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ON THE EARTHQUAKE RESISTANT DESIGN OF REINFORCED CONCRETE (R.C.) CHIMNEYS

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ABSTRACT

Design of tall R.C chimneys has been a difficult task due to specific nature of this special application structure and to the unknown characteristics of the earthquakes occurring during service life of these chimneys. Tall R.C chimneys are preferred over steel chimneys due to their improved vibrational performance over steel chimneys against wind and earthquake loadings. The present investigation includes some of the basic analysis considerations of ten varying height unlined chimneys ranging from 300 to 1103 feet and with varying top and bottom diameters. The same chimneys have also been analysed by using pseudo static analysis (PSA), equivalent lateral static force method as defined by ACI committee report 307-88 published in 1991 procedure and lumped mass dynamic analysis (LMDA) by using the response spectrum given in ACI 307-88 and also by using a local response spectrum which has been used for designing world famous hydraulic projects of Pakistan . Comparative results indicate that LMDA and ACI 307-88 procedure results are almost similar for all the chimneys. The study suggests that the safe earthquake resistance design of unlined chimneys may be based on the proposed simplified PSA method which contains height sensitive equations to obtain the results in the close proximity of ACI 307-88 and LMDA approaches. The suggested modified PSA method is useful for all seismic zones as specified by ANSI A58.1 and for any peak ground acceleration. This method is helpful to the designer to obtain a good and almost a final design of a given height of chimney instead of using lengthy ACI 307-88 and LMDA techniques.

KEYWORDS

Tall R.C Chimneys; ACI 307-88; ACI 307-79; Modified pseudo static analysis; Roded chimney model; Earthquake resistant, Lumped masses.

INTRODUCTION

R.C chimneys are one of the basic elements in the modern industry e.g., power plants , chemical plants, steel mills etc., for exhausting the toxic gases at high altitude. One of the primary advantages of tall R.C Chimneys is their improved resistance to wind induced vibrations in comparison to steel chimneys (Dryden et al.,1940). The height and top diameter of chimney are chosen so that exit velocity and effluent gases dispersion is within limits while bottom diameter is controlled by structural and foundation requirements (Rumman et al., 1968). Typically a tapering chimney, with varying top and bottom diameters, has been used for relatively high altitudes and a constant size chimney has been used for relatively smaller heights. Current state of the art to analyse a chimney is by lumped mass dynamic analysis LMDA using response spectrum technique. Besides this other approximate tools are also available such as ACI committee report 307-79 (Manual of Concrete Practice Part-4, 1998) published in 1988, ASME/ANSI STS-1 (ASME, 1988), ANSI A58.1 and UBC procedures. These standards or codes may not yield the same results (Shih-Lung Chu et al., 1990) but ACI 307-88 (Manual of Concrete Practice Part-4, 1991) covers the relevant aspects of all the procedures mentioned above. In this investigation a relatively simpler method for analysis of unlined chimneys based on the old classical pseudo static method has been developed after analysing the selected chimneys by ACI 307-88 and LMDA methods. In the modified PSA approach some multipliers are suggested which are height sensitive and are multiplied throughout the height to get the results in the closed proximity of LMDA and ACI 307-88 approaches. For study ten sample chimneys, as given in Table- 1, are picked up from table 4.2.1 of ACI 307-88 report and are analysed for all five zones defined by ANSI A58.1 by all three methods i.e., LMDA, ACI 307-88 and proposed PSA. Figure-1 presents a generalized Roded model of typical chimney used in LMDA . A brief description of each method is outlined as under.

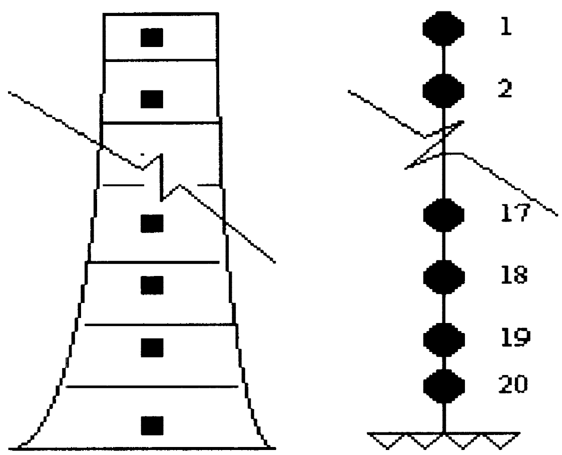

Fig. 1 Idealized roded model of chimney showing lumped masses at element centres.

Table 1. Dimensions and periods of 10 sample chimneys

Total Chimney height, ft	First mode period, SAP-90 Sec	First mode period, ACI-307-88 Sec	First mode period, Proposed PSA Sec	Top diameter, ft	Base diameter, ft	Thickness at top, in	Thickness at base, in
300	1.4	1.33	1.44	25.16	30.00	8.00	10.00
570	1.90	1.74	1.88	86.98	86.98	15.25	15.25
594	2.22	1.91	2.06	37.67	56.59	10.00	37.00
635	2.83	2.69	2.91	56.83	58.08	12.00	27.00
670	2.00	1.85	2.00	94.17	101.67	16.25	24.00
700	3.15	2.93	3.17	30.75	57.85	9.00	22.75
895	4.12	3.76	4.07	33.75	67.84	9.00	29.50
997	4.48	4.26	4.61	40.46	77.33	9.50	32.00
1037	5.05	4.75	5.13	55.46	74.25	11.00	45.00
1103	5.12	4.89	5.28	41.46	80.70	10.00	38.00

LUMPED MASS DYNAMIC ANALYSES [LMDA] USING RESPONSE SPECTRUM.

A Rodded model has been employed for the computer analysis and the masses at the centre of different sections are lumped as shown in Fig. 1. Response spectrum as mentioned in the ACI 307-88 has used for analysis and is shown in Fig. 2. A response spectrum developed for world famous hydraulic structures in Pakistan for comparison purposes has also been used alongwith analysis package SAP-90 by considering 5% damping. First 5 modes used for the calculation of shear & Moments using CQC (Complete Quadratic Combination) technique have been considered. The analysis has been done for all the zones specified by ANSI A58.1 using the same scaling ratios as explained by ACI-307-88 and for all chimneys given in Table 1 . The results of the two response spectra appear to be same. Therefore, primarily the response spectrum specified by ACI-307-88 has been used for comparative study.

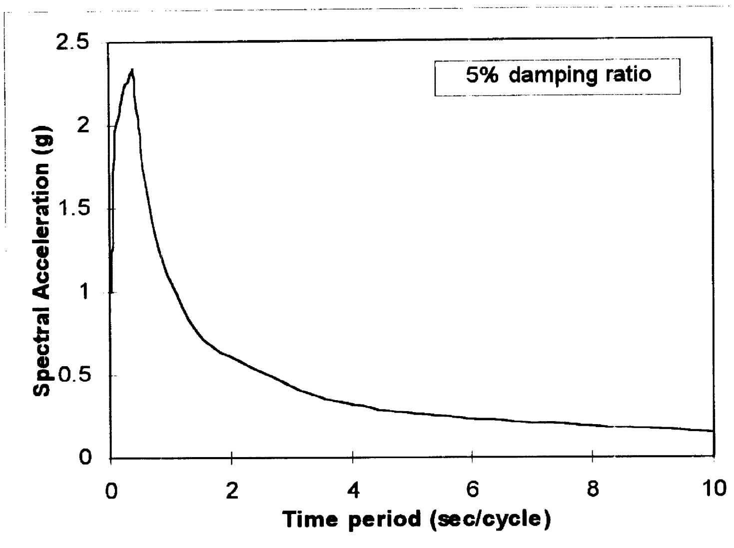

Fig. 2. Normalized Horizontal Elastic Seismic Response Spectrum

ACI-307-88 REINFORCED CONCRETE CHIMNEY DESIGN APPROACH

Before 1979 some simple approaches were formulated for the design of R.C chimneys (Rumman et al., 1968, ACI Standards and Specifications for Chimneys Manual of Concrete Practice Part-4 ,1991). The ACI 307-79 (ACI Manual of Concrete Practice Part-4, 1988) was the first effort towards the proper design of chimneys based on the working stress technique. Afterwards ACI 307-88 was presented based upon the state of the art ultimate strength design technique. The formulae described by ACI 307-88 contain several height sensitive multipliers giving a more realistic picture of the distribution of forces as well as moments when compared with ACI 307-79. The recommended values of Use factor, the numerical coefficients for base shear, the distribution of lateral forces and the multipliers for moment and shear have all resulted from calibration study of both dynamic analysis and equivalent static force method of presented chimneys to get compatible results. As can be seen from curve in Fig. 4,5, this approach is in close proximation with the dynamic analysis results and therefore, may be used for the initial proportioning of the chimney components. ACI 307-88, however, do not give the exact picture of the vibrational characteristics of a chimney when subjected to a severe earthquake therefore the dynamic analysis approach seems to be more precise of all the techniques mentioned.

In ACI-307-88 approach lateral forces at different levels are calculated by the Eq-4 by using Z values specified in ANSI 58.1 alongwith U = 2. The value of U was left on the discretion of Engineer in the earlier version i.e., ACI 307-79.

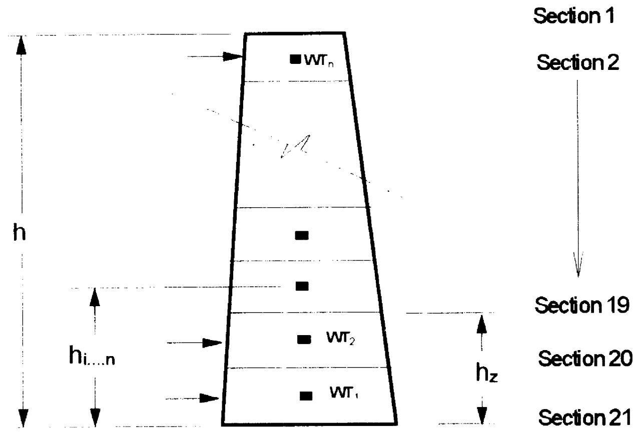

Fig. 3. Generalized force model of ACI 307-88

$$V = ZUC(WT_1) \tag{1}$$

$$C = 0.13/\sqrt{T_1} \leq 0.26 \tag{2}$$

$$T_1 = \frac{5\,h^2}{d(b)}\;\frac{\rho ck}{Eck}\;\frac{t(h)}{t(b)} \tag{3}$$

$$F_n = V\,\frac{WT_n.\,h_n^2}{WT_n.\,h_n^2} \tag{4}$$

$$M_z = J_m^{Z}\left[\Sigma_i^{n} F_{i\ldots,n}\,(h_{i\ldots,n} - hz)\right] \tag{5}$$

for $0 \leq h_z/h \leq 0.3$

$$J_m^{z} = 11.1\,(J_m^{base} - J_m^{0.3h})\,(0.3 - h_z/h)^2 + J_m^{0.3h} \tag{6}$$

for $0.3 \leq h_z/h \leq 1.0$

$$J_m^{z} = 2.78\,(J_m^{0.9h} - J_m^{0.3h})\,(h_z/h - 0.3)^2 + J_m^{0.3h} \tag{7}$$

$$J_m^{0.9h} = 1.15 + 0.025\,T_1^2 \tag{8}$$

$$J_m^{0.3h} = 0.3 + 0.004\,(6 - T_1)^3 \tag{9}$$

$$J_m^{base} = 0.4 + (6 - T_1)^3/300 \tag{10}$$

For $T_1 > 6$ sec, use $J_m^{0.3h} = 0.3$ and $J_m^{base} = 0.4$

Where

Z = Zone coefficient for according to ANSI A58.1
V = Total Base Shear
U = Use factor taken as 2.0
C = Numerical coefficient for base shear
T_1 = Fundamental time period of vibration of chimney, sec/cycle.
WT_1 = Total weight of chimney including lining, lb.
h = Height of chimney above base, ft.
h_z = Height above base to the level designated as z, ft.
h_n = Height above base to the level designated as 1,2...n, ft.
F_n = Equivalent lateral static force applied to a level designated as 1,2,...n, lb.
J_m' = Moment multiplier at the chimney level h_z
h = Chimney height above base, ft
t(h) = Thickness of shell at top, ft
t(b) = Thickness of shell at bottom, ft
d(b) = Mean diameter at bottom, ft.
ρck = Mass density of concrete, kip-sec^2/ft^4
Eck = Modulus of elasticity of concrete, kip/ft^2

PROPOSED PSEUDO-STATIC ANALYSIS [PSA]

In classical pseudo static analysis based on Newton's 2nd law of motion F =-ma the lumped masses at centers of different sections are multiplied by the effective peak ground acceleration to find the lateral forces at different sections. Moments at different levels are then accordingly calculated. To simulate the results comparable with dynamic analysis a range of multipliers have been developed based on the ACI 307-88 approach. The suggested multipliers are time period dependent and obtained by regression analysis. In this technique a chimney is divided into equal twenty sections but the number of sections for a given chimney height should not be less than 10 for good results. Average masses at the centre of gravity of each section is calculated and then the mass is multiplied by the specified effective peak ground acceleration. Moments at every level are calculated. These moments are then multiplied by correlation multipliers which are described below. The results of the three approaches for all ten chimneys analysed for zone 2 of ANSI A58.1 are shown in Fig. 4 & 5 which show a very close correlation.

for $T_1 \leq 5$ sec/cycle, and for $0 < h_z/h < 0.3$

$$J_m^{z} = J_m^{0.3h} \quad (11)$$

for $0.3 \leq h_z/h \leq 1.0$

$$J_m^{z} = 5\,(J_m^{0.9h} - J_m^{0.3h})\,(h_z/h - 0.3)^2 + J_m^{0.3h} \quad (12)$$

$$J_m^{0.9h} = 1.38 + 0.03\,T_1^2 \quad (13)$$

$$J_m^{0.3h} = 0.36 + 0.0048\,(6 - T_1)^3 \quad (14)$$

for $T_1 > 5$ sec/cycle

$$J_m^{0.9h} = 2.53 + 0.05\, T_1^2 \qquad (15)$$

$$J_m^{0.3h} = 0.66 \qquad (16)$$

$$T_1 = \frac{5.407\, h^2}{d(b)} \frac{\rho ck}{Eck} \frac{t(h)}{t(b)} \qquad (17)$$

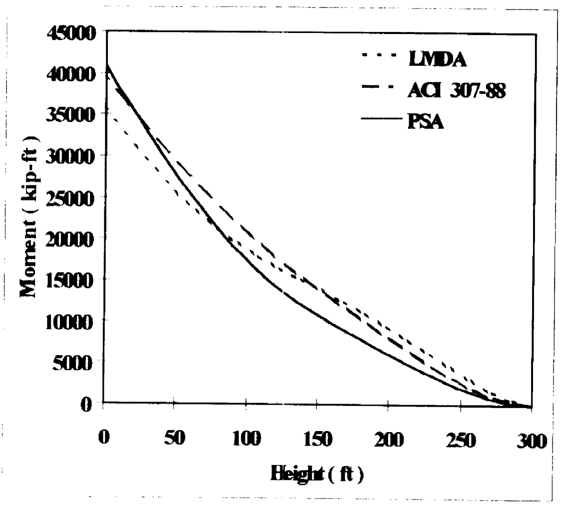

Fig. 4a. 300 ft. high Chimney

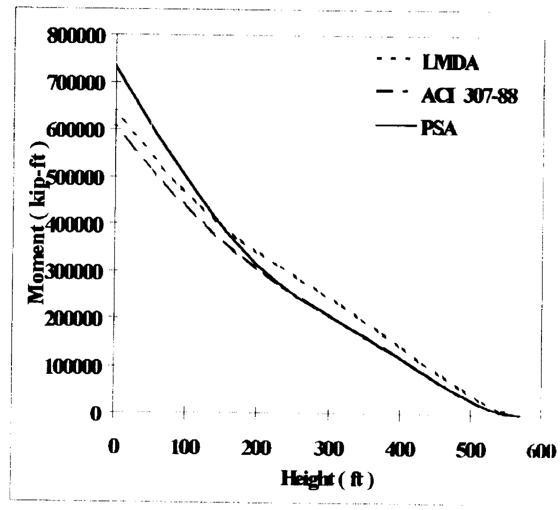

Fig. 4b. 570 ft. high Chimney

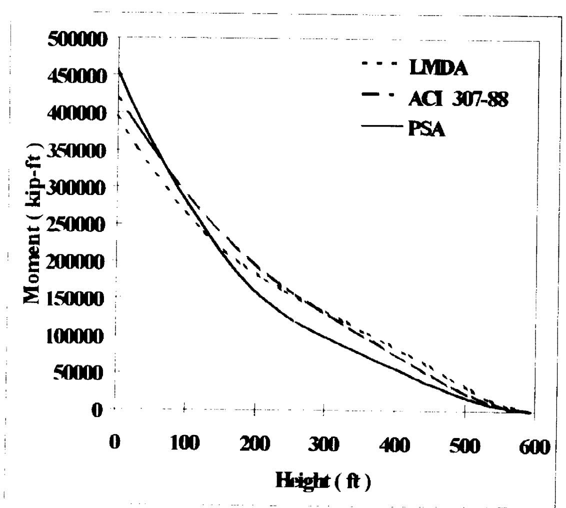

Fig. 4c. 594 ft. high Chimney

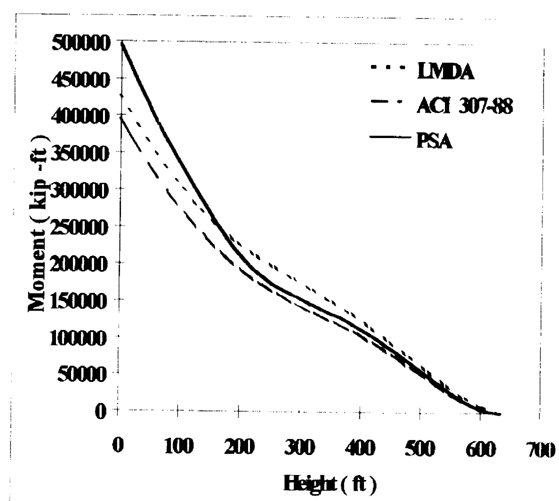

Fig. 4d. 635 ft. high Chimney

Fig. 4. Moment-Height Relationships by using three different Analysis methods

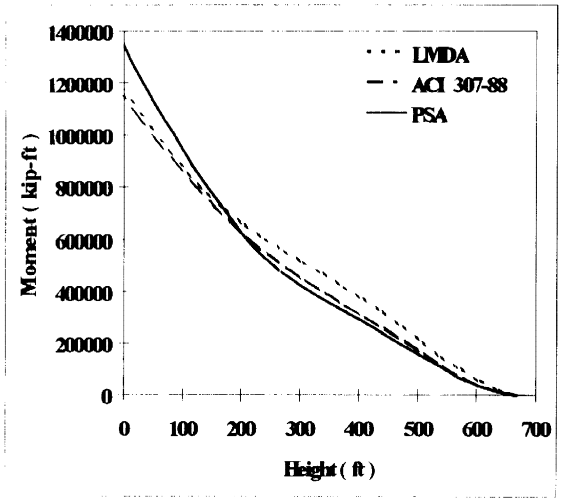

Fig. 5a 670 ft. high chimney

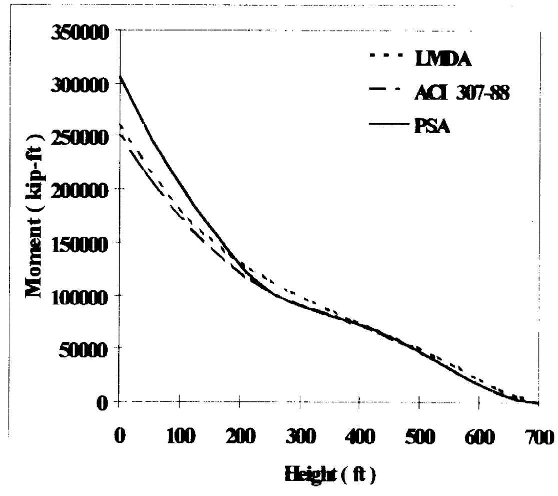

Fig. 5b. 700 ft. high chimney

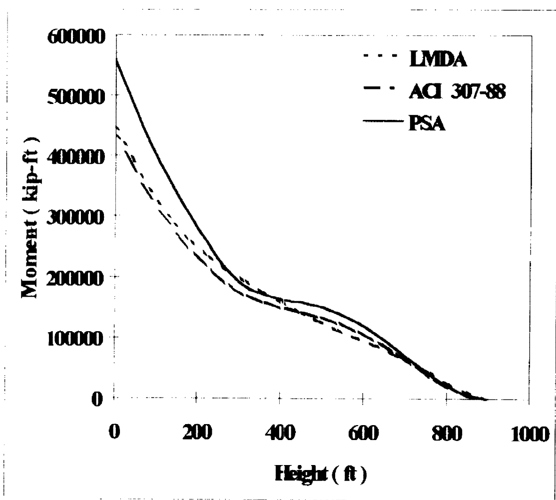

Fig. 5c. 895 ft. high chimney

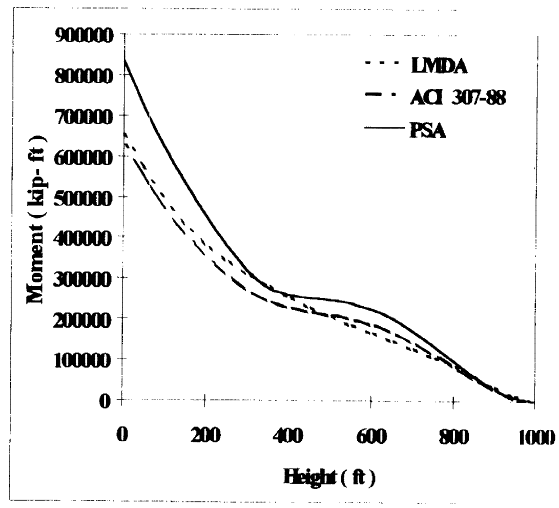

Fig. 5d. 997 ft. high chimney

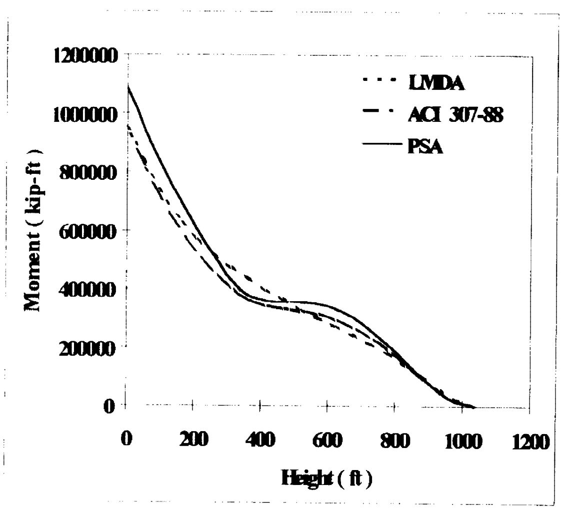

Fig. 5e. 1037 ft. high Chimney

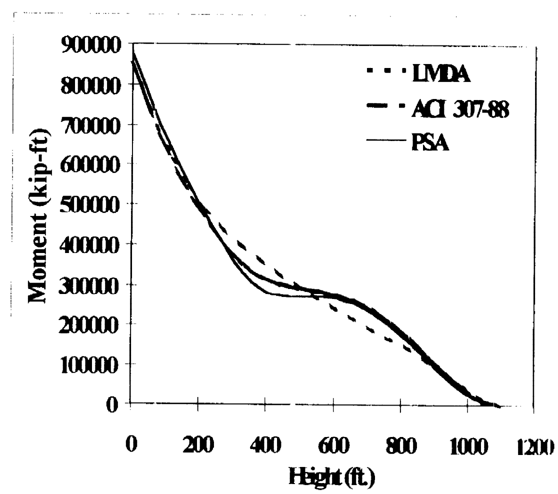

Fig. 5f. 1103 ft. high Chimney

Fig. 5. Moment-Height Relationships by using three different Analysis methods

CONCLUSIONS AND RECOMMENDATIONS

1. The proposed PSA method is simpler and gives comparable results for various chimney heights and for any described pre-selected effective peak ground acceleration and for all seismic zones.

2. ACI-307-88 gives almost similar results compared with LMDA as it contains height sensitive multipliers.

3. It is recommended that tall R.C. chimneys may be analysed and dimensioned even by proposed PSA method after multiplying the original PSA moment values by the proposed moment multipliers and the results will be almost similar for those obtained by the lengthy ACI 307-88 technique and LMDA.

4. The PSA procedure is simpler one and should be used for an initial chimney sizing.

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