Under-ream Piles under Lateral Loads

by

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and

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Introduction

Foundations of structures like bridge abutments, piers, dolphines, anchorages, waterfront structures, transmission line towers etc. are subjected to high magnitudes of lateral forces in addition to compressive and uplift forces. The conventional practices is to make the foundations massivie enough to withstand the uplift forces and lateral loads. The ability of piles to resist lateral loads depend on the stiffness of the pile and the development of lateral soil resistance along the pile length. The soil conditions, the pile size and type of pile, the embedment of the pile head into the pile cap, length of the pile, the type of loading and the number of piles, are the important factors in the evaluation of the lateral pile load capacity. The allowable lateral load is governed by the acceptable lateral movement of the pile cap.

The underream piles (Figure 1) provide a solution to the problem as these have considerable uplift resistance and can resist the lateral loads more effectively. Underream piles are bored concrete piles having one or

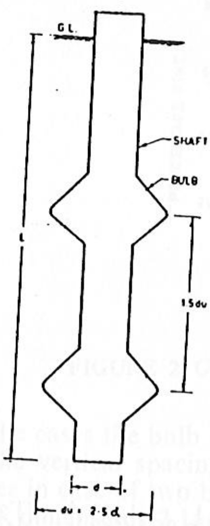

FIGURE 1 Under-ream pile

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more bulbs formed by enlarging the base of bore-holes by an underreaming tool (IS 2911 part III-1973). Single pile or group of piles can be used in a particular situation depending upon the magnitude of loads coming on the foundation under each leg of tower. Design of these pile foudations can be done in accordance with the Safe Load Table given in Indian Standard Code on the subject. The lateral load capacity of piles given in this Table is a rough guide as these are based on lateral load tests on single or double underream piles. Further, though limited, field tests on piles under lateral loads have indicated the Tabular values to be on conservative side. Therefore, the study was undertaken to examine the effect of various aspects of these underream piles e.g. the size of shaft diameter of pile, the number of bulbs, depth of pile, locating the bulb at top etc. Prototype and model piles were tested under lateral loads in cohesionless soils.

Model tests

Model tests were conducted on timber piles embeded in sand. The sand was procured from a local river bed. The grain-size analysis curve is shown in Figure 2. It is poorly graded fine sand (SP) as per Indian Standard: 1498-1970 classification. The details of the piles tested are listed in Table 1.

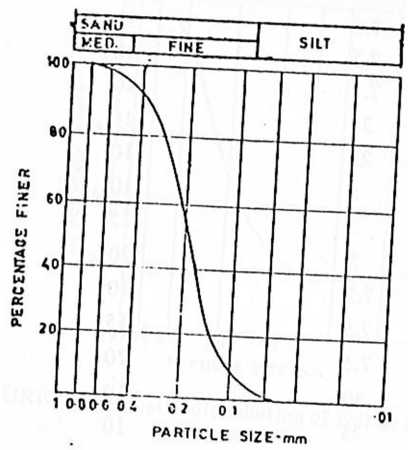

FIGURE 2 Grain size distribution of soil in model tests

In all the cases the bulb diameter was kept 2.5 times the shaft diameter of pile. The vertical spacing between two bulbs was 1.5 times the bulb diameter in case of two bulb piles. The tests were carried out in a steel tank of dimensions 2.1m x 1.3m x 1.6m. The tank was filled with sand in layers of 10cm and each layer was compacted by vibrating it with needle vibrator, (Figure 3). The uniformity of density obtained in vibrated sand mass was checked by placing small containers at different depth and at different places in one horizontal plane. It was observed that the density was almost the same throughout the soil mass. The piles were held in position at the required level and the sand was filled in tank before and after placing the pile in position.

TABLE 1

Details of Test Piles

Type of pile	Diameter (d) (cm)	Length/Diameter	Z_{max}
Straight	5	10	1·92
-do-	5	15	2.88
-do-	5	20	3.84
-do-	7.5	10	2.08
-do-	7.5	15	3.12
-do-	7.5	20	4.16
-do-	30	8	2 01
-do-	30	10	2.51
-do-	37.5	8	2.10
Single under-ream	5	10	1.92
-do-	5	15	2.88
-do-	5	20	3.84
-do-	7.5	10	2.08
-do-	7.5	15	3.12
-do-	7.5	20	4.16
-do-	30	10	2.51
-do-	25	10	2.42
Double under-ream	5	10	1.92
-do-	5	15	2.88
-do-	5	20	3.84
-do-	7.5	10	2.08
-do-	7.5	15	3.12
-do-	7.5	20	4.16
-do-	30	10	2.51
-do-	25	10	2.42

$E_{R.C.C.} = 1.5\times10^{5}$ kg/cm^2
$E_{timber} = 9.6\times10^{4}$ kg/cm^2
$n_h = 0.245$ kg/cm^3 for loose sand deposit, (After Mc-Corekle)

Field tests

Field tests were carried out near St. Gabreil's Academy, a part of Roorkee Cantonment. The site was chosen because of the availability of ground water table beyond 10 meters from ground level to simulate the model test conditions. The soil at the test site is a thick deposit of silty sand and is classified as SM according to I.S. 1498-1970 and the grain size distribution curve is shown in Figure 4. The standard penetration

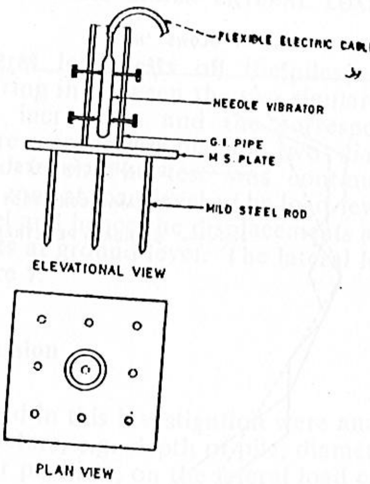

FIGURE 3 Apparatus for vibrating sand (not to the scale)

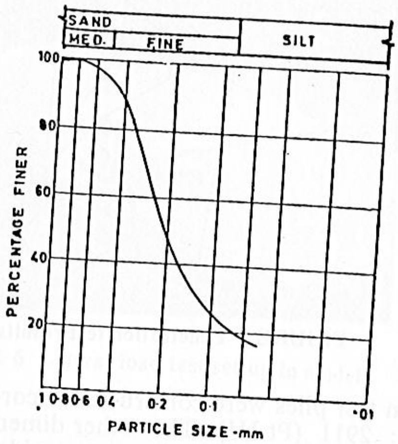

FIGURE 4 Grain size distribution of soil at test site

ests and dynamic cone penetration tests were performed at the site. These ests revealed that the penetration resistance of soil increases linearly with lepth beyond 1 m in depth as shown in Figure 5.

The average properties of the in-situ soil up to a depth of 3m are as sted below:

Natural moisture content	—	8% to 9%
Dry density	—	1.5 gm/cc
Angle of internal friction (ϕ)	—	15° to 19°
Cohesion (c)	—	0.35 to 0.45 kg/cm²

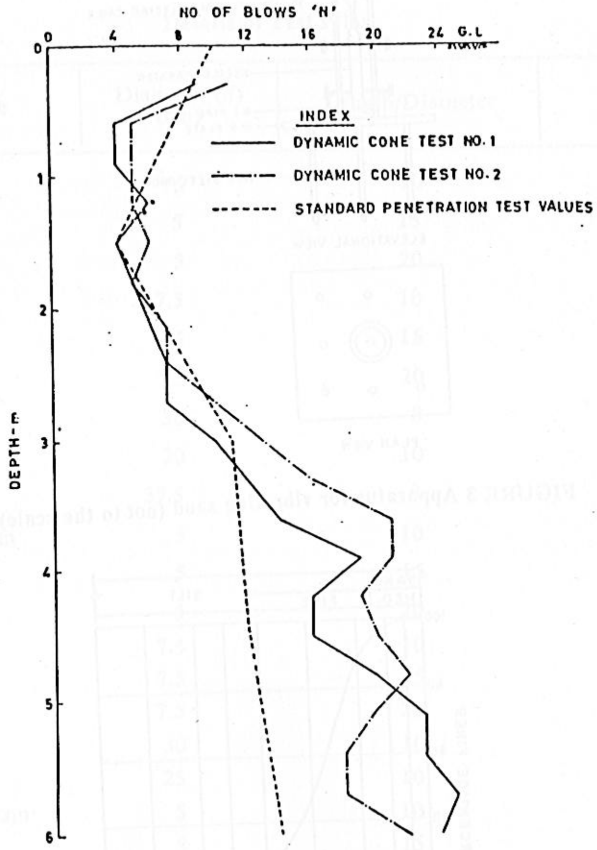

FIGURE 5 Penetration test results

The underream test piles were constructed according to the procedure laid down in IS: 2911 (Pt.III). The other dimensional details of these piles are included in Table 1. Each pile was provided with a pile cap at its top of the size 45 cm x 45 cm and 35 cm deep.

The pile cap was provided to give a smooth and uniform surface for loading assembly and for fixing of dial gauges for deflection readings.

Test procedure

Lateral loads on the model piles were applied through a wire rope passing over a frictionless pulley, one end of which was attached to the hook, fixed at pile top and the other end was tied to the loading pan as shown in Figure 6. The load was applied in suitable increments so as to get sufficient number of points to draw the load-settlement curve of an individual pile. The magnitude of each increment was kept approximately one fifth of the expected ultimate load of each pile. The next increment was applied when the rate of horizontal displacement fell down to 0.02 mm per hour.

In the field the lateral load tests on the piles were carried out by placing jack and proving ring in between the two similar piles. Here also the load was applied in increments and the corresponding horizontal displacements of piles were recorded by placing two dial gauges in one horizontal line at the load level. The test was continued till the total displacement exceeded 12 mm at load level. The load level was very close to the natural ground level and hence the displacements at load level may be taken as displacements at ground level. The lateral load test set-up in the field is shown in Figure 7.

Test results and their discussion

The tests results obtained in this investigation were analysed to study the effect of various parameters, e.g. depth of pile, diameter of pile shaft, number of bulbs and their position, on the lateral load carrying capacity of the pile. The following are the observations:

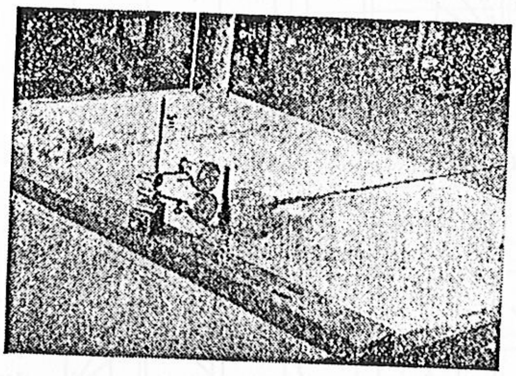

FIGURE 6 Lateral load test set-up in model

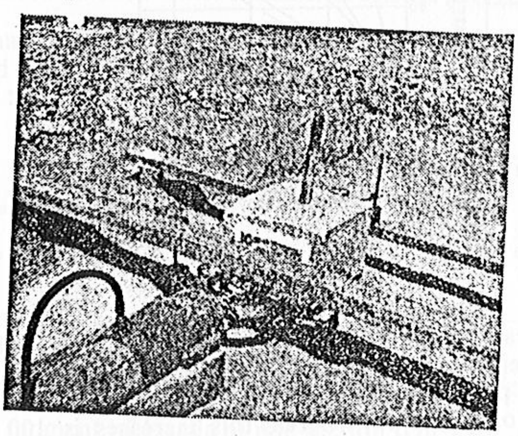

FIGURE 7 Lateral load test set-up in field

Effect of Depth of Pile

Horizontal load versus deflection at ground level for the pile of 5 and 7.5 cm shaft diameter with length to diameter ratios of 10, 15 and 20 are given in Figure 8 to 10. These curves were obtained in model tests on straight piles and piles having one and two bulbs. Figure 11 shows similar curves obtained from field lateral load tests on two 30 cm shaft diameter straight bored reinforced cement concrete piles having lengths of 240 and 300 cm.

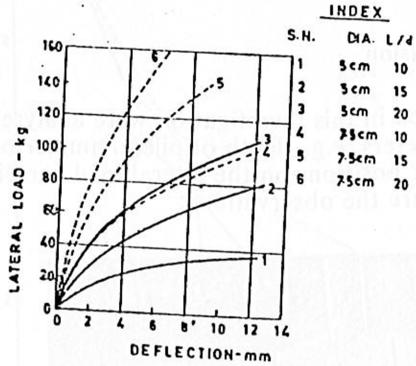

FIGURE 8 Effect of depth in straight shaft piles under lateral loads

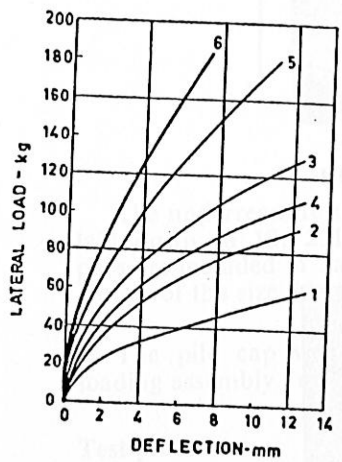

FIGURE 9 Effect of depth in single underream pile

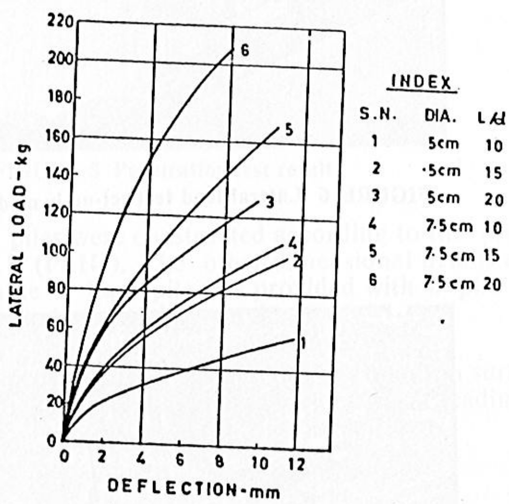

FIGURE 10 Effect of depth in double underream pile

All these figures indicate an increasing trend in the lateral load taken by piles with increase in their length to diameter ratios. Table 2 shows an increase of 55 to 95 per cent in the lateral load taken by piles as we compare between L/d ratio of 10 and 15, whereas this increases is 100 to 170 per cent in case of piles with L/d ratio of 20 w. r. t. piles of L/d equal to 10.

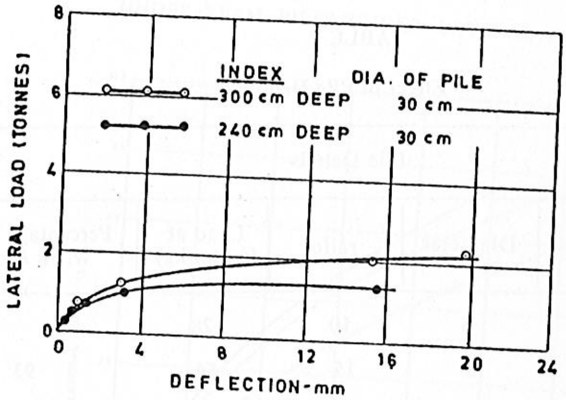

FIGURE 11 Effect of depth of pile under lateral loads

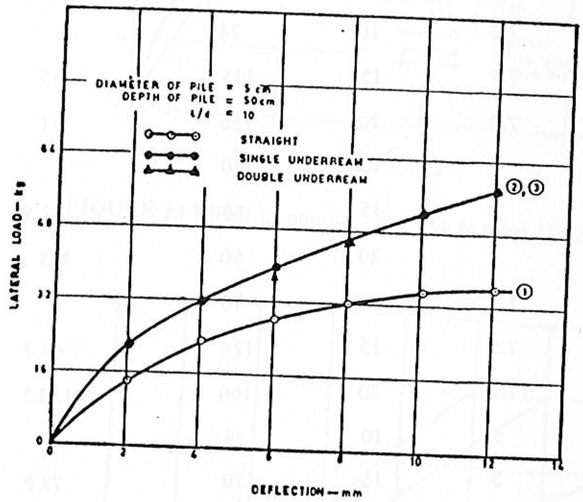

FIGURE 12 Effect of number of bulbs in piles ($L/D = 10$)

This may be on account of all the test piles behaving as short rigid piles. Short rigid piles are those which have $Z_{max} \leqslant 5$ (4,8,9) Z_{max} is defined as follows :

$$Z_{max} = \frac{L}{T}$$

where L = Length of pile (cm)

T = Relative stiffness factor (cm)

$$= \sqrt[5]{\frac{EI}{n_h}}$$

E = Modulus of Elasticity of Pile material (Kg/cm²)

I = moment of inertia of pile section (cm⁴)

n_h = constant of horizontal subgrade reaction (kg/cm³)

TABLE 2

Effect of Pile Depth

Type	Pile Details			
	Diameter	$\frac{L}{d}$ ratio	Load at (6 mm/kg)	Percentage increase w.r.t. $L/d = 10$
Straight pile	5	10	28	
	5	15	54	93
			93	
	5	20	76	170
	7.5	10	74	
	7.5	15	115	55
	7.5	20	156	111
Single bulb pile	5	10	40	
	5	15	65	62.5
	5	20	90	125
	7.5	10	76	
	7.5	15	126	65.7
	7.5	20	160	110.5
Two bulb pile	5	10	38	
	5	15	70	78.9
	5	20	100	163
	7.5	10	74	
	7.5	15	120	62
	7.5	20	182	146

Z_{max} values for all the test piles have been tabulated in Table 1. Field pile tests on straight shaft piles also show similar increasing trend.

Effect of number of bulbs in a pile

Both laboratory and Field tests indicate that there was sufficient gain in the lateral load taken by a single-underream pile as compared to straight pile (Figure 12 to 15). This improved behaviour may be due to the availability of a resisting couple on account of frictional forces above the bulb level. But there was no advantage by providing one more bulb i.e. a two bulb pile had practically exhibited the same load-displacement behaviour as that of a single bulb pile under lateral loads.

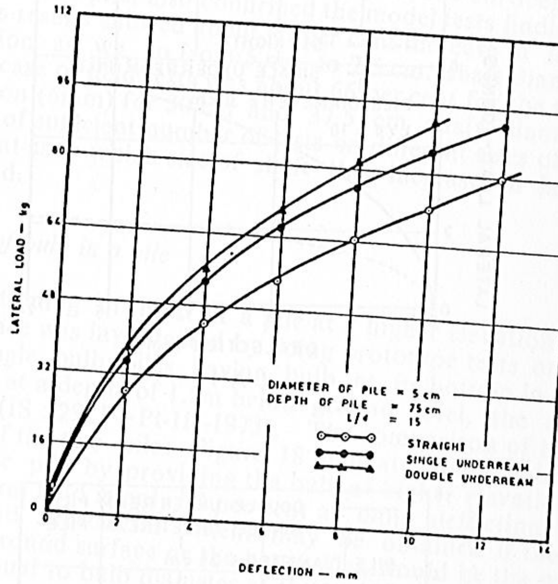

FIGURE 13 Effect of number of bulbs in piles ($L/D = 15$)

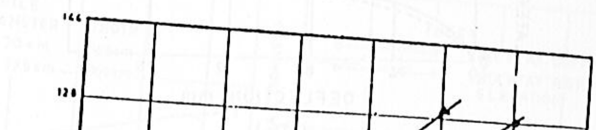

FIGURE 14 Effect number of bulbs in piles ($L/D = 20$)

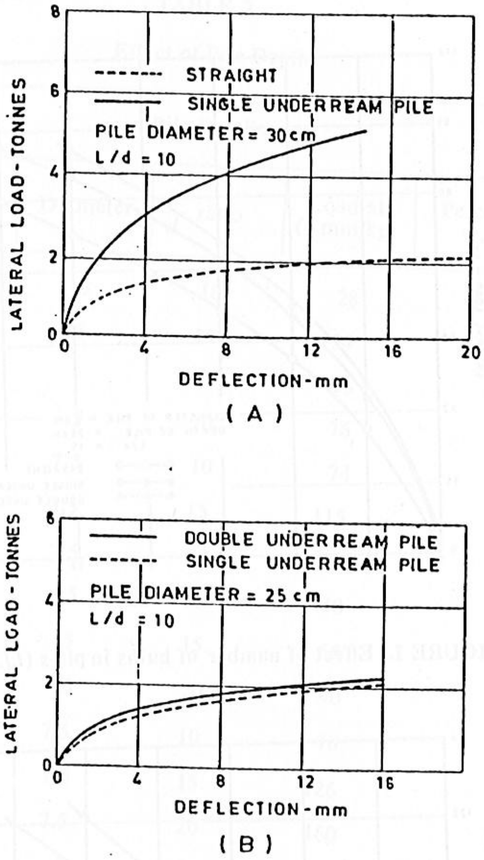

FIGURE 15 Effect of Number of bulbs in piles

Effect of size of shaft diameter of pile

Laboratory test results on model piles (Figure 16) clearly showed that the lateral load taken by a pile increased as its shaft diameter increased. This increase was more pronounced in case of straight piles where as the increase showed a reducing trend in case of underream piles.

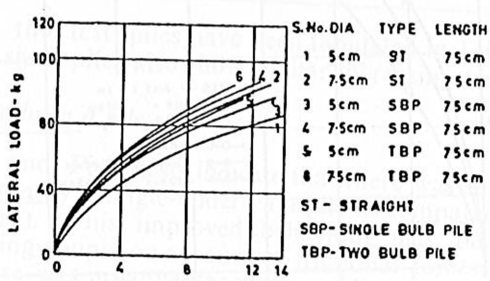

FIGURE 16 Effect of size of shaft diameter of pile

Field tests on 30 cm. and 37.5 cm. shaft diameter, 300 cm deep reinforced concrete straight bored pile, also confirmed the model tests findings, Figure 17. Model tests results showed about 40 per cent increase in lateral load at 6mm deflection as we go from 5 cm. to 7.5 cm. shaft diameter piles. This increase in case of field tests was about 66 per cent for the same value of lateral deflection (6mm) for 30 cm and 37.5 cm shaft diameter piles. In the absence of sufficient number of tests on different sizes of piles it is difficult to say that as to which size of shaft this increase in lateral load would be observed.

Effect of position of bulb in a pile

Effect of positioning of bulb in a pile at a higher elevation than the conventional practice was investigated by doing prototype tests on 30 cm shaft diameter single bulb piles having bulb at its bottom in one case, (conventional) and at a depth of 1.5m below ground level, the minimum depth prescribed (IS : 2911—Pt-III-1973). The comparison of the load-settlement curves of the two piles Figure 18 indicate some gain in the increase in the lateral load by providing the bulb at higher elevation. The increase in the lateral load is only 13 per cent at 6mm deflection for the test pile. More and substantial benefit may be obtained if the bulb is provided just at ground surface or the better idea would be the widening of shaft diameter equal to bulb diameter at the top of pile close to ground surface.

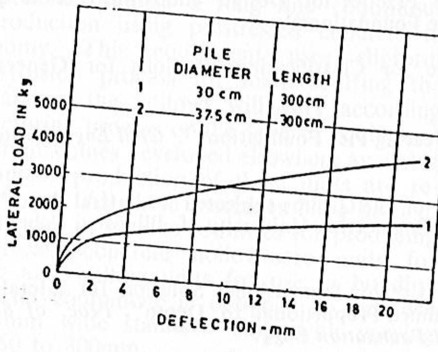

FIGURE 17 Effect of Shaft diameter of pile on its lateral load capacity

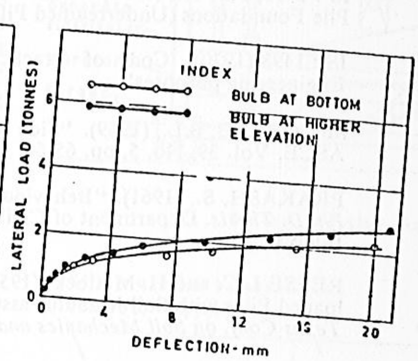

FIGURE 18 Effect of position of bulb on lateral load

Conclusions

Based on the limited test results conducted in the laboratory on wooden piles embedded in sand and also in the field on prototype reinforced cement concrete piles embedded in silty sand, the following conclusions could be drawn :

1. The lateral load taken by piles increased with increase in depth and shaft diameter of pile.

2. Lateral load taken by a pile increases to a great extent by the addition of one bulb at the base of pile.

3. No definite trend was observed in case of double underream piles as compared to single underream piles.
4. It has also been observed that the lateral load taken by a pile increased by providing the bulb at higher elevation.

Acknowledgement

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