

# Effect Analysis of Delay Time on Strength of Cement Stabilized Mixture

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**Abstract.** To improve the efficiency of construction, reduce the curing period, it's necessary to determine the effect of delay time on the strength of cement stabilized mixtures. Through indoor simulated test and one-time vibration forming of specimen, which is control of different vibration time and degree of compaction, the cement stabilized specimens with different compactness are delayed 0 to 15h respectively. Test 7d unconfined compressive strength, elastic modulus, splitting strength and so on. Compared with different models, different places of retarded cement, coarse aggregate and fine aggregate, and it is delayed by 0 ~ 168h respectively. Then analyze 7 days unconfined compressive strength and secondary vibration settlement value. The test results show that delayed vibration 12h secondary compression can still increase the intensity. Under the same compaction degree (98%), there is a boundary point (delay vibration in 9h~12h), the specimen compressive strength, compressive elastic modulus, splitting strength are higher than the respective reference value.

## 1. Introduction

The traditional method is finishing paving the second layer before reaching the initial setting time of cement, which results in short construction length, easy to form cracks, poor economic results.

Diao [1] discussed the effect of setting time on mechanical properties and dry shrinkage properties of Portland cement. Zhang et al [2] comprehensively and systematically analyzed the delay of construction roller compaction of two ash material and the recoverability of the early strength and so on. Kolek [3] and others mentioned that in order to make a good combination between the upper and lower layers, the upper part of the layer needs to be vibrate again. Krishna et al. [4] concluded that some tiny cracks may be due to the passage of time after the two vibration and the early concreting of the concrete layer. Research shows that vibration improves many properties of hardened concrete, and the compressive strength is increased by about 14%, the density of water tightness and concrete density is bigger, then the surface appearance has improved [5,6]. The main chemical process that occurs within 2 hours after concrete pouring is the formation of calcium hydroxide, calcium silicate hydrate. The secondary vibration of the concrete after initial setting has the effect of liquefying the concrete again instantaneously and decomposing some of the weaker calcium hydroxide that has formed [7]. Wang [8] studied the difference in performance of concrete under vibration mixing and non-vibration mixing conditions, vibration mixing can increase the gas content of concrete mixture, reduce the slump of concrete, improve the cohesiveness and water retention, and enhance concrete strength and early age strength obviously. Kassie [9] demonstrated the effect of vibration on the compressive strength of concrete at certain delay intervals before and after the initial setting and final



setting time. Yang et al [10] proposed that the vibration of concrete cement mixing can improve the quality of concrete and production efficiency. Vibration can destroy small cement group and increase the surface binding force of aggregate and cement slurry. Zheng <sup>[11]</sup> analyzed the strength variation characteristics and influencing factors of secondary vibration concrete. Zheng et al <sup>[12]</sup> analyzed and found the reasons for the secondary vibration to increase the concrete strength. And the optimal time of the second vibration was determined.

## 2. Material selection and mix proportion

### 2.1. Material selection

Test 1 chooses the retarded cement from Cement Plant P.032.5 and concrete indicators refer to Table 1. The coarse aggregate is limestone rubble in Mianchi County and concrete indicators refer to Table 2. The fine aggregate is limestone chip (0~5mm) in Mianchi County and concrete indicators refer to Table 3. The mix proportion is 1#: 2#: 3#: 4#: Cement = 21: 33: 17: 29: 4, and concrete indicators refer to Table 4. Test 2 choose the retarded cement from Cement Plant P.042.5 and concrete indicators refer to Table 5. The coarse aggregate is limestone rubble in Yongchuan County and concrete indicators refer to Table 6. The fine aggregate is limestone chip (0~5mm) in Yongchuan County and concrete indicators refer to Table 7. The mix proportion is 1#: 2#: 3#: 4#: Cement = 20: 33: 17: 30: 4, and concrete indicators refer to Table 8.

**Table 1.** The test indicator of retarded cement from Cement Plant P.032.5.

Initial setting time (min)	309	Final setting time (min)	372
3d flexural strength (Mpa)	3.7	28d flexural strength (Mpa)	9.2
3d compressive strength (Mpa)	17	28 compressive strength (Mpa)	40.4
Fineness (%)	1.3	Sulfur trioxide (%)	2.54
Magnesium oxide (%)	3.62	Chloride ion content (%)	0.021

**Table 2.** The various indicators of limestone rubble in Mianchi County (coarse aggregate).

Test item	Requirements	Experimental value
Crushing value (%)	≥26	19.3
Needle-like content (%)	10~30	10.5
	5~10	13.8
<0.075mm content (%)	<1	0.5

**Table 3.** The various indicators of limestone chip (0~5mm) in Mianchi County (fine aggregate).

Test item	Specification for materials	Requirements	Experimental value
0.075mm pass rate (%)	0~5mm	≥15	14.3
Plasticity index	<0.6mm	<9	3.6
Liquid limit (%)		<28	12.8
Sand equivalent (%)	0~5	>60	68

**Table 4.** The mixture proportion of test 1.

Material proportion	1#: 2#: 3#: 4#: Cement = 21: 33: 17: 29: 4								
Sieve pore	31.5	26.5	19	9.5	4.75	2.36	0.6	0.075	
Item									
Synthetic gradation	100	98.2	81.4	50.6	31.5	21.1	11.3	5.2	
Maximum dry density	2.41g/cm <sup>3</sup>		Optimum moisture content				4.8%		

**Table 5.** The test indicator of retarded cement from Cement Plant P.042.5.

Initial setting time(min)	353min	Final setting time(h-min)	435min
3d flexural strength(Mpa)	3.8	28d flexural strength (Mpa)	10.1
3d compressive strength(Mpa)	21.2	28 compressive strength (Mpa)	48.2
Fineness (%)	1.3	Sulfur trioxide (%)	2.54
Magnesium oxide (%)	3.32	Chloride ion content (%)	0.021

**Table 6.** The various indicators of limestone rubble in Yongchuan County (coarse aggregate).

Test item	Requirements	Experimental value
Crushing value (%)	≥26	20.1
Needle-like content (%)	10~30	10.1
	5~10	14.2
<0.075mm content (%)	<1	0.4

**Table 7.** The various indicators of limestone chip (0~5mm) in Yongchuan County (fine aggregate).

Test item	Specification for materials	Requirements	Experimental value
0.075mm pass rate (%)	0~5mm	≥15	12.3
Plasticity index	<0.6mm	<9	2.1
Liquid limit (%)		<28	10.2
Sand equivalent (%)	0~5	>60	73

**Table 8.** The mixture proportion of test 2.

Material proportion	1#: 2#: 3#: 4#: Cement = 20: 33: 17: 30: 4								
Sievepore	31.5	26.5	19	9.5	4.75	2.36	0.6	0.075	
Item									
Synthetic gradation	100	98.2	80.1	51.6	33.5	21.8	10.3	4.8	
Maximum dry density	2.41g/cm <sup>3</sup>		Optimum moisture content				4.8%		

### 3. Test Method

#### 3.1. The test procedure of cement stabilized mixture

1) To make results comparable, experiments are conducted with the same materials and equipment under the same condition. The mixture is tested based on vibrating compaction, and the optimum moisture content is 4.8%, the compactness is 98%.

2) After the specimens shaping, the delay time of revibration is 3,6,9,12 and 24h and 0 hour of which doesn't need revibration.

3) In order to approximately simulate the situation of field vibration, on the surface of the molded specimen, a 15mm thick rubber pad is laid for the damping cushion. Then the vibration is carried out, and the standard method is used to keep health after mold unloading.

#### 3.2. The test procedure of cement-stabilized mixture specimens that adopt different delay time of revibration

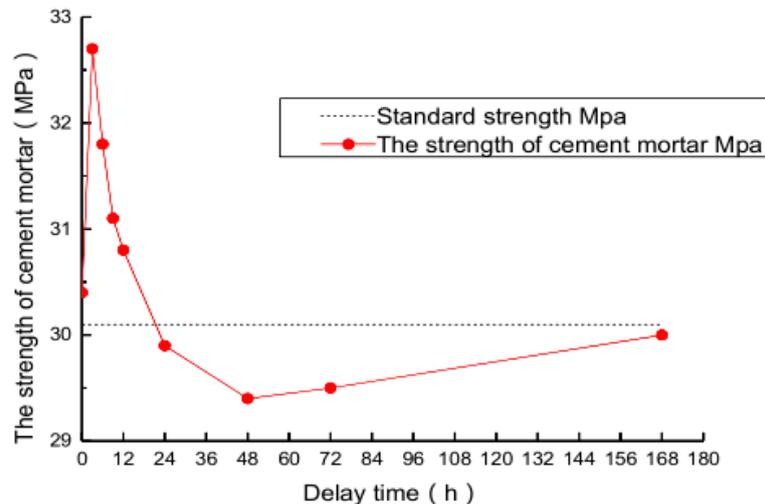
The vibration time varies from two layers of 25, 45s and 60s to shape the specimens (The degree of compaction is 96%, 98% and 100% in turn). Then delaying the different time and make the second

vibration. In order to approximately simulate the situation of field vibration, on the surface of the molded specimen, a 15mm thick rubber pad is laid for the damping cushion. Then the vibration is carried out, and the standard method is used to keep health after mold unloading.

#### 4. Results analysis and discussion

##### 4.1. The analysis of delay time that affects the strength of cement mortar

Analyzing the change rule of cement mortar in different delay time by conducting standard test about the strength of cement mortar. The concrete indicators refer to Figure 1.

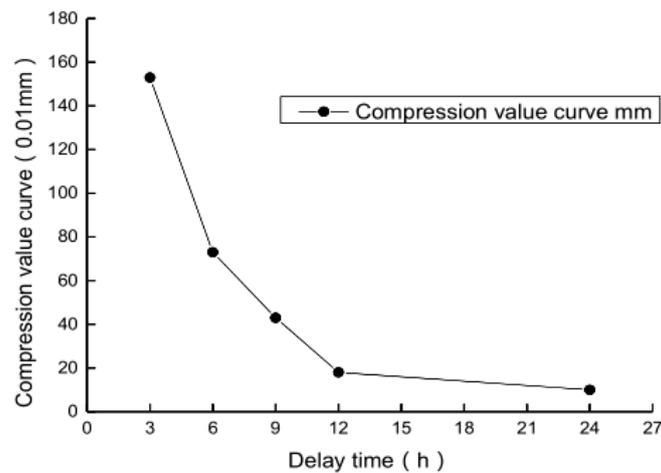


**Figure 1.** Change of cement mortar strength.

As is analyzed in Figure 1, revibration is of benefit to form the strength of cement mortar within 12 hours delay and the strength of cement mortar has an increasing trend within 0~3 hours delay, which indicates that revibration exactly has an effect on the internal structure of cement mortar. During this time, cement hydrates incompletely and hydration products prevent its' further hydrating. Revibration causes fracture of the cladding layer, void between the structures is filled, which promotes further hydrating. The strength of the cement mortar is in decline when revibration delays 3~12 h, but it is still above the standard strength. During this time, cement hydration has come to a stable structure; however it begins to fracture on account of revibration, which results in strength reduction. The strength of cement mortar gets damn close to the standard one when revibration delays 168 hours, and it makes aggregate become denser and stronger. Until then the cement hydration comes to an end, the strength of the specimen itself can resist the influence of external vibration force, thus revibration has little effect on cement hydration.

##### 4.2. The analysis of delay time that affects the cement stabilized mixture

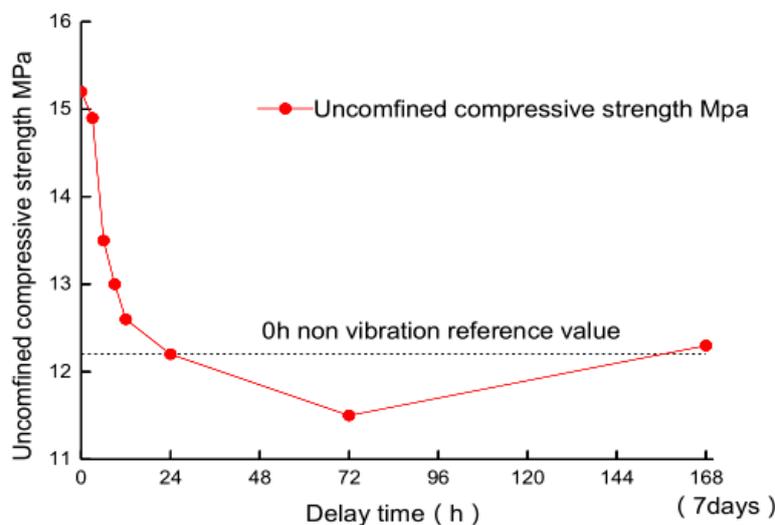
4.2.1. *Secondary Vibration Settlement Value.* With revibration, the specimens produce compression, value of which changes over delay time referring to Figure 2:



**Figure 2.** Change of compression value curve.

With the delay time increasing, the compression value of specimens is decreasing, and the compression curve becomes flat 12 hours later. And the interaction between aggregate become stronger when strength has formed over the whole mortar. And compact texture and resistance developing makes the compression value begin to decrease.

*4.2.2. Unconfined Compressive Strength.* The specimens are under standard maintenance condition. The relationship between unconfined compressive strength and delay time was shown in Figure 3.

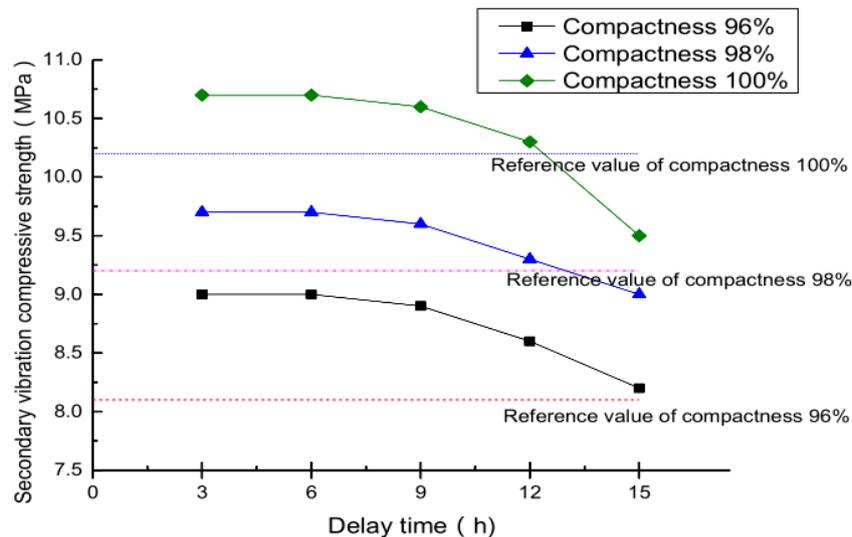


**Figure 3.** Variation diagram of unconfined compressive strength.

Based on the average intensity of non-secondary vibration delayed by 0h, the strength of the second vibration is higher than the reference strength after the second vibration in the period of 0-24h. The inflection point of the curve is about 12 hours, which is in good agreement with the inflection point of the sinkage curve. The unconfined compressive strength decreases with the delay time increasing, but is still higher than the reference strength in the range of 0-24 hours. In this stage the secondary vibration is favorable to the formation of cement stable strength. The cement hydration products overlap with each other during the second vibration, and the aggregate particles are re-wrapped. However, with the increase of the delay time, the hydration products form a stable embedded structure, which leads to a slow decrease in strength.

#### 4.3. The analysis of delay time that affects the strength of cement stabilized mixture

Vibratingly molded specimens with 2 layers  $\times$  25s, 2 layers  $\times$  45s, and 2 layers  $\times$  60s (compaction degree is 96%, 98%, 100%,) respectively delay different time, then second vibration compaction, after stripping standard maintenance, determine the delay time-strength relationship, shown in Figure 4.

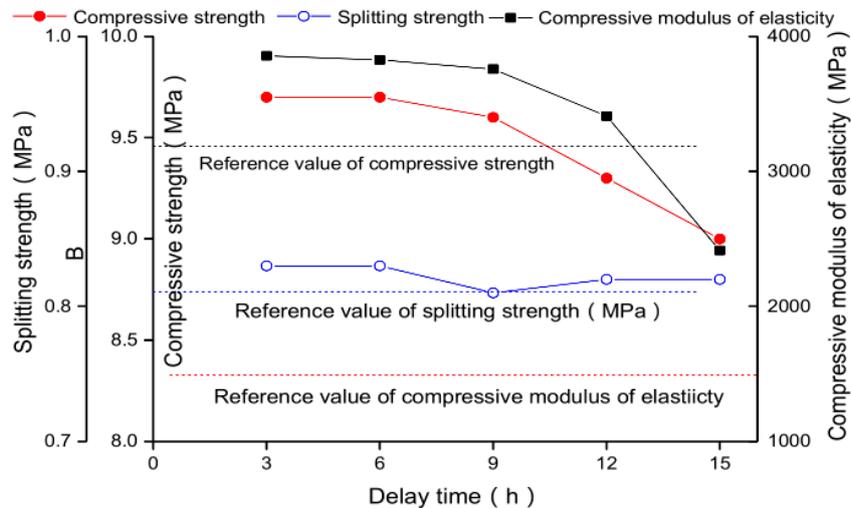


**Figure 4.** Change diagram of delay time and strength.

The higher the degree of compaction, the denser the mixture, the smaller the porosity of the mixture, and the larger the reference strength. Within 0h-12h, with the increase of delay time, the strength of the cement-stabilized mixture decreases, and the strength of the mixture decreases, the closer to the reference strength is to that of the mixture after the second vibration. After a delay of 9 hours, the compression strength of the three compacted specimens decreased with the increase of the second vibration. At this stage, the cement hydration has formed stable and dense crystals, and the strength of the specimens decreases because of the destruction of the crystal structure by the second vibration. After 15 hours delay, the compressive strength of 96% compacted specimens is still higher than the reference strength, which means that the aggregate inlaying is too loose in 96 compactness specimens. The lower the initial degree of compaction, the greater the strength increase after the second vibration in a certain boundary time.

Due to 96% compaction, the internal aggregating of the specimen is too loose. The secondary vibration compressive strength of 100% compactness is the same as that of 98% compactness. Considering the workability and economy of construction, the compaction degree is 98% in the following tests.

The change trend of compressive strength, compressive modulus of elasticity and splitting strength (98% compactness) of specimens with different delay time is shown in Figure 5.



**Figure 5.** Variation of compressive strength, compressive modulus of elasticity and splitting strength at different delay times.

The compressive strength, splitting strength and compressive modulus of elasticity are decreasing within 0-9 hours, the curve is steeper and the deceleration is faster, but both are higher than the reference values. The inner aggregate of 98% compacted specimen is compacted and the hydration products are wrapped around the aggregate, which prevents further reaction. Within 9h-12h, the existence of a certain limit point is known from the quadratic vibration curve, which makes the compressive strength, compressive modulus of elasticity and splitting strength still higher than the respective reference values.

## 5. Conclusion

(1) The settlement value of the second vibration tends to be flat within a certain limited time (12h delay vibration). Although the unconfined compressive strength decreases, it is still higher than the reference strength, and the secondary settlement can improve the strength.

(2) Under the same compaction degree (98%), there is a boundary point (delay vibration in 9h~12h), the specimen compressive strength, compressive elastic modulus, splitting strength are higher than the respective reference value.

## 6. Reference

- [1] Diao G Z. Research of Properties and Hydration Mechanisms of Portland cement and Calcium Aluminate Cement Compound System [D]. China Building Materials Academy in partial fulfillment of the requirement, 2005.
- [2] Zhang C. Study on Construction Characteristics of Lime and Fly Ash Material [D]. Chang'an University, 2003.
- [3] Kolek J. The external vibration of concrete. Civil Engineering.1999.
- [4] Krishna R M.V. Rathish Kumar P. and BalaBhaskar N.V.R.C. Effect of re-vibration on compressive strength of concrete. Asian journal of civil engineering (Building and Housing).2008, 9(3): 291-302.
- [5] Vollick C. A. *Revibration produces better concrete*. Concrete Construction Magazine, February, 1959.
- [6] Bustani S. A., Achuenu, E. *Strength properties of revibrated concrete*. Nigerian journal of construction technology and management, 1999, 2(1).
- [7] Too late to revibrate? - Problem Clinic [J]. 2004 (March).
- [8] Wang B. Vibratory Mixing Mechanism and Experimental Study on Improving the Concrete Performance [D]. Chang'an University, 2014.

- [9] M. M. Kassim Effects of revibration on early age retarded concrete Transactions on The Built Environment, 2012, 124: 1743-3509.
- [10] Yang Z X Z. Study on the test of Separated vibration mixing for cement stabilized crushed aggregate [D]. Chang'an University, 2017.
- [11] Zheng R J. Study of Revibration and Characteristic of Concrete Strength [D]. Huazhong University of Science & Technology, 2004.
- [12] Zheng R J, Xu Y F, Xu W S et al. Study of Strength of Revibrating Concrete [J]. J of HUST. (Urban Science Edition), 2004(01): 69-72.