

Study on Mix Ratio of Lightweight Aggregate Concrete for BRB Application

Yongxu Chen, Xiaosheng Song

North China University of Science and Technology, Tangshan 063000, China

ABSTRACT

As a new type of energy dissipation damping mechanism widely used in recent years, anti-buckling bracing still has some shortcomings such as self-importance. In this paper, the composition of anti-buckling support, its working principle and weight reduction ideas and methods are explained first, and then the test process and methods of light aggregate are described, and then the possible problems of light anti-buckling support are explained, and finally the possible problems are put forward for practical application.

KEYWORDS

Anti-buckling support; Working principle; Light weight; Weight reduction; Practical application

1. INTRODUCTION

In recent years, the new anti-buckling support of shock absorber mechanism has been widely used. It is composed of core material sliding mechanism, grouting concrete and restraint mechanism. Such structure solves the problems of excessive buckling and fracture of the support. However, the traditional anti-buckling support is self-heavy and cannot be applied to the large-span structure, and the lightweight anti-buckling support is designed to reduce its weight, so as to achieve the purpose of reducing the self-weight of the anti-buckling support.

2. COMPOSITION AND MECHANISM OF ANTI-BUCKLING SUPPORT

2.1. Transverse Composition of Anti-buckling support

The anti-buckling support consists of three parts: core material, peripheral sleeve and non-bonding material, as shown in Figure 1. Also known as core unit, constraint unit and sliding mechanism unit.

- (1) Core unit: It is the main force unit in the component, and all the axial force generated by the earthquake is borne by it. Due to the different stiffness and energy consumption requirements, the section form can be divided into a zigzag, cross shape, T shape, double T shape, rectangular and so on.
- (2) Restraint unit: used to constrain the core material laterally to prevent the core unit from buckling under axial pressure of the traditional support, so that the buckling support can smoothly enter the yield energy dissipation stage.
- (3) Sliding mechanism unit: In order to prevent the compression and expansion of the core material from producing friction with the external constraint, resulting in the axial pressure passing to the constraint mechanism.

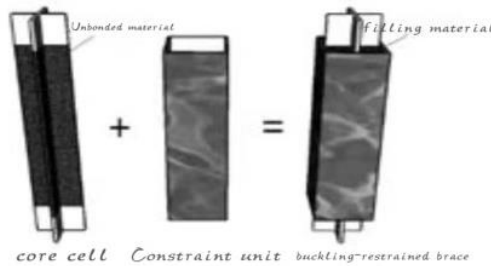


Figure 1. Composition of anti-buckling support

Image source: Research status of anti-buckling bracing

2.2. Longitudinal Composition of Anti-buckling support

It consists of five parts in total: constrained yield section, transition section, connection section, unbonded expandable material and buckling constraint mechanism, as shown in Figure 2.

(1) Connection segment: a mechanism outside the sleeve and connected to the core material for the installation of the buckling support, usually bolted and welded.

(2) Constrained yield section: It mainly plays an energy dissipation role, and the external constraint sleeve is used, and the steel used needs to ensure a certain yield strength and good ductility, which can realize the yield energy consumption under repeated load. (3) The transition section: also located in the sleeve, connect the working section and the connecting section to avoid connection damage, and increase the cross-section area of the transition section to ensure the elastic working stage, in order to prevent stress concentration, the cross-section should be gently increased.

(4) Non-bonded expandable materials: reduce the impact of friction between the core material and the restraint mechanism on the support performance. Commonly used non-bonded materials are rubber, polyethylene, silicone, latex and so on.

(5) buckling restraint mechanism: the mechanism is mainly filled with grouting material in the hollow casing, and the internal grouting material must have a certain strength, so as to effectively limit the displacement buckling of the core material.

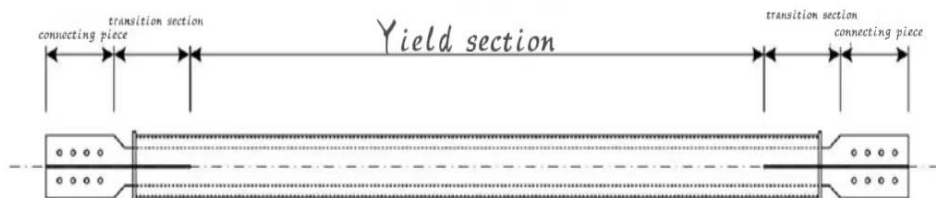


Figure 2. Longitudinal composition of anti-buckling bracing

Image source: Review of current status and research progress of anti-buckling bracing [10].

2.3. Anti-buckling Support Mechanism

The anti-buckling brace achieves the effect of energy dissipation and shock absorption through repeated tensile compression, which reduces the earthquake damage to the main structure, and then realizes the purpose of buckling and shock absorption.

3. RESEARCH ON LIGHTWEIGHT AGGREGATES

According to the corresponding anti-buckling support specifications, the compressive strength of the grouting material inside the buckling support should not be less than 35MPa. At the same time, to achieve the purpose of weight reduction, the density of light aggregate should be less than 1950kg/m³, in addition to facilitate construction, light concrete should also ensure a certain collapse and flow.

Lightweight concrete (LC) consists of cement mortar and lightweight aggregate, and high-quality

lightweight concrete requires high-quality cement slurry, mortar and high-quality lightweight aggregate.

At present, the common light aggregates are pumice, expanded perlite, ceramite and so on.

According to Rashad research shows that the use of a certain amount of pumice stone is beneficial for weight loss, but the use of pumice stone will reduce mechanical strength and workability, but also increase dry shrinkage and water absorption. Therefore, it is also necessary to study the negative effects of pumice on concrete, which makes the adaptation of pumice light concrete complicated.

In addition to pumice, expanded perlite can also be used as a lightweight aggregate, compared to pumice, expanded perlite also has a certain thermal insulation properties, so expanded perlite aggregate is more used for thermal insulation applications.

In addition, studies have shown that the weight of concrete decreases with the increase of expanded perlite (EPA). Expanded perlite in the content of more than 20% can play a role in thermal insulation lightweight, but will cause insufficient strength. The effect of weight reduction is not obvious when the content of expanded perlite is less than 20%.

Compared with the above two kinds of lightweight aggregates, ceramic particles have many superior properties. In addition to the light weight, the strength is also relatively high.

The following is a comparison of the three lightweight aggregates, the results of which are shown in Table 1.

Table 1. Performance comparison of three kinds of lightweight aggregates

nature	pumecrete	Expanded perlite	Ceramsite concrete
quality	lighter	lighter	lighter
Strength	General	General	Preferably
Remaining effects	exist	exist	without

Through comparison, it can be seen that although light aggregate pumice stone and expanded perlite can also play a role in weight reduction, they have different degrees of defects compared with ceramic particles, so ceramic particles are chosen as the aggregate of this light aggregate.

Market ceramics can be roughly divided into clay ceramics, coal ash ceramics and shale ceramics, and the cross section shape is shown in Figure 3.



Figure 3. Cross sectional shapes of clay, ash and shale ceramics

Image source: Research review on performance and application of lightweight ceramisite concrete [14].

Shale ceramite has fewer holes and dense interior, so it has higher strength, which is suitable for light concrete with higher strength. At the same time, due to the high density, the aggregate will not float. The workability is relatively high, and the collapse degree can reach more than 100mm through adaptation.

Compared with fly ash and shale ceramics, clay ceramics have lower density, and their strength is relatively small, which may not meet the strength requirements of buckling support grout. Moreover, due to the spherical ceramic particles, the porosity may be too large, and the slurry is not dense enough, thus affecting the strength. At the same time, due to the light weight, this greatly increases the possibility of floating aggregate, which will lead to uneven distribution of ceramic particles in the

grout, further affecting the strength.

Compared with other ceramides, pulverized coal ash ceramics have the advantages of relatively high strength, relatively low thermal conductivity, heat insulation performance and chemical stability, but the water absorption is very high, it is difficult to prepare high-strength concrete, the concrete density is high, and the requirements for construction needs are often not met, so the economic benefits are not obvious.

The properties of the three ceramides are compared, as shown in Table 2 below.

Table 2. Physical and mechanical properties of three kinds of ceramics

performance	Clay ceramisite	lytag	Shale ceramisite
density/ kg^{-3}	400	840	800
cylinder compressive strength	4.5	5.0	8.7
1h Water absorption (%)	5.8	19.3	3.6

Data Source: Review of properties and applications of lightweight ceramite concrete [14].

Through the above analysis, shale ceramics are selected as the light aggregate of the lightweight aggregate concrete.

4. EXPERIMENT OF ORDINARY CONCRETE AND LIGHT AGGREGATE CONCRETE

4.1. Experimental Materials

4.1.1. Ordinary concrete materials

Cement: P·O42.5 grade cement, density 3100kg/m³;

Admixture: All indexes of first-class fly ash of a manufacturer in Zhengzhou, Henan meet the standard value;

Fine aggregate: ordinary river sand, particle size 0 ~ 5mm, continuous gradation, fineness modulus 2.8;

Coarse aggregate: gravel, particle size 20 ~ 30mm;

Admixture: Naphthalene series high efficiency water reducing agent, water reducing rate of 12% ~ 20% (content of 0.5% ~ 1% of cement);

Water: tap water

4.1.2. Lightweight aggregate concrete materials

Cement: P·O42.5 grade cement, density 3100kg/m³;

Admixture: All indexes of first-class fly ash of a manufacturer in Zhengzhou, Henan meet the standard value;

EVA emulsion: 1318 emulsion, milky white, can increase the bonding strength of ceramisite and slurry;

Fine aggregate: shale ceramic sand, water absorption rate 10%, bulk density, 800kg/m³, particle size 0 ~ 5mm, continuous gradation, fineness modulus 3.0;

Coarse aggregate: high strength stone shale ceramic, water absorption rate of 4 ~ 6%, density of 800 kg/m³, particle size of 5 ~ 10mm, continuous gradation; Admixture: high efficiency naphthalene water reducing agent, water reducing rate of 12% ~ 20% (content of 0.5% ~ 1% of cement);

Water: tap water

4.2. Sand Screening Experiment

In order to successfully prepare light aggregate concrete, it is necessary to ensure that the fineness modulus of the sand meets the corresponding requirements. Because the particle size of the sand from

the manufacturer is uneven, it is necessary to conduct a screening experiment to prepare the sand that meets the requirements of the fineness modulus. The following is the screening experiment of ordinary sand and ceramic sand respectively.

Ordinary fine sand:

Table 3. Experimental data of ordinary fine sand screening

Dry pattern weight		Plain sand		
g		500		
Screen side length	The remaining amount is calculated	Oversize weight (g)	Divide the screening balance%	Cumulative screening%
mm	$m_r(g)$			
4.75	480.9	19.10	3.82	3.82
2.36	382.9	98.00	19.62	23.44
1.18	236.9	146.00	29.23	52.67
0.60	179.9	57.00	11.41	64.08
0.30	131.7	48.20	9.65	73.73
0.15	103.5	28.20	5.65	79.37
Sieve bottom		103.50	20.72	100
Total sieve		500		
Modulus of fineness		2.85		

Note: The data in the table are the average value of two sieves, and the difference of fineness modulus is less than 0.2

The fineness modulus of the sand should be calculated according to the following test: (accurate to 0.01)

$$\mu_f = \frac{(\beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6) - 5\beta_1}{100 - \beta_6}$$

Shizhong: μ_f —Modulus of fineness of sand

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ —They are nominal diameters 5.00mm, 2.50mm, 1.250mm, 0.630mm, 0.315mm, 0.160mm Cumulative sieve on the square hole screen;

Shale ceramic sand:

Table 4. Experimental data of shale ceramic sand screening

Dry pattern weight		Plain sand		
g		500		
Screen side length	The remaining amount is calculated	Oversize weight (g)	Divide the screening balance%	Cumulative screening%
mm	$m_r(g)$			
4.75	440	60	12.10	12.10
2.36	320	120	24.02	36.03
1.18	240	80	16.01	52.05
0.60	190	50	10.01	62.06
0.30	70	120	24.02	86.08
0.15	20	50	10.01	96.09
Sieve bottom		20	4.00	100
Total sieve		500		
Modulus of fineness		3.09		

The fineness modulus of the sand should be calculated according to the following test: (accurate to 0.01)

$$\mu_f = \frac{(\beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6) - 5\beta_1}{100 - \beta_6}$$

Shizhong: μ_f —Modulus of fineness of sand

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ —They are nominal diameters 5.00mm, 2.50mm, 1.250mm, 0.630mm, 0.315mm, 0.160mm Cumulative sieve on the square hole screen;

Through the above-mentioned screening experiments, the fineness modulus of ordinary sand and ceramic sand meet the corresponding requirements.

4.3. Mix Ratio Calculation

4.3.1. Mix ratio of ordinary concrete

According to the specification "Ordinary concrete mix design Code" JGJ 55-2011, (hereinafter referred to as "General Regulations"), the mix design of ordinary concrete is carried out. First, the mix design of strength LC35 was carried out, and then the concrete mix ratio was adjusted according to the General Regulation JGJ 55-2011, and three control groups were set up: C-1, C-2 and C-3. The concrete mix ratio is shown in Table 5.

Table 5. Mix of ordinary concrete

Serial number	concrete	water	sand	macadam	flyash	additive kg
C-1	326.740	189.120	730.590	1095.885	57.660	3.844
C-2	344.230	189.120	704.290	1101.590	60.740	4.040
C-3	385.506	189.120	702.935	1054.403	68.031	4.535

4.3.2. Mix ratio of light aggregate concrete

According to the specification "Technical Specification for Light Aggregate Concrete" (JGJ51-2002), (hereinafter referred to as "light gauge") the mix ratio of light aggregate concrete is designed. The mix design of LC35 intensity was first carried out, and then the mix ratio was adjusted according to the Light regulation (JGJ51-2002), and three control groups were set up: L-1, L-2 and L-3. The concrete mix ratio is shown in Table 6.

Table 6. Mix ratio of lightweight aggregate concrete

Serial number	concrete	water	Ceramic sand	ceramsite	flyash	additive kg
L-1	475.20	196.75	359.87	799.36	63.60	4.752
L-2	432.00	196.75	359.87	799.36	57.60	4.320
L-3	388.80	196.75	359.87	799.36	51.84	3.888

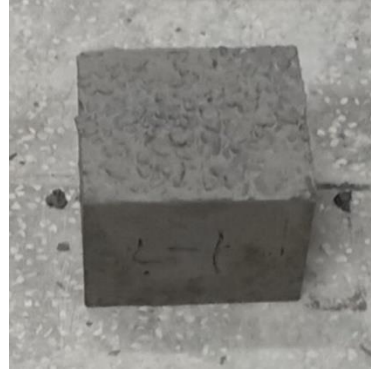
4.4. Preparation and Experimental Loading of Test Blocks

4.4.1. Preparation of test block

Ordinary concrete test blocks and light aggregate test blocks were prepared by using different thickness and fine aggregates, and the configuration test blocks were shown in Figure 4.



Ordinary concrete test block



Lightweight aggregate concrete test block

Figure 4. Ordinary concrete test block and light aggregate test block

Ordinary concrete test block: Three test blocks in each group, a total of nine test blocks. The axial compression test was carried out for each test block with the size of 100 mm×100 mm×100 mm, and the average value of 3 data was taken as the test result for each group. The molded test block was placed in the room for standard maintenance for 28 days. The specific test block numbers and parameters are shown in Table 7. Lightweight aggregate concrete test block:

Similarly, each group is to be mixed with three test blocks, a total of nine test blocks. The axial compression test was carried out for each test block with the size of 100 mm×100 mm×100 mm, and the average value of 3 data was taken as the test result for each group. The molded test block was placed in the room for standard maintenance for 28 days. The specific test block numbers and parameters are shown in Table 7.

Table 7. Test block number and parameters

Serial number	Water cement ratio (water-binder ratio)	slump	instar (d)	Theoretical design strength (MPa)
C-1	0.417	30mm	28	40.7
C-2	0.467	150mm	28	35.0
C-3	0.492	80mm	28	32.5
L-1	0.414	95mm	28	40.7
L-2	0.455	110mm	28	35.0
L-3	0.507	90mm	28	32.5

Note: The amount of water-reducing agent for group C-2 test block is 1.5.

4.4.2. Experimental loading

The test and loading system are designed according to the requirements of "Standard for Performance test method of ordinary concrete Mix" (GB/T 50080-2016) and the standard "Light aggregates and test methods Part 2: Test method for light Aggregates" (GB/T 17431.2-2010).

According to the above preparation standard, this experiment is divided into ordinary concrete test blocks and light aggregate test blocks, with a total of 6 groups of 18 test blocks. The average value of three test blocks in each group is taken as the mechanical property index of the final test block.

The test block loading experiment was carried out on the universal press of a university in Northern China. During the experiment, the test block should be stably and continuously loaded, and the axial compression of each test block should be ensured. During the loading process, the speed is maintained at 2mm/min, and the test can be stopped when the test block is broken and the failure load drops to 80% of the peak load. The loading process of universal press and test block is shown in Fig. 5 and Fig. 6.



Figure 5. Universal press



Figure 6. Test block pressurization

4.5. Comparison and Analysis of Experimental Results

After the completion of the experiment, various physical and mechanical properties of ordinary concrete test blocks and light aggregate concrete test blocks were summarized, as shown in Table 8 and Table 9.

Table 8. Experimental results of ordinary concrete

Serial number	water-binder ratio	Compressive strength (MPa)	slump(mm)	Actual density (kg/m ³)
C-1	0.492	33.3	35mm	2290
C-2	0.467	35.4	150mm	2330
C-3	0.417	41.5	85mm	2390

Note: The amount of water-reducing agent for group C-2 test block is 1.5.

Table 9. Experimental results of lightweight aggregate concrete

Serial number	water-binder ratio	Compressive strength (MPa)	slump (mm)	Actual density (kg/m ³)	weight-loss ratio %
L-1	0.507	32.2	100	1766	26.10
L-2	0.455	35.7	120	1711	28.50
L-3	0.414	40.1	85	1606	32.80

Through comparative analysis, we can conclude that:

- (1) Light aggregate concrete is about 1/3 lighter than ordinary concrete.
- (2) C-1 and L-1 have poor strength and low fluidity.
- (3) C-2 and L-2 have the best fluidity and ease, and are more suitable for construction grouting, with strong strength and moderate cement dosage.
- (4) The strength of C-3 and L-3 is high, but the fluidity is poor and the amount of cement is too much.

5. SHORTCOMINGS AND DEFICIENCIES

- (1) Anti-buckling support in a variety of environments, such as high temperature, humidity, seawater corrosion, anti-freeze, etc.
- (2) The strength of lightweight aggregate used for buckling support is generally not particularly high, and further research should be carried out in terms of high strength.
- (3) At the same time, the lightweight anti-buckling support should also be considered whether it is economic, whether it can be promoted, and whether it is universal.

REFERENCES

- [1] Wang Ting, Zhang Lei, Cui Pengyan. Structure and mechanism of anti-buckling support [J]. Housing and Real Estate, 2019(02): 165.
- [2] Lu Hongfei, Chen Baokui. Research status and Engineering Application of anti-buckling bracing [J]. Construction Technology, 2019 (48): 1292. (in Chinese)
- [3] WEI Xiaoyu, Shen Jingfeng, Xu Bin. Research Progress of anti-buckling bracing [J]. China Water Transport, 2018, 18(01): 126-128.
- [4] HE Yutong, DING Sunwei, XU Tiangang. Research progress and application development of anti-buckling bracing for seismic components [J]. Special Structures, 2022, 39(04): 17-34.
- [5] Lin Shuzhi, Yao Linli. Research progress of anti-buckling bracing at home and abroad [J]. Fujian Architecture, 2012, (12): 5-8.
- [6] Zhao Junxian, Wu Bin. Working mechanism and stability design method of anti-buckling bracing [J]. Earthquake Engineering and Engineering Vibration, 2009, 29(03): 131-139.
- [7] Research status and Key theoretical issues of anti-buckling bracing [J]. Journal of Disaster Prevention and Reduction Engineering, 2010, 30:93-100.
- [8] ZHANG Jian. A Brief discussion on the new research progress of anti-buckling bracing [J]. Sichuan Building Materials, 2017, 43(11): 89-90.
- [9] ZHANG Zhi, Dong Jiao. Review on research progress of anti-buckling bracing [J]. Guangdong Building Materials, 2017, (03): 71-74.
- [10] Hu Po, White Jade Star. Review on current status and research progress of anti-buckling bracing [J]. Sichuan Building Materials, 2022, 48(05):47-48.
- [11] GENG Zhong, Reliability Engineering [M]. International College of Kela University, Thailand, 2023, (06): 143-145
- [12] CAO Zheng, ZHU Yajing, WU Xiaojun, WANG Qin, TANG Jinmei, WU Xinfeng, SHI Danda. Research review on preparation of lightweight concrete [J]. Practical Technology of Concrete, 2022, 9(395):184-192.
- [13] YUAN Nan, Huo Weixing, LUO Jing, WANG Yufeng, Li Jipeng, ZHANG Chongyin, Duan Jingkuan, WANG Ying, SHI Danda, WU Xinfeng. Review on technical problems of lightweight concrete [J]. Concrete and Cement Products, 2019, 4(04):27-31.
- [14] WU Xiaoqin, Chen Keke, Xu Yaling. Review on performance and application of lightweight ceramite concrete [J]. Ecological Building Materials, 2012, (06):43-46.
- [15] Cao Xianzhi. Research and Application of ceramic lightweight concrete wall materials [D]. Southeast University: Southeast University, Jiangning District, Nanjing, Jiangsu Province, 2022-1-19.
- [16] Zhu Ling, WU Huiqin, Cen Vanli, Shi Fangyu, Chen Yuliang. Experimental study on elastic modulus of light aggregate concrete with pulverized coal ash pottery [J]. Journal of Guangxi University of Science and Technology, 2021, 32(2):26-32.