Slope Stabilization Using the Shotcrete Grid Beam System in Japan

by Yuji Samaru and Koji Sugiyama

Continuous grid beam structures made of shotcrete have been used for over 30 years in Japan to stabilize natural and man-made cut slopes. This slope stabilization structure, generally called "Grid Beam," is widely applied in Japan. It was used in more than 4600 slope stabilization sites in Japan in the year 2002 alone. The Grid Beam system is often used independently to protect slope surfaces from erosion, or used as a supporting structure, combined with ground anchors or soil nails to stabilize the slope against failures. The area surrounded by the beams is often revegetated to improve aesthetics and harmonize the installation with the surrounding environment (see Fig. 1). Due to the geometric flexibility of this system, the concrete beams can easily follow the undulations of natural slopes and maintain good contact with the surface.

Shotcrete Grid Beam

Basic Structure

The main components of the Grid Beam system include unique formwork made of steel wire mesh and a required amount of standard reinforcing bar, based on structural calculations. The wire mesh formwork is delivered as folded units. A slope worker unfolds them (Fig. 2) and fabricates the formwork on the slope, fastening them to the surface using anchor bolts. Typical dimensions of a beam cross section are 8 × 24 × 24 in. (200 × 600 × 600 mm), depending on the retaining capacity required. The typical spacing between two adjacent beams ranges from 5 to 10 ft (1.5 to 3 m), center to center.

Ground Anchor and Soil Nail

The Grid Beam system is often used in combination with ground anchors or soil nails where they are required to stabilize the slope. In this application, a guide pipe is installed in advance at an intersection of beams during formwork fabrication (see Fig. 3). After completing concrete placement by shotcreting, a hole is drilled through the guide pipe and a ground anchor is inserted and stressed against the Grid Beam which serves as an anchor pad. Anchor heads with corrosion protection caps are shown in Fig. 4.

Shotcrete Characteristics

Portland cement-based mortar is generally used for shotcrete in Japan. Wet-mix shotcrete is predominantly used because of its homogeneity in quality and high work efficiency. The standard design strength of Grid Beam shotcrete is normally in the range of 2175 to 3480 psi (15 to 24 MPa), slightly less than the requirements for shotcrete in western countries.

Fig 1: Grid Beam system of harmonizing with the surrounding environment

Fig. 2: Installation of Grid Beam formworks

Revegetation within Grid Beam Frames

The slope surface surrounded by the beams is either shotcreted to protect it against erosion or revegetated by installing plant based materials using the same shotcrete equipment to improve aesthetics and environmental integrity. As shown in Fig. 5, the Grid Beam becomes covered with grasses and shrubs as time goes by.

Design Considerations

The Grid Beam design, including the cross section dimensions, required amounts of reinforcement, spacing between beams, and required strength, is determined from the following perspective:

1) Stability of the target slope (that is, required retaining capacity to stabilize the target slope); and
2) Force applied to an intersection of Grid Beams (that is, tension transferred from ground anchor or soil nail). Generally, the maximum tension which can be born by the Grid Beam is in the range of 300 to 500 kN.

Stress is normally analyzed in terms of bending and shear stresses on the Grid Beam. Deformation and stress intensity of the Grid Beam, when a certain load is applied, is analyzed as a continuous beam supported at intersections or as a continuous beam attached to the surface of elastic ground, depending on the properties of the slope materials.

Case Example—Stabilization above Tunnel Portal

Tunnel Portal Site

A shallow sliding failure was anticipated above a tunnel portal on the Tateyama Highway, located in a suburb of Tokyo. Therefore the target area was cut and reshaped in advance and stabilized by the Grid Beam system together with soil nail installation (see Fig. 6 and 7). At intersections of the concrete Grid Beams, 1157 pieces of soil nail 1 in. (25 mm) in diameter and 16 l ft (5.0 m) long were installed to cover the target area of 5442 yd^2 (4550 m^2). The dimension of the Grid Beam cross section was 12 x 12 in. (300 x 300 mm) with reinforcement of 4 steel reinforcing bars of a diameter 0.6 in. (16 mm). The standard spacing between two parallel beams was 6.7 ft (2.0 m). A 20 in. (50 cm) thick plant base layer was installed inside the beam frame using the same shotcrete equipment. The total piping length from the plant to the spray location was 722 ft (220 m) with a vertical interval of 427 ft (130 m). The required unconfined compressive strength of the shotcrete was 3480 psi (24 MPa). The biggest challenge of this site was to pump materials over a long distance without losing suitable plastic properties for shotcrete

Fig. 3: Guide pipes are installed

Fig. 4: Anchor heads and Grid Beam

Fig. 5: Grid Beam covered with grasses

application and, at the same time, to satisfy product quality and strength requirements.

Materials and Mixture Design

Standard mixture proportions used for this site are shown in Table 1. Portland cement and admixtures, such as a high-performance water reducing agent and thickening agent, were used.

Shotcreting Method

Equipment system used for pumping the wet-mix shotcrete to construct the shotcrete Grid Beams is shown in Fig. 8. A water reducing agent and thickening agent were added and mixed with portland cement and fine aggregate in a truck mixer. After mixing, materials were delivered to the spray nozzle on the slope using a piston pump and were sprayed

Fig. 6: Before installation

Fig. 7: After installation

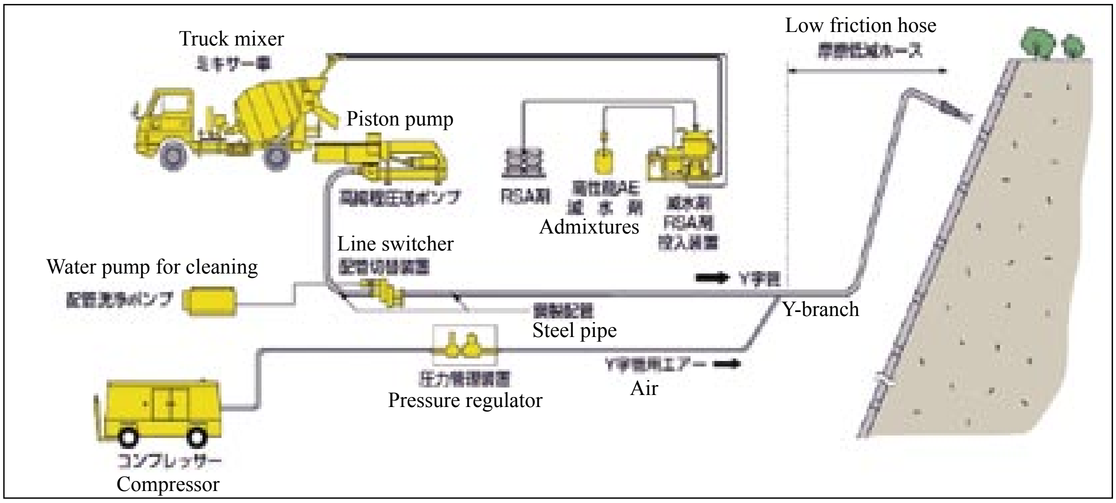

Fig. 8: Pumping wet-mix shotcrete

Table 1: Standard mixture proportions used to construct Grid Beam

Gmax	Slump	Water binder ratio (*w*/*c*)	Sand aggregate ratio	Standard mixture proportions kg/m³					
				Water (*w*)	Cement (*c*)	Fine aggregate	Coarse aggregate	Chemical admixture	Thickening agent
—	9 in. (225 mm) ±10%	52.0%	100%	257 (434 lb/yd³)	494 (833 lb/yd³)	1482 (2500 lb/yd³)	—	7.4 (12.5 lb/yd³)	4.9 (8.3 lb/yd³)

to construct beams. Compressed air was added at a Y-branch 66 linear ft (20 m) before the nozzle.

Procedure

1. Proper operation of each part of the equipment, gauges, and proper connection of pipes are checked before operating the piston pump.
2. Cement paste is pumped first to lubricate and form a thin layer of the paste inside the pipe.
3. Slump of the material is confirmed to stay within the range of 9 in. (225 mm) ±10% (see Fig. 9).
4. To obtain optimum filling and compaction performance, the air pressure is set at 44 to 73 psi (0.3 to 0.5 MPa) at the regulator.
5. The material loses fluidity immediately after shotcreting so that the slump suddenly becomes reduced to approximately an 3 in. (80 mm) ±1 in. (30 mm) level. This mitigates sloughing (see Fig. 10).
6. After placement, it is a common practice in Japan to finish the beam surface with a trowel to provide a better surface texture (see Fig. 11).

Quality Control

During Grid Beam construction, 33 sampling boxes were prepared in the same way as used for the Grid Beams by shotcreting into a box made of the same steel mesh formwork as shown in Fig. 12. Six test pieces were cored from each sampling box. Unconfined compressive strength tests were performed on three cores at 7 days and the other three at 28 days after sampling box preparation and the results were averaged respectively. The average unconfined compressive strength of all the cores at 28 days was 5018 psi (34.6 MPa), which well exceeded the design strength of 3480 psi (24 MPa), with a coefficient of variation of 8.2% (see Fig. 13).

Fig. 9: Slump measurement

Fig. 11: Surface finishing in progress

Fig. 10: Shotcrete work in progress

Fig. 12: Sampling box made of steel mesh formwork

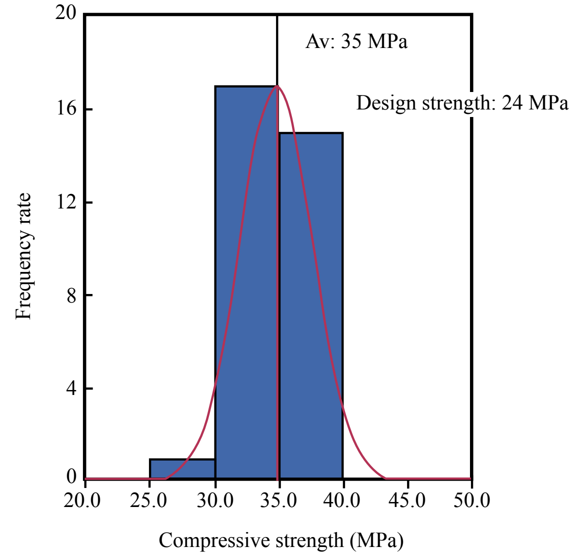

Fig. 13: Histogram of strength test results

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*JSCE fellow **Yuji Samaru**, PhD, is President of Raito Kogyo Co., Ltd., Japan, one of the leading specialist contractors in Japan, specializing in such areas as slope stabilization, slope greening, and ground improvement. He has been making efforts to improve the status of specialist contractors in the construction industry in Japan. Samaru is President of the Japan Anchor Association and of the Japan Slope Protection Association, the largest association of slope contractors in Japan. He led the development team of the Pumping Delivery Shotcrete System for Grid Beam construction at Raito Kogyo.*

***Koji Sugiyama**, a former member of the JSCE Concrete Subcommittee and of the Shotcrete Grid Beam Association, has been extensively involved in technical development activities of Raito Kogyo Co., Ltd., and is a corporate officer in charge of the Development Division of the company. He was a key member of the development team for the Pumping Delivery Shotcrete System for Grid Beam construction.*