Paper No. 24

SEISMIC DESIGN OF MULTISTOREYED CONCRETE FRAMES WITH ANALYSIS OF COST

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SYNOPSIS

The Author presents the results of his study of the increase in cost of multistoreyed concrete frames due to incorporation of seismic factor in the design.

Very little work has been done, uptil now, in connection with the relationship between the seismic factor and cost of multistoreyed framed structures. Particularly no work seems to have been done for concrete frames.

This paper deals with the study of multistoreyed reinforced concrete frames ranging from one to ten storeys in height. The frames are designed for varying degree of lateral forces corresponding to different earthquake intensities. This provision for earthquake allowance involves additional expenditure. The relationship between the increase in cost and the seismic factor is examined.

INTRODUCTION

In the regions frequented by earthquakes, structures need special designing against seismic forces. In the case of an earthquake, the movement of the foundation of a building is transmitted to the superstructure. Since the superstructure has to accelerate from rest to motion, inertia forces act on the superstructure in a direction opposite to that of the earth movement. The shearing forces in each storey due to dynamic loading result from the inertia forces of all the masses above that storey. Seismic design consists of making the structure strong enough to resist the dynamic loading.

It is not practicable to use the dynamic equation for every design as the computations are extremely complex on account of the large number of factors involved. Moreover, the dynamic behaviour of most structures is not fully known. Usual practice, therefore, is to formulate an equivalent statical method of design. The procedures followed by different building codes are to assume the shape of the shear force distribution and then derive an empirical formula for the equivalent horizontal static force co-efficient.

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Since earthquake waves may strike a building at any angle, buildings should be strong enough to resist lateral forces in any direction. However, the waves can be resolved into two components parallel to the major and minor axes of the building and therefore it is sufficient to investigate its strength in the two perpendicular directions only. In a framed building the longer frames along the major axis and the shorter frames along the minor axis have to be individually made strong for lateral seismic loading. The shorter frames are more susceptible to lateral loads. For the investigation we take up a single shorter frame along the minor axis of the building and consider the lateral strength in its own plane.

Every building has its own natural period of vibration. If the period of vibration of an earthquake coincides with the natural period of vibration of the building, excessive stresses are produced in the structure due to resonance.

For earthquake resistant design of multistoreyed buildings, the design formula, according to Indian standard specification (I S 1892–1962) is

$$V=\frac{0.35\,S}{N+0.9\,(S-8)}\,CW$$

where

V = Total horizontal shear force

S = Total number of storeys in the building (It shall be taken as 13 when the number of storeys is 13 or less)

N = No. of storeys above the one under consideration.

C = Seismic Coefficient.

W = Weight of the structure above the storey under consideration.

For buildings having not more than 13 storeys this formula simplifies to the form suggested by Jaikrishna (1958).

$$V=\frac{4.5}{N+4.5}\,CW$$

Earthquake resistant design of a structure involves additional cost and a compromise has to be drawn between the increase in cost and the additional safety it ensures. Therefore, a systematic study of the relation between the seismic coefficient of design and the increase in cost for different types of building frames should prove helpful in deciding whether it would be practicable to incorporate seismic loading in the standard design practice of our country. In the present study a number of R. C. C. frames with two bays and different storey heights were designed at first without considering seismic loading and then considering seismic loading. The increase in cost due to seismic design over usual design was calculated. The relationship of this increase in cost with the number of storeys and the seismic factors was obtained.

DESIGN OF FRAMES

The present study is restricted to R. C. C. framed structures of the following description.

The frames consist of two bays of 25 feet each so that the floor space can be divided into two rows of rooms (Fig. 1) one being a row of large rooms and the other one being of small rooms. The two rows of rooms will be separated by a corridor formed in the bay containing the row of small rooms. The wall for the corridor is assumed to be having its own footing, so that it does not affect the design of the frame. The floor heights have been kept as 12′–0″. The frames have been placed 12′–0″ centre to centre.

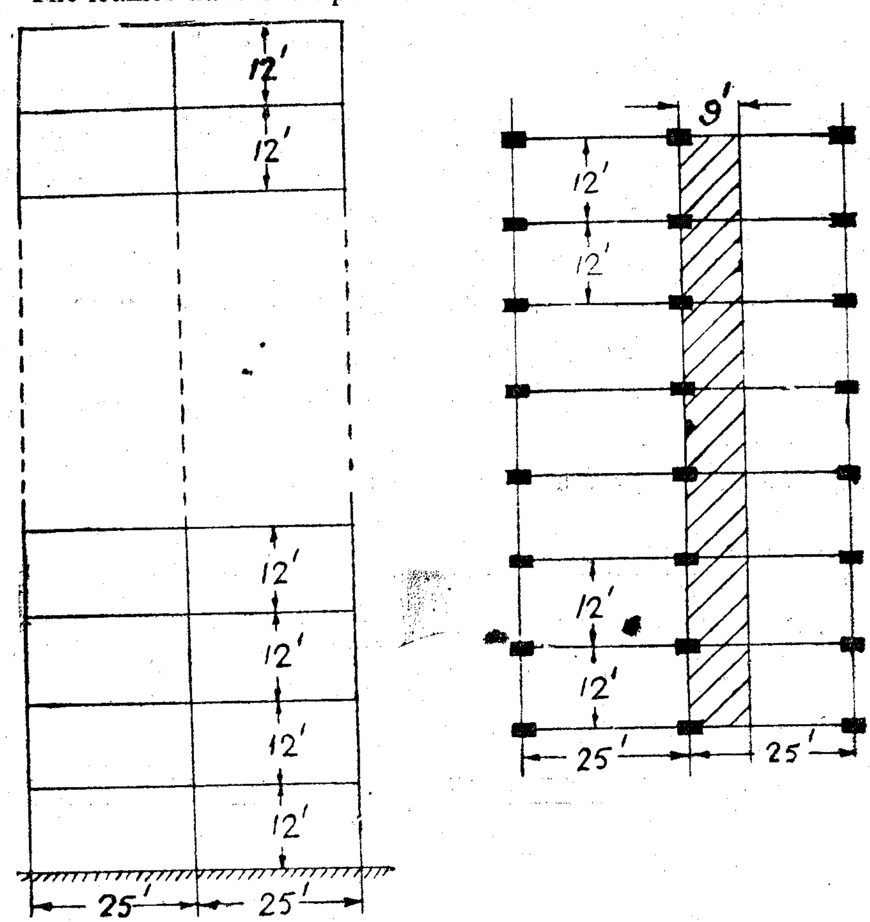

Fig. 1 Multistoreyed Framed Structure

Usual Design

The frames are designed for dead load, live load and wind load. The procedure adopted is as follows.

(i) Various loads are calculated making suitable assumptions for the self-weight of different members.

(ii) A preliminary design is worked out with the help of approximate methods. The column sizes are so chosen that the "Principles of Multiples" may be applied to the frame.

(iii) Dead load analysis is done by using "Kani's method" (Kani, 1957), an iterative process.

(iv) Live load analysis is carried out by "Substitute frame metood" (Jaikrishna & Jain 1960). Moments are calculated for a few suitable frames and the remaining moments are obtained by interpolation.

(v) Combined effect of dead and live loads was then examined, so that the stresses do not exceed the permissible limit.

(vi) Wind load analysis is carried out with the help of "Modified substitute Cantilever Method" (Kloucek, 1958).

(vii) The stresses caused due to the combined effect of dead loads, live loads, and wind loads are checked so that they do not exceed the permissible limit which is $33\frac{1}{3}\%$ in excess of those allowed in the code for normal loading.

(viii) The foundation is lastly designed as a reinforced concrete raft, to provide the necessary bearing area and also making it strong enough to resist the moments.

As a specimen design, the design of the 10-storeyed frame is shown. The other frames (8, 6, 4, 2 and 1 storeyed) were designed similarly. The final design of the 10-storeyed frame is shown in the Table 1.

The foundation is designed as shown is Fig. 2.

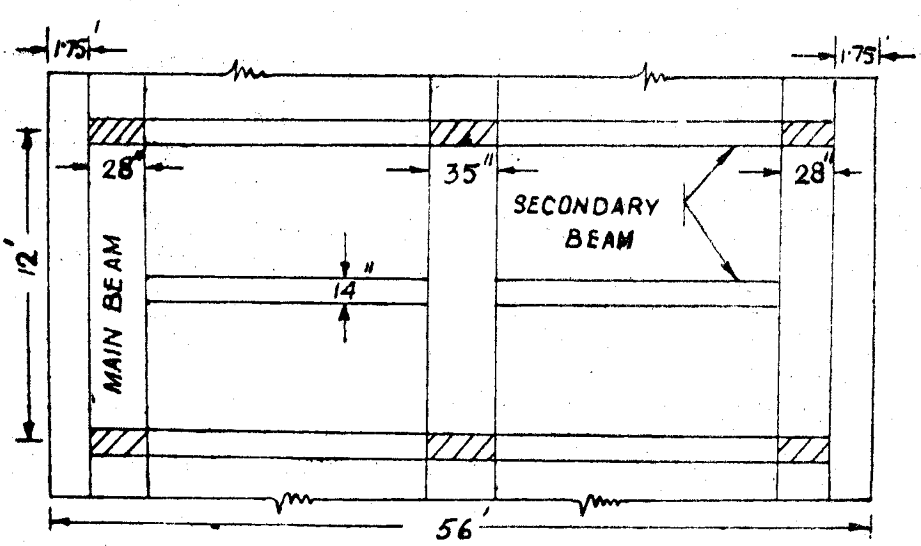

Fig. 2 Design of Foundation

The slab is made 8″ thick. The secondary beams are 14″×28″. The outer beams (main) are made 28″×31″ and the central beams 35″×32″, suitable reinforcements are provided in the slab and in the beam.

TABLE - 1
USUAL DESIGN OF 10 STOREYED FRAME

COLUMN STOREY	EXTERIOR		INTERIOR	MAX STRESS
1st	14" × 28", 1"φ	CONCRET = 65.2 CFT, STEEL = 2720 C.IN	14" × 35", 1¼"φ	CONCRETE = 40.8 C.FT, STEEL = 2130 C.IN
2nd	14" × 28, 1"φ	65.7 C.FT, 2720 C.IN	14" × 35", 1"φ	40.8 C.FT, 1360 C.IN
3rd	14" × 28", 1"φ	65.2 C.FT, 1816 C.IN	14" × 35", 1"φ	40.8 C.FT, 908 C.IN
4th	14" × 24", 1⅛"φ	56 C.FT, 1815 C.IN	14" × 30", 1⅛"φ	35 C.FT, 1152 C.IN
5th	14" × 24", 1"φ	56 C.FT, 1815 C.IN	14" × 30", 1"φ	35 C.FT, 680 C.IN
6th	14" × 24", 1"φ	56 C.FT, 1360 C.IN	14" × 30", 1"φ	35 C.FT, 452 C.IN
7th	14" × 20", 1"φ	46.6 C.FT, 1815 C.IN	14" × 25", 1"φ	29.2 C.FT, 452 C.IN
8th	14" × 20", 1"φ	46.6 C.FT, 1815 C.IN	14" × 25", 1"φ	29.2 C.FT, 452 C.IN
9th	14" × 16", 1"φ	37.4 C.FT, 1815 C.IN	14" × 20", 1"φ	23.3 C.FT, 452 C.IN
10th	14" × 16", 1"φ	37.4 C.FT, 904 C.IN	14" × 20", 1"φ	23.3 C.FT, 452 C.IN
BEAM SECTION	26" × 14"; 3", 7.0 in²; 2.3", 3.51 in²			CONCRETE = 1240 C.FT, STEEL = 63,000 C.IN

TOTAL VOLUME OF CONCRETE = 2104 C.FT

TOTAL VOLUME OF STEEL = 90573 CU IN = 52.4 C.FT

Dynamic Design

In this case, the wind forces are replaced by earthquake forces and the analysis is done by "Modified Substitute Cantilever method". Sections are designed for the combined moments and thrusts due to dead load, live load and earthquake load.

Earthquake forces are calculated according to the simplified formula (See Introduction)

$$\text{Sheer} = \frac{4.5}{N+4.5} \times CXW$$

Calculations of Earthquake forces for the 10-storeyed frame, corresponding to a seismic co-efficient of 20% g, are shown in the Table 2.

Table–2. Earthquake Forces.

		Shear (Kips)	Eqvt. force (Kips)
10th Storey	$\frac{4.5}{0+4.5} \times 0.2 \times 113$	22.60	22.60
9th Storey	$\frac{4.5}{1+4.5} \times 0.2 \times (113+118)$	37.80	15.20
8th Storey	$\frac{4.5}{2+4.5} \times 0.2 \times (231 \times 118)$	48.40	10.60
7th Storey	$\frac{4.5}{3+4.5} \times 0.2 \times (349+118)$	56.00	7.60
6th Storey	$\frac{4.5}{4+4.5} \times 0.2 \times (467+122)$	62.40	6.40
5th Storey	$\frac{4.5}{5+4.5} \times 0.2 \times (589+122)$	67.40	5.00
4th Storey	$\frac{4.5}{6 \times 4.5} \times 0.2 \times (711+122)$	71.40	4.00
3rd Storey	$\frac{4.5}{7+4.5} \times 0.2 \times (833+122)$	74.80	3.40
2nd Storey	$\frac{4.5}{8+4.5} \times 0.2 \times (955+122)$	77.60	2.80
1st Storey	$\frac{4.5}{9+4.5} \times 0.2 \times (1077+122)$	80.00	2.40

The design for 0.2g is shown in the Table 3.

Similarly, the earthquake designs for 0.15g, 0.1g, and 0.05g are carried out for the 10-storeyed frame.

TABLE - 3

SEISMIC DESIGN OF 10 STOREYED FRAME FOR 0.2g

COLUMN STOREY	EXTERIOR		INTERIOR	
1st	14" × 28", 12 in²	CONCRETE = 62.2 c.ft STEEL = 6900 c in²	14" × 35", 15 in²	CONCRETE = 40.8 c.ft STEEL = 4320 c.in
2nd	14" × 28", 10 in², 4"	65.2 c.ft 5760 c.in	14" × 35", 12 in²	40.8 c ft 3450 c in
3rd	14" × 28", 8 in²	62.5 c ft 4600 c in	14" × 35", 8 in²	40.8 c.ft 2300 c.in
4th	14" × 24", 10 in²	56 c.ft 5760 c.in	14" × 30", 10 in²	35 c.ft 2,880 c.in
5th	14" × 24", 8 in²	56 c.ft 4,600 c.in	14" × 30", 8 in²	35 c.ft 2,300 c.in
6th	14" × 24", 8 in²	56 c.ft 4,600 c.in	14" × 30", 8 in²	35 c.ft 23.00 c.in
7th	14" × 20", 10 in²	46.6 c.ft 5,760 c.in	14" × 25", 10 in²	29.2 c.ft 2880 c in²
8th	14" × 20", 10 in²	46.6 c.ft 5,760 c.in	14" × 25", 10 in²	29.2 c.ft 2880 c.in
9th	14" × 16", 10 in²	37.4 c.ft 5,760 c.in	14" × 20", 10 in²	23.3 c.ft 2880 c.in
10th	14" × 16", 8 in²	37.4 c.ft 4,600 c in	14" × 20", 5 in²	23.3 c.ft 1,440 c in
BEAM SECTION	26" × 14", 18 in², 18 in²			CONCRETE = 1240 c.ft STEEL = 144,000 c.in

TOTAL VOLUME OF CONCRETE = 2104 C.FT

TOTAL VOLUME OF STEEL = 225,730 C.in = 130 C.F.T.

The design shown for the 10-storeyed frame was repeated for 8-storeyed, 6 storeyed 4 storeyed, 2 storeyed and 1 storeyed frames, obtaining the design in each case with respect to wind load, earthquake allowances of 0.2g, 0.15g, 0.1g, 0.05g over and above dead load and live load.

COST ANALYSIS

For the purpose of comparing the cost of buildings designed for different purposes, we calculate the cost of structural frame, the floors, the foundation and assume that other details of the buildings and the various electrical and sanitary fittings contribute about half of the total cost of the complete building.

Rates assumed* :—

Concrete in multistoreyed frame, excluding cost of steel but including cost of bending and placing of reinforcement	Rs. 4.00 per cu. ft.
Steel in reinforcement ...	Rs. 170.00 per cu. ft.
Cost of flooring ...	Rs. 3.00 per sq. ft.
Foundation concrete, including cost of steel	Rs. 6.00 per cu. ft.

Sample calculation for 10-storeyed building :—

Initial cost $=(2104\times4+52.4\times170+6000\times3+1054\times6)\times2.0$
$=83{,}300$

For earthquake allowance of 0.2g, Increase in cost
$=(130-52.4)\times170=13{,}192$

Therefore, per cent increase in cost $=\dfrac{13{,}192}{83{,}300}\times100=15.8\%$

Per cent increase in cost for earthquake allowance of 0.15g

$$=\frac{(97.6-52.4)\times170}{83{,}300}\times100=9.2\%$$

Per cent increase in cost for Earthquake allowance of 0.1g

$$=\frac{(66.0-52.4)\times170}{83{,}300}\times100=2.8\%$$

Per cent increase in cost for Earthquake allowance of 0.05g is nil.

For different buildings, the initial cost, per cent increase in cost due to earthquake allowances given in non-dimensional form in the Table 4. The initial cost of one-storeyed building is calculated as Rs. 7056, which is assumed to be unity. The other costs are expressed as ratios to this cost of one storeyed building.

*Rates pertaining to the year base 1952.

Table--4

Cost of Buildings.

Building	Initial cost	Increase in cost due to Earthquake allowances of		per cent increase
		20% g	1.87	15.8%
		15% g	1.09	9.2%
10-Storeyed	11.80	10% g	0.327	2.8%
		5% g	nil	nil
		20% g	1.76	19.5%
		15% g	1.12	12.4%
8-Storeyed	9.05	10% g	0.555	6.1%
		5% g	nil	nil
		20% g	1.36	20.1%
		15% g	0.93	13.8%
6-Storeyed	6.75	10% g	0.438	6.5%
		5% g	0.014	0.21%
		20% g	0.91	20.6%
		15% g	0.62	14.1%
4-Storeyed	4.40	10% g	0.232	7.5%
		5% g	0.024	0.55%
		20% g	0.45	20.9%
		15% g	0.31	14.4%
2-Storeyed	2.15	10% g	0.17	7.8%
		5% g	0.024	1.1%
		20% g	0.178	17.8%
		15% g	0.14	14.0%
1-Storeyed	1.00	10% g	0.08	8.0%
		5% g	0.015	1.5%

Relationship between Seismic Factor, Cost and Number of Storeys

The percentage increases in cost of different buildings corresponding to various earthquake allowances are plotted and the graphs obtained thereby. Each curve in Fig. 3 shows the variation of percentage increase in cost due to different earthquake allowances for a certain building. The increase in cost is expressed as a percentage of the cost of the building not designed for earthquake forces but designed for wind forces. Each curve in Fig. 4 shows the variation of percentage increase in cost with the number of storeys of buildings for a certain fixed earthquake allowance.

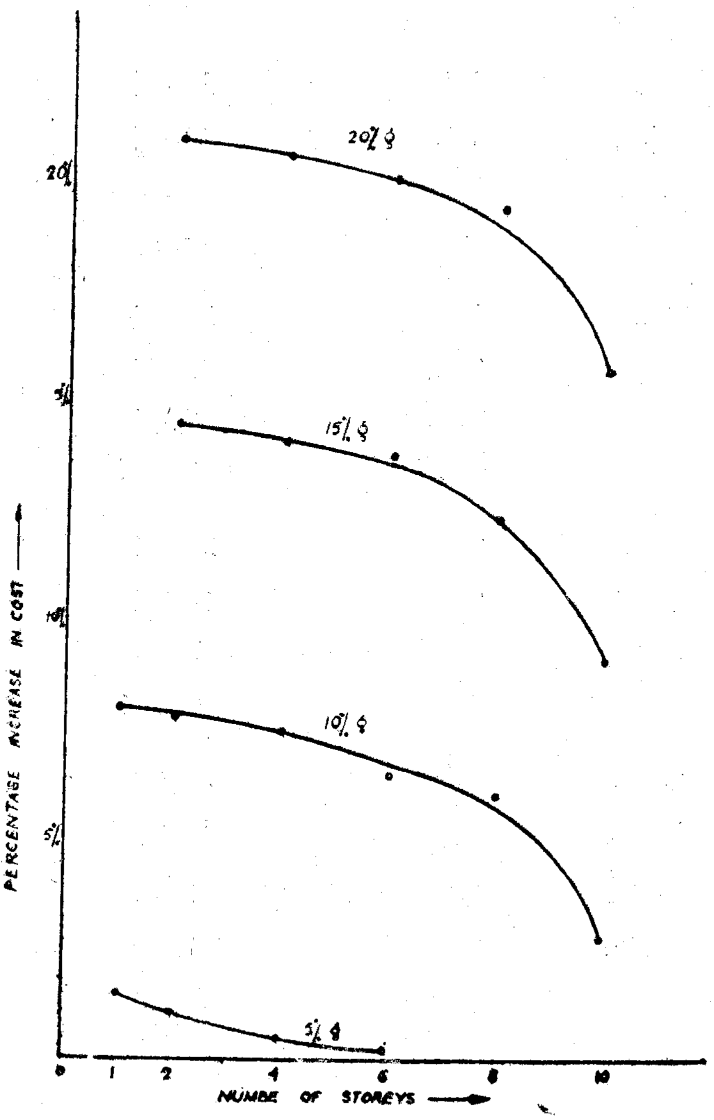

Fig. 3 Increase in Cost Vrs. Seismic Factor.

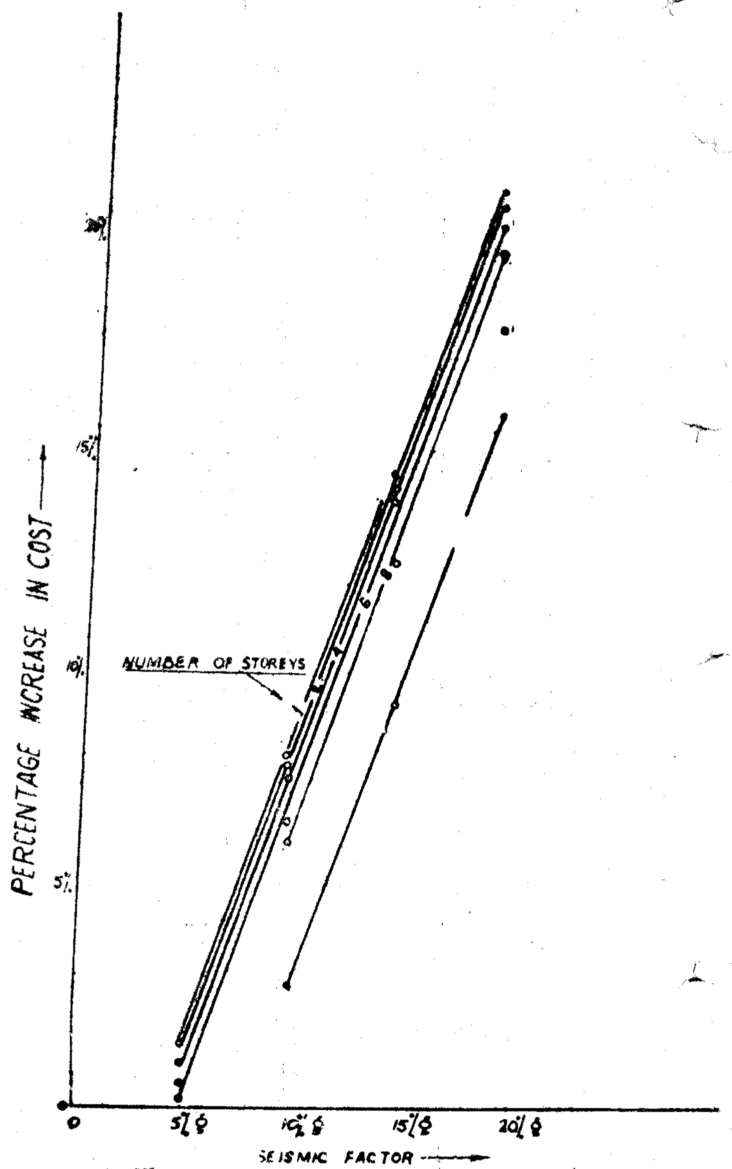

Fig. 4 Increase in Cost Vrs. Number of Storeys.

CONCLUSIONS

For the same height of building percentage increase in cost rises linearly with increase in seismic factore. If the same seismic factor is used for design of a number of buildings, the percentage increase in cost is less for taller buildings.

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