The New Earthquake Resistant Reinforcement Method for Concrete Structures

-Adoption of Post-Installed Shear Reinforcement Bar Method –

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Background and Purpose

The Tokyo Metropolitan Waterworks Bureau (hereinafter referred to as, "Tokyo Waterworks") promotes earthquake-resistant projects in order to prepare against earthquakes which are likely to hit directly Tokyo metropolitan area.

The facility reported in this paper is the largest distribution reservoir (Fig. 1) in Tama district with a capacity of approximately 70,000 m³, and supplying water to approximately 75,000 people. Although it is a relatively new structure completed around 20 years ago, the design is by the previous earthquake resistance standards. According to the structural analysis with present earthquake-resistant standard which has been carried out since 2009, the facility did not have required seismic performance (performance that does not have a serious effect on the function) against level 2 of earthquake motions (the largest scale earthquake motion assumed at that point).

Additional concrete is generally used as a seismic reinforcement method for reinforced concrete reservoirs. However, this method is disadvantageous in reducing the amount of water stored.

Therefore, Tokyo Waterworks decided to adopt "post- installed shear reinforcement bar method (Fig. 2) ". With this method, Tokyo Waterworks can improve the shear strength alone and secure the toughness by considering the water supply population, without reducing reservoir capacity of the water storage. However, note that, if using this method, it is necessary to pay attention to avoid damaging the main rebar in the existing concrete when inserting the reinforcement bar.

This paper reports a reinforcement method by "post- installed shear reinforcement bar method" to a concrete structure where main rebars densely arranged. This method has been considered as its difficulty being employed.

Fig.1 Yarimizuoyama Water Supply Station

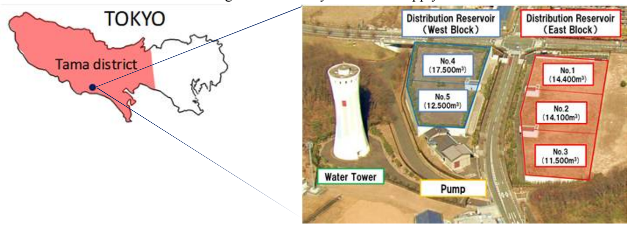
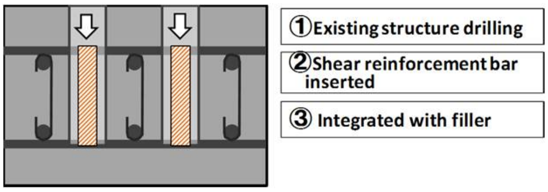


Fig.2 Post- installed shear reinforcement bar method



Comparison and Discussion of the Construction Method

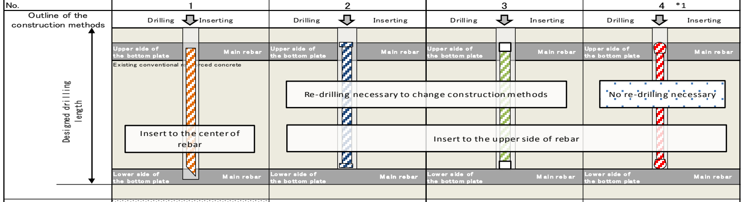
According to an initial study of this construction, the numbers between No. 1-3 in table 1 shows comparison of the post- installed shear reinforcement bar methods. By considering the following three points, Tokyo Waterworks adopted a method No.1 by using reinforcing bar where the tip of a shear reinforcing bar is processed obliquely (hereinafter referred to as the "oblique tip type") and a method of using inorganic mortar capsule as a fixing agent for reinforcement bar.

① As it is necessary to construct a dense main rebar, it can reduce the drilling hole diameter
② Workability.
③ Economic efficiency.

When using the oblique tip type, it is necessary to insert shear reinforcement bar to the depth of the center of the main rebar on the lower side of the bottom plate.

Table 1 Comparison of post- installed shear reinforcement bar methods

Comparison of construction methods			After re-examination		
		Initially			
No.		1	2	3	4 *1
Outline of the construction methods		Drilling ⇩ Inserting	Drilling ⇩ Inserting	Drilling ⇩ Inserting	Drilling ⇩ Inserting
Drill hole diameter (when using D19)		**28mm**	36mm	34mm	**28mm**
Shear Reinforcement Bar		**Oblique tip type**	Plate adhesive type	Ceramic cap type	**Both-ends headed type**
		Constructed at the site	Constructed in the factory	Constructed at the site	**Constructed in the factory**
Filling method		Insert inorganic mortar capsules	Inject cement type grout	Inject cement type grout	**Insert inorganic mortar capsules**
Effective rate *2		0.85	0.90	0.94	0.89
Workability *3		28.5pieces/day	24.5 pieces/day	9 pieces/day	28.5 pieces/day
Economic efficiency *4		1.00	1.13	1.19	**1.06**
Evaluation	Initial	○ (Adopted)	△	△	
	Re-examination	△ (Partly adopted)	×	×	○ (Adopted)



※1 No.4 was not in use at the time of designing.
※2 Coefficient indicates the effectiveness to the improvement of shear strength (in the case of the concrete thickness 1.0 m and reinforcing bar diameter D19)
※3 In the case of concrete thickness 1.0 m, diameter of reinforcement bar D 19, and using rock drilling machine
※4 Relative comparison (As of November 2015).

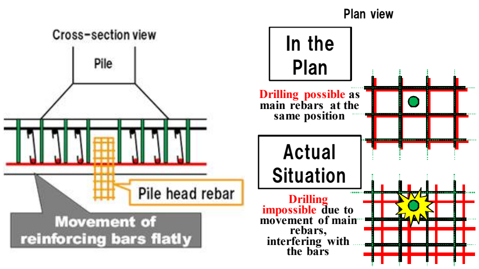
Issues at the Time of Construction and Restudy of Construction Methods

【Issues at the Time of Construction】
・Tokyo Waterworks could find only the position of the main rebars on the upper side of the bottom plate before construction.
・Tokyo Waterworks was unable to drill to the required depth due to contacting with the main rebars on the lower side.
・This is because the west block is the pile foundation form. (Fig. 3)

【Restudy of Construction Methods】
・Re-examined the three construction methods (No.2～No.4) in Table 1.
・Decided to use reinforcement bars with hemispherical heads at both-ends of No. 4("both-ends headed type") .
・Both-ends headed type is necessary to manufacture reinforcement bars in the factory.
・On the other hand, as fixing force of the rebars increases.
・This is why both-ends headed type is unnecessary to increase the amount of reinforcement bar even if reinforcement bars cannot only be inserted to required depth.
・Both-ends headed type is also possible to use the hole already drilled in contact with the main rebars.
⇒Preventing an increase in the construction period and the construction cost significantly.

【The effective shear force rate】
・Post- installed shear reinforcement bar cannot bear 100% of the shear force handled by a standard hook rebar.
・The reinforcement efficiency increases as the effective shear force rate (The effective rate) gets closer to 1.0.
・When the oblique tip type is inserted to the center of the main rebars , the effective rate is 0.85.
・When the both-ends headed type stops at a high position of the upper part of the main rebars , the effective rate is 0.89.
・When the both-ends headed type is inserted to the main rebars position, the effective rate is 0.9.

Fig.3 Cause analysis



Conclusion

【Additional concrete reinforcement method (ordinary method)】
・Most of the concrete underground structures are reinforced only from the inside for earthquake resistance.
・The significant issues are a reduction in effective capacity and a prolonged construction period.
・In some cases, there were cases requiring further seismic reinforcement due to increasing bending strengthening.

【The latest post- installed shear reinforcement bar method】
・This method increases only shear reinforcement without decreasing effective capacity and can secure toughness.
・This method has superior in workability and economy due to using simple equipments.

Fig.4 Construction Process

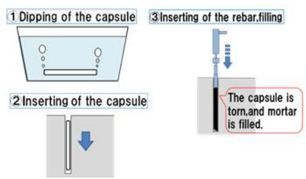


Fig.5 Construction Situation

The concrete structures which occupy most of the main water supply facilities don't have sufficient shear strength against large-scale earthquakes due to effective countermeasures being unestablished. Therefore distribution reservoir and earthquake resistance rate of purification facility were 53.3% and 27.9% in 2016.
This latest method eliminates the bottleneck in the seismic reinforcement of concrete structures and greatly contributes to the improvement of earthquake resistance of water supply facilities.