-m^2) surface area.

A cockpit located at the end of the distributor houses the controls for an operator to manipulate the boom direction and flow of concrete. A new prototype model is remote controlled and prevents collision against existing columns by inputing their grid coordinates into the system. The weight of the robot is 4.97 tons (4,513 kg) and can be raised up the column by jacks for the next concrete pour. On average, the relocation procedure takes only 1.5 hr (see Fig. 12).

Performance Record

In all of the 17 projects using the HCD, the required manpower was reduced on average by 30%. The number of persons needed to spread and finish the concrete floors averaged 8–9 workers. Unlike the conventional concrete pump, the HCD eliminated the four or five workers needed to carry the pump and distribute the bulk volume of the concrete.

CONCLUSION

The paucity of construction R&D spending by American firms is alarming in comparison to their Japanese counterparts. According to a

J. Constr. Eng. Manage., 1988, 114(1): 133-143

1986 MIT survey by the writer, of the ten largest Japanese contractors who responded, 100% indicated they conduct R&D. In contrast, of the 11 largest U.S. contractors who responded, only three indicated they conduct R&D (9). A task-force for the Strategic Transportation Research study found that research on highway construction in 1982 was only 0.17% of our total $1,000,000,000,000 investment in highways (Moavenzadeh 1986).

Further compounding these deficiencies are the short-time horizons characteristic of U.S. firms, especially during periods of reduced profits. Of the 18 U.S. cement companies that had their own labs before the recession of the 1970's, only six had labs afterwards (Moavenzadeh 1986). Meanwhile, Japanese construction firms like Ohbayashi continued to increase the budget and staff of their labs despite declining profits over the past years.

More importantly, there is a definite correlation between such R&D expenditures and increasing market share. It is no coincidence that Japanese contractors working in the U.S. are now the fastest growing nationality group. Of the 39 Japanese contractors ranked among the top 250 international contractors, 22 reported new U.S. contracts two years ago. Their combined total has rocketed nearly 170% to $1,800,000,000 from 1984 to 1985 (Pinyan 1986). Last year, Japanese contractors did $2,500,000,000 in American contracts, a 39% increase from 1985 (Waldman 1987). By using the advanced technologies developed in these labs, Japanese firms are bidding directly against American contractors and are winning. The same shield-tunnel system mentioned previously in Table 1 was used by Ohbayashi in 1979 for winning the bid on a sewage tunnel in San Francisco, California. Remarkably, the bid price was $2,300,000 lower than the second-lowest bid and $5,000,000 below the engineer's estimate (Moavenzadeh 1986). Today, Ohbayashi is performing tunneling jobs in Los Angeles, Minneapolis, and Washington, D.C., and has captured a significant share of the U.S. tunneling market, a market traditionally held by U.S. firms. Even more significant are the recent jobs won by Japanese firms for dams (Elk Creek Dam, Oregon) and deep diaphragm cut-off walls (Department of the Interior, Wyoming).

Given the increased competitiveness in today's construction industry and the technologies that are needed, it would behoove U.S. construction firms to follow the lead set by major Japanese contractors. America's increasing dependence on the government for funding research and development stands in direct contrast to that in Japan, where 2/3 of the research and development is funded by private industry, the majority of that directed towards the commercial marketplace (Paulson 1980a). The policy of "retrenchment to protect our domestic market," as expressed by the president of one of the largest U.S. construction firms, is a prescription for decreasing market share, loss of jobs, and perhaps bankruptcy, as has been the case with the American steel and automotive industries. At stake is America's largest industry, one that performs $400,000,000,000 of work each year and employs 5,500,000 people.

Acknowledgments

The writer would like to express his deep appreciation to all of the members of the Ohbayashi Corporation Technical Research Institute, Special Construction Techniques Department, and Machinery and Equipment Department for supplying information on and photos of the R&D laboratory, the dynamic floor system, and the robotic beam and column erectors. Those individuals included Dr. Akiro Kohno (Director, R&D Laboratory), Messrs. Masayasu Higashi (Manager, R&D Planning and Administration Dept.), Okuda (Chief Engineer, Special Construction Techniques Department), Wakisaka (Manager, R&D Lab Robotics Section), and Toshio Nakamura (Machinery and Equipment Department).

The writer would also like to thank Dr. Motoki Kondo (Director, Takenaka Komuten Technical Research Laboratory), Messrs. Iwao Uchizaki (Construction Equipment Unit, Takenaka Komuten R&D Laboratory), and M. Hoshino (Takenaka International U.S.A., Ltd.) for their generous time and assistance in supplying information on and photos of several technologies including the horizontal concrete distributor robot.

Finally, the writer would like to express appreciation to Professor Boyd C. Paulson, Department of Civil Engineering of Stanford University, for reviewing the manuscript and providing numerous excellent suggestions.

Appendix. References

Dynamic floor system. (1986). Ohbayashi corporation, Tokyo, Japan.

Horizontal concrete distributor. (1986). Takenaka Technical Research Laboratory, Tokyo, Japan.

Moavenzadeh, F. (1986). "Construction: A reawakening giant." *Proc. Korean Institute of Construction Technology/Massachusetts Institute of Technology Joint Workshop on Technological Frontiers in Construction*, 34–63.

Ohbayashi Corporation Technical Research Institute report. (1985). Ohbayashi Corporation, Tokyo, Japan.

Paulson, Jr., B. C. (1980a). "Construction management in Japan." *J. Constr. Div.*, ASCE, 106(C03), 281–295.

Paulson, Jr., B. C. (1980b). "Research in Japanese construction industry." *J. Constr. Div.*, ASCE, 106(C01), 1–16.

Pinyan, C. T. (1986). "Foreigners step up U.S. invasion." *Engineering News Record*, 217(22), Nov. 27, 12–13.

"Seismic floor floats during quakes." (1978). *Engineering News Record*, 201 (1–25), Jul. 20, 17–18.

Sherman, P. J. (1986). " 'Up-down' construction: a feasibility of its application in the U.S." thesis presented to the Massachusetts Institute of Technology, at Cambridge, Mass., in partial fulfillment of the requirements for the degree of Master of Science.

Waldman, P. "Shimizu to buy minority stake in U.S. builder." *The Wall Street Journal*, CCIX(103), May 28, 4.

J. Constr. Eng. Manage., 1988, 114(1): 133-143