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Characteristics of Cement Stabilized Masonry Blocks Prepared from Brick Masonry and Concrete Waste - Experimental Study

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ABSTRACT

This experimental study deals with utilization of brick masonry and concrete waste in preparation of cement stabilized masonry block(CSMB). Brick masonry waste and concrete waste are crushed into granular form and designated as brick powder (BP) and fine recycled concrete aggregate (FRCA) respectively. BP and FRCA are used in 70:30 proportions and cement content is varied as 6%, 8%, and 10%. The static compaction method is used to fix the optimum water content as 16% for all the three mixes. The size of the CSMB units is 190×90×90 mm and it is tested for dry density, wet compressive strength, water absorption and rate of moisture absorption. Correction factors reported in the literature are used to arrive at uniaxial compressive strength. The compressive strength of CSMB units of size 190x90x90 are found to be in excess of 3.5MPa, except for 6% cement content, with correction factor = 0.58. A simple equation is proposed to compute the representative 28 days wet compressive strength of CSMB units without correction factors as f = 0.8 C, with C as % of cement in the mix. The water absorption of CSMB units are within permissible limit of 18%. The rate of moisture absorption of the units is found to follow an exponential trend. Nearly 50% of absorption is found to take place in the first 30 mins of soaking. To study the influence of size, CSMB units of size 290x190x90 mm with 8% cement are cast and wet compressive strength is determined on the cubes 70 mm and 90 mm cut from the CSMB units 290x190 x90 mm, as well as, on the units also. The 70 mm and 90 mm cube samples cut from CSMB units show a decrease of 32% and 35% in wet compressive strength when compared with 70.6 mm cube samples cast from the same mix. The 28 days wet compressive strength of CSMB units 290 x190 x90 mm with aspect ratio as 0.47 is about 70% more than the strength attained with units 190 x90x90 mm with aspect ratio as 1.0.

Keywords : Concrete and brick masonry waste, Cement Stabilized Masonry Blocks (CSMB), Fine recycled concrete aggregate (FRCA), Brick powder (BP)

I. INTRODUCTION

Recycling of construction and demolition waste (C&D) and using in civil engineering applications is a way forward to achieve sustainable construction, as it reduces consumption of natural resources and minimizes landfill. Concrete and brick masonry waste constitutes a major portion of C&D waste in India. It is widely accepted that recycled concrete aggregates can be utilized in concrete mixes as numerous experimental studies demonstrate its reliability. Recycling of brick masonry waste has not driven much attention of the researchers as very few studies are available in the literature. These studies are focused on the production of concrete mixes with brick masonry waste being used as a partial replacement for aggregates [1, 2, 3, 6] and cement [4, 5, 6]. It has been observed that the low unit weight and higher water absorption, limits the usage of brick waste in the concrete mixes [1, 3, 6, 7]. Poon and Chan [8], concluded the use of 25% crushed clay brick satisfies the compressive strength requirements for Grade B paving blocks as prescribed by ETWB of Hong Kong for the trafficked area. Sadek [9] has prepared a solid cement bricks of different grades using brick aggregates for load bearing and non-load bearing units

Hypothesis and objectives

The authors of the present study is of the opinion that both concrete and masonry waste can be utilized for the production of masonry units by using the techniques adopted for SSB. In view of the experimental evidence outlined in the literature [10-19] with respect to suitable grading and composition of the soil for making SSB, the authors of the present study consider BP recovered from the brick masonry waste has the potential for making blocks suitable for masonry. The masonry waste cannot be easily recovered as pure brick powder, due to the presence of adhered mortar on its surfaces. Hence, during the process of recycling masonry waste, it is natural to expect that the recovered material will consist of brick powder, as well as, a finer fraction of adhered cement mortar. The recycling of concrete waste also generates FRCA, which is largely unutilized. This experimental study is carried out to ascertain the suitable mix composition comprising of BP and FRCA for the production of CSMB units.

Materials and mix constitutents

Physical properties of materials

The 43 grade ordinary Portland cement conforming IS 8112:2013 [20] were used in this study. The properties were tested as per IS 4031 [21, 22, 23, 24, 25, 26]. The physical properties of BP and FRCA were tested as per the procedures specified in IS 2386-1963 [27]. The physical properties of cement, BP, FRCA are listed in Table I. The gradation curve of BP and FRCA are depicted in Fig.1

TABLE I. PHYSICAL PROPERTIES OF CEMENT, BP AND FRCA

Sl.no	Attributes	Cement	BP	FRCA
1	Specific Gravity	3.08	2.41	2.2
2	Specific Surface Area	-	-	-
3	Standard Consistency (%)	30	-	-
4	Initial Setting Time (min)	80	-	-
5	Final Setting Time (min)	210	-	-
6	Fineness Modulus	-	1.47	2.21
7	Fineness (%)	5.94	-	-

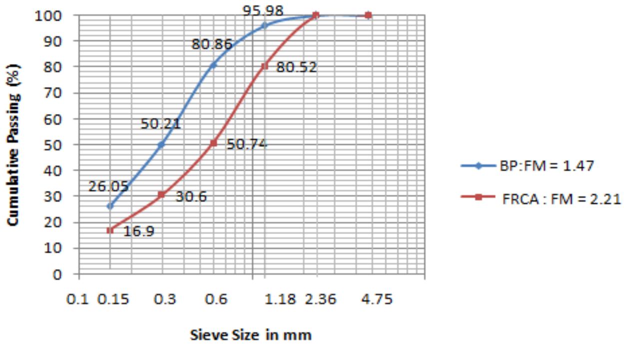

Fig. 1. Gradation curve of BP and FRCA

Chemical composition of BP and FRCA

The chemical constituents of BP and FRCA are listed in Table II.

TABLE II. CHEMICAL COMPOSITION OF BP AND FRCA

Sl.no	Oxides content (%)	BP	FRCA
1	Silicon dioxide (SiO_2)	88.53	68.15
2	Alumina oxide	0.12	0.16
3	Ferric oxide (Fe_2O_3)	5.68	3.08
4	Calcium oxide (CaO)	0.98	14.43
5	Magnesium Oxide	0.75	0.8
6	Loss on Ignition	3.11	13.3

Mix constituents

The basic mix was assumed to consist of BP and FRCA only. Several trial mixes were formulated with BP and FRCA in varying proportions out of which BP and FRCA at 70% and 30% by weight as constituents were preferred from mouldability consideration. Cement content in mixes was varied as 6%, 8% and 10% by weight of the basic mix. Three mixes considered in the study is designated as 6C | 8C| 10C.The mix constituents are listed in Table III.

TABLA III. MIX CONSTITUENTS (KG/M^3)

Mix designation	6C	8C	10C
BP	1190	1190	1190
FRCA	510	510	510
C	102	136	170

Experimental work

The experiments were carried out in three phases. In the first phase, cubes of size 70.6mm were casted for all the three mixes and wet compressive strength at 28 days were assessed. In the second phase, CSMB units of size 190 x 90 x 90mm were casted and it is tested for dry density, wet compressive strength, water absorption and rate of moisture absorption. In the third phase, a CSMB units of size 290 x 190 x90mm were casted to assess the size effects on the compressive strength. The cubes of size 70 and 90 mm were extracted from 290 x 190 x 90mm units and the compressive strength was determined.

Experimental studies on cube specimens

1) Optimum moisture content(OMC)

The water content in the mix influences the strength of CSMB specimens. Higher water content results in formation of capillary pores, consequently reduction in the strength. However sufficient water content is also necessary in order to achieve maximum compaction. Hence, the trail studies were carried out to fix moisture content for each mix.

2) Casting of cube specimens

Dry mix of BP, FRCA and Cement were prepared on the tray. The required amount of water is added and it is thoroughly mixed on the tray using trowel. Seven cubes of size 70.6 mm were prepared by varying moisture content from 13 to 19% by weight of the basic mix for all the designated mixes. The mix were filled into the moulds up to the top and with a collar in place excess material was filled and compacted up to a pressure of 3.0MPa using UTM machine of 1000 KN capacity. After compaction the excess material is removed and the surface is finished with trowel.

3) Determination of OMC

The cubes were demoulded after 24 hours and the weight of each cube is recorded to assess their bulk densities. Next, the cubes were kept in the oven for 24 hours at a temperature of 100±5oC. After 24 hours, the cubes were removed from the oven and it is kept in the ambient temperature and then dry weight is recorded. The dried cubes are then kept in the water for 24 hours to assess their water absorption as well as void ratio and porosity.

4) Determination of wet density and wet compressive strength

Six cubes were prepared for each mix combinations and these cubes were subjected to intermittent spray curing for 28 days. After curing, the cubes were tested for wet density and wet compressive strength as per IS 3495 (Part1): 1992 [29].

Experimental studies on CSMB Units

The block size of 190 x 90x90 mm were considered for casting CSMB units. This is the one of the sizes recommended in IS 1725: 2013 [28]. To assess the size effects, the CSMB units of size 290 x 190 x 90mm was cast.

5) Casting CSMB units

The procedure as outlined in section A.2 is followed to cast the CSMB units. Spray curing is employed for

28 days and the wet gunny bags is covered throughout the curing period.

6) Testing of CSMB units

Six CSMB units were tested for dry density, wet compressive strength, water absorption and rate of moisture absorption. The description of testing procedure along with the standards followed is discussed in the following section.

Dry density

The dry density of the CSMB units were tested as per the guidelines outlined in IS 1725:2013 [28]. The CSMB units were kept in the oven at a temperature of 100 ± 50C for 24 hours. Later the units were cooled to room temperature. The dimensions and the unit weight of the CSMB units were measured in order to calculate the dry density of the units.

Wet compressive strength

CSMB units were tested for wet compressive strength as per the procedures given in IS 3495 (Part-1):1992 [29]. The units were kept in the water for 48 hours, later it is removed from the water and the surface of the units is wiped with dry cloth in order to achieve saturated surface dry condition. The load on the CSMB specimens were applied at a rate of 2.9 kN/sec.

Water absorption test

The water absorption test was carried out as per IS 3495 (Part-2): 1992 [30]. The CSMB units were kept in the oven at a temperature of 100 ± 5°C and the corresponding dry weight were recorded. After that the units were immersed in water for 24 hours and then the weight was recorded. The amount of increase in weight of the units is expressed in percentage.

Rate of moisture absorption

After keeping the specimens in an oven at 100 ± 5°C, the dry weight was recorded. Then the units were soaked in the water and the corresponding weight were taken at an interval of 15, 30, 60, 120, 1440 and 2880 min. The rate of moisture absorption is calculated and expressed as percentage increase in weight with respect to their dry weight.

7) Correction for friction effects

This confinement of specimens by platen restraint increases the apparent strength of the material. Hence the compressive strength that are obtained during the test are largely influenced by the dimensions of the units. In the literature several correction factors are proposed to arrive at representative uniaxial compressive strength. In this study the correction factors proposed by Krefeld [31] for fired clay bricks and Heathcote and Jankulovski [32] for SSB are used. These correction factors are based on aspect ratio and it is listed in Table IV

TABLE IV CORRECTION FACTORS (CF) FOR END CONFINEMENT [33]

Correction factor	Aspect ratio				
	0.4	*0.7*	*1*	*3*	*≥ 5.0*
Krefeld's (Fired clay bricks)	0.5	0.6	0.7	0.85	1
Heathcote & Jankulovski (SSB)	0.25	0.4	0.58	0.9	1

8) Testing CSMB units to assess size effect

CSMB units of size 290x190x90 mm was prepared with BP and FRCA at 70% and 30% constituent levels with 8% of cement. Except for the size, all other parameters are kept exactly similar to 190x90x90 mm units. To study the influence of size, compressive strength was determined on the cubes 70 mm and 90 mm cut from the CSMB units 290x190 x90 mm, as well as, on the units also.

Results and discussions

Cube test results

9) OMC of the mixes

Test results of cube specimens with moisture content varying from 13 % to 19% for each of the three mix variants are given in Table V. It is observed that, 16 % water content yields minimum porosity and maximum bulk density for all the three percentages of cement contents used in this study

TABLE V.OPTIMUM MOISTURE CONTENT OF THE MIXES

Cement (%)	BP (%)	FRCA (%)	Water Content (%)	Compacted Density (kg/m³)	Water Absorption (%)	Void Ratio	Porosity
6	70	30	13	1791	22.15	0.63	0.387
			14	1876	15.15	0.372	0.271
			15	1876	17.73	0.45	0.31
			16	**1961**	**14.12**	**0.337**	**0.252**
			17	1904	15.58	0.377	0.274
			18	1933	14.35	0.342	0.255
8	70	30	13	1848	18.21	0.443	0.307
			14	1990	16.12	0.386	0.279
			15	2047	16.04	0.386	0.279
			16	**2103**	**14.65**	**0.354**	**0.262**
			17	2075	15	0.359	0.264
			18	2047	15.35	0.37	0.27
			19	2075	15.09	0.365	0.267
10	70	30	13	1819	20.14	0.473	0.321
			14	1933	16.26	0.397	0.284
			15	1990	16.23	0.392	0.281
			16	**2103**	**13.56**	**0.334**	**0.25**
			17	2018	15.85	0.381	0.276
			18	2103	13.6	0.334	0.25
			19	2047	15.15	0.359	0.264

10) Wet density and 28 days compressive strength of cube specimens

The test results pertaining to wet density and 28 days wet compressive strength are given in Table VI.

11) Statistical analysis of cube test results

The statistical analysis of test results is listed in Table VII. The statistical parameters are normalized with respect to mix 6C.

TABLE VI. WET DENSITY AND 28 DAYS WET COMPRESSIVE STRENGTH

Mix	6C	8C	10C
Wet density (kg/m³)	1989	1989	1989
	2003	1961	1989
	2003	1989	1989
	1932	1932	1989
	1961	1989	1961
	1947	1989	1989
Wet comp. strength (MPa)	3.43	6.68	7.26
	3.43	6.1	6.78
	3.23	5.9	7.14
	3.49	5.72	6.8
	3.57	6.38	7.2
	4.03	6.4	6.12

TABLE VII. STATISTICAL ANALYSIS OF CUBE TEST RESULTS

Mix	Wet density (kg/m³)				Wet compressive strength (MPa)			
	μ	*σ*	*Min*	*Max*	*μ*	*σ*	*Min*	*Max*
6C	1973	30.18	1932	2003	3.53	0.27	3.23	4.03

8C	1975	23.79	1932	1989	6.2	0.36	5.72	6.68
10C	1984	11.43	1961	1989	6.88	0.43	6.12	7.26

12) Inference

The compressive strength is found to increase by 1.75 times, as the cement content is increased from 6% to 8%. However, with increase of cement content from 8% to 10% only a negligible increase in the strength is observed

Test results of CSMB units

13) Density and wet compressive strength

The density and wet compressive strength of CSMB units are listed in Table VIII.

TABLE VIII. DENSITY AND WET COMPRESSIVE STRENGTH OF CSMB UNITS AT 28 DAYS

Mix	**6C**		**8C**		**10C**	
	Dry	***Wet***	***Dry***	***Wet***	***Dry***	***Wet***
Density kg/m³	175	201	183	205	185	206
	1816	2040	1875	2057	1777	2034
	1761	2018	1826	2050	1839	2034
	1819	2057	1842	2037	1875	2076
	1836	2076	1849	2076	1868	2014
	1806	2060	1842	2053	1836	2040
Wet compressive strength (MPa)	4.58		5.46		9.31	
	5.36		7.61		7.05	
	4.5		5.94		9.96	
	4.7		6.16		6.3	
	4.9		6.39		6.51	
	5.23		6.36		9.54	

14) Statistical analysis of test results

The statistical analysis of the test results reported in Table 8 is listed in Table IX. It is noted that the representative value of average compressive strength in wet conditions, is more than 1.4, 1.8 and 2.3 times of the minimum requirement for the mix comprising 6 %, 8% and 10% of the cement content. The ratio of average wet and dry density is found to be in the range of 1.11 to 1.14.

TABLE IX. DESCRIPTIVE STATISTICS OF DENSITY AND WET COMPRESSIVE STRENGTH OF CSMB UNITS

Parameters	6C			8C			10C		
	Density (kg/m³)		f_{wet} (MPa)	Density (kg/m³)		f_{wet} (MPa)	Density (kg/m³)		f_{wet} (MPa)
	Dry	Wet		Dry	Wet		Dry	Wet	
μ	1799	2044	4.88	1844	2055	6.32	1841	2044	8.11
Min	1755	2014	4.5	1826	2037	5.46	1777	2014	6.3
Max	1836	2076	5.36	1875	2076	7.61	1875	2076	9.96

15) Correction due to end effects

The geometric correction factor based on aspect ratio is equal to unity can be assumed as 0.7 and 0.58 as per, Krefeld [33] and Heathkote [34] respectively. The corrected compressive strength of CSMB units are listed in Table X. With the correction factor of 0.7 or 0.58, the mix with 8 and 10% cement content meet the minimum strength requirement of 3.5MPa. CSMB units with cement content as 6%, fails to satisfy the minimum strength requirement of 3.5 MPa.

TABLE X.CORRECTION DUE TO END EFFECTS

Size of CSMB	**Aspect ratio**	**Compressive strength**	**Mix composition**		
			6C	8C	10C
190x90x90	1	Test Result	4.9	6.32	8.1
		Corrected value with CF = 0.7	3.4	4.42	5.7
		Corrected value with CF = 0.58	2.8	3.67	4.7

16) Water absorption

The water absorption test results of six units of each of the three mix compositions are listed in Table XI, along with their statistics. It is observed that this important property is also in compliance with the maximum absorption limit of 18% as per IS 1725:2013[28].

TABLE XI. WATER ABSORPTION (%) AFTER 24 H.

Sl.no	6C	8C	10C
1	15.7	12.2	10.5
2	13.5	9.7	10.4
3	15	12.3	10.5
4	14	10.6	10.8
5	14.2	12.3	10.5
6	14.5	11.5	11.7
Statistical measures			
μ	14.8	11.3	10.7
σ	0.78	1.08	0.5

17) Rate of moisture absorption

The test results of rate of moisture absorption of six CSMB specimens of all the three mix compositions are given in Table XII. The plot of the variation of the rate of absorption with time is found to follow an exponential trend as shown in Fig.2. Nearly 50% of absorption takes place in the first 30 min of soaking for 8% and 10% of cement content. At 120 minutes of immersion time, the absorption is found to be at 91.3%, 89% and 78% of absorption at 2880min, for the mix 6C, 8C, and 10C respectively.

TABLE XII. RATE OF MOISTURE ABSORPTION

Cement (%)	Moisture absorption in %					
	15min	*30 min*	*60 min*	*120min*	*1440 min*	*2880 min*
6	11	12.9	14.4	14.9	15.7	15.9
	10	11	12	12.9	13.5	14.5
	10.9	12.	14	14.3	15	15.5
	10.6	11	12.	13	14	14.4
	11	12.	13	13.5	14.2	14.5
	10.7	12	13.	13.7	14.5	15
8	6.2	8.2	9.9	11.4	12.2	12.4
	5.6	6.9	8	8.8	9.7	9.9
	5.7	7.3	8.9	10.7	12.3	12.5
	4.6	6.4	7.8	9.4	10.6	10.9
	6.2	8.1	9.7	11.3	12.3	12.3
	6.2	7.4	9	10.4	11.5	11.6
10	4.5	5.3	6.7	8.6	10.5	11.6
	4.9	5.8	7	9	10.4	11.3
	4.7	5.5	6.8	8.8	10.5	11.4
	4.6	5.7	7.3	9	10.8	11
	4.7	5.6	7	8.9	10.5	11.3
	5.1	6.6	8.1	9.9	11.7	11.9

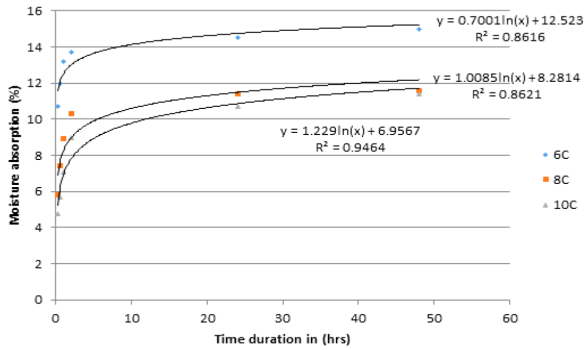

Fig. 2. Plot of average absorption versus time

18) Size effect on wet compressive strength of CSMB units

Test results are listed in Table XIII, along with the pertinent results listed in Table VI with respect to 70.6 mm cubes and Table VIII with respect to CSMB units 190 x 90 x 90 mm cast from similar mix composition.

TABLE XIII. WET COMPRESSIVE STRENGTH OF CAST AND CUT CUBE SPECIMENS AND 190X90X90 MM AND 290 X 190 X 90 MM CSMB UNITS

Sl.no	70.6 mm cube specimens cast (Table VI)	70 mm cube specimens cut from 290 x190 x90 mm	90 mm cube specimens cut from 290 x190 x 90 mm	190 x90 x 90 mm block cast (Table	290 x190 x90 mm block cast

				VIII)	
1	6.68	4	4.29	5.46	12.0
2	6.1	4.8	3.68	7.61	11.1
3	5.9	3.72	4.07	5.94	10.5
4	5.72	4.9	3.45	6.16	9.14
5	6.38	3.83	4.05	6.39	10.0
6	6.4	4.18	4.48	6.36	11.8
Average	6.2	4.2	4	6.3	10.8
Mini	5.7	3.7	3.5	5.5	9.1
Max	6.7	4.9	4.5	7.6	12.1

Following observations are made:

1. The 70 mm and 90 mm cube samples cut from CSMB units show a decrease of 32% and 35% in wet compressive strength when compared with 70.6 mm cube samples cast from the same mix. The reduction is thought to be due to the possibility of lack of uniformity with respect to mix composition as well as the compaction owing to the large size of the units.
2. The 90 mm cube samples cut from CSMB units show a 5% reduction in wet compressive strength when compared with 70 mm cube samples cut from the same units, in spite of the aspect ratio being unity in both the cases. This reduction of strength in 90 mm cube specimens may be attributed to the decrease in the zone of confinement with the increase in specimen size and tending towards unconfined uniaxial compressive strength.
3. It is interesting to note that the average strength attained by 190x90x90 mm units is almost the same as the strength attained by 70.6 mm cubes cast from the same mix composition. In both the cases, the aspect ratio is unity. Typically, the strength attained by 190 x90x90 mm units should have been slightly lesser than the strength attained by the 70.6 mm cube specimens due to the increase in specimen size. This may be due to the presence of frictional forces over large contact area (190mmx90mm) available with the CSMB units.
4. The 28 days wet compressive strength of CSMB units 290 x190 x90 mm with aspect ratio as 0.47 is about 70% more than the strength attained with units 190 x90x90 mm with aspect ratio as 1.0. This observation is in conformity with the observation that the apparent uniaxial strength increases with a decrease in aspect ratio. However, the cube specimens cut from the units show a reduction in strength of about 37% when compared with the strength attained by 190 x90x90 mm units.
5. The correction factor for CSMB units 290 x190 x90 mm works out to (1/1.71 = 0.58) to get the strength of CSMB units 190x90x90 mm. The results signify the influence of units size on compressive strength.
6. Assuming the cube specimens cut from the blocks to represent the intrinsic strength, the correction factor for 190x90x90 mm units works out to 0.63 and for 290x190x90 mm units as 0.37, which are in between the values proposed by Krefeld [33] for fired clay bricks and K. Heathcote and E Jankulovski [34] for SSB as listed in Table 4.
7. The aforementioned observations are based on the limited test data generated during the course of this study. To validate these observations, a large number of self-similar specimens have to be tested.

Conclusions

i. CSMB - 190 x 90 x 90 mm units with 8 and 10% of cement content have the potential to attain strengths in excess of the minimum strength = 3.5MPa.

ii. The procedure envisaged in this study to make CSMB units has ensured that the minimum required a dry density of 1750 kg/m^3 can be achieved.

iii. The percentages of water absorption of CSMB units are found to be higher, but are, still within the permissible limit of 18%. The higher water absorption is thought to be due to the porous nature of FRCA.

iv. The plot of the variation of the rate of moisture absorption with time is found to follow an exponential trend. Nearly 50% of absorption is found to take place in the first 30 min of soaking for 8 % and 10% of cement content.

v. The 70 mm and 90 mm cube samples cut from CSMB units show a decrease of 32% and 35% in wet compressive strength when compared with 70.6 mm cube samples cast from the same mix.

vi. The 28 days wet compressive strength of CSMB units 290 x190 x90 mm with aspect ratio as 0.47 is about 70% more than the strength attained with units 190 x90x90 mm with aspect ratio as 1.0. This observation is in conformity with the observation that the apparent uniaxial strength increases with a decrease in aspect ratio.

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