コンクリート工学年次論文報告集, Vol.18, No.1, 1996

論文 Experiment Investigation and DEM Simulation of Filling Capacity of Fresh Concrete

Hongwei CHU[*1] Atsuhiko MACHIDA [*2] and Nobuyasu SUZUKI[*3]

ABSTRACT: This paper is comprised of two parts with part one showing filling capacity of fresh concrete flowing through U-Box container and box with meshes by giving a group of newly obtained multiple regression formulae based on four fundamental factors of fresh concrete including W/C, s/a, dosage of superplasticizer and viscous agent whereas part two illustrating the procedures of fresh concrete flowing through U-box and meshes by first trial of using 2D DEM method.
KEYWORDS: DEM, fresh concrete, multiple liner regression, flowing capacity, filling capacity, spatial passing capacity

1. INTRODUCTION

In Japan a special attention is focusing on the high workability of fresh concrete especially on the techniques of self-filling concrete from the consideration of economical factors and quality assurance. Considerable researchers have been doing a lot of experimental works with different mix proportion and different type of materials by using different type of containers , based on which some empirical knowledge on flowing capacity, filling capacity, spatial passing capacity and resistance against segregation was summarized [1]. Mix proportioning of concrete for practical works have been undertaken under the accumulated experience. In this paper the author has put forward a set of multiple linear regression formulae by which slump flow, air content, time for slump flow of 50 cm in diameter, flowing time through cone 75 funnel, flowing time through box 75 funnel, time up to 15 cm height through U-shape box, time up to 20 cm height through U-shape box and gravity percentage of fresh concrete passing through meshes available in 11 cases of experiment are correlated with four fundamental factors as W/C, s/a, dosage of viscous agent as percentage of water content and dosage of superplasticizer as percentage of cement. The equations show quite good agreement with experimental results.

On the other hand numerical simulation as one useful tool is widely utilized to investigate the mechanism of fresh concrete when flowing through various kinds of boundary conditions for the theoretical needs. Different researchers have broken through differing path of two main routes: one is to treat fresh concrete as viscous fluid with yielding value and viscous coefficient [2]; the other is to assume as particulate assemblage [3]. The properties of fresh concrete are very complicated and difficult to describe in determinative terms. Some symptoms of interparticle interference between coarse particles of fresh concrete as arch forming and segregation when flowing through suddenly changed section enable the researchers to assume fresh concrete as particulate assemblage and to introduce and modify Distinct Element Method (DEM for abbreviation hereinafter) to deal with the

*1 Graduate School of Engineering, Saitama University, Student Member of JCI
*2 Department of Civil Engineering, Saitama Universiy, Member of JCI
*3 Department of Civil Engineering, Saitama University, Undergraduate Student

properties of fresh concrete described in literature [4]. In this paper the author attempts to apply DEM method to simulate the procedure of fresh concrete flowing through U-shape box and passing through meshes by offering displacement history diagram, velocity history diagram and force history diagram. The interparticle interference can be vividly demonstrated by showing force history diagram at different time intervals.

2. EXPERIMENTS

2.1 MATERIALS

In this research ordinary Portland cement, gravel, viscous agent and superplasticizer were utilized as listed in Table 1.

Table 1. Properties of Material

Material	Specific Gravity	F.M.	Absorption
O.P.C.	3.16	-----	------
Sand	2.49	2.07	3.09%
Gravel(Gmax=20mm)	2.67	6.73	1.2%

2.2 DESCRIPTION OF EXPERIMENT

(1). Apparatus

Five types of apparatus are used including slump cone, 75 cone funnel (O75 cone for short), 75 box funnel (□75 box for short), U-shape box and mesh. U-shape box and mesh are illustrated in Fig. 1 and Fig. 2.

(2). Mix proportion and results

11 cases are designed to investigate the workability of fresh concrete and experimental results are depicted in Table 2.

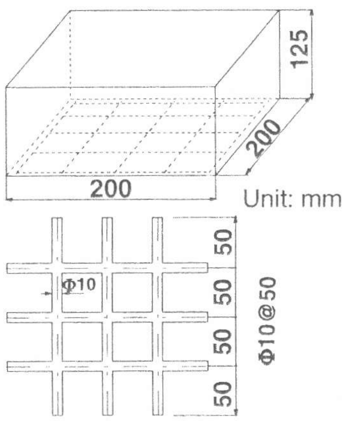


Fig 1. Geometry of mesh

2.3 DISCUSSION OF EXPERIMENTAL RESULTS

(1). Flowing capacity

There are three points which can be observed in Fig. 3 and Fig. 4. One indicates that a minimum value of s/a exists, beyond this value the flowing time is quite similar when slump flow is similar. Another is that three types of apparatus including slump cone, O75 cone, □75 box used to evaluate the fluidity of fresh concrete shows quite correlated results and it is possible to adopt a typical one and unify the fluidity evaluation criterion of fresh concrete. The third interesting phenomenon is that there is no difference on flowing time through O75 cone and □75 box with similar height and volume capacity irrespective of their different section shape .

(2). Filling capacity and passing capacity

s/a has a considerable influence on the properties of filling capacity and spatial passing capacity of fresh concrete as observed in Fig. 5 and Fig. 6. As demonstrated in Fig 3. a minimum s/a approximately valued 0.45 also exits for two figures. If s/a is over 0.45, O75 and □75 time in Fig. 3, BT time in Fig. 5 and pp in Fig. 6 show approximately same magnitudes respectively.

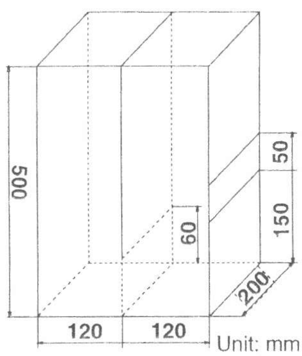


Fig 2. Geometry of U-shape box

(3). Empirical formulae

It is recognized that four of the fundamental factors dominate the properties of fresh concrete, enumerated as W/C, s/a, dosage of viscous agent and water reduction agent such as superplasticizer etc. Because these four factors are correlated and interacted simple description of the relationship between one measurement of properties of fresh concrete with one selection of the above four factors

Table 2 Experiment Results

No.	W/C	s/a	W[1]	C[2]	VA[3]	SP[4]	SF[5]	SFT[6]	O75[7]	□75[8]	Air	AT[9]	BT[10]	PP[11]
					%	%	cm×cm	s	s	s	%	s	s	%
1	0.54	0.35	180	333	0.44	2.4	55×55	31	83	255	2.4	-	-	52.2
2		0.4					63×61	18	29.2	51.9	3.1	6	15.5	83.77
3		0.45					56×55	24	20.5	18	6	5	15.1	87.03
4		0.47					51×52	52	21.2	20.4	8	4.8	17.8	91.51
5		0.5					52×53	24.8	16.77	18.3	9.6	2.9	14.77	89.01
6		0.52					50×53	27	16.5	15.4	9.7	2.4	10.9	92.32
7	0.34	0.45		529	0.3	4	63×61	18	29.2	51.9	1.2	3.5	7.7	84.93
8	0.36			500	0.2	2.5	64×64	12	22.2	20.5	2.6	1.6	3.5	88.01
9	0.4			450	0.1	2	67×71	8.5	16.8	16.77	2.6	1.8	3.5	79.03
10	0.45			400	0.2	2	71×76	6.4	10.2	10.2	5.6	2.7	6.3	88.98
11	0.5			360	0.2	2	65×70	12.6	16.6	16.4	5.9	2.1	4.6	59.17

NOTE: 1--Water; 2--Cement; 3--Viscous Agent; 4--Superplasticizer; 5--Slump Flow; 6--Time for Slump Flow of 50 cm in Diameter; 7-- Time through O75 cone funnel; 8--Time through □75 box funnel; 9--Time flowing up to 15cm height through U-shape box; 10--Time flowing up to 20 cm height through U-shape box; 11--Gravity percentage of fresh concrete passing through mesh.

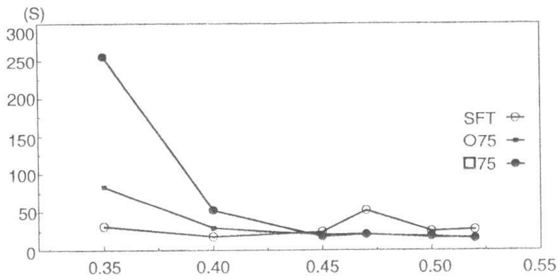


Fig. 3 s/a with SFT, O75 time and □75 time

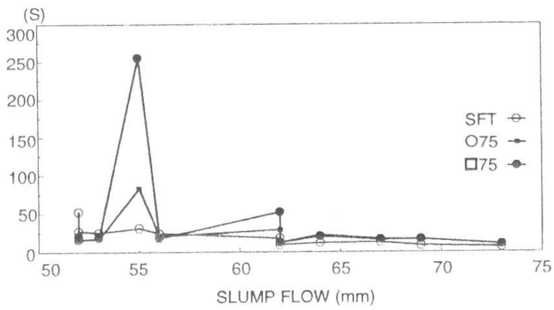


Fig 4. SF with SFT, O75 time and □75 time

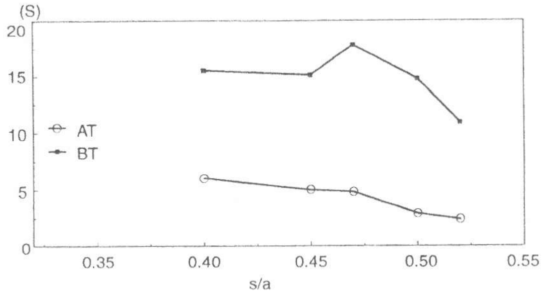


Fig 5. s/a with Filling Time AT and BT

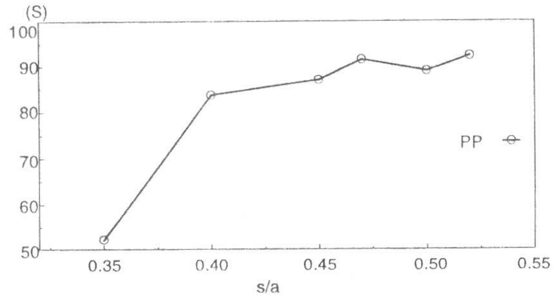


Fig 6. s/a with Passing Percentage

has been proved to be an unsatisfactory attempt. Therefore in this paper multiple liner regression between various kinds of measurable variables and four preceding factors are put together to generate a set of empirical formulae. The dependent variables and coefficients are tabulated in Table 3 with the indication of correlation determinant R^2. All regression formulae show very good correlation especially for air, etc. which are over 0.90. Now we select to plot the experimental data compared with predicted data in Fig. 7 and Fig. 8.

Table 3. Multiple liner regression factors

	SP[1]	s/a	VA[2]	W/C	CONSTANT	*R^2
SF	-4.0676	-35.5389	-17.4755	-64.5271	123.2144	0.9027
SFT	-5.1056	22.8436	84.7689	-13.2343	0.8554	0.6065
Cone	-3.1231	-346.6309	81.1496	-40.4396	179.8756	0.7805
AIR	-0.6432	48.7743	1.1412	21.2742	-25.7876	0.9529
PP	-21.1172	205.1608	153.7158	-281.4184	125.0914	0.7324
Box	-4.1011	-279.2394	80.8879	-43.7182	152.9959	0.7912
AT	0.4514	-30.9182	7.1877	5.1836	11.5888	0.92
BT	-0.8224	-27.6738	37.8516	4.9201	10.1588	0.91

Note: 1--Superplasticizer expressed as gravity percentage of cement; 2--Visous agent expressed as gravity percentage of water; *--Correlation Determinant; others same as defined in Table 2.

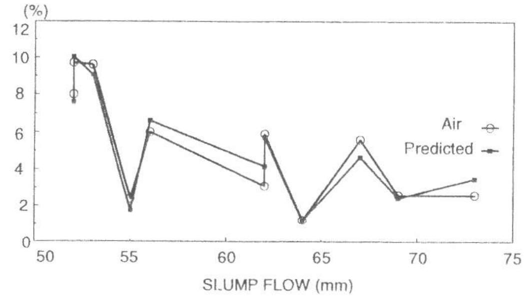


Fig 7. Comparison of air and predicted value

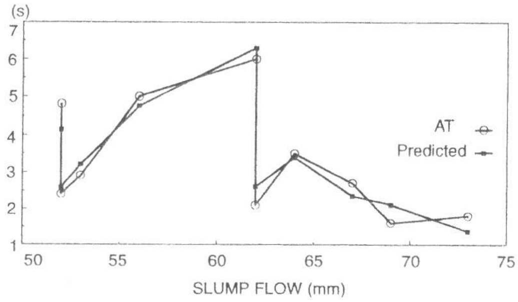


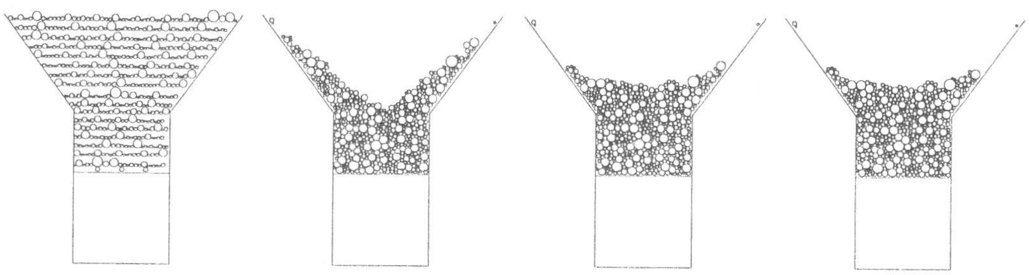
Fig 8. Comparison of AT and predicted value

3. DEM SIMULATION

3.1 PASSING CAPACITY SIMULATION

(1). Data packing

The whole simulation procedure is quite like the practical experimental process. First one particulate assemblage is generated according to the size distribution available from sieving experiment. Then the particulate assemblage is placed in a container formed by DEM elements and begins to pack under the gravitational force itself. The flowing procedure can be visualized by a computer



T= .00s T= 0.20s T= 2.00s T= 6.00s

Fig. 9 Presentation of particles packing in MESH program and also can be observed in Fig. 9.

(2). Simulation result

Different set of parameters concerning the properties of particles will dramatically influence the simulation outcomes. Here we will give a set of parameters listed in Table 4 and show the corresponding results in Fig. 10. Obviously the position of rebars is the location of serious particle interference which can be illustrated in force and velocity history diagram of Fig. 10. Force and velocity history diagrams are drawn according to the magnitude and direction from simulation results proportional to the maximum one.

3.2 FILLING CAPACITY SIMULATION

(1). Data preparation

The same procedure as described above will be repeated and the packing process can be similarly handled.

(2). Simulation result

When packing is finished redundant particles are removed and simulation can be commenced. It is very useful to demonstrate the displacement history, velocity history and force history because it can help us to locate the reason of uncompleted filling or flowing. Serious particle interference can be clearly seen in the specific zone located in small-opened outlet as demonstrated in Fig.

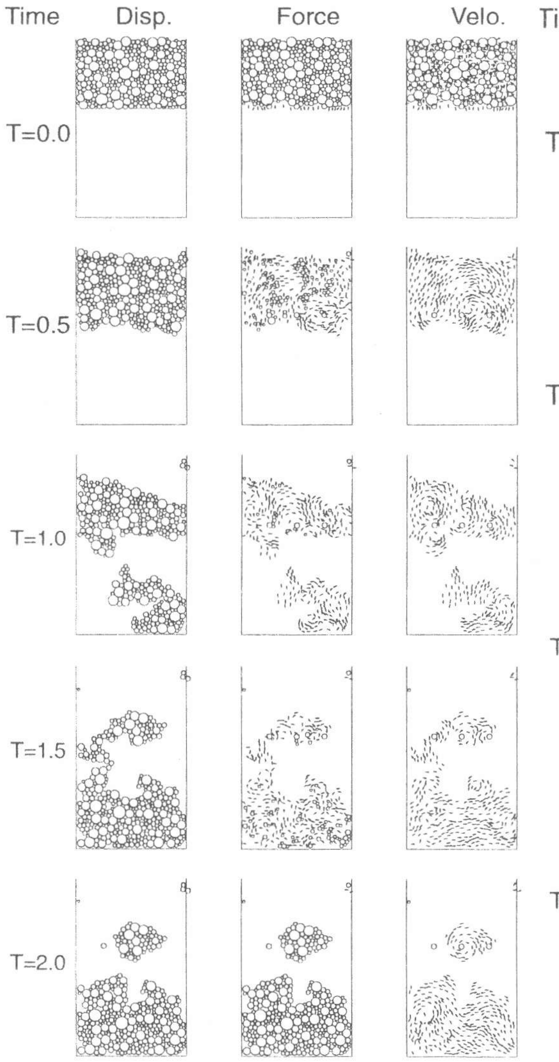


Fig. 10 Presentation of flowing through mesh

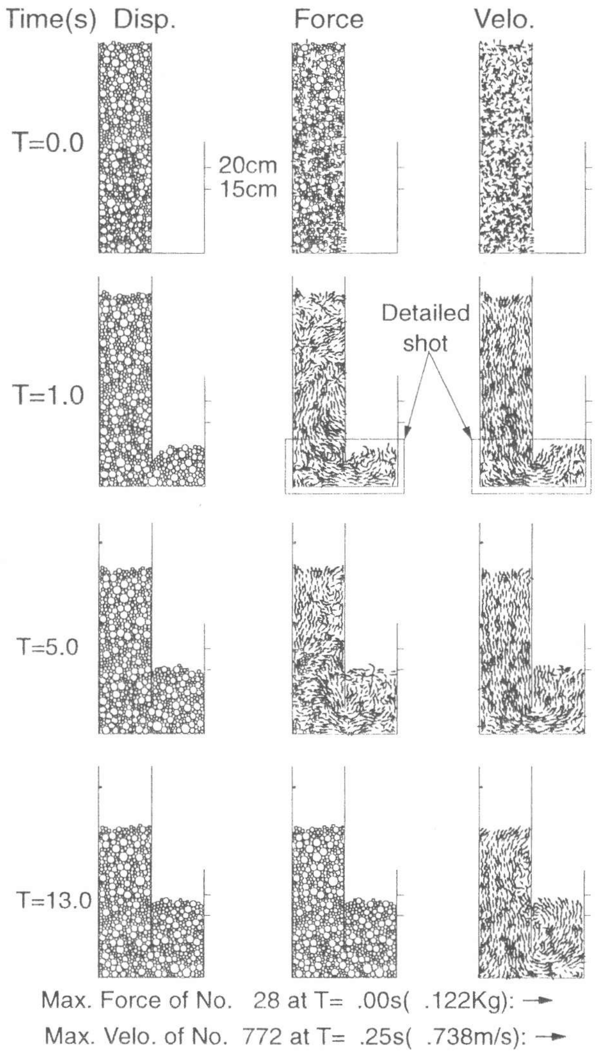
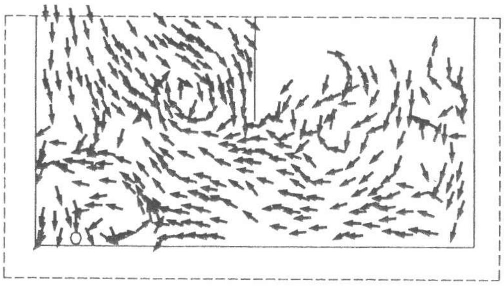


Fig. 11 Presentation of flowing through U-Box



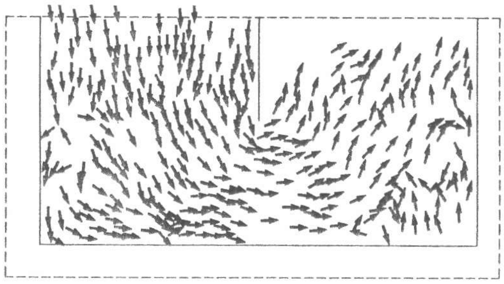


Fig. 12 Detailed shot of Fig. 11

11. We also take a detailed shot of force and velocity distribution at T=1.0s as shown in Fig 12. This enables us to visualize the interference at the outlet of U-shape box.

Table 4. DEM parameters for MESH

Spring constant Normal K_n	6×10^{-2} kgf/mm	Friction Coef. of particles μ_p	0.01
Spring constant Tangential K_s	1.5×10^{-2} kgf/mm	Friction Coef. of wall and particle	0.01
Dashpot coef. normal η_n	5.7×10^{-4} kgf·s/mm	Allowance of spring tension λ	1.2%
dashpot coef. Tangential η_s	7×10^{-4} kgf·s/mm	Time Step Δt	10^{-5}s
Particle no. Nel	330	Simulation Time	2.0s

4. CONCLUSION

From the above research, the flowing conclusion can be drawn listed below:

(1). A minimum s/a exists beyond which different mix proportioning will generate fresh concrete with similar workability concerning flowing capacity, filling capacity and spatial passing capacity on the condition of similar slump flow. In other words if s/a is controlled beyond the minimum bound, then it is a quite ease to make quality control over the high fluidity of concrete. Of course for different type of materials the magnitude of s/a will differ from each other.

(2). Concerning flowing capacity slump flow, O75 cone and □75 box show good agreement with each other, that means that it is possible to select one type of apparatus concerning flowing capacity evaluation and unify the criterion of judgment.

(3). Regression formulae are given to slump flow, time for slump flow of 50 cm in diameter, air content, time through O75 cone, time through □75 box, time flowing up to 15cm height through U-shape box, time flowing up to 20 cm height through U-shape box and gravity percentage passing through mesh based on four fundamental factors of fresh concrete such as W/C, s/a, dosage of superplasticizer and dosage of viscous agent. The experimental results can be followed well by regression formulae with correlation coefficient R^2 as high as 0.95.

(4). DEM method is a good method to estimate the mechanism of spatial passing capacity. The rebars have the possibility to stagnate fresh concrete from flowing by forming arch. This serious particle interaction is also illustrated by velocity and force history diagrams.

(5). Filling capacity of fresh concrete can also be investigated by DEM method . Velocity and force history diagrams depict clearly the interparticle interference when passing through suddenly changed outlet.

REFERENCE

(1). SHINDOH, T. et al. (1991) Fundamental study on properties of super workable concrete. Proceedings of the JCI, Vol. 13, No.1 pp179-184 (in Japanese)

(2). TANIGAWA, Y. et al. (1992) Flow simulation of fresh concrete by Dynamic Viscoplastic Analysis. Transactions of the JCI, Vol. 14, pp9-16

(3). NABETA, K. et al. (1994) Flow simulation of fresh concrete by Distinct Element Method. Proceedings of the JCI, Vol. 16, No.1, pp479-484 (in Japanese)

(4). CHU, H., MACHIDA, A., IWASHITA, K., (1995) Two dimensional Numerical simulation of flow behavior of fresh concrete by DEM method. Proceedings of the 50th Annual Conference of JSCE, 5, pp1026-1027