- Technical Paper -

EXPERIMENTAL STUDY ON EFFECTS OF WJ TECHNIQUE ON JOINING SURFACE OF EXTERNAL REINFORCEMENT TECHNIQUE

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ABSTRACT

Waterjet (WJ) technique is used in the joining surface of the existing reinforced concrete (RC) frame and reinforcing steel braced RC frame in the external reinforcement technique. The differentiation in the shear capacity of the joining surface is investigated to comprehend the effect of the WJ. Scope of the study is to increase the shear capacity and reduce the required amount of the anchorage bars. Shear force-displacement relationship was obtained from externally reinforced RC frames with varying joining surface systems. WJ technique increases the shear capacity in the joining surface efficiently.

Keywords: WJ technique, external reinforcement, shear strength, friction

1. INTRODUCTION

In earthquake prone countries such as Japan and Turkey, reinforcement of the existing low quality RC building stock is one of the most important study areas in structural engineering. Nevertheless conventional strengthening methods are still generally applied techniques, new applications such as FRP systems and external reinforcing techniques are developed promising for a less construction time and more convenience to the inhabitants. In this experimental study, a set of specimens, which are reinforced externally by steel braced RC frames according to Manual for External Seismic Retrofit of Existing Reinforced Concrete Buildings [1], are tested. Main aim of the experiment was to investigate the efficiency of the WJ technique used in the joining surface of the existing and reinforcing RC frames to increase the shear capacity of the joining surface and reduce the amount of required anchorage bars. WJ, which is high pressured water and abrasives sprayed through a hose, is a technique used to cut/rough concrete materials. In this study this technique is used to rough the existing RC frame's external beam surface to create a friction force between old and new cast RC elements.

2. TEST PROGRAMS

2.1 Materials

(1) Reinforcing materials

As longitudinal reinforcement SD295 type D10 deformed bars and as lateral reinforcement SD345 type D6 bars are used. SD295 D13 bars were used as anchorage bars. Material test results of the reinforcing bars are given in Table 1. In this table, σ_y, ε_y, σ_u and E_s represent yield strength, yield strain, ultimate strength and elasticity modulus of the reinforcements, respectively.

Table 1 Material test results of reinforcement bars

Type	σ_y (N/mm^2)	ε_y (%)	σ_u (N/mm^2)	E_s (kN/mm^2)
D6(SD345)	384	0.19	571	200
D10(SD295)	353	0.18	525	223
D13(SD295)	351	0.19	504	187

Properties of the steel profiles used for the braces are summarized in Table 2. Steel profiles with 6, 9 and 12mm thicknesses were used. All the profiles were SM490 type.

Table 2 Material test results of steel profiles

Type	t (mm)	σ_y (N/mm^2)	ε_y (%)	σ_u (N/mm^2)	E_s (kN/mm^2)
SM490A	6	365	0.18	527	207
	9	406	0.20	540	206
	12	367	0.19	492	200

The steel braces were embedded to the reinforcing RC frame by D13 headed anchor studs.

(2)Concrete

First cast reinforced concrete body, which represents the existing frame, has a relatively weak compressive strength according to the reinforcing frame to achieve a realistic condition. Compressive strength of the existing frames and the reinforcing frames are 20.1N/mm^2 and 31.3N/mm^2, respectively. The properties of the concrete used are shown in Table3.

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Table 3 Material test results of concrete

	σ_B (N/mm^2)	f_{ctk} (N/mm^2)	E_c (N/mm^2)
Existing	20.1	1.70	30900
Reinforcing	31.3	2.46	34100

In Table 3, σ_B, f_{ctk} and E_c notations are representing the compressive strength, tensile strength and elasticity modulus of concrete.

2.2 Test Setup

Test setup is consisting of two actuators to subject the cyclic shear force and two axial jacks for axial loading. A 350mm height bedding with high compressive strength concrete, is used to place the specimens. Specimens are fixed to the slab through the bedding. Upper parts of the specimens are fixed to the steel beam, which is controlled by the actuators and jacks. A drawing of the test setup is shown in Fig.1.

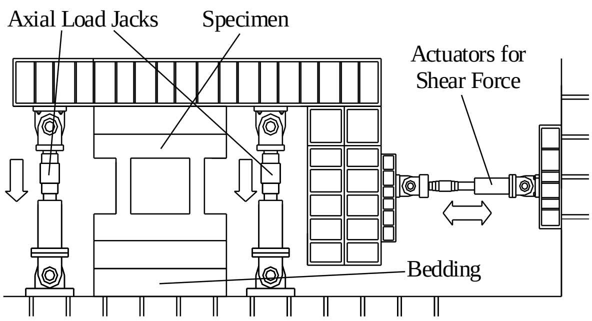

Fig.1 Test setup

2.3 Loading Method

The specimens are subjected to cyclic loading. Loading cycles are shown in Fig.2. Horizontal displacements of the specimens were controlled with a transducer, which have a gauge length of 100mm, on both sides.

Nevertheless, all along the tests, a 10% of the axial compressive capacities of the existing columns were subjected as an existing dead load.

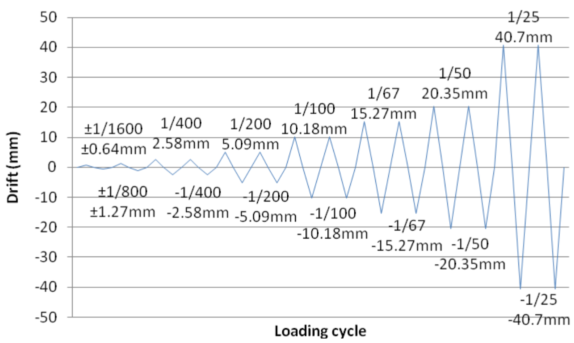

Fig.2 Drift – loading cycle chart

2.4 Specimen Properties

Fig.3 gives the drawings of the specimens. Five specimens, including the control specimen, were tested. No.1 specimen is the control specimen, which has only the existing frame, without any seismic retrofit. The columns of the existing frames have a 200mmx200mm cross-section and a 700mm height. These columns have SD295 type 8-D10 longitudinal reinforcement bars and SD345 type 2-D6@50 lateral reinforcements. The upper beams have a 445mmx300mm cross-section and SD295 type 8-D13 longitudinal and SD345 type 2-D6@100 lateral reinforcements. The lower beams have the same amount of the reinforcements with a 445mmx335mm cross-section. Beam cross-sections were particularly designed larger than the column cross-sections to avoid severe damage due to beam failures.

The reinforcing frames are consisting of two parts. Firstly the RC frame part, which has higher compressive strength according to the existing part and secondly the steel brace part. Steel braces are embedded to the RC frames with headed anchor studs. Reinforcing RC frames' columns have 175mmx200mm cross-sections with 700mm height. Beams have the same cross-section with the columns with an opening of 800mm in length. Lower beams have cantilevers of 300mm on both sides. Columns and beams have SD295 type 4-D10 bars as longitudinal reinforcement and SD345 2-D6@100 as lateral reinforcements.

As seen from Fig. 3, existing columns and reinforcing columns were not connected with a 10mm of opening. Existing and reinforcing frames anchoraged by the joining beam surfaces, which will be mentioned as joining surfaces. The anchorage bars were embedded to the existing frame with 156mm, which is $12d_a$. d_a is the diameter of the anchorage bar.

In Table 4, important parameters of the specimens are shown. In this table, Pa and K represent cross-sectional area percentage of the anchorage according to the joining surface area and average roughness depth value, respectively.

Table 4 Parameters of the specimens

Specimen	Pa (%)	Remark	K (mm)
1	-	-	-
2	2.33	Manual[1]	-
3	0.69	0.3xM	1.70
4	0.69	0.3xM	-
5	0.26	0.1xM	2.45

As seen from the table, two of the specimens have only anchorage and the remaining two have both anchorage and WJ roughening. Remark column shows the condition of each specimen according to the manual [1]. No.2 specimen was designed as described in the manual and had adequate amount of anchorage bars. The amount of the anchorage bars are calculated according to the shear capacity of the new system. The amount of the used anchorage bars of the consequent specimens are described according to No.2. No.3 and No.4 specimens have about 30% of the required amount of the anchorage bars and No.5 specimen has about 10% of the required amount.

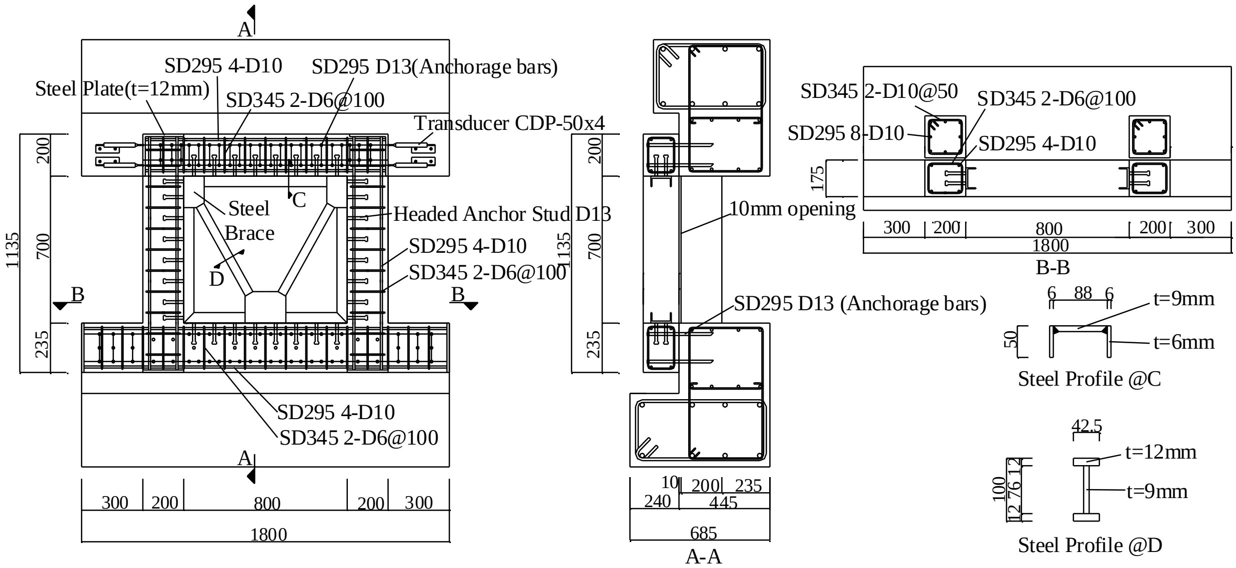

Fig.3 Specimen plans

Besides, No.3 and No. 5 have WJ roughening. No.3 has an average depth of 1.70mm and No.5 has 2.45mm. In Fig. 4, roughness surfaces with their average and maximum values are shown. The roughening depths are obtained on site by a laser meter controlled by a computer.

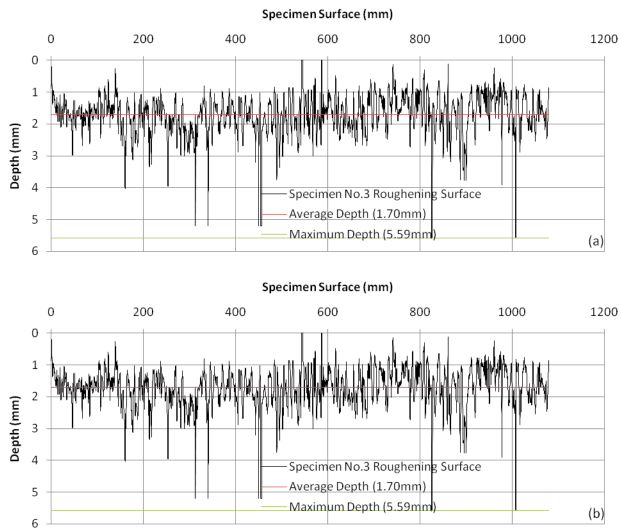

Fig.4 (a)Roughness surface of No.3, (b)roughness surface of No.5

The procedure of the WJ application and measuring can be seen in Fig.5. WJ application was tested on different compressive strengths with different distance between a spraying nozzle of water and concrete surface under constant water pressure. According to the obtained roughness levels due to different pressures, fitting pressure levels were estimated.

Fig.6 shows the conditions of the joining surfaces of upper beams of specimens. The dimensions of the joining surface are 200mmx1200mm. No.2 has 44-D13, No.3 and No.4 have 13-D13 and No.5 has only


Fig.5 (a)WJ procedure, (b)roughened surface (c)measurement

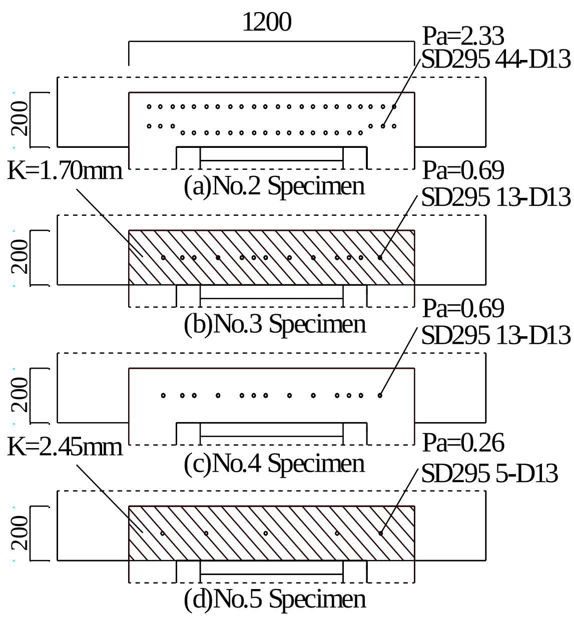

Fig.6 Joining surfaces of upper beams

5 anchorage bars. Hatched areas represent the WJ roughening.

Lower beams have 64-D13 anchorage bars in order to prevent a collapse due to separation of the lower part. In addition, WJ roughened specimens' lower beams have roughened surfaces. Lower roughening surface is 200mmx1800mm.

3. RESULTS

The results of the carried out tests are summarized in Table 5. Q values are the maximum and minimum lateral loading values. These lateral forces act as shear forces on the joining surface.

Table 5 Test results

Specimen	Pa (%)	K (mm)	Q (kN)		
			max	min	ave.
1	-	-	138.8	-133.5	136.2
2	2.33	-	713.9	-688.8	701.4
3	0.69	1.70	633.9	-603.4	618.7
4	0.69	-	539.5	-512.9	526.2
5	0.26	2.45	511.9	-536.1	524.0

First of all, the efficiency of the external seismic retrofit method is significantly high. Even the worst condition, No.5, increased the shear capacity 3.85 times.

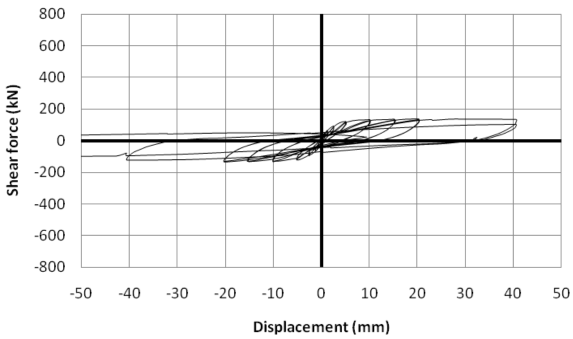

Fig.7 Shear force-total horizontal displacement diagram of No.1

In Fig.7, the behavior of control specimen is seen. Control specimen started to yield in 1/100 cycle. Specimen reached its maximum value 138.8kN in 1/50 cycle and minimum value -133.5kN in -1/50 cycle. In control specimen, experiment extended until 1/11rad. At the end hinges occured in the joint parts of columns and bending failure mode was observed.

In Fig.8 the control specimen can be seen in 1/11 cycle with hinges at the joints.

No.2, specimen which designed according to the manual, represented the best performance. In cycles 1/67 and -1/100 was bore the maximum and minimum shear forces, which are 713.9kN and -688.8kN. After reaching the maximum bearing capacity, specimen maintained a similar level. Due to eccentricity, severe damages occurred in the existing frame and test stopped. The behavior of the specimen can be seen in Fig.9.

No.2 is shown in Fig.10.

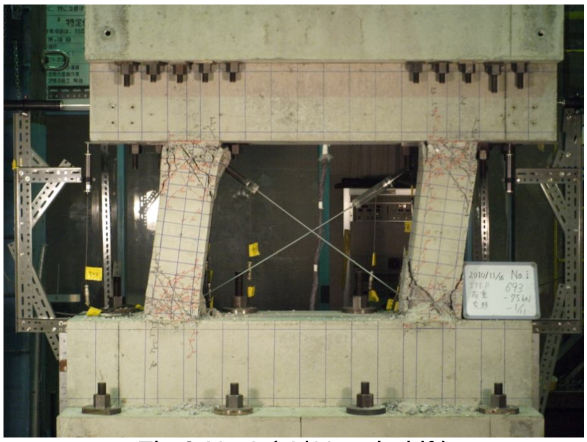

Fig.8 No.1 (-1/11 rad. drift)

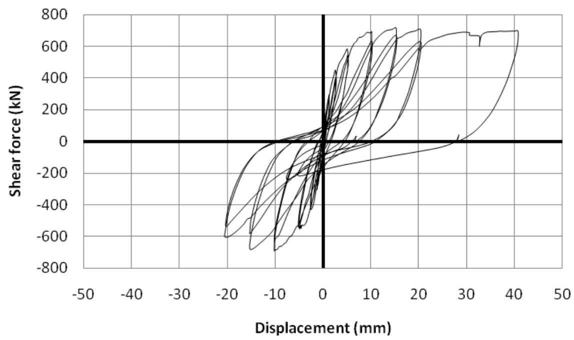

Fig.9 Shear force-total horizontal displacement diagram of No.2

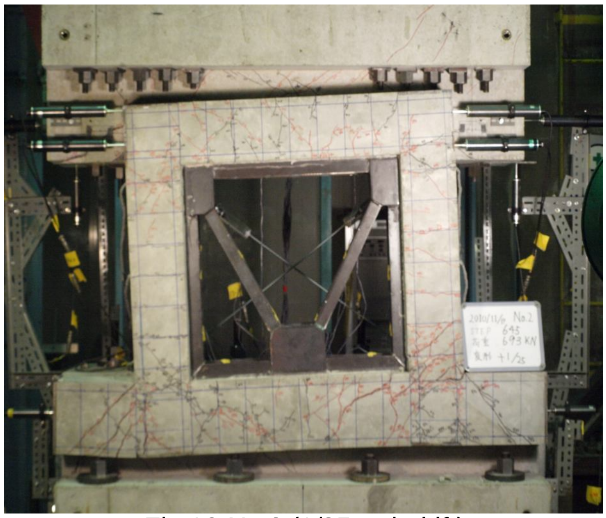

Fig.10 No.2 (1/25 rad. drift)

The behavior of No.3 is shown in Fig.11. As mentioned this specimen has 30% of the anchorage amount of No.2 and in addition has a roughened surface by WJ. As maximum and minimum lateral loads, this specimen bore 633.9kN at 1/100 and -603.4kN at -1/100 cycles. After reaching the maximum value the curve started to decrease and in the last cycle shear capacity became too similar with No.4. No.3 is shown in Fig.12.

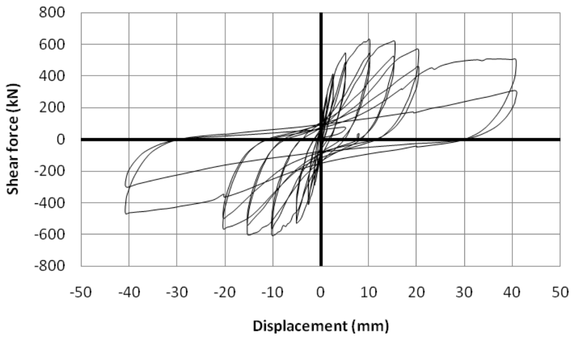

Fig.11 Shear force-total horizontal displacement diagram of No.3

Fig.12 No.3 (1/25 rad. drift)

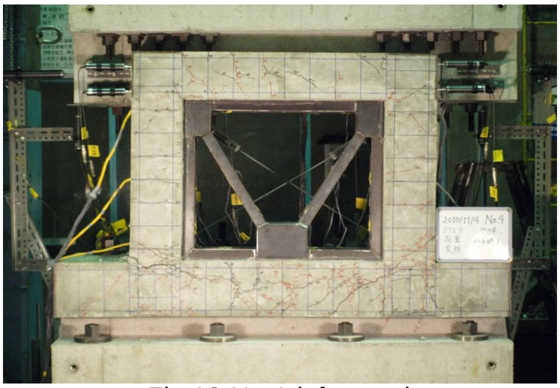

Fig.13 No.4 (after test)

No.4, as seen in Fig.13, has the same amount of anchorage with No.3 except WJ roughening. This specimen reached the maximum lateral force at 1/100 cycle with 539.5kN. After reaching maximum value the capacity started to reduce until 1/25 cycle. In this cycle specimen restored reached almost the same value with 1/100 cycle.

Specimen’s behavior is shown in Fig.14.

Last specimen, No.5, had only 10% of the required amount of the anchorage bars. Besides, this specimen has WJ roughening in the joining surface. The maximum and minimum lateral loads carried by this specimen are 511.9kN and -536.1kN. These extreme values were obtained in 1/100 and -1/100 cycles. Similar to No.4, after a decreasing period, this specimen restored and reach 80% of the maximum value in 1/25 cycle. The behavior of this specimen is shown in Fig.16. Fig.15 shows specimen No.5.

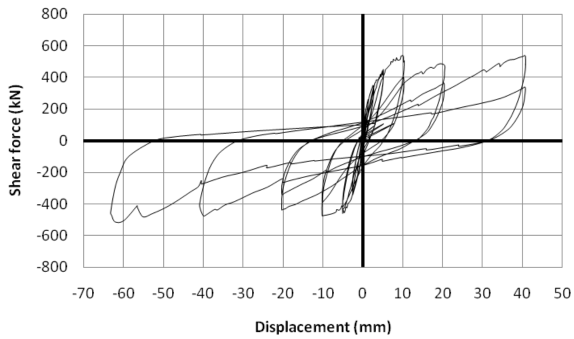

Fig.14 Shear force-total horizontal displacement diagram of No.4

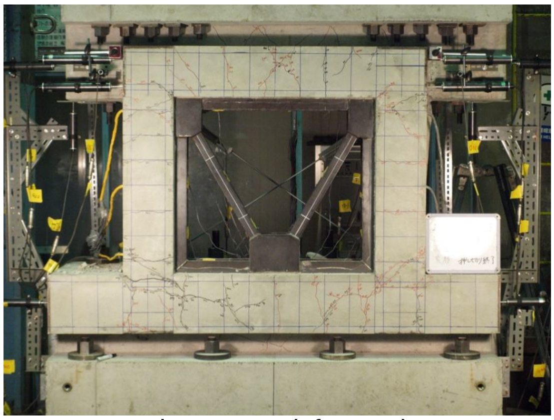

Fig.15 No.5 (after test)

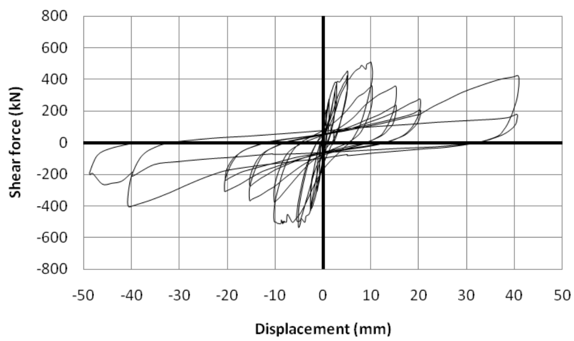

Fig.16 Shear force-total horizontal displacement diagram of No.5

In Fig.17, all specimens can be seen in the positive loading region. As seen in the graph, the externally reinforcing with steel braced frames contributed significantly in all four specimens. No.2, designed according to the manual, achieved the maximum efficiency by increasing the capacity 5.15 times.

Secondly, No.3 represented a good behavior. Only by using 30% of the required amount, it increased the shear capacity 4.54 times. Also this means No.3 achieved 88% of the maximum lateral loading value of No.2.

No.4 and No.5 contributed almost the same values, 3.86 and 3.85 times. No.5 had only 10% of the

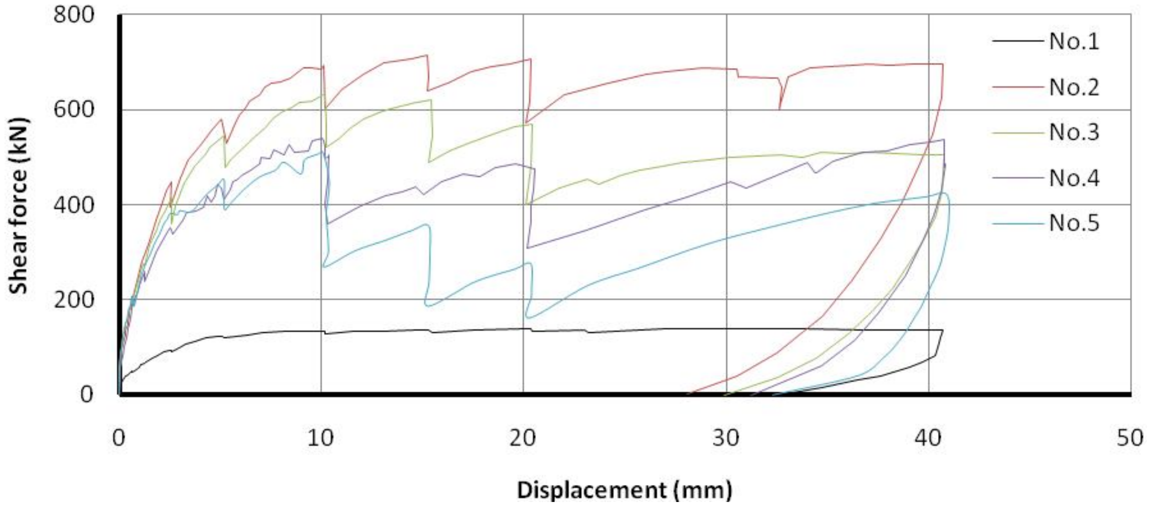

Fig.17 Shear force-total horizontal displacement diagram of all specimens

required anchorage, with an average value of 2.45mm roughness depth.

In Fig.17, it is also seen that specimens with WJ application, performed best in 1/100 cycles. After that cycle they both decrease.

Other important parameter in this study is the displacement differentiation between existing and reinforcing frames. It is observed that, the less slip occurred specimens behave better. No.2 and No.3 had the smallest slips, so they can act more close to a monolithic state. When the slip starts to increase in specimen No.3, it started to lose the efficiency. On the other hand, specimens No.4 and No.5 show a poor behavior. The slip–horizontal displacement relation can be seen in Fig.18.

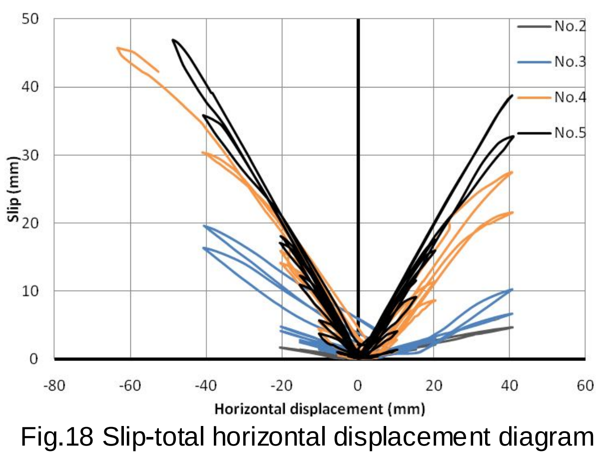

Fig.18 Slip-total horizontal displacement diagram of all specimens

4. CONCLUSIONS

(1) The significant contribution of external reinforcement is observed. Designing the retrofitting system according to the manual [1], increases the shear capacity efficiently. No.2 carried 701.4kN, 5 times of the control specimen's strength.

(2) WJ roughening system creates controllable surface roughening, which contributes sufficiently for the shear transfer in the joining surface.

(3) It is seen that by using WJ technique, the amount of anchorage bars can be reduced effectively. 618.7kN, 4.54 times of the control specimen and 88% of the lateral force bore by No.2 is carried by No.3 with 30% of the anchorage.

(4) It is observed that slip between existing and retrofitting elements is one of the important factors. Friction surface created by WJ loses efficiency by the increasing slip.

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