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Title	PROPOSING A SIMPLE METHOD FOR ASSESSING CONCRETE PUMPABILITY
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Description	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
Relation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, G-5-5.
Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), G-5-5
Issue Date	2013-09-13
Doc URL	https://hdl.handle.net/2115/54435
Type	conference paper
File Information	easec13-G-5-5.pdf

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PROPOSING A SIMPLE METHOD FOR ASSESSING CONCRETE PUMPABILITY

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ABSTRACT

As a method for easily assessing concrete pumpability, we examined a technique in which acceleration sensors are attached to a concrete conveying pipe to measure the characteristics of vibrations caused by aggregates inside the pipe. Our experiments showed that measuring acceleration near the lower end of a tapered pipe makes it possible to correctly assess concrete pumpability based on the aberration and size of acceleration values. Our experiments also revealed the following: If we compare the pumping conditions in which concrete is smoothly pumped from start to finish and is discharged from the concrete conveying pipe nozzle at a constant level and the blockage condition immediately before the concrete completely stops flowing out of the nozzle, the vibration amplitude in the blockage condition reveals the effects of differences in the percentage of fine aggregate and in the pumping conditions; and these differences correlate with the coefficient of variation for the pump hydraulic pressure.

Keywords: Pumpability, blockage, frequency characteristics, Amplitude, Pump hydraulic pressure.

1. INTRODUCTION

In recent years concrete pumps have become essential for concrete construction to transport concrete to the location of placement, and are therefore being used at many construction sites. However, due to differences in construction and pumping conditions, as well as concrete mixture, the pressure inside conveying pipes is not always maintained at the same level. Nevertheless, there is usually no method for checking the conditions of concrete being placed at construction sites. As a result, blockage and other unexpected problems occur, thereby decreasing transportation efficiency.

Past studies (Tsujimura 1988) have revealed how concrete causes blockage. However, since there is usually no method for assessing concrete pumpability at construction sites, blockage is detected only when concrete stops flowing from the pipe nozzle.

Blockage not only presents a problem with regard to the work required to unclog the pipe, but also

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is problematic in that heavy stress is placed on concrete pumps and conveying pipes at the time of clogging or up to immediately before it. Therefore, it is critical to assess concrete pumpability at the construction site. At present, however, there are no means to assess the conditions of concrete while it is being pumped through conveying pipes.

In this study, we propose a method for measuring concrete pumpability that uses an acceleration sensor attached to the pumping pipe when concrete is being pumped. We studied how to assess concrete pumpability based on the frequency characteristics of vibrations that occur in different types of conveying pipes. We also studied how concrete mixing conditions affect concrete pumpability.

2. EXPERIMENT

2.1. Mix proportions

Table 1 shows mixture proportions of mortar and concrete in which there are three levels of sand-coarse aggregate ratio (s/a). The unit water content and water-cement ratio were designed to be 175 kg/m^3 and 50% for all types of concrete, respectirely. The target values of slump and air content are listed in table 1.

Table 1: Mix proportions mortar and concrete

Symbol	s/a (%)	w/c (%)	s/c (%)	Vg/Vm (%)	Unit weight (kg/m^3) W	Target slump (cm)	Target air (cm)
M-120	-	50	2.2	0	298	120±10*	-
No.1-20	45	50	2.2	62	175	20.0±1.0	4.5±1.0
No.1-15						15.0±1.0	
No.1-8						8.0±1.0	
No.1-3						3.0±1.0	
No.2-20	41		2.0	70.4		20.0±1.0	4.5±1.0
No.2-15						15.0±1.0	
No.2-8						8.0±1.0	
No.2-3						3.0±1.0	
No.3-20	36.5		1.8	80		20.0±1.0	4.5±1.0
No.3-15						15.0±1.0	
No.3-8						8.0±1.0	

*mortar flow (mm)

2.2. Experimental method

We conducted pumping test in accordance with the JSCE-F509-2010 standard (Japan Society of Civil Engineers 2012) using test equipment. In this experiment, we pumped concrete at an elevation

angle of 9.9 degrees with a piston speed of 1.25 cm/s; we visually inspected pumping conditions and measured the average and coefficient of variation of the pump hydraulic pressure. In order to calculate the hydraulic pressure for the tapered part of the pipe, we subtracted the hydraulic pressure obtained by using only a straight pipe (P2) from the hydraulic pressure obtained by using a straight pipe and a tapered pipe (P1) (P1 – P2). The hydraulic pressure was measured at intervals of 0.1 seconds using a dynamic strain gauge.

In order to examine the effects of measurement positions, acceleration sensors were attached to a total of four different locations: one on a straight pipe and three on a tapered pipe. On the tapered pipe, measurements were made at three different points: 1) a measurement point at the entrance of the tapered pipe, where the pipe's diameter is the same as that of the straight pipe; 2) a measurement point in the middle of the tapered pipe, where its diameter narrows from 155 mm to 100 mm; 3) a measurement point where the tapered pipe's diameter is at its narrowest. Acceleration sensors were attached to the bottom of the concrete conveying pipe at all four points in order to ensure the replicability of measurement data. After taking measurements, we assessed the pumpability from the relationship between frequencies and vibration amplitudes based on the acceleration measured as well as the results of FFT analysis.

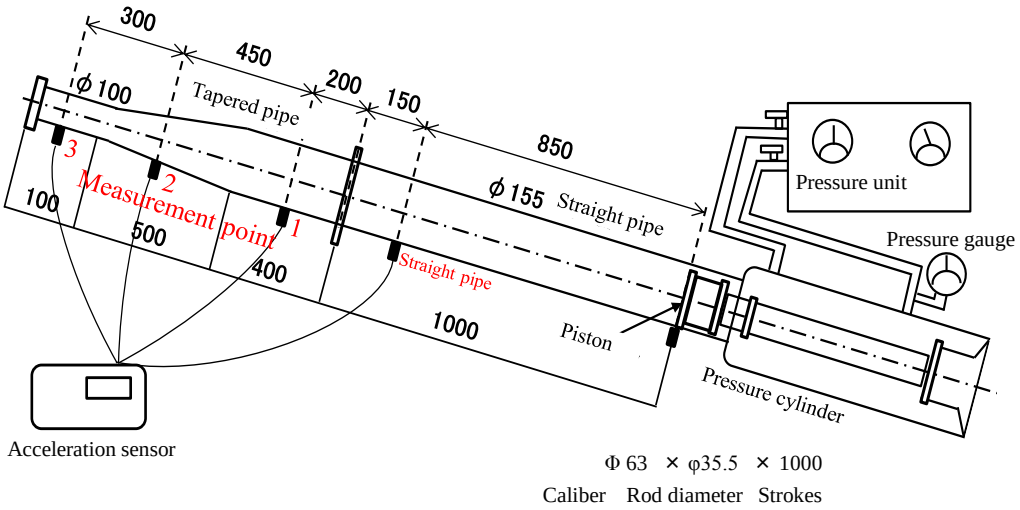

Figure 1: Pumping test equipment and attachment positions of acceleration sensors

3. RESULT AND DISCUSSION

In this study, we defined the results of a pumping test in which concrete was smoothly pumped from start to finish and discharged from the concrete conveying pipe nozzle in a constant state as the smooth pumping state; the results of a pumping test in which concrete was irregularly

discharged from the nozzle as the unstable pumping state; and the state where concrete was not discharged at all from the nozzle as blockage. The results of a pumping test up to immediately before blockage occurred were defined as the blockage state.

As shown in the Table 2, the results of smooth pumping showed better performance in terms of pumpability compared to the Japan Society of Civil Engineers' Guidelines for Concrete Pumping. Also, results for the smooth pumping state were not affected by the percentage of fine aggregate. Data on the test for the blockage state showed the coefficient of variation for pump hydraulic pressure became larger as the percentage of fine aggregate became lower. These results indicate that the percentage of fine aggregate and pumping conditions correlate with the coefficient of variation for pump hydraulic pressure.

Table 2: Pumping conditions

Pumping conditions	Symbol	Slump (cm)	Average of the pump hydraulic pressure (Mpa)	Coefficient of variation of the pump hydraulic pressure (%)
Smooth	M-120	120*	0.044	14.97
	No.1-20	21.0	0.051	18.38
	No.1-15	16.0	0.088	14.98
	No.1-8	9.0	0.084	14.23
	No.2-20	20.0	0.048	24.46
	No.2-15	16.0	0.124	12.33
Smooth→Unstable	No.3-20	21.5	0.046	40.03
Unstable→Blockage	No.2-8	7.5	0.504	91.67
Blockage	No.1-3	4.0	0.845	54.18
	No.2-3	4.0	0.654	63.83
	No.3-15	15.0	0.527	87.08
	No.3-8	9.0	0.583	80.52

*mortar flow (mm)

As shown in the Figure 2, the mortar contained no coarse aggregates, there were no aberration in the acceleration value and on average the acceleration value was small. The results of the measurement of a straight pipe with s/a = 41% showed a small acceleration value with no significant aberrations. The results for other target slumps with the same composition showed similar tendencies, suggesting similar results for pipes with no such resistance to pumping as found in the tapered pipes. The measurement results for tapered pipes reveal the following: In the smooth pumping state, the acceleration was constant throughout the duration of measurement with no aberrations in the acceleration value; however, as a result of transition from the unstable pumping state to blockage (targeted slump: 7.5 cm), the acceleration repeatedly showed small aberrations during the first half of the measurement, from around 5 seconds, and finally started to show large values and aberrations from around 15 seconds. In the blockage state (target slump: 4.0 cm), the acceleration rapidly increased at around the 20 second mark, reaching the highest level among tests

conducted with the same composition. These tendencies in different pumping conditions differ in terms of measurement time and acceleration. However, similar results were obtained for other mixing conditions. These results indicate that concrete pumpability can be relatively easily assessed from the level of aberrations in acceleration measured on a tapered pipe.

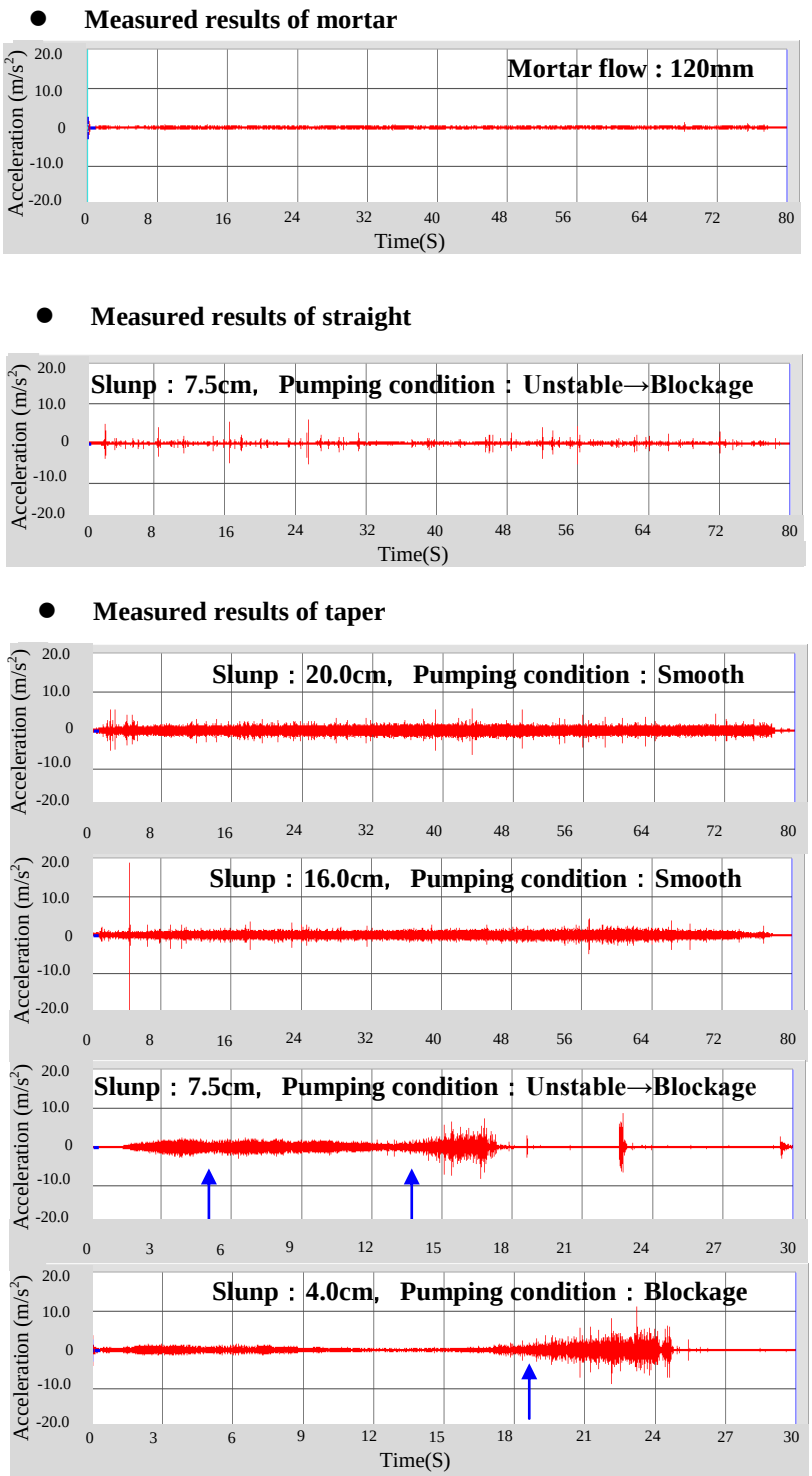

Figure 2: Relationship between time and acceleration

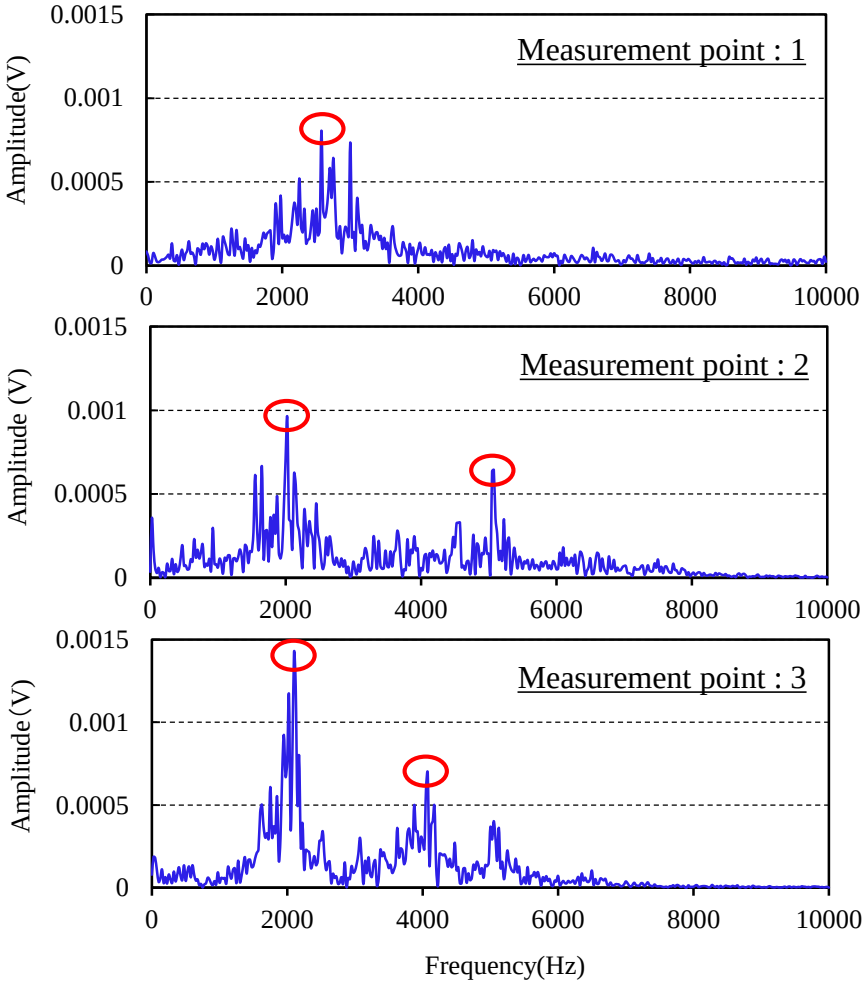

Figure 3: Relationship between frequency and amplitude

As the figure 3 shows, the vibration amplitude peaked at a frequency around 3,000 Hz at Measurement point 1 and at a frequency around 2,000 Hz at Measurement points 2 and 3. Also, at Measurement points 2 and 3, values close to the vibration amplitude peaks were observed at frequencies around 4,000 Hz and 6,000 Hz. This is likely due to the following: The diameter of the tapered pipe was small at Measurement points 2 and 3, which caused aggregates to collide with each other and against the pipe's wall with greater frequency, thereby increasing friction with the wall. Similar results were also obtained for the smooth pumping state, in which the acceleration variation was also large. These results lead us to believe that, in order to assess pumping conditions, it is more effective to perform measurements at Measurement point 1, where frequency aberrations occur less often.

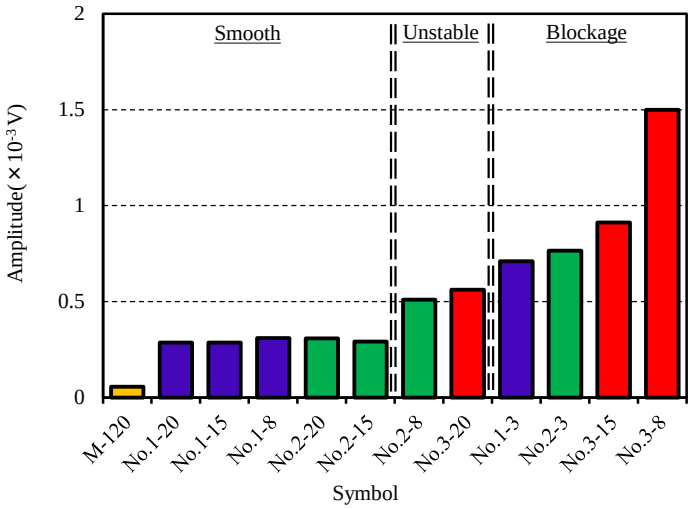

Figure 4: Amplitude peak values of each type (each pumping condition)

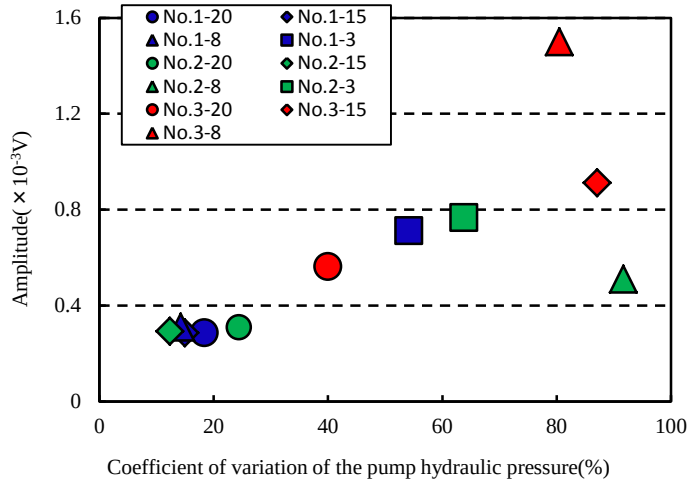

Figure 5: Relationship between amplitude and coefficient of variation of the pump hydraulic pressure

As the figure 4 and figure 5 shows, the vibration amplitude peak value in the smooth pumping state is approximately five times as large as the peak value for mortar. However, comparisons between different types of concrete showed that the vibration amplitude peak value was constant irrespective of the size of slumps or the percentage of fine aggregate. Within the range of Vg/Vm of mixing conditions used in experiments for this study, there may be no significant difference between vibration amplitude peak values in the smooth pumping state. In the future, however, there is a need to examine the effects of the shape of coarse aggregates, which is also likely to affect pumping. The vibration amplitude peak value in the unstable pumping state was approximately twice, and in the

blockage state three to five times, as large as the peak value in the smooth pumping state. In the blockage state, unlike in the smooth pumping state, the peak value tended to be larger as the percentage of fine aggregate decreased. Data on the relationship between vibration amplitude peak values and the coefficient of variation for pump hydraulic pressure showed that, in the blockage state, the peak value was higher for larger coefficients of variation for pump hydraulic pressure, indicating a correlation between the coefficient of variation for pump hydraulic pressure and vibration amplitude peak values.

4. CONCLUSIONS

It is possible to assess concrete pumpability from aberrations and levels of acceleration measured at a point near the lower end of a tapered pipe (Measurement point 1).

The vibration amplitude peak value for concrete pumping measured by an acceleration sensor is observed at a frequency around 3,000 Hz, based on the relationship between frequencies and vibration amplitudes at Measurement point 1.

Comparisons between the smooth pumping and blockage states show that the percentage of fine aggregate and the differences in pumping conditions affect the vibration amplitude in the blockagestate. Such effects of pumping conditions correlate with the coefficient of variation for the pump hydraulic pressure.

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