FY2013 JSCE Innovative Technique Award for the Development of the RB (Rib Bar) Seismic Reinforcement Method

1. Background of development

In Japan, the Hyogoken-Nanbu Earthquake that occurred in 1995 caused significant damage to existing infrastructure. After the earthquake, the infrastructure underwent extensive seismic reinforcement work.

The column members of reinforced concrete (RC) elevated bridges generally are seismically reinforced using the steel plate covering method for reasons of workability and economy. Photo 1 shows an example of this reinforcement method. The method speeds reinforcement work by using relatively large heavy-construction machinery. This machinery, however, requires large workspaces around the columns and conveyance passageways. In urban districts, however, the areas under RC elevated bridges are often occupied by retail shops, warehouses, and other facilities, as shown in Photo 2. The time and cost needed to relocate and restore these facilities can delay the reinforcement work.

Photo 1. Seismic reinforcement method using steel plate coverings (requires heavy machinery)

Retail shop　　　　Warehouse or place of business

Photo 2. Examples of narrow areas under elevated bridges

Reinforcing RC elevated bridges in narrow areas where partitioning walls, mounted objects, shops and facilities, and other items are located near the columns, requires a seismic reinforcement method that can minimize relocations and restoration work.

To this end, we developed the RB (Rib Bar) seismic reinforcement method, which streamlines the seismic reinforcement of RC elevated bridges in obstructed and/or narrow areas. The aims were to accelerate seismic reinforcement work and reduce installation costs.

2. Overview of technology

2.1 Differences from conventional reinforcement methods

Figure 1 is a diagram of the reinforcement method using steel plate coverings that is generally used for the RC column members of elevated bridges. In this method, a reinforcing steel plate is wrapped around the full vertical length of the column and the gap is filled with mortar or other materials. If obstructions are mounted on the column surface, they need to be removed and later restored. Moreover, the steel plates are delivered and installed using heavy machinery, which requires adequate workspace around the columns, so obstacles in the workspace must be removed and later restored.

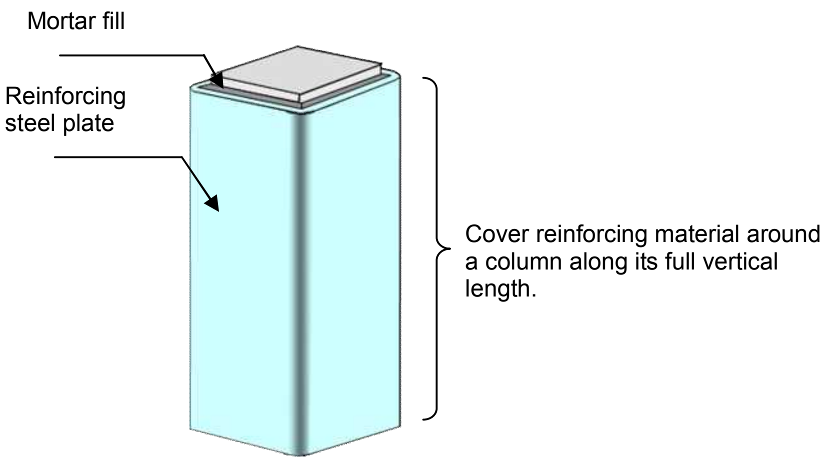

Figure 1. Conventional reinforcement method using steel plate coverings

In contrast, the RB seismic reinforcement method is very simple, consisting only of support materials at the column corners connected with reinforcing steel materials, as shown in Figure 2. Thus, reinforcement work can be carried out while objects on the columns remain in place. Moreover, the reinforcing steel materials are not attached to the column surface, but arranged so that they enclose the columns. Therefore, a column with an obstructing wall requires only simple drilling to install the reinforcing steel materials. This minimizes the removal and restoration of obstructing walls.

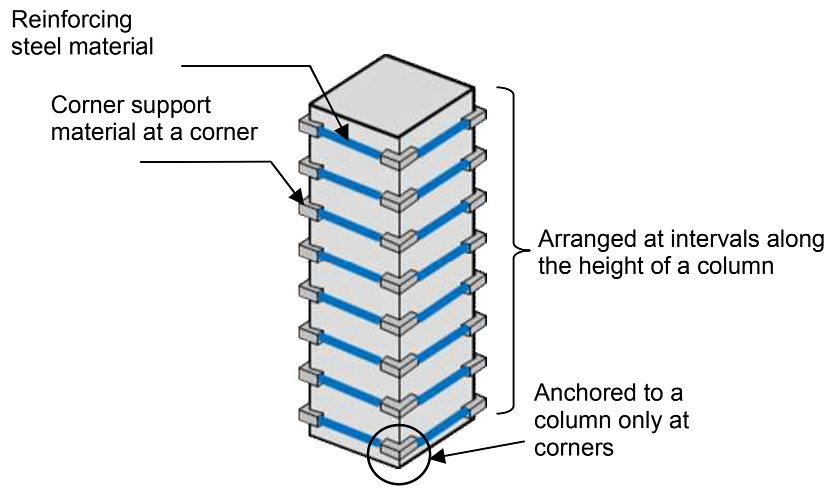

Figure 2. RB (Rib Bar) seismic reinforcement work method

2.2 Developing a new seismic reinforcement design method

1. Verifying the seismic reinforcing effects of steel reinforcements around an RC column

Generally, the seismic performance of RC columns can be enhanced by increasing the number of hoop ties within the column section. However, this cannot be done in seismic reinforcement work. Therefore, our aim was to effectively increase seismic performance by placing steel reinforcements outside the section.

To find a method for increasing seismic performance, we conducted cyclic loading tests using the test device and loading method shown in Figure 3. The parameters were the arrangement and fixing method of the reinforcing steel materials. Figure 4 shows the results of the loading tests on four test columns: a column with no reinforcement, a high-density hoop-tied RC column, a column reinforced by the RB method and covered with mortar around the column, and a column with reinforcing steel materials anchored only by support materials at the corners. The results verified that a reinforced RC column properly anchored at the column corners will exhibit remarkably improved seismic performance whether or not a mortar covering was used.

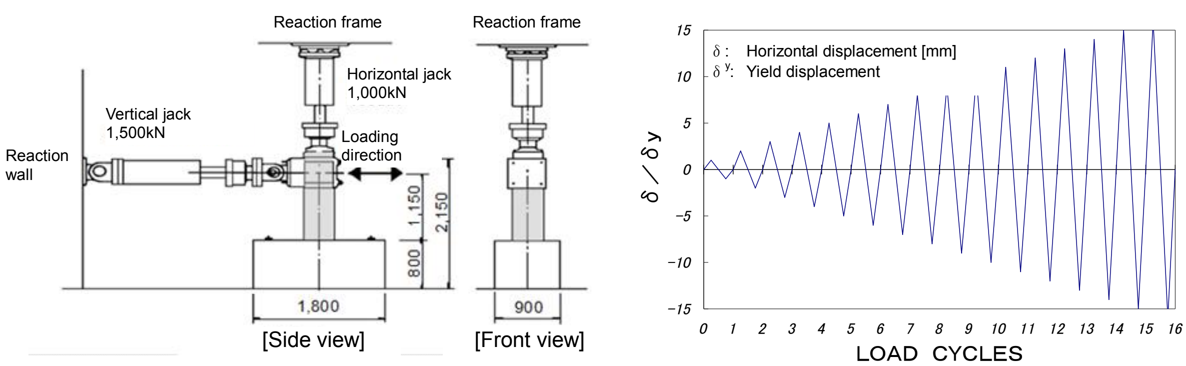

Figure 3. Test device and loading method for verifying seismic performance

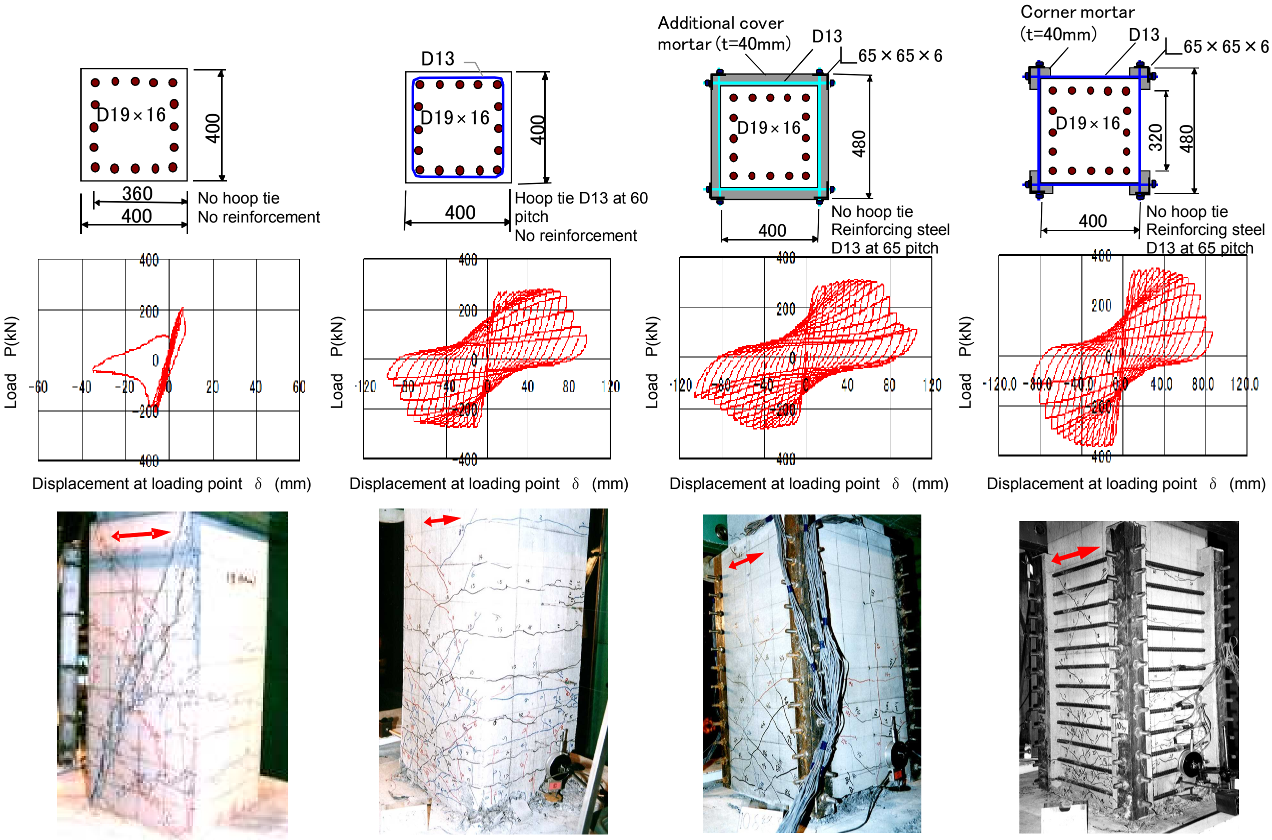

Figure 4. Results of loading test 1 (load - displacement curves, and photos when the load fell)

2. Determining the arrangement of the reinforcing steel materials

Figure 5 shows the results of the loading test in which steel L-shaped corner support materials were divided or widely spaced. The results verified that corner support materials can efficiently increase the seismic performance of an RC column even when the materials are installed separately.

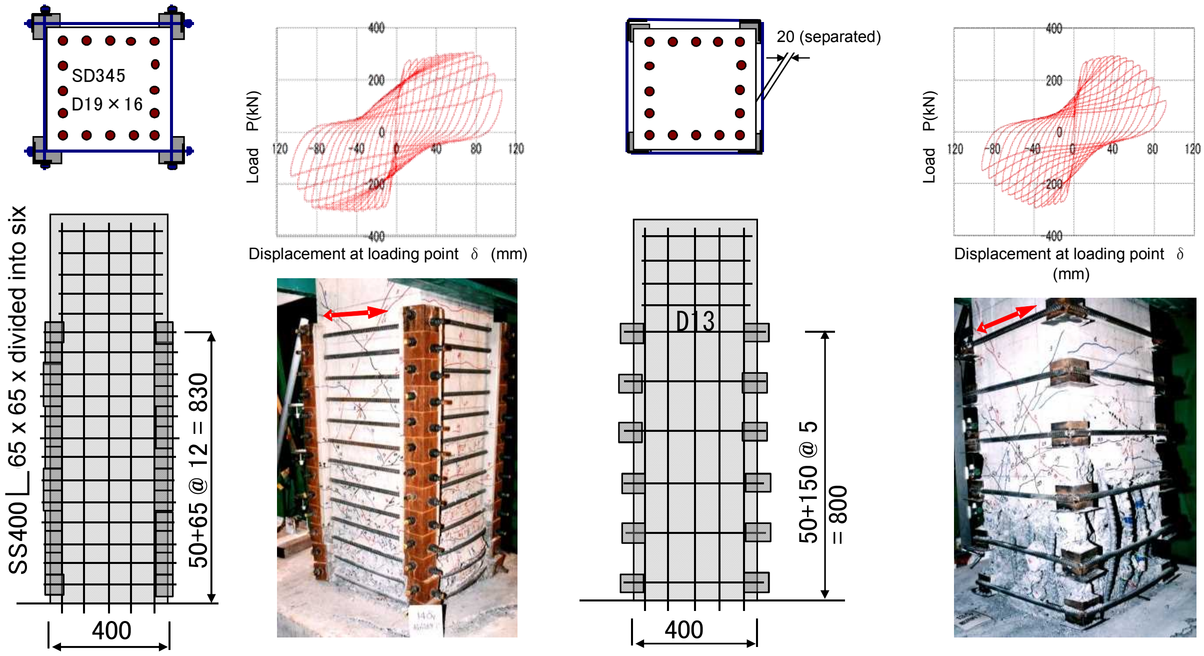

Figure 5. Results of loading test 2 (load - displacement curves, and photos when the load fell)

A loading test was conducted with full-sized test pieces to determine the amount of reinforcing steel materials to use outside the column section. The test verified that placing reinforcing steel materials outside the column section increased the shear strength to about 1.5 times or more the maximum acting shear force. This enhances the seismic performance enough to prevent the collapse of elevated bridges in major earthquakes as large as the Hyogoken-Nanbu Earthquake.

3. Determining the shape of corner support materials

The corner support material must effectively reinforce the RC section and not collapse under a tensile force that is greater than the yield load acting on the reinforcing steel material. Photo 3 shows a strength test for a simulated arrangement of corner support materials.

Photo 3. Strength test for corner support material

The corner support materials were repeatedly tested to verify their strength before we determined the final specifications of the materials (strength, shape, etc.).

2.3 Advantages of the developed reinforcement method

1. RC columns with a partitioning wall can be reinforced.

Photo 4 shows an RC column with an architectural partitioning wall. The column was reinforced using the developed reinforcement method.

Photo 4. Column with a partitioning wall

When railway station facilities, etc., are under an elevated bridge, partitioning walls or other structures may be attached to the RC columns. When applying the conventional seismic reinforcing method of steel plate coverings on such RC columns, the partitioning walls must be removed and restored. In the developed seismic reinforcement method, the wall is drilled and the reinforcing steel materials are inserted through the wall. Because the wall does not need to be removed, the reinforcement work can be completed more quickly and at a lower cost.

2. RC columns with attached objects can be reinforced.

Photo 5 shows an RC column with a bracket. The column was reinforced using the developed reinforcement method.

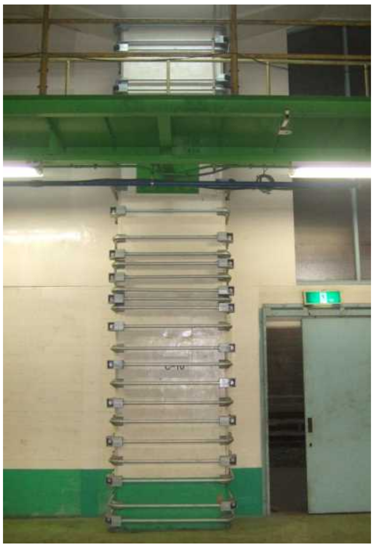

Photo 5. Column with an attached bracket

Using the conventional reinforcing method, the cables or brackets must be removed from RC columns before the columns can be reinforced with steel plate coverings, etc. In the developed method, the reinforcing materials are installed at intervals. Because the developed method allows for flexible spacing that satisfies the design conditions, the reinforcing work can be carried out around any attached objects. Therefore, the reinforcement work can be completed more quickly and at a lower cost.

3. The compact reinforcement members can be installed in narrow spaces.

Photos 6 and 7 show RC columns very near a railway track. The columns were reinforced using the developed reinforcement method. No heavy machinery was used for the reinforcement work.

Photo 6. Column in a narrow space near a railway track

Photo 7. Columns in a narrow space near a railway track

For RC columns in narrow areas, conventional reinforcement methods, such as steel plate coverings, require adjacent facilities to be relocated and passageways secured, and the use of the area must be suspended while the work is done. The developed work method uses lightweight and compact materials that can be transported to the site and installed using only manpower. This eliminates the need for large delivery passageways and construction spaces, which enables efficient reinforcement work even in narrow spaces.

4. The simple reinforcing structure allows installation around objects.

Photo 8 shows an RC column in a narrow space and surrounded by electric equipment and piping. The column was reinforced using the developed method without removing the equipment and piping.

Photo 8. RC column in an occupied area and surrounded by obstacles

Columns inside a facility or surrounded by equipment can be reinforced using conventional work methods only after the facilities and equipment are moved elsewhere. The developed reinforcement method uses a simple reinforcing structure that can be installed while the area is occupied. Thus, reinforcement work can be carried out without relocating the facilities under elevated bridges, significantly reducing the burden on concerned parties.

3. Development of reinforcement method

Full-scale seismic reinforcement work began in 1995, primarily under elevated bridges in spaces that were not occupied. The work then shifted to spaces that were occupied, which prompted us to begin developing the reinforcement method in 1997.

The seismic performance of the reinforced structures was verified by static peak-to-peak cyclic loading testing using test pieces that simulated existing RC columns. Following this testing, we started developing the precast corner support materials. These were tested in 1999 and subsequently put into actual use.

Later, the design of the corner supports was refined. Currently, there are four major types of corner supports: the cast-in-place type (comprised of L-shaped steel and mortar), the cast iron type, the cast steel type, and the steel type (comprised of L-shaped steel and steel material). The different types are used according to the site environment and the amount of reinforcing steel material required. Figure 6 shows the development process for the corner supports.

4. Effects of development

1. Reduced costs for relocation

With conventional reinforcement methods, the railway station facilities, etc., in the space under the elevated bridge must suspend their operations and relocate until the reinforcement work is done. This delays the start of the reinforcement work and raises costs. Moreover, the costs to relocate the electric, air-conditioning, and other equipment far exceed the costs of the actual reinforcement work. In contrast, the developed reinforcement method does not require major facilities to relocate, significantly reducing the cost of the reinforcement work.

2. Reduced costs for removal and restoration work

Conventional reinforcement methods require any partitioning walls or brackets attached to the RC columns to be removed before the reinforcement work can begin. After the work is completed, the walls or brackets must be restored. In contrast, the developed reinforcement method minimizes the area in which walls and brackets must be removed and restored, reducing the overall cost of reinforcement work.

3. Significantly shorter work period

The developed reinforcement method requires minimal relocation, removal, and restoration work, particularly in areas used as retail shops, railway station facilities, etc., thereby significantly shortening the work period.

5. Conclusion

The developed reinforcement method is simple and uses lightweight reinforcing members installed intervals around the RC columns to improve seismic performance. The method has significantly enhanced the overall earthquake resistance and safety of RC structures, including RC elevated bridges, where seismic reinforcement work had been hindered.

The reinforcement method has been adopted by many railway operators and applied to about 6,500 RC columns for elevated bridges and other structures. The elevated bridges that had been reinforced by this method experienced no damage from the Great East Japan Earthquake. The method has been selected by the Ministry of Land, Infrastructure, Transport and Tourism for inclusion in their guidelines. Subways and government buildings also are increasingly using this method of seismic reinforcement. Thus, the developed reinforcement method has greatly improved the earthquake resistance of Japan’s essential infrastructure.