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EXPLANATION OF CONCRETE FILLING DEFECT ON MORTAR LOSS MODEL

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Problems with filling can lead to rebar corrosion and impair the durability and all other functional aspects of reinforced concrete structures. However, the prevention of concrete filling defects is left to the skill, judgment, and experience of on-site operators. In this research, we develop a methodology for quantitatively estimating the rate of occurrence of concrete filling defects. By this, we hope to promote the efficient and effective prevention of such defects at construction sites. Therefore, as a model for defective filling, we propose a mortar loss model in which the mortar component of concrete free falling into the frame adheres to the reinforcing bars in the frame, and based on that, we conducted an experiment. Using actual measurement data, we quantitatively estimated the risk of defective filling.

Keywords: Concrete work, Filling defect, Honeycomb, Mortar loss model.

1 INTRODUCTION

Modern concrete is a building material that is semi-permanent in durability. This said, this durability can be significantly impaired by problems during construction. One such problem is poor filling. Problems with filling can lead to rebar corrosion and impair the durability and all other functional aspects of reinforced concrete structures. Likewise, the poor filling is well known as a factor behind the peeling, separation and eventual fallout of concrete fragments, a phenomenon that puts passersby at risk of serious injury.

Concrete filling defects occur with alarming frequency and remain a serious problem. A research committee of the Japan Concrete Institute found that filling defects existed within 39% of medium- to high-rise reinforced concrete (RC) multifamily dwellings, with only 3% of potential occurrences successfully prevented beforehand (JCI 2008). Over the years, much research has been conducted on the prevention of concrete cracking; yet, in contrast, there have been few academic studies on the defective filling. It is true that construction companies generally have in-house guidelines to prevent such defects. This said, there is no industry-wide set of uniform views or methodology. Usually, the prevention of concrete filling defects is left to the skill, judgment, and experience of on-site operators.

In this research, we develop a methodology for quantitatively estimating the rate of occurrence of concrete filling defects. By this, we hope to promote the efficient and effective prevention of such defects at construction sites. Working with a "mortar loss model" (described within the paper), the authors measure "mortar loss," which here means the amount of mortar found to adhere (stick) to rebar mesh within a test frame. They then apply their measurements to a wall construction case study and, within it, estimate the risk of defective concrete filling.

2 PROPOSITION OF A MORTAR LOSS MODEL

Cited as a major factor behind defective concrete filling is the intricate, excessively dense rebar mesh characteristic of many construction projects. The conventional model for rebar/concrete separation (Figure 1) has that aggregate tends to get caught in gaps between reinforcing bars, blocking any further flow of concrete beyond that point. Note, however, that the conventional model fails to explain why filling defects occur with particular frequency when pouring walls. Here, we point out that when pouring a concrete wall, the tremie pipe often cannot be inserted all the way to the bottom of the frame and so the concrete must be poured down from above. It is this characteristic, we think, that accounts for this high frequency of filling defects.

In this research, we propose a new model for defective filling. Under our "mortar loss model" (Figure 2), concrete pours freely down into the frame, whereupon a portion of the mortar component adheres to reinforcing bars within the frame. Here, an arrival of concrete containing excess aggregate at the bottom of the frame is deemed to be indicative of defective filling.

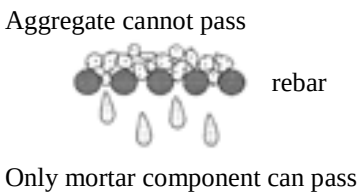


Figure 1. The conventional model.

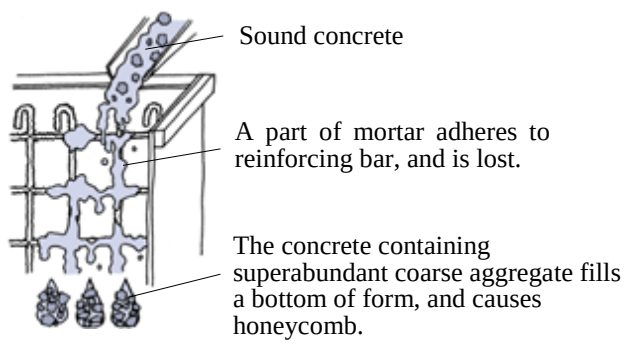


Figure 2. Mortar lost model atoncrete placing.

3 MEASUREMENT OF LOSS MORTAR

3.1 Experimental Method

3.1.1 Concrete samples: formulation and mixing

Table 1 tabulates the materials used to concrete test samples: ordinary Portland cement (OPC), tap water (W), sea sand (S) and crushed stone (G). Mix proportions of concrete test samples are shown in Table 2. We prepared for four mix proportions and assigned target slump and target slump flow values to each. All were prepared by first dry mixing ordinary Portland cement and sea sand, injecting water, mixing to uniformity and then adding crushed stone. The air content of the mixed concrete was 4.5 ± 1.5%. In consideration of the time dependence of slumping behavior, we subjected the concrete samples to testing within two hours after water injection.

Table 1. Using materials.

OPC: density 3.16g/cm³
S: density(surface-dry) 2.59g/cm³, F.M.2.4
G: density(surface-dry) 2.70g/cm³, F.M.6.9

Table 2. Mixture proportions; kg/m³.

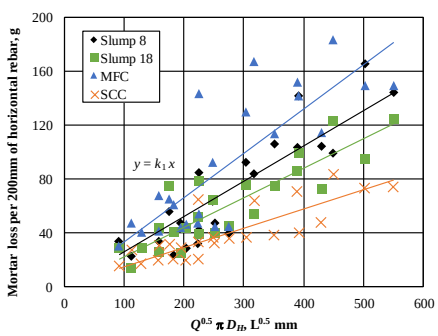
	Type	W/OPC	W	OPC	S	G
I	Slump 8cm	50%	161	322	750	1,087
II	Slump 18cm	50%	175	350	764	1,010
III	MFC	50%	175	350	823	949
IV	SCC	35%	170	486	871	796

3.1.2 Measurement method

We poured our concrete samples into test frames (200mm wide, 200mm thick, 200mm high) and measured the amount (mass) of mortar that adheres to rebar within them ("loss mortar"). The frames had no bottom plate. Thus, all concrete other than loss mortar simply flowed out through the bottom. Test parameters are, type of concrete formulation; the amount of concrete flowing through the frame; and diameter/arrangement of rebar within each frame. For rebar, we used a deformed reinforcing bar of diameter 13, 16, 25, or 32 mm. The rebar was arranged within each frame as one horizontal bar; as one vertical bar; or as two horizontal bars/ two vertical bars (four points of intersection). On the other hand, we collected experimental data about the influence of rebar position and sparseness on loss mortar. Frames arranged nine horizontal bars at intervals of 100~200mm or one horizontal bar 200~1,800mm long were used for the experiments.

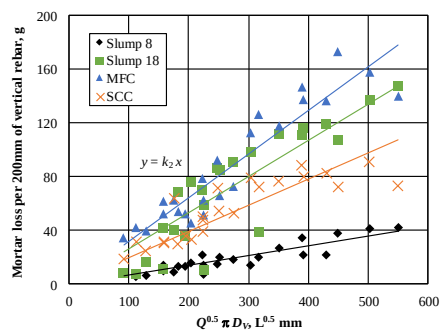
3.2 Experimental Results and Discussion

Figures 3 and 4 show relations between (1) the product of (a) the square root of flow volume and (b) total rebar periphery, and (2) loss mortar mass. We see that the amount of loss mortar is proportional to this product. Here, we propose Equations (1) and (2) as means to calculate loss mortar mass due to horizontal and vertical bars.



	Slump 8	Slump 18	MFC	SCC
R^2	0.95	0.95	0.92	0.93
k_1	0.26	0.22	0.33	0.14

Figure 3. The change in loss mortar mass with horizontal bar.



	Slump 8	Slump 18	MFC	SCC
R^2	0.96	0.94	0.98	0.95
k_2	0.071	0.27	0.32	0.19

Figure 4. The change in loss mortar mass with vertical bar.

$$M_{H200} = k_1\sqrt{Q}\pi D_H \tag{1}$$

$$M_{V200} = k_2\sqrt{Q}\pi D_V \tag{2}$$

M_{H200}: Mortar loss per 200mm of horizontal rebar, g
M_{V200}: Mortar loss of 200mm of vertical rebar, g
Q: Concrete flow volume, L
D_H: Diameter of horizontal rebar, mm
D_V: Diameter of vertical rebar, mm
k_1, k_2: Constant, g/L$^{0.5}$mm

The change in loss mortar mass with horizontal/vertical bar intersection is shown in Figure 5. We note that loss mortar mass is proportional to the product of (a) the square root of the sum of mortar loss at horizontal and vertical rebar and (b) the square of rebar diameter. Here, we

propose Equation (3) as a function with which to calculate the amount of loss mortar as a result of such intersections.

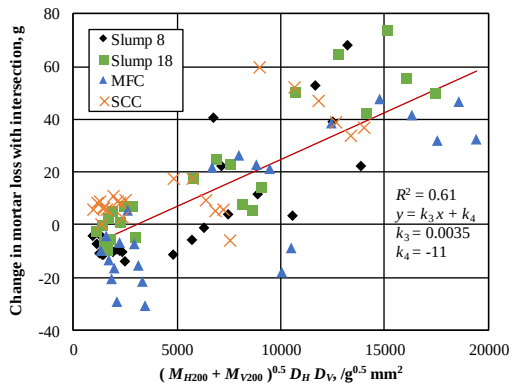


Figure 5. The change in loss mortar mass with horizontal/vertical bar intersection.

$$M_I = k_3\sqrt{M_{H200} + M_{V200}}D_H D_V + k_4 \tag{3}$$

M_I: Change in mortar loss with horizontal/vertical bar intersection, g
k_3: Constant, g$^{0.5}$/mm^2
k_4: Constant, g

Figure 6. shows the influence of horizontal bar position and sparseness on loss mortar. The most loss mortar adheres to the second bar from the top. On the third and under the bar, the amount of loss mortar decreases with sequence and converges on a constant value. The constant value increases with increasing interval of the horizontal bar.

Figure 7 shows the influence of vertical bar position on loss mortar. The most loss mortar adheres to the vertical bar in the range from the top down to 200mm. The vertical bar in the others range has loss mortar of about 0.4 times as compared with the range from the top down to 200mm.

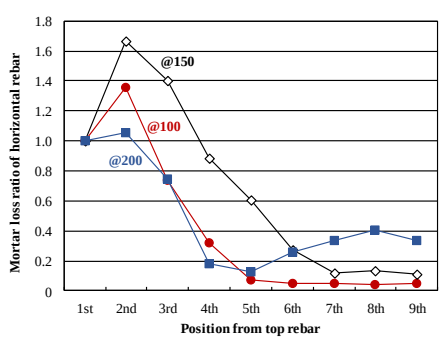


Figure 6. The influence of horizontal bar position and sparseness on loss mortar.

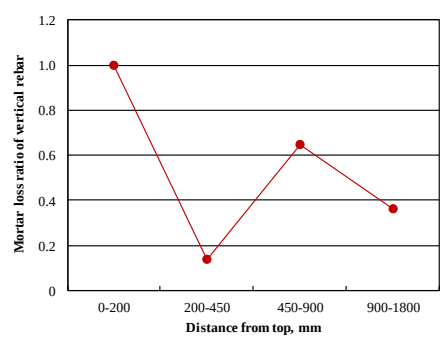


Figure 7. The influence of vertical bar position on loss mortar.

4 ESTIMATION OF DEFECTIVE FILLING RISK

We next utilize our mortar loss model to estimate the risk of defective filling when pouring concrete to form a wall of a reinforced-concrete structure. The rebar mesh for this test wall was

determined in reference to a wall formwork presented by the Architectural Institute of Japan as a standard for structural calculations (AIJ 2010). Concrete materials and their formulation are as described earlier in this paper. The dimensions of the wall are taken as a floor height of 3,600mm and a thickness of 200mm. The mortar component of the concrete is assumed to adhere to rebar over a horizontal distance of 200mm. The angle of repose of concrete containing excess aggregate at the bottom of the frame is assumed to be 45°: value of crushed stone (Glover 1995). Here, we utilized Equations (4) and (3') to calculate the total amount of loss mortar to result as concrete is poured into rebar-meshed frames.

$$M = \sum \frac{M_{H200} L_H}{200} \gamma_{Hi} + \sum \frac{M_{V200} L_V}{200} \gamma_{Vi} + \sum M'_I \tag{4}$$

$$M'_I = k_3 \sqrt{M_{H200}\gamma_{Hi} + M_{V200}\gamma_{Vi}} D_H D_V + k_4 \tag{3'}$$

M: Total amount of mortar loss, g
L_H: Horizontal rebar length, mm
L_V: Vertical rebar length, mm
γ_{Hi}, γ_{Vi}: Correction factor
M'_I: Corrected change in mortar loss with horizontal/vertical bar intersection, g

γ_{Hi} is assumed to be the value in Table 3. γ_{Vi} is assumed to be 1.00 in the range from the top down to 200mm, 0.38 in the range under 200mm. k_1~k_4 are assumed to be the value in Figures 3~5.

Table 3. Correction factor.

Interval	Position from top rebar				
	1st	2nd	3rd	4th	5th, Under
100mm	1.00	1.35	0.74	0.32	0.05
200mm	1.00	1.05	0.74	0.27	0.27

The unit coarse aggregate bulk volume within the concrete arriving at the bottom of the frame is calculated with Equation (5) as a function of the amount of loss mortar thus obtained.

$$G_{BV} = \frac{G_V + \frac{\Delta M}{\Delta Q}\frac{1}{\rho}}{G_{lim}} * 10^{-3} \tag{5}$$

G_{BV}: Unit coarse aggregate bulk volume, m^3/m^3
G_V: Absolute volume of coarse aggregate in sound concrete, L/m^3
ρ: Density of mortar component, kg/L
G_{lim}: Solid content of coarse aggregate, m^3/m^3

For the purposes of this paper, we take a risk of defective filling to arise when the mortar fraction is no longer able to fill in gaps/voids produced as aggregate fills on its own. More specifically, we judge this risk to occur when the unit coarse aggregate bulk volume is over $0.76 m^3/m^3$.

Calculated results are shown in Figure 8. Under rebar interval of 100mm and concrete slump 18cm, the unit coarse aggregate bulk volume is over 0.76 from the bottom of the frame up to a distance of about 130mm into the frame (a situation suggestive of a risk of forming a defective filled layer). The rebar arrangement, which is highly intricate, is predicted to present a comparatively high risk of defective filling (and from a higher level from the bottom of the

frame). This is because of the increase of mortar loss at the vertical bar with narrowing of the interval. On the other hand, SCC is predicted to present a comparatively low risk of defective filling. This is because of a little absolute volume of coarse aggregate in SCC.

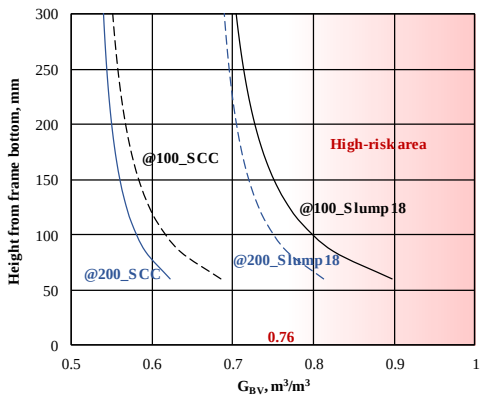


Figure 8. Calculated results.

5 CONCLUSIONS

Our findings are as follows:

(1) As a model for defective filling, we propose a mortar loss model in which the mortar component of concrete falling freely down into a frame is considered to adhere to rebar inside the frame. Concrete arriving at the bottom of the frame thus contains an excess amount of aggregate, a situation considered prone to the defective filling.

(2) The amount of loss mortar adhering to horizontal and vertical bars is taken to be proportional to the product of (a) the square root of concrete flow volume and (b) rebar periphery. The change in the amount of loss mortar resulting from rebar intersections can be approximated as a linear function of the product of (a) the square root of the sum of mortar loss at horizontal and vertical rebar and (b) the square of rebar diameter.

(3) The most loss mortar on of horizontal bar adheres to the second bar from the top. On the third and under the bar, the amount of loss mortar decreases with sequence and converges on a constant value. The constant value increases with increasing interval of the horizontal bar. On the other hand, the most loss mortar of vertical bar adheres to the range from the top down to 200mm.

(4) Using actual measurement data, we quantitatively estimated the risk of defective filling. Here, an intricate rebar arrangement is more prone to defective filling, and SCC is less prone to the defective filling.

Acknowledgments

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References

AIJ, *Architectural Institute of Japan Standard for Structural Calculation of Reinforced Concrete Structures*, 2010.

Glover, T. J., *Pocket Ref.*, Sequoia Publishing, 1995.

Japan Concrete Institute, Study on the Occurrence Probability of Risk Factors in Concrete Construction, *Concrete Construction Board Meeting Report*, ISBN 978-4-931451-87-2-C3050, 2008.