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Out-of Plane Shear Reinforcing Method for the walls of Underground Existing RC Structures

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Abstract

A retrofit method for RC underground structure, such as box culvert, was developed. Walls, floors and roofs of box culvert can be retrofitted by the post-installed shear reinforcing bars. High strength steel bars, which have yield strength of 1080N/mm^2, are inserted into holes drilled from the inside of culvert as shear reinforcement, and glued. By attaching multiple round nuts as mechanical anchor at both end if bar, enough bond strength between the bar and existing concrete is provided after insterting. Because of the number of holes can be reduced due to the higher strength of bar, drilling work can be saved significantly, compared to the case utilizing ordinal steel bars. Shear loading test was conducted on shear strengthened specimens by this retrofit method. Followings were outcomes. 1) Shear strength were well increased, 2) Shear contribution of the bar becomes greater as the depth of RC section deeper, 3) Evaluation formula of the shear strength utilizing this method was proposed based on the experimental results.

Keywords: retrofit, post-installed shear reinforcement, culvert, out of plane, high strength steel bar, mecanical anchor.

1. Introduction

An example of underground RC structure includes box culvert. There are many box culverts that shear reinforcement is a little or none, because the allowable shear strength in old design cord was not conservative comparing with latest one. Therefore, they have a possibility of shear failure by seismic load. It is necessary to add shear reinforcement for seismic retrofit. This method prevents the old culvert shear failing by post-installed reinforcing bars to drilled hole from inside the culvert in out of plane direction. As additional shear reinforcement, utilization of high strength reinforcement makes drilling work reduce. The utilization of mechanical anchor on the additional steel bars provides good bond between existing concrete and additional steel bars. The strength of the high strength steel bar that made by PC reinforcement rod is 1080N/mm^2. The diameter of the mechanical anchor was designed in order to put into the ϕ53mm drilled hole, and the number of the mechanical anchor was two to provide enough bond between existing concrete and additional steel bars. The post-installed shear reinforcement outline is shown in Fig.1. The drilled hole must not penetrate because groundwater that is behind the wall comes inside through the hole. In addition, the drilled hole must not reach to the deeper existing reinforcement because the drill may damage the existing reinforcement. The behavior of post- installed shear reinforcement utilizing multi-mechanical anchored high strength steel bar is not clear.

This paper describes the result of shear loading test, and proposes the estimation of shear strength in case of this retrofit method.

2. Outline of shear loading test

2.1 The specimens

For example of specimen, reinforcement detail of “D075PW16-M12P” is shown in Fig.2. In the left side of shear span, the drill approached from the top to make the hole. And in another side, one approached from the bottom of the beam. This method can estimate shear strength conservatively using both shear span even though the influence of the drilled direction was unknown. A core drill was used to reduce damage of the concrete. The hole does not penetrate.

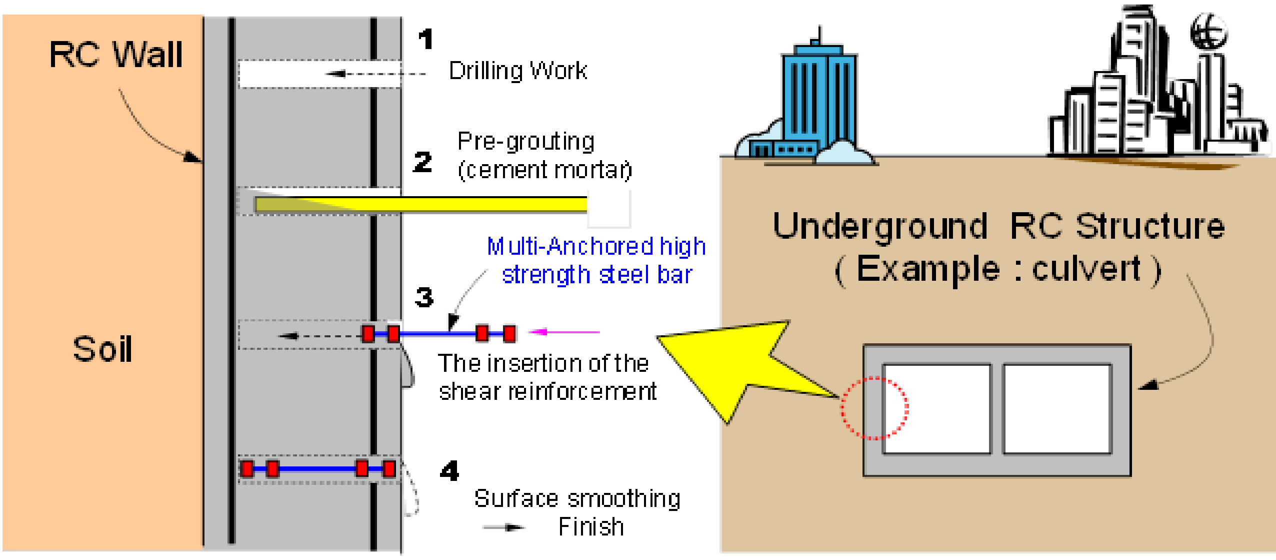

Fig. 1 – Outline of this method (Post-installed shear reinforcement)

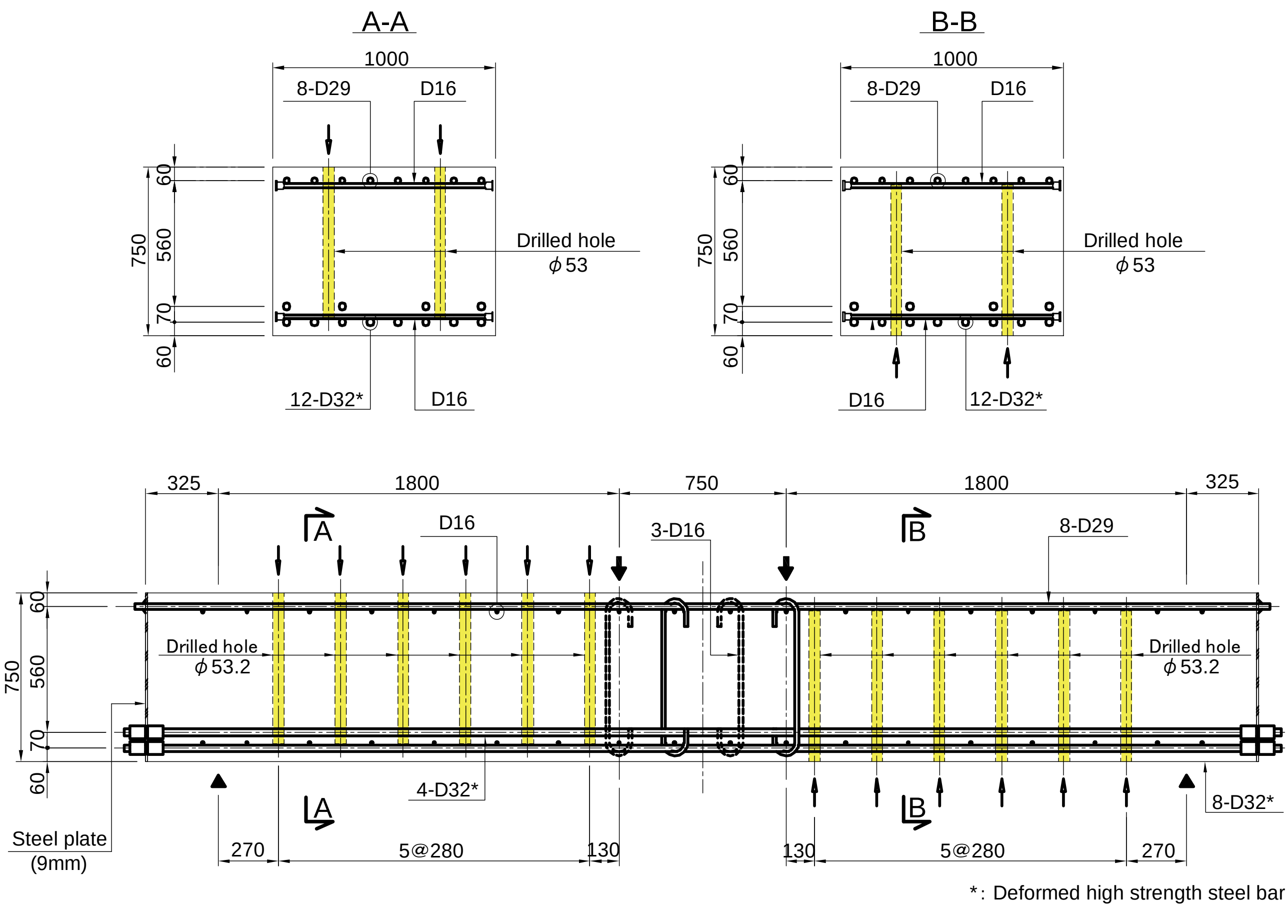

Fig. 2 – Side view and cross section detail of specimen (D075PW16-M12P)

The parameter is shown in Table 1. The parameters are cross section depth (D), the size of the high strength steel bar (ϕ13, ϕ17, ϕ 19), shear reinforcement ratio (p_w), direction of the grout and utilization of primer. Shear span ratio of all specimens was fixed as 2.61. Deformed high strength steel bar was used as longitudinal rebar of all specimens to avoid flexure failure. Multi-mechanical anchor that was used at the both end of high strength steel bar is shown in Fig.3. The bearing area ratio was defined the value that divided the bearing area of the anchor by the area of high strength steel bar. The value is 10, 12,14 in case of using high strength steel bar ϕ13,ϕ17,ϕ19.

Table 1 – The parameters

Specimens	Size of the Cross Section			Span		Added shear reinforcement			Grout *** in the driled hole	
	Width B (mm)	Depth D (mm)	Depth of Rebar d (mm)	Shear span a (mm)	Shear span ratio a/d	Reinforcing ratio pw (%)	Number & Size (mm)	Pitch (mm)	Direction V : ↓ * H : →	** Primer
D050PW16-S10N	1000	500	440	1150	2.61	0.16	2-ϕ13	@180	↓	-
D075PW00	1000	750	690	1800	2.61	0.00	—	—	-	-
D075PW11-S10N	1000	750	690	1800	2.61	0.11	2-ϕ13	@250	↓	-
D075PW16-S10N	1000	750	690	1800	2.61	0.16	3-ϕ13	@250	↓	-
D075PW21-S10N	1000	750	690	1800	2.61	0.16	4-ϕ13	@250	↓	-
D075PW16-M12P	1000	750	690	1800	2.61	0.16	2-ϕ17	@280	↓	○
D075PW24-M12P	1000	750	690	1800	2.61	0.24	3-ϕ17	@280	↓	○
D075PW24-M12N	1000	750	690	1800	2.61	0.24	3-ϕ17	@280	↓	-
D075PW10-L14P	1000	750	690	1800	2.61	0.10	1-ϕ19	@280	↓	○
D075PW10-L14N	1000	750	690	1800	2.61	0.10	1-ϕ19	@280	↓	-
D075PW20-L14P	1000	750	690	1800	2.61	0.20	2-ϕ19	@280	↓	○
D075PW20-L14N	1000	750	690	1800	2.61	0.20	2-ϕ19	@280	↓	-
D100PW16-S10N	1000	1000	940	2450	2.61	0.16	3-ϕ13	@250	↓	-
D100PW16-M12P	1000	1000	940	2450	2.61	0.16	2-ϕ17	@280	↓	○
D100PW16-M12NH	1000	1000	940	2450	2.61	0.16	2-ϕ17	@280	→	-
D100PW20-L14P	1000	1000	940	2450	2.61	0.20	2-ϕ19	@280	↓	○
D100PW20-L14N	1000	1000	940	2450	2.61	0.20	2-ϕ19	@280	↓	-
D100PW20-L14NH	1000	1000	940	2450	2.61	0.20	2-ϕ19	@280	→	-

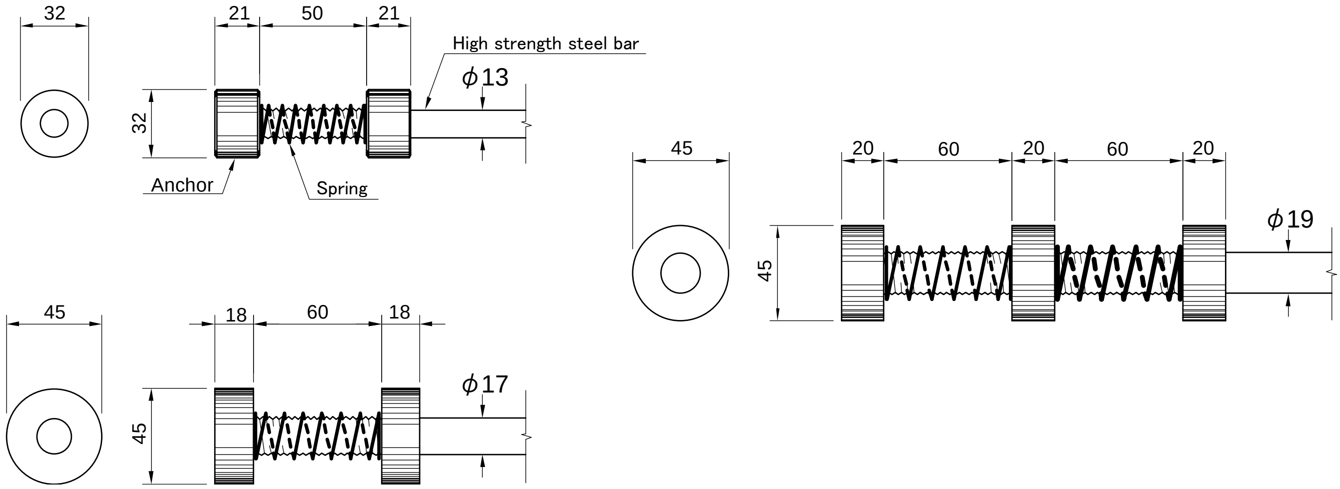

Fig. 3 – Multi-mechanical anchor at the both end of high strength steel bar

2.2 Material properties

All specimen were poured concrete that mix proportion is shown in Table 2. The material properties of steel bars is shown in Table 3, and one of concrete and motar is shown in Table 4.

Table 2 – Mix proportion of concrete

W (kg/m^3)	C (kg/m^3)	W/C (%)	Sand (kg/m^3)	Aggregate (kg/m^3)
168	276	61	813	1026

*air content : 4.5% **maximum aggreagate size : 20mm

Table 3 – Material properties of steel bars

Steel		Yield * strength (N/mm^2)	Tensile strength (N/mm^2)	Young's modulus (kN/mm^2)
Longitudinal Rebar D32 (SBPR1080/1230)	S10 series	1159 *	1293	200
	M12 series L14 series	1169 *	1299	197
High Strength Steel bar (SBPR1080/1230)	ϕ13	1234 *	1309	207
	ϕ17	1201 *	1286	205
	ϕ19	1206 *	1285	205

* : 0.2% proof stress

Table 4– Material properties of concrete

Specimen \ Material	Concrete			Mortar *	
	Material age (day)	Conpressive strength (N/mm^2)	Young's modulus (kN/mm^2)	Material age (day)	Conpressive strength (N/mm^2)
D050PW16-S10	37	31.9	23.5	18 (15)	75.5 (78.2)
D075PW00	28	32.4	23.2	-	-
D075PW11-S10	29	32.4	23.1	10 (7)	80.6 (72.8)
D075PW16-S10	30	29.3	22.3	11 (8)	
D075PW21-S10	33	31.7	23.3	14 (11)	89.9 (81.4)
D075PW16-M12P	54	26.9	-	32 (25)	86.6 (79.1)
D075PW24-M12P	21	32.2	-	15 (8)	80.7* (73.3)*
D075PW24-M12N	39	37.9	26.6	16	95.7
D075PW10-L14P	20	30.9	27.0	14 (8)	80.7 (73.3)
D075PW10-L14N	38	36.9	-	32 (20)	102.6 (92.6)
D075PW20-L14P	55	27.8	-	13 (7)	80.7** (73.3)**
D075PW20-L14N	37	32.5	27.0	31 (19)	104.8 (93.5)
D100PW16-S10	44	33.9	24.1	23 (20)	78.3 (73.2)
D100PW16-M12P	46	26.3	23.2	24 (17)	85.0 (77.0)
D100PW16-M12NH	41	36.9	-	25 (15)	89.5 (80.9)
D100PW20-L14P	49	27.1	-	25 (18)	85.0*** (77.0)***
D100PW20-L14N	42	36.0	-	28 (18)	89.4 (80.8)
D100PW20-L14NH	33	32.0	23.6	15	93.4

* : ( ) is the used mortar strength in Right Side shear span of Beam

** : Estimated value from the data of D075PW10-L14P

*** : Estimated value from the data of D100PW20-L14P

2.3 Loading method

The specimens are monotonic loaded as simple beam. Loading and bearing point were shown in Fig.2. Shear span ratio of all specimens was fixed as 2.61. In the case that shear span ratio is over 2.5, it is expected that arch action of concrete strut is not effectively expected in shear strength. Therefore, larger shear span was employed, because it is desirable to estimate that action as conservatively as possible.

3. Experimental results

3.1 Load-displacement relationship

The test results is summarized in Table 5. Obtained load-displace relationship are shown in Fig.4~Fig.9 in case of cross section depth is 750mm. When the shear reinforcement increased, the experimental shear strength increased. Fig.10 show the relationship between shear reinforcement ratio (p_w) and shear strength on S-series. Experimental shear strength is smaller than the one that was calculated with truss analogy assuming yield strength of shear reinforcing bar. But the difference becomes small when the cross section depth becomes large. Table 5 shows that the ratio of experimental steel shear contribution to calculated one were 0.36~0.87. The ratio is smaller in case of using primer in spite of same additional shear reinforcement condition. Fig.4~Fig.9 also show the behavior. It is not good to use primer for this post-installed shear reinforcing method.

Table 5– Summary of test results and calculated values

Specimens	Size of the Section		Added shear reinforcement			Grout in the driled hole		Shear strength (kN)				α ***
	Width B (mm)	Depth D (mm)	Reinforcing ratio pw (%)	Number & Size (mm)	Pitch (mm)	Direction V : ↓ H : →	Primer	Experimental V_u	Calculated ** V_u^{cal} *	V_C^{cal} *	V_S^{cal} *	$\frac{V_u - V_C^{cal}}{V_S^{cal}}$
D050PW16-S10N	1000	500	0.16	2-ϕ13	@180	↓	–	609	996	387	609	0.36
D075PW00	1000	750	0.00	—	—	–	–	561	530	530	0	–
D075PW11-S10N	1000	750	0.11	2-ϕ13	@250	↓	–	985	1195	530	665	0.68
D075PW16-S10N	1000	750	0.16	3-ϕ13	@250	↓	–	1112	1510	513	997	0.60
D075PW21-S10N	1000	750	0.16	4-ϕ13	@250	↓	–	1389	1856	526	1330	0.65
D075PW16-M12P	1000	750	0.16	2-ϕ17	@280	↓	○	969	1514	498	1016	0.46
D075PW24-M12P	1000	750	0.24	3-ϕ17	@280	↓	○	1057	2052	529	1523	0.35
D075PW24-M12N	1000	750	0.24	3-ϕ17	@280	↓	–	1343	2081	558	1523	0.52
D075PW10-L14P	1000	750	0.10	1-ϕ19	@280	↓	○	745	1156	522	634	0.35
D075PW10-L14N	1000	750	0.10	1-ϕ19	@280	↓	–	957	1187	553	634	0.64
D075PW20-L14P	1000	750	0.20	2-ϕ19	@280	↓	○	1050	1772	504	1268	0.43
D075PW20-L14N	1000	750	0.20	2-ϕ19	@280	↓	–	1327	1798	530	1268	0.63
D100PW16-S10N	1000	1000	0.16	3-ϕ13	@250	↓	–	1837	2011	658	1353	0.87
D100PW16-M12P	1000	1000	0.16	2-ϕ17	@280	↓	○	1601	1996	618	1378	0.71
D100PW16-M12NH	1000	1000	0.16	2-ϕ17	@280	→	–	1749	2070	692	1378	0.77
D100PW20-L14P	1000	1000	0.20	2-ϕ19	@280	↓	○	1444	2345	624	1721	0.48
D100PW20-L14N	1000	1000	0.20	2-ϕ19	@280	↓	–	1908	2407	686	1721	0.71
D100PW20-L14NH	1000	1000	0.20	2-ϕ19	@280	→	–	2053	2381	660	1721	0.81

*: $V_u^{cal}=V_C^{cal}+V_S^{cal}$ "V_C^{cal}"is contribution of concrete. "V_S^{cal}"is contribution of shear reinforcement of steel.
: The calculated value with JSCE design code. *: Reduction factor of added shear reinforcment comparing with calculeted value.

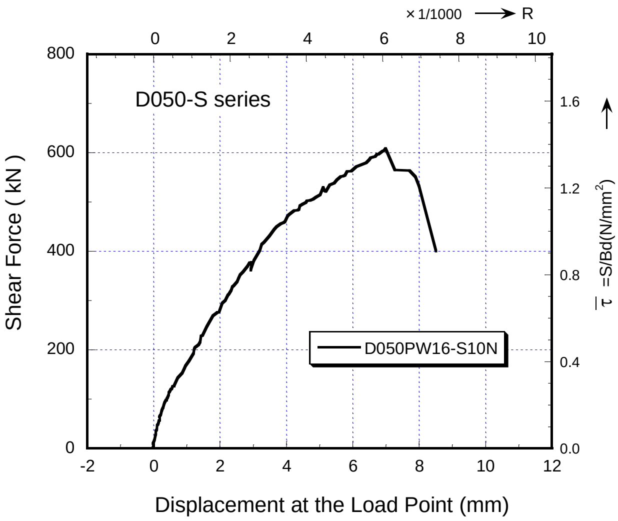

Fig. 4 – S-δ (D050 S-seris)

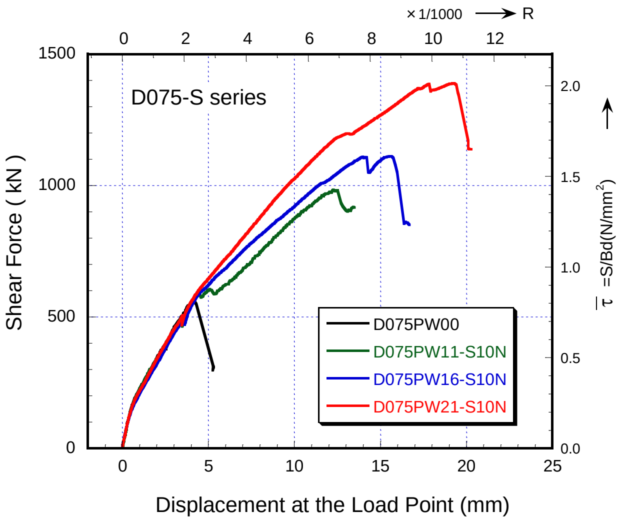

Fig. 5 – S-δ (D075 S-seris)

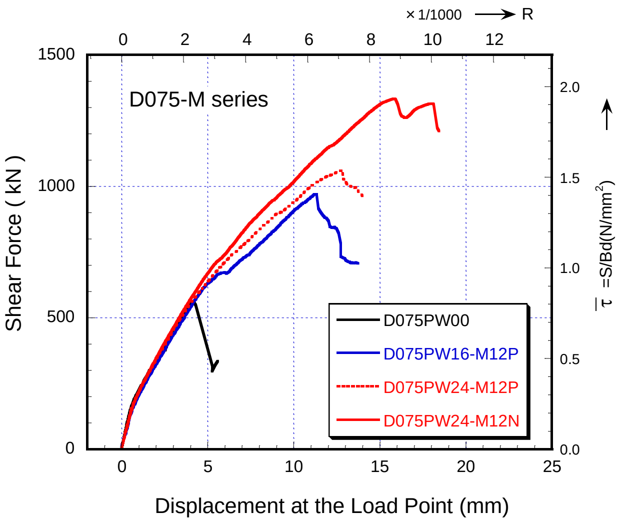

Fig. 6 – S-δ (D075 M-seris)

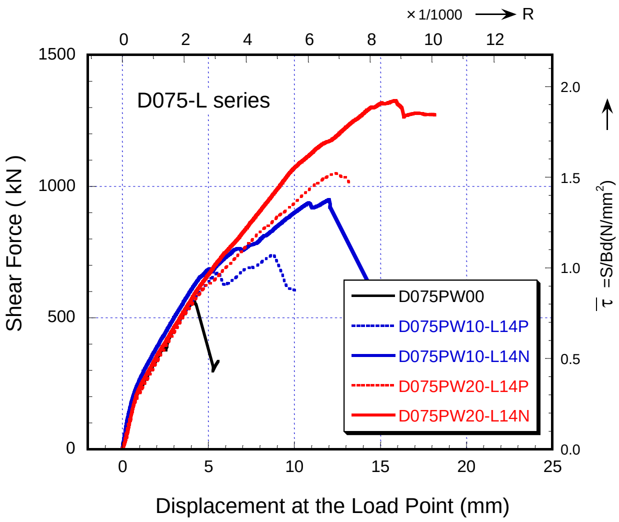

Fig. 7 – S-δ (D075 L-seris)

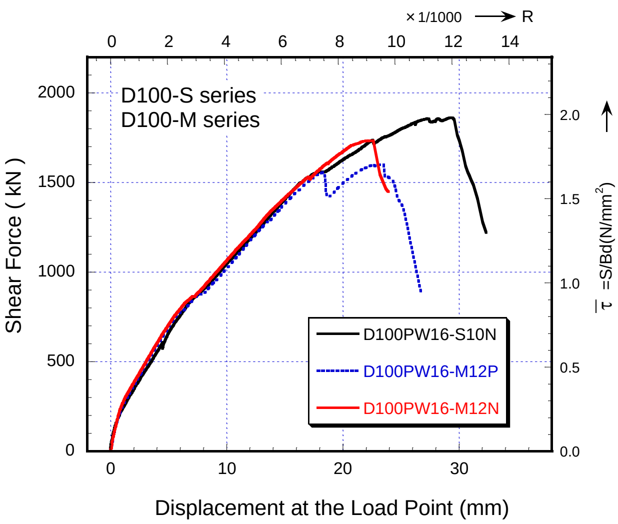

Fig. 8 – S-δ (D100 S-seris, M-seris)

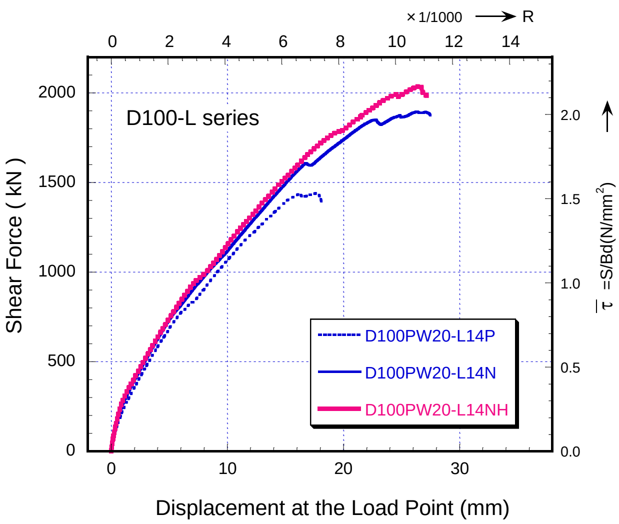

Fig. 9 – S-δ (D100 L-seris)

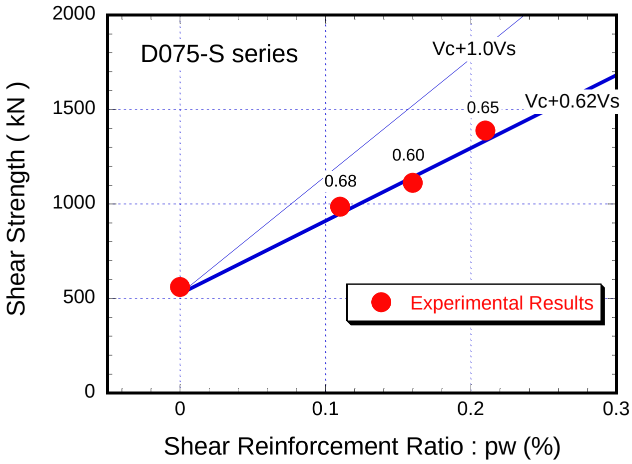

Fig. 10 (a)

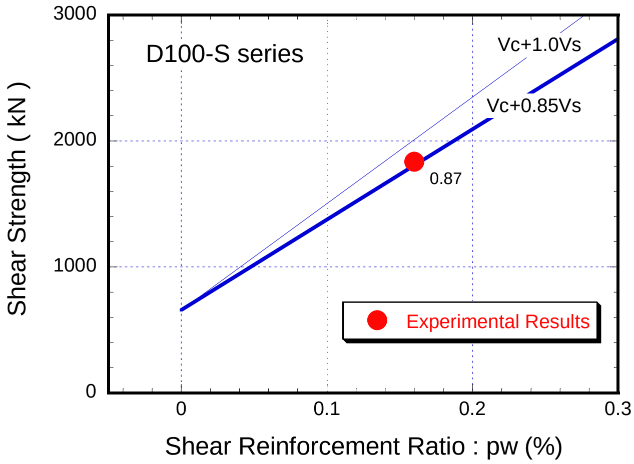

Fig. 10 (b)

Fig. 10 – Shear reinforcement ratio-Shea strength relationship (a : D=750mm, b : D=1000mm)

3.2 Shear contribution of post-installed shear reinforcement

Fig.11 shows the strain distribution of high strength steel bar in "S-series" at the peak load. When the depth of cross section is 500mm, the shear reinforcement did not yield. But when the depth of cross section becomes larger (D=1000mm), the strain becomes bigger and reached yield strain. It seemed the reason why experimental result does not reach the calculated value that assuming yield strength of high strength steel bar. That will be caused by the un-perfect-bond between existing concrete and multi-anchored high strength steel bar.

Therefore, the depth of cross section is a influence factor of shear contribution by post-installed shear reinforcement.

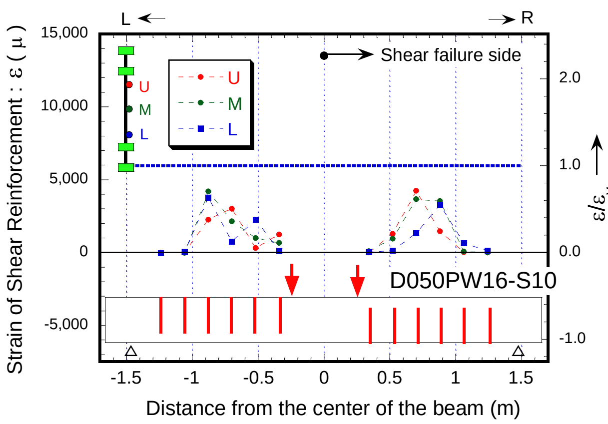

Fig. 11 (a)

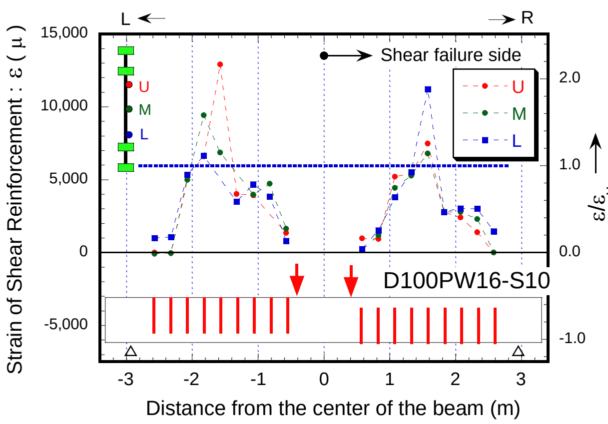

Fig. 11 (b)

Fig. 11 – Strain distribution of high strength steel bar in "S-series" (a : D=500mm, b : D=1000mm)

4. Evaluation of experimental results

The relationships between the depth of longitudinal reinforcement and the reduction factor are shown in Fig.12. The "reduction factor (α) " means as mentioned above the ratio of experimental steel shear contribution to calculated one (α was shown in Table.5). The "depth of longitudinal reinforcement (d) " is the distance that subtracted concrete cover from the depth of cross section. Therefore, "d" is near the depth of cross section. On the other hand, the proposed reduction curves are shown in the same figure. The proposed curve aimed the result that was obtained in case of without primer. The proposed curve for ϕ13 (S-series) can be expressed by Eq. (1) and Eq. (2), and one for ϕ 17 and ϕ 19 (M and L-series) can be expressed by Eq. (3) and Eq. (4).

The shear strength can be estimated with above equations and below Eq.(5) in case of post- installed shear reinforcement utilizing multi-mechanical anchored high strength steel bar.

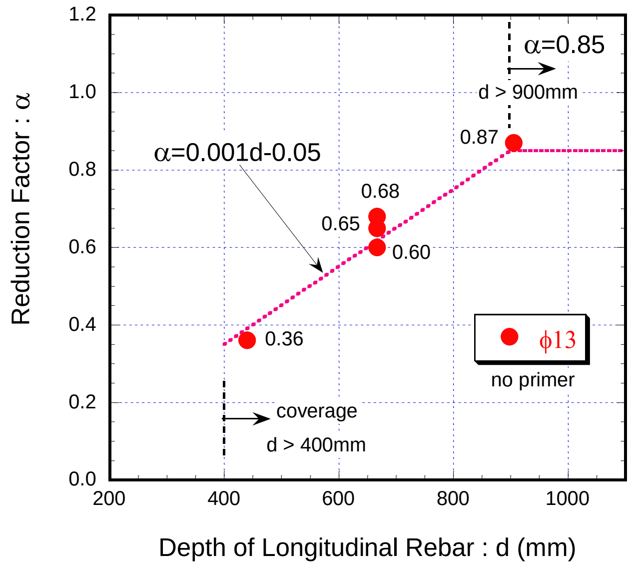

Fig. 12 (a)

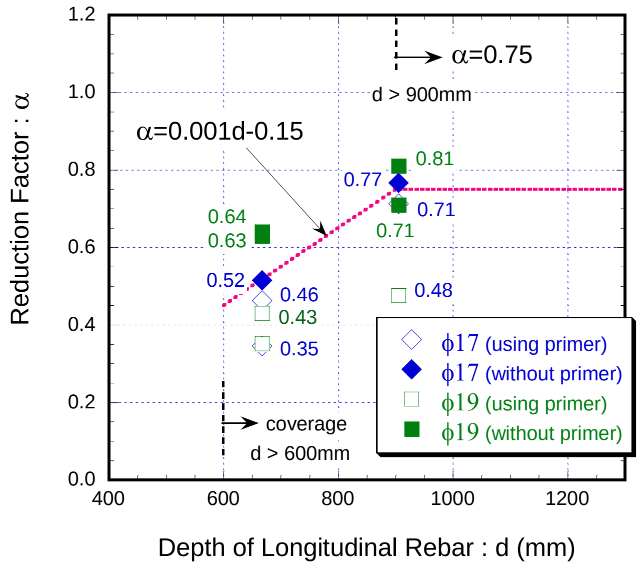

Fig. 12 (b)

Fig. 12 – Relationship between α and d (a : "S-series", b : "M-series" and "L-series")

$$\alpha = 0.001 \cdot d - 0.05 \quad (400mm \le d \le 900mm) \tag{1}$$
$$\alpha = 0.85 \quad (900mm < d) \tag{2}$$

$$\alpha = 0.001 \cdot d - 0.15 \quad (600mm \le d \le 900mm) \tag{3}$$
$$\alpha = 0.75 \quad (900mm < d) \tag{4}$$

$$V_u = V_c^{cal} + \alpha \cdot V_s^{cal} \tag{5}$$

Where,

d : depth of longitudinal reinforcement (mm)

V_u : calculated shear strength

V_c^{cal} : calculated shear contribution of concrete

α : reduction factor calculated by Eq.(1)~Eq.(4)

V_s^{cal} : calculated shear contribution of steel reinforcement

The relationship between experimental shear strength and calculated one is shown in Fig.13. According to JSCE design code [1], V_c^{cal} and V_s^{cal} were calculated. When the V_s^{cal} was calculated, the yield strength of the high strength steel bar was substituted into V_s^{cal} equation for yield strength of usual steel bar.

Calculated shear strength can sufficiently estimate experimental results except for the case that used primer. Using this estimation, it is possible to design for shear retrofit against shear force demand.

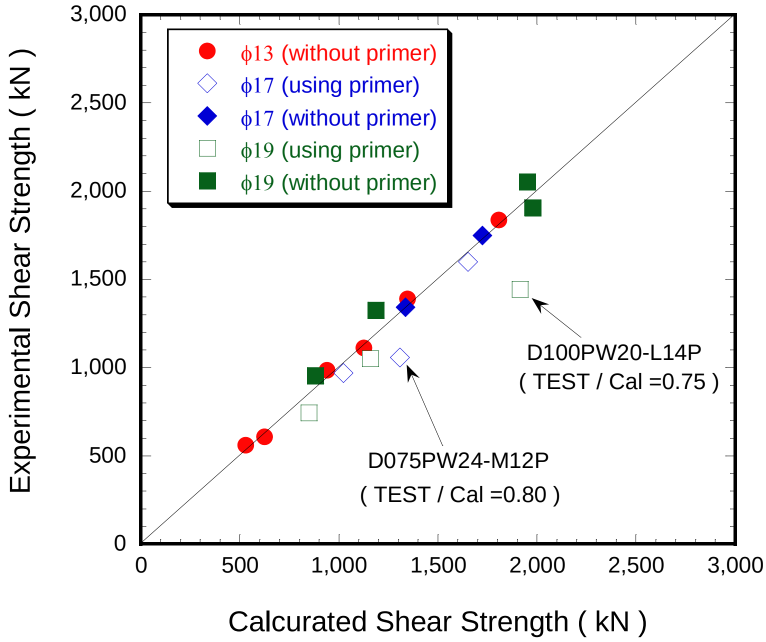

Fig. 13 – Relationship between experimental and calculated shear strength

5. Conclusion

Shear loading test of RC beam that was post-installed shear reinforcement utilizing multi-anchored high strength steel bar has been conducted. Results are summarized as follows.

1. Shear strength is possible to strengthen by post- installed shear reinforcement utilizing multi-anchored high strength steel bar.
2. Shear strength does not reach one that was calculated assuming yield strength of multi-anchored high strength steel bar because post-installed shear reinforcement does not act incompletely.
3. The incomplete shear contribution can be estimated by the function of depth of longitudinal reinforcement.
4. Shear strength that was post-installed shear reinforcement can be estimated by the total shear contribution of concrete and post-installed reinforcement.
5. This retrofit method and proposed shear strength estimation are useful to retrofit existing underground structures against seismic shear force.

6. References

[1] JSCE (Japan Society of Civil Engineering): *Standard Specification for Concrete Structures, Design*, December 2012, pp.180-181.

