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Paper

RESEARCH ON THE SAFETY DISTANCE FROM A NOZZLE

— Measurement of Safe Standoff Distances of WJ and ASJ —

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ABSTRACT

Now high pressure water jets are used in various fields. According to the increase of the fields, a considerable number of the accidents that water jet hits a nozzle operator or some others have occurred especially in the fields where a hand held nozzle is used. In this paper the author proposes a reproducible method to measure the safe standoff distance, that is the distance from the head of a water jet nozzle to the boundary of hazard area in which people are possible to be injured. In this method a sheet of swine skin is used as the reference material that is substituted for human skin. The standoff distance is changed continuously by moving the nozzle. The safe standoff distance is measured from the length of injury on the swine skin. Also, it is reported as examples of the results measured by this method, that the sufficiently-safe standoff distances of the water jets used in their works are at least 2.5 m in the case of water jet without any abrasive and 3.5 m in the case of abrasive suspension jet.

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1. INTRODUCTION

High pressure water jet was developed roughly half a century ago, and now not only the jet of water without any abrasive but also abrasive water jets are used in various fields. With the increase of fields and the expansion of each field in this period, a lot of accidents have occurred resulting from water jetting operations. Especially in the fields where a hand held nozzle is used, considerable number of the accidents that water jet hits a nozzle operator or people around have happened.

Such an accident as water jet hits a human body is a typical accident that occurs in water jetting operation. So the author has done researches with co-researchers on this accident and its prevention as very important issues relating to the safety of water jetting operation. One of their results is [1] in the reference. As some results obtained from our recent researches, the author proposes a reproducible method to measure the safe standoff distance, that is the distance from the head of a water jet nozzle to the boundary of hazard area in which people are possible to be injured by the jet discharged from the nozzle, and reports on sufficiently-safe standoff distances of the water jets used in their works, water jet without any abrasive and abrasive suspension jet, as examples of the results measured by this method.

In this report, the jet of water without any abrasive is abbreviated as WJ, and the abrasive suspension jet is done as ASJ.

2. THE EXPERIMENTAL APPARATUS USED IN THIS RESEARCH AND THE METHOD TO MEASURE SAFE STANDOFF DISTANCE

The experimental apparatus used in this research consists of a water jet system, a nozzle assembly, a sheet of swine skin that is the reference material substituted for human skin, and their surroundings. The nozzle assembly includes a water jet nozzle and a nozzle moving machine. The water jet system shown in Figure 1 consists of a pump module and a slurry module, and feeds water to the nozzle assembly through a high pressure hose of 50 m in length. Tap water is filtered and pressurized in the water jet system, and mixed with abrasive there if necessary, and then discharged from the nozzle.

When ASJ is discharged, the majority (about 90 %) of the flow from the high pressure pump bypasses the discharge vessel via the abrasive concentration orifice. The pressure loss across this orifice provides the pressure difference to drive about 10 % of the water flow through the discharge vessel to generate a discharge of abrasive. Flow into the vessel causes abrasive particles to be fluidized in the vessel. The high concentration slurry generated in an outlet of the vessel is then diluted by the majority of water flow. The slurry then enters the hose. When WJ is discharged, all the flow from the high pressure pump bypasses the discharge vessel.

Structure of the water jet nozzle is schematically descried in Figure 2. The pump module supplies a flow of up to 5.5 L/min of water at pressures of up to 69 MPa to the slurry module. A high pressure pump is supplied with water from a feed tank having a capacity of 42 L. The supply water is filtered through the in-line filter element of 20 μm. A diesel engine of 7 kW provides the motive power for the pump. The discharge vessel has a volume of 12 L. In this research, the delivery pressure in the pump module is regarded as the pressure in the upper side of water jet nozzle.

Olivine sand is used as the abrasive in ASJ. Figure 3 shows the particle size distribution of the olivine sand used in this research. The distribution is measured by the screening in which JIS-standard sieves are used. Flow rate of the jet discharged from the water jet nozzle is measured as 5.1 L/min by means that WJ is discharged from the nozzle in 2 min at the pressure of 60 MPa and collected in a tank.

Figure 4 is a photo showing the nozzle assembly and a sheet of swine skin, the reference material, and their surroundings. The water jet nozzle is set on the nozzle moving machine to discharge the jet vertically downward, namely in the plumb line direction. The nozzle moving machine is able to position the nozzle at any point and to move it any distance at any velocities vertically and horizontally at the same time. A rectangular sheet of raw skin of roughly 30 cm in width and 1 m in length is cut out from the whole skin of a swine and used in an experiment. The sheet is kept in a refrigerator the temperature in which is between $-25°\mathrm{C}$ and $-50°\mathrm{C}$, and defrosted just before the experiment. Two sheets of wire mesh are piled under a sheet of swine skin and placed on a thick and rectangular wooden board, and all of them are fixed one another with nails. The layer of wire mesh sheets are set for the water that penetrates through a sheet of swine skin flows out easily. If the wire mesh would not be placed there, the water would remain between the sheet of swine skin and the board and would push the sheet by its pressure. This means that in this case extra and interfering force would be exerted not necessarily on the sheet from its backside in the experiment.

The standoff distance SD is defined as the distance between the nozzle head and the hitting point of water jet on surface of swine skin, H, as shown in Figure 5. The point S shows the start point of nozzle head moving path SE, and the point A shows the start point of hitting point moving path AB on the surface of swine skin. The standoff distances SD_A and SD_S, those are just the same each other, are defined as the distance between the points A and S. In the same way, the point E shows the end point of the nozzle head moving path SE, and the point B shows the end point of the hitting point moving path AB on the surface of swine skin. The standoff distances SD_B and SD_E, those are just the same each other, are defined as the distance between the points B and E. The point P_1 is a border point of penetrating and nonpenetrating injuries in the path AB on the surface of swine skin. The point P_2 is a border point of nonpenetrating injury and the part of no injury in the path AB.

The length L_1 is length of the penetrating injury along the path AB. The length L_2 is total length of the penetrating and nonpenetrating injuries along the path AB. The length L_3 is distance between the points A and B on the surface of swine skin. The length x_h is distance between the points A and H along the path AB on the surface of swine skin. So dx_h/dt means increasing rate of the distance x_h, namely moving velocity of the point H along the path AB. In the same way, $d(SD)/dt$ means increasing rate of the standoff distance SD.

It is thought to be quite usual that a hitting point of the jet is passing across the body at high speed in such case as a nozzle operator hits the body of himself or the nearby people with the water jet from his hand held nozzle in an accident. But in this method it dares to be chosen that the hitting point H is moved on swine skin at the very slow speed of $dx_h/dt \approx 1\ \mathrm{cm/s}$ for the sufficiently-safe standoff distance, that is the sufficiently-safe distance from a water jet nozzle to the boundary of the hazard area in which people are possible to be injured by the jet discharged from the nozzle, is obtained. The nozzle is moved in the direction where the standoff distance SD increases or decreases continuously at the rate of $d(SD)/dt \approx \pm 1\ \mathrm{cm/s}$ in the same time.

Experiments are done twice in same conditions without some exceptions. The hitting angle of the jet against the surface of swine skin, θ, that is shown in Figure 5, is adjusted usually as $\theta = 90°$, and exceptionally as $\theta = 45°$ or $\theta = 135°$. The hitting angle θ is set by tilting the sheet of swine skin with wooden board from the horizontal as shown in Figure 6. In the followings, to show all the experimental results using the similar format including the tilted cases, the moving velocity of the nozzle, $\boldsymbol{v_n}$, are shown by the moving velocity of the nozzle in the direction parallel to the surface of swine skin, that is x-direction, $\boldsymbol{v_{nx}}$, and the moving velocity of the nozzle in the direction perpendicular to the surface of swine skin, that is y-direction, $\boldsymbol{v_{ny}}$. The nozzle moving velocities $\boldsymbol{v_{nx}}$ and $\boldsymbol{v_{ny}}$ are related to the moving velocity of the nozzle in horizontal direction, $\boldsymbol{v_{nH}}$, and the moving velocity of the nozzle in vertical direction, $\boldsymbol{v_{nV}}$, as shown in Figure 6. All of these 4 velocities are in a plane.

For the marking of the points A and B on the surface of swine skin, in each experiment the nozzle is stopped for a few minutes at the point S just before the nozzle starts to be moved, and also it is stopped for a few minutes at the point E just after it reaches to the point. The identifications of the border point between the penetrating and the nonpenetrating injuries, P_1, and the border point between the nonpenetrating injury and the part of no injury in the path AB, P_2, are done by means of the visual observation by more than one person just after each experiment.

The penetrating injury means the injury the part of which the jet hits and passes through to its rear side. So a penetrating injury is in the shape of a laceration on the surface of swine skin. The nonpenetrating injury means the injury the part of which the jet hits and makes injury in but does not pass through. So a nonpenetrating injury is in the shape similar to a depression or an abrasion on the surface without any penetrating injury. In the case of ASJ, the part where the change of color is observed without any penetrating injury is considered as a nonpenetrating injury, because a change of color caused by the invasion of abrasive into the tissue of skin is observed clearly on the surface the part of which the jet hits but does not pass through.

By using a tensile tester, tensile strength of the swine skin used as the reference material is measured as $(3 \sim 30)$ MPa as shown in Figure 7. In this figure, each point shows the average value of the measurements those are obtained from the $(5 \sim 6)$ sheets with nearly-same thickness sampled from one or more swine(s), and the error bars of each point shows the unbiased standard deviations of measured values.

From this figure it is understood that the tensile strength of swine skin is quantitatively very similar to that of human skin the tensile strength of which is $(3 \sim 13)$ MPa.[2] It is confirmed that usage of swine skin as the reference material substituted for the human skin is quite meaningful in this measurement where mechanical properties of the reference material are very important, though influential mechanical properties are not thought to be only the tensile strength. So that the author proposes the usage of swine skin as the reference material substituted for the human skin.

3. MEASURED RESULTS AND DISCUSSIONS

The measured results obtained in this research are shown in Table 1. In this table, the increasing rate dx_h/dt is an average moving speed of the hitting-point H calculated from the distance between the points A and B in the path AB, L_3. The increasing rate $d(SD)/dt$ is an average value calculated from SD_A and SD_B. The safe standoff distance based on the penetrating injury, SSD_1, is obtained as the standoff distance at the border point P_1, and the safe standoff distance based on the nonpenetrating injury, SSD_2, is obtained as the standoff distance at the border point P_2.

Figures 8 to 10 show the experimental results in the cases that WJ hits the sheets of swine skin perpendicularly. The ranges of standoff distance SD are different and partially overlapping with one another. Each photo of swine skin that was taken just after each experiment is in the top and a set of explanations is placed just below. Every number of (10 ~ 11) letters in the figures (not limited in these figures) is the index of each experiment, which makes every datum traceable. It is observed from these figures that according to the increase of SD (from left to right in the photos and Figures 8 to 10 in that order) the injury becomes gradually to be from serious to slight and finally disappeared in the experiments. From these results and Table 1 it is obtained that WJ used in this research makes penetrating injury within the range of $SD \leq (40 \pm 5)$ cm and nonpenetrating injury within the range of (40 ± 5) cm $\leq SD \leq (100 \pm 20)$ cm on the sheets of swine skin.

Figures 11 and 12 show the experimental results in the cases that ASJ hits the sheets of swine skin perpendicularly. It is observed from these figures that according to the increase of the standoff distance SD the injury becomes gradually to be from serious to slight and finally disappeared in the experiments, too. From these results and Table 1 it is obtained that the ASJ used in this research makes penetrating injury within the range of $SD \leq (60 \pm 5)$ cm and nonpenetrating injury within the range of (60 ± 5) cm $\leq SD \leq (150 \pm 15)$ cm on the sheets of swine skin.

Figures 13 and 14 show the experimental results in the cases that ASJ hits the sheets of swine skin obliquely. In the cases that ASJ hits a sheet of swine skin obliquely with the hitting angles of $\theta = 45°$ and $135°$, it is observed that ASJ used in this research makes nonpenetrating injury at least on a sheet of swine skin in case of $SD \leq (135 \pm 10)$ cm. The ranges of SD in which these jets makes nonpenetrating injury at least is nearly same as those of Figures 11 and 12, in which ASJ hits the sheets of swine skin perpendicularly.

The results mentioned above are obtained from the experiments in which the jet is discharged from the nozzle that is going off gradually into the distance from the surface of swine skin. Figure 15 shows the results obtained from the experiment in which the jet was discharged from the nozzle that is approaching from the distance to the surface of swine skin. In this case it is observed that ASJ used in this research makes nonpenetrating injury at least on a sheet of swine skin in the case of $SD \leq (140 \pm 12)$ cm. The ranges of SD in which this jet makes nonpenetrating injury at least is nearly same as those in the other cases where ASJ hits a sheet of swine skin.

The safe standoff distances SSD_1 and SSD_2 are $SSD_1 = (40 \pm 5)$ cm and $SSD_2 = (100 \pm 20)$ cm in the case that WJ hits a sheet of swine skin perpendicularly, and $SSD_1 = (60 \pm 5)$ cm and $SSD_2 = (150 \pm 15)$ cm in the case that ASJ hits a sheet of swine skin perpendicularly. The safe standoff distance SSD_2 is $SSD_2 = (135 \pm 10)$ cm in the case that ASJ hits a sheet of swine skin obliquely with the hitting angles of $\theta = 45°$ and $135°$, and is nearly same as the values in the cases of the perpendicular though it was a little bit smaller. As any clear effects of the moving speed (including directions) of the nozzle to SSD_1 and SSD_2, are not observed, it seems that the effects is smaller or negligible, though the author never think that the safe standoff distances are not affected by the nozzle moving speed at all.

So that based on SSD_1 the safe standoff distances of the water jets used in this research are roughly 50 cm in the case of WJ and 70 cm in the case of ASJ, and based on SSD_2 the safe standoff distances are roughly 120 cm in the case of WJ and 170 cm in the case of ASJ. Sufficiently-safe standoff distances of the water jets used in this research are thought to be 2.5 m in the case of WJ and 3.5 m in the case of ASJ, those are roughly 5 times SSD_1 and the double of SSD_2 in both of the cases.

As in this research there is such a weak point as the identifications of the positions of the points P_1 and P_2 are resorted to the visual observation, the uncertainties of SSD_1 and SSD_2 became somewhat bigger. But the uncertainty of SSD_1 was significantly smaller than that of SSD_2 by the reason why the identification of the point P_1 is much easier than that of the point P_2. So the author thinks that the sufficiently-safe standoff distances of the water jets should be judged as 5 times SSD_1 at least, the value of which is obtained from the method mentioned above, except such cases as all of the nozzle operator and the others around wear the appropriate personnel protective equipment.

4. CONCLUSIONS

The author proposed in this paper a reproducible method to measure the safe standoff distance by using a sheet of swine skin substituted for human skin, and showed the safe standoff distances of water jet and abrasive water jet used in their work measured by this method.

The author is going to continue the research on the method to measure the safe standoff distance in the future.

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[2] Yamada, H.: Strength of biological materials, The Williams & Wilkins Company Baltimore 1970, p.225.

Nomenclature

A	Start point of the hitting point moving path on swine skin.
B	End point of the hitting point moving path on swine skin.
E	End point of the nozzle head moving path.
H	Hitting point of the jet on swine skin.
L_1	Length of penetrating injury
L_2	Total length of penetrating and nonpenetrating injuries
L_3	Distance between the points A and B in hitting point moving path on swine skin.
P_1	Border point of penetrating and nonpenetrating injuries in the hitting-point moving path on swine skin.
P_2	Border point of nonpenetrating injury and part of no injury in the hitting-point moving path on swine skin.
S	Start point of the nozzle head moving path.
SD	Standoff distance of the nozzle
$\dfrac{d\,(SD)}{dt}$	Increasing rate of the standoff distance of nozzle
SD_A $(= SD_S)$	Standoff distance at the start point of hitting point moving path, A. (= Standoff distance at the point S)
SD_B $(= SD_E)$	Standoff distance at the end point of hitting point moving path, B. (= Standoff distance at the point E)
SSD_1	Safe standoff distance based on the penetrating injury
SSD_2	Safe standoff distance based on the nonpenetrating injury
t	Time
v_n	Moving velocity of the nozzle
v_{nH}	Moving velocity of the nozzle in horizontal direction
v_{nV}	Moving velocity of the nozzle in vertical direction
v_{nx}	x-directional moving velocity of the nozzle
v_{ny}	y-directional moving velocity of the nozzle
x_h	Distance between the points A and H in hitting point moving path on swine skin.
$\dfrac{dx_h}{dt}$	Increasing rate of the distance between the points A and H in hitting point moving path on swine skin. (Moving velocity of the hitting point H on swine skin)
θ	Hitting angle of the jet on swine skin

Table 1. Experimental results

No.	Jet type	P MPa	θ (nominal) degree	v_{nx} mm/min	v_{ny} mm/min	SD_A mm	SD_B mm	L_1 mm	L_2 mm	L_3 mm	$\frac{dx_h}{dt}$ mm/min	$\frac{d(SD)}{dt}$ mm/min	SSD_1 mm	SSD_2 mm	Index of experiment
1	WJ	56	90	600	600	10	713	450	700	700	599	601	460	≧ 713	20080825-1A
2	WJ	59	90	600	600	10	718	390	660	660	579	621	400	≧ 718	20080825-1B
3	WJ	60	90	600	600	310	803	39	462	505	607	593	349	772	20080825-2A
4	WJ	60	90	600	600	310	813	40	470	500	598	602	350	783	20080825-2B
5	WJ	60	90	600	600	500	1,188	0	661	690	601	599	≦ 500	1,161	20080826-1A
6	WJ	60	90	600	600	500	1,294	0	676	794	600	600	≦ 500	1,176	20080826-1B
7	WJ	60	90	600	600	900	1,505	0	210	603	599	601	≦ 900	1,110	20080826-5A
8	WJ	60	90	600	600	900	1,505	0	250	593	594	606	≦ 900	1,150	20080826-5B
9	WJ	60	90	600	600	1,000	1,505	0	107	545	623	577	≦ 1,000	1,107	20080826-4B
10	ASJ	60	90	600	300	25	330	630	630	630	610	295	≧ 330	≧ 330	20071205-4
11	ASJ	60	90	600	600	25	625	630	630	630	615	585	≧ 625	≧ 625	20071205-5
12	ASJ	60	90	600	600	498	1,075	100	520	520	569	631	568	≧ 1,075	20071206-2
13	ASJ	60	90	600	600	500	1,080	120	520	520	567	633	620	≧ 1,080	20071206-1
14	ASJ	60	90	600	600	940	1,620	0	480	615	570	630	≦ 940	1,420	20071206-3
15	ASJ	60	90	600	600	940	1,615	0	430	610	570	630	≦ 940	1,370	20071206-4
16	ASJ	60	90	600	600	1,000	1,875	0	525	855	593	607	≦ 1,000	1,525	20080827-1A
17	ASJ	60	90	600	600	1,000	1,905	0	469	892	596	604	≦ 1,000	1,469	20080827-1B
18	ASJ	60	90	300	300	1,000	1,855	0	441	820	294	306	≦ 1,000	1,441	20080828-5A
19	ASJ	60	90	300	300	1,000	1,855	0	455	838	297	303	≦ 1,000	1,455	20080828-5B
20	ASJ	60	90	900	900	1,000	1,850	0	330	835	892	908	≦ 1,000	1,330	20080828-6A
21	ASJ	60	90	900	900	1,000	1,865	0	325	845	889	911	≦ 1,000	1,330	20080828-6B
22	ASJ	60	90	600	600	1,100	1,778	0	417	673	598	602	≦ 1,100	1,517	20080827-2A
23	ASJ	60	90	600	600	1,100	1,805	0	512	698	597	603	≦ 1,100	1,612	20080827-2B
24	ASJ	60	90	600	300	1,250	1,805	0	435	1,082	592	304	≦ 1,250	1,468	20080828-4A
25	ASJ	60	90	600	300	1,250	1,805	0	428	1,082	592	304	≦ 1,250	1,464	20080828-4B
26	ASJ	60	45	1,011	403	1,000	1,877	0	361	1,010	621	539	≧ 1,000	1,313	20080902-3A
27	ASJ	60	45	1,011	403	1,000	1,727	0	385	1,045	656	457	≦ 1,000	1,268	20080902-3B
28	ASJ	60	135	180	427	1,000	2,007	0	348	990	584	594	≦ 1,000	1,354	20080902-4A
29	ASJ	60	135	180	427	1,000	2,052	0	430	1,035	584	594	≦ 1,000	1,437	20080902-4B
30	ASJ	60	90	600	-600	1,800	745	0	770	1,035	594	-606	≦ 745	1,515	20080902-1A
31	ASJ	60	90	600	-600	1,800	753	0	546	1,024	593	-607	≦ 753	1,299	20080902-2A

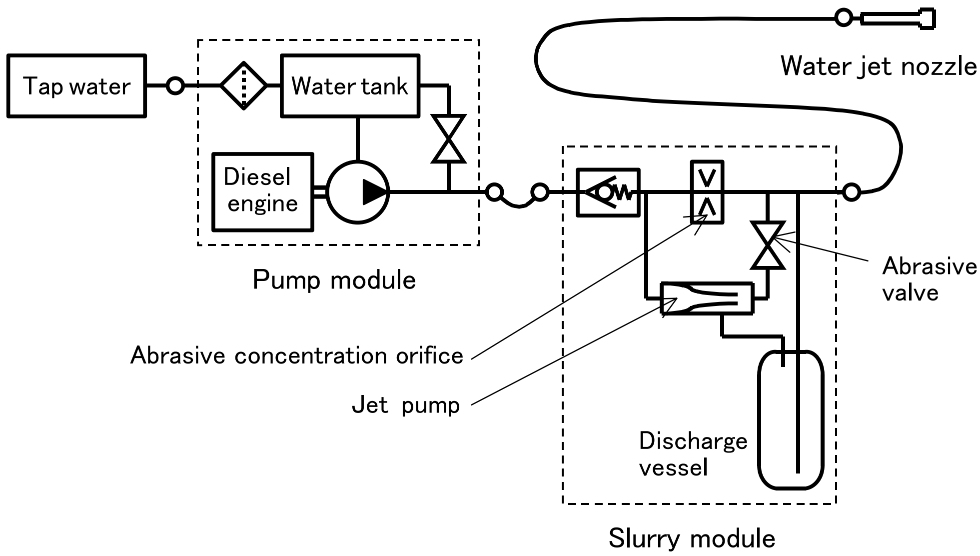


Figure 1. Schematic diagram of the water jet system used in this research.

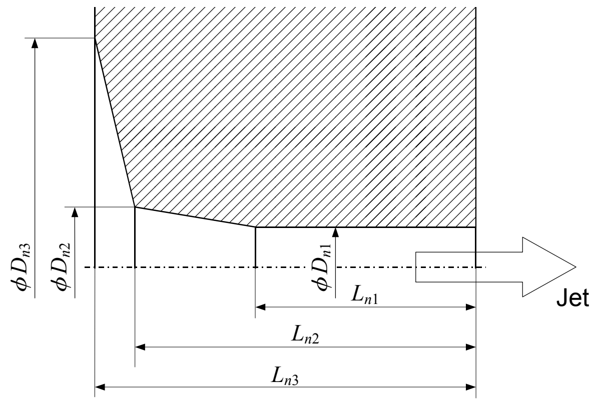


Figure 2. Internal structure of the nozzle used in this research.

$D_{n1} = 0.56$ mm, $D_{n2} = 0.74$ mm,
$D_{n3} = 3.40$ mm, $L_{n1} = 18.35$ mm,
$L_{n2} = 22.65$ mm, $L_{n3} = 25.40$ mm

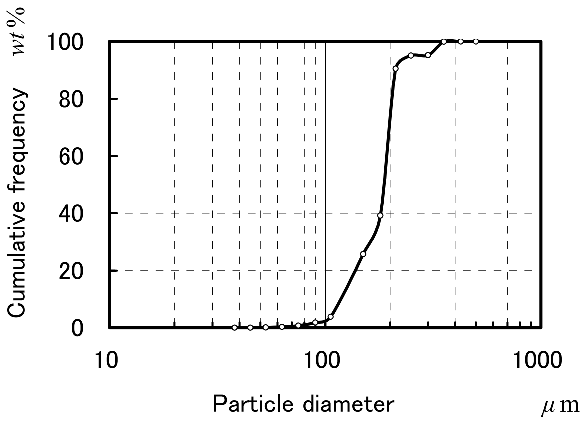


Figure 3. Particle size distribution of abrasives

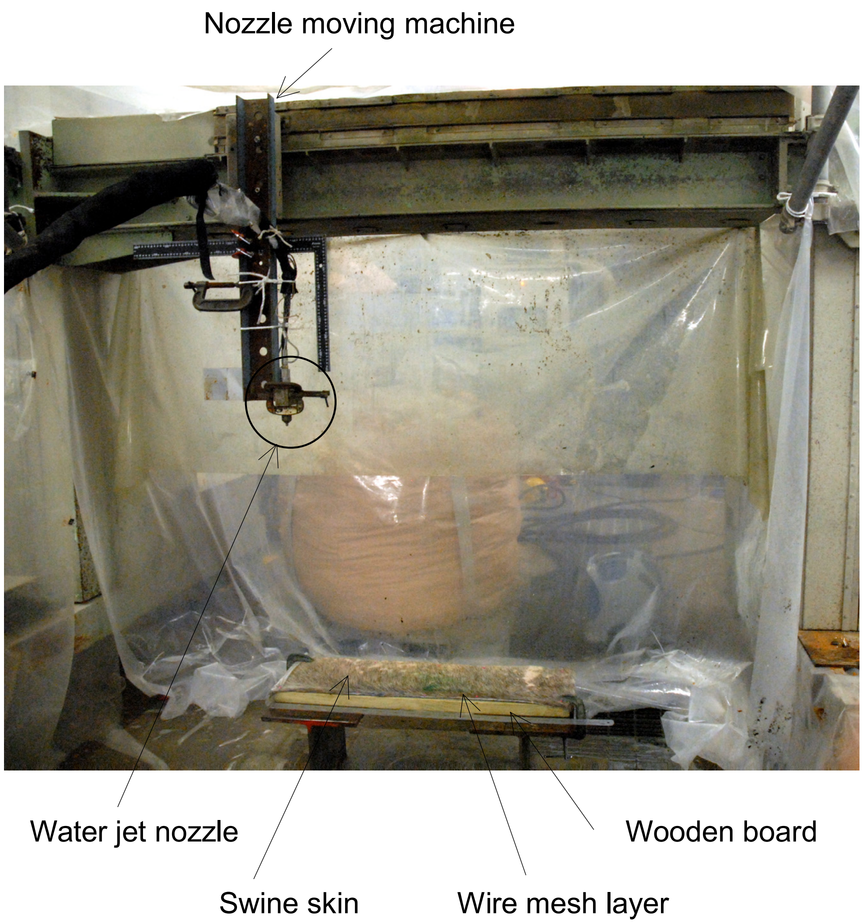


Figure 4. A photo of the nozzle assembly that consists of a water jet nozzle and a nozzle moving machine, a sheet of swine skin, and their surroundings. This photo was taken in the experiment No. 5 shown in Table 1.

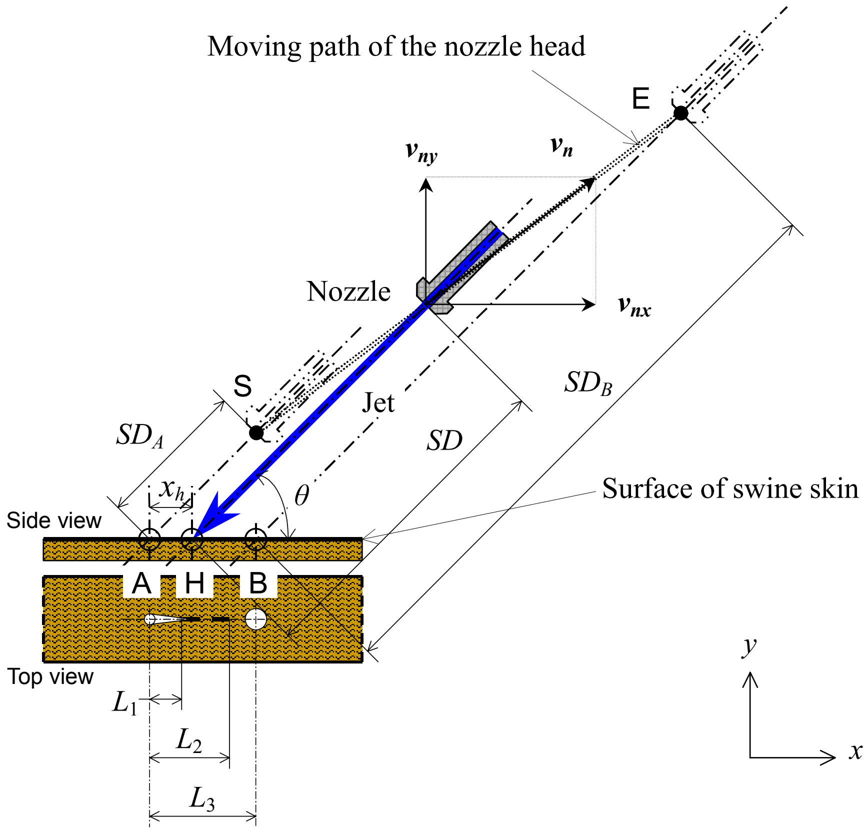


Figure 5. The water jet nozzle, the moving path of nozzle head and the hitting point of water jet on swine skin, H.

A : Start point of the hitting point moving path
B : End point of the hitting point moving path
E : End point of the nozzle head moving path
H : Hitting point of the water jet on the surface of swine skin
S : Start point of the nozzle head moving path

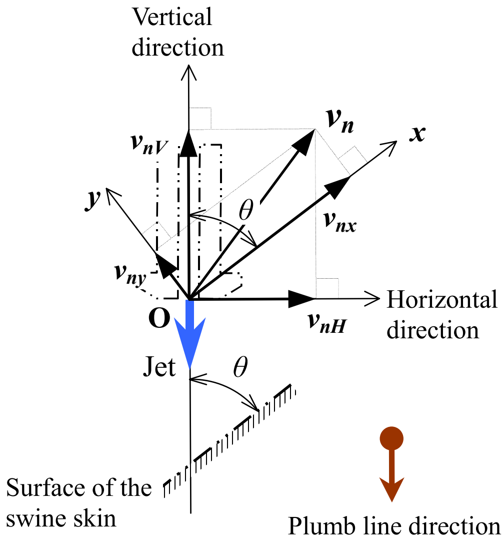


Figure 6. Relations among nozzle moving velocities

$$v_{nx} = v_{nH} \sin\theta + v_{nV} \cos\theta$$

$$v_{ny} = -v_{nH} \cos\theta + v_{nV} \sin\theta$$

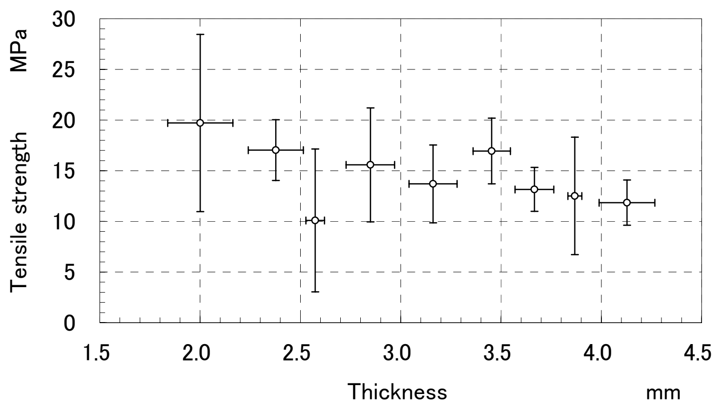
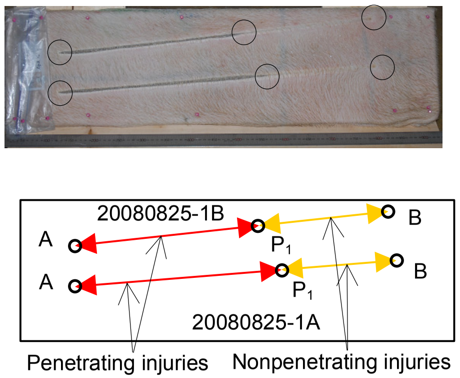
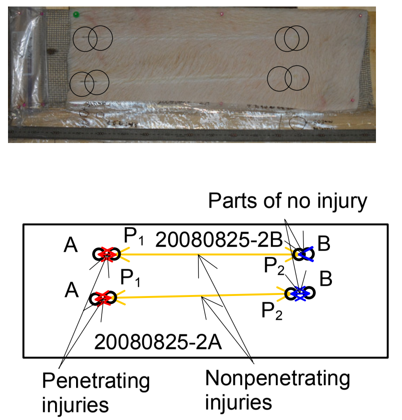


Figure 7. Tensile strength of swine skin



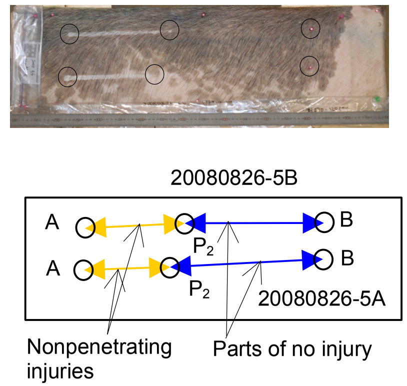
Specification		
Jet type	WJ	
P	20080825-1A	56 MPa
	20080825-1B	59 MPa
θ (nominal)	90°	
v_{nx}	600 mm/min	
v_{ny}	600 mm/min	
SD_A	20080825-1A	10 mm
	20080825-1B	10 mm
SD_B	20080825-1A	713 mm
	20080825-1B	718 mm

Figure 8. Results in the cases that WJ caused penetrating and nonpenetrating injuries in the hitting point moving path AB on swine skin. (see No. 1 and No. 2 in Table 1)



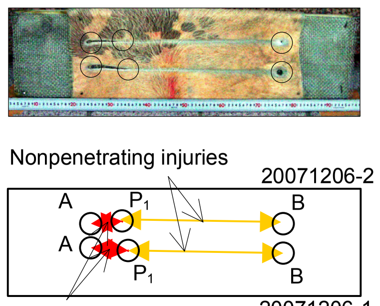
Specification		
Jet type	WJ	
P	60 MPa	
θ (nominal)	90°	
v_{nx}	600 mm/min	
v_{ny}	600 mm/min	
SD_A	20080825-2A	310 mm
	20080825-2B	310 mm
SD_B	20080825-2A	803 mm
	20080825-2B	813 mm

Figure 9. Results in the cases that WJ caused penetrating and nonpenetrating injuries and also left the parts of no injury in the hitting point moving path AB on swine skin. (see No. 3 and No. 4 in Table 1)



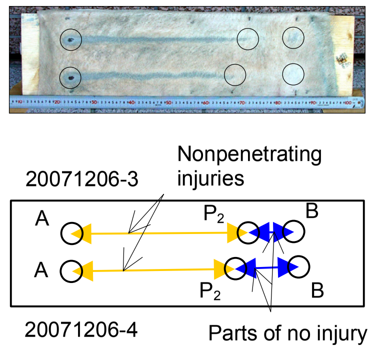
Specification		
Jet type	WJ	
P	60 MPa	
θ (nominal)	90°	
v_{nx}	600 mm/min	
v_{ny}	600 mm/min	
SD_A	20080826-5A	900 mm
	20080826-5B	900 mm
SD_B	20080826-5A	1,505 mm
	20080826-5B	1,505 mm

Figure 10. Results in the cases that WJ caused nonpenetrating injuries and left the parts of no injury in the hitting point moving path AB on swine skin. (see No. 7 and No. 8 in Table 1)



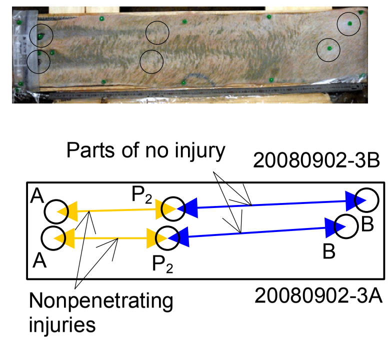
Specification		
Jet type	ASJ	
P	60 MPa	
θ (nominal)	90°	
v_{nx}	600 mm/min	
v_{ny}	600 mm/min	
SD_A	20071206-1	500 mm
	20071206-2	498 mm
SD_B	20071206-1	1,080 mm
	20071206-2	1,075 mm

Figure 11. Results in the cases that ASJ caused penetrating and nonpenetrating injuries in the hitting point moving path AB on swine skin.
(see No. 12 and No. 13 in Table 1)



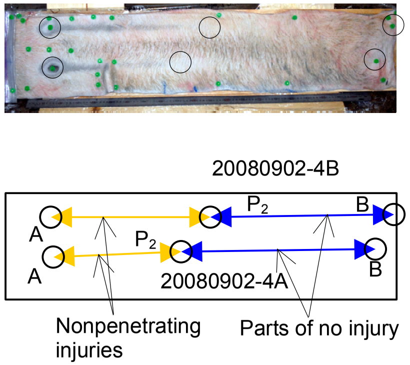
Specification		
Jet type	ASJ	
P	60 MPa	
θ (nominal)	90°	
v_{nx}	600 mm/min	
v_{ny}	600 mm/min	
SD_A	20071206-3	940 mm
	20071206-4	940 mm
SD_B	20071206-3	1,620 mm
	20071206-4	1,615 mm

Figure 12. Results in the cases that ASJ caused nonpenetrating injuries and left the parts of no injury in the hitting point moving path AB on swine skin.
(see No. 14 and No. 15 in Table 1)



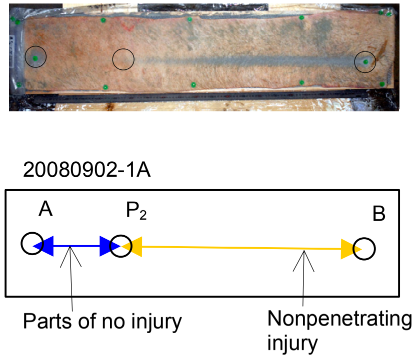
Specification		
Jet type	ASJ	
P	60 MPa	
θ (nominal)	45°	
v_{nx}	1,011 mm/min	
v_{ny}	403 mm/min	
SD_A	20080902-3A	1,000 mm
	20080902-3B	1,000 mm
SD_B	20080902-3A	1,877 mm
	20080902-3B	1,727 mm

Figure 13. Results in the cases that ASJ hit swine skin at the hitting angle θ = 45° along the hitting point moving path AB.
(see No. 26 and No. 27 in Table 1)



Specification		
Jet type	ASJ	
P	60 MPa	
θ (nominal)	135°	
v_{nx}	180 mm/min	
v_{ny}	427 mm/min	
SD_A	20080902-4A	1,000 mm
	20080902-4B	1,000 mm
SD_B	20080902-4A	2,007 mm
	20080902-4B	2,052 mm

Figure 14. Results in the cases that ASJ hit swine skin at the hitting angle θ = 135° along the hitting point moving path AB. (see No. 28 and No. 29 in Table 1)



Specification	
Jet type	ASJ
P	60 MPa
θ (nominal)	90°
v_{nx}	600 mm/min
v_{ny}	-600 mm/min
SD_A	1,800 mm
SD_B	745 mm

Figure 15. A result in the case that ASJ discharged from the nozzle approaching to the swine skin hit its surface along the hitting point moving path AB. (see No. 30 in Table 1)

[End]