Calculation of equivalent lateral seismic forces based on ASCE 7-02 and KTP 2-89

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ABSTRACT

This paper describes the equivalent lateral force procedure according KTP 2-89 and ASCE 7-02, and it gives light upon the differences between these two standards. KTP 2-89 has not been updated for a long time now, as of year 1989. Being aware of the development and changes that other standards have achieved in the past decades, it is of major interest to have an understanding of the today differences. The equivalent lateral seismic force procedure, is one way of representing the seismic effect on the building during the structural analysis and design stage. The lateral earthquake design force at the base and the lateral force distribution along the building height depend on different modification factors and design spectra, which are different for each standard and require a lot of calculations. In this context, this paper presents a spreadsheet which facilitates the calculation of base shear, distributed lateral force along the building height, and the overturning moment, both based on KTP and ASCE 7-02. By describing a case study of a building, some quantitative differences between the two standards are shown.

Keywords: Equivalent lateral force procedure, ASCE 7-02, KTP, spreadsheet

INTRODUCTION

The Albanian national code, KTP, has received the latest updates in its 1989 version. This code was firstly published in 1963, was revised in 1978 and coming to its latest version in 1989. At the other side ASCE 7-02 has been updated regularly, with the latest version in 2010, although here we will use year 2002 version.[1] Since then Albania is characterized by a rapid urbanization and uncontrolled spreading of the construction sector which inevitably brought to the construction of many abusive buildings. In this context, the comparison with a well established code, of a part of analysis stage, is of great interest in order to understand how we have designed buildings in these years.

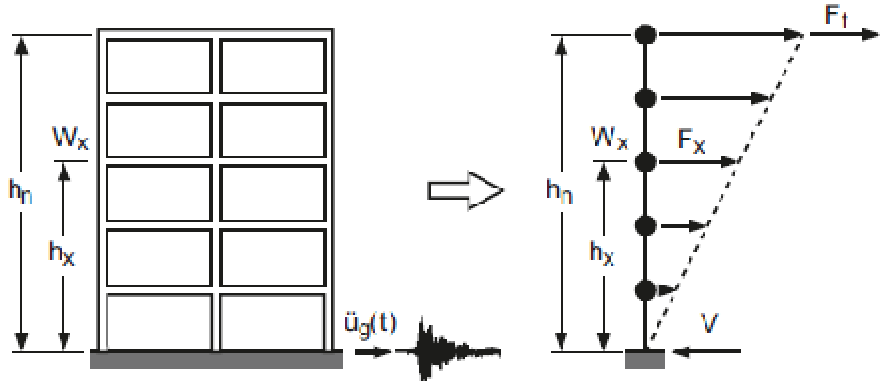
EQUIVALENT LATERAL FORCE PROCEDURE

Different areas of the world are considered as 'earthquake territories', and when building in these areas, it is necessary to consider seismic forces when designing any structure. Albania, has a relatively high rate of seismicity, so while doing structural calculations and designing structural elements it is very important to take into consideration the seismic risk. There are several methods which can be used for seismic analysis, such as Time History Analysis, Pushover Analysis, Response Spectra Analysis, or Equivalent Lateral Force Procedure. While the first two ones are mainly used for academic purpose, the third and fourth are widely used in the design sector of the buildings.

Equivalent Lateral Force Procedure is a very useful tool of estimating the seismic effect on the structure and it is widely used, although it also has some limitations. This method is generally used in relatively regular buildings, although some modifications have achieved to get good results even for high rise buildings.[1] The biggest advantage of this method is its simplicity in calculations in comparison with the other methods. For this reason it is the most commonly used design procedure, and has been codified in various forms since the 1960s.[2]

Seismic loads are different in their action and are not proportional to the exposed area of the building, but rather are proportional to the distribution of the mass of the building above the particular level being considered. Earthquakes apply loads to structures in an indirect fashion. The ground is displaced and since the structures are connected to the ground, they are subjected to sudden movements. These movements generate accelerations in the building leading to differential movement of the building levels. These deformations cause horizontal shears to be produced. Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.[1] Calculations of base shear depend mainly on soil conditions at the site, proximity to potential sources of seismic activity, level of ductility, total weight of the structure and its fundamental natural period of vibration. Equivalent lateral force procedure determines the base shear based on empirical formulas, and then distributes it to each floor as trying to equilibrate the seismic load. There are many equations which are used to determine base shear, and they can be found in codes. Each formula calculates the seismic force as a fraction of the building's weight.

Fig. 1. Static lateral seismic force distribution.



It is clear that no external forces are applied above ground by earthquake, but rather it is the time varying inertial forces which are replaced by equivalent static forces that are applied to each floor level. Equivalent Lateral Force Procedure is based on the fact that the first mode is dominant for earthquakes and some structures undergo some inelastic deformation during earthquake.[4] The free body diagram of the structure, when subjected to seismic excitation, is considered to be a simple vertical cantilever with lumped masses. In this method, design seismic forces are determined by a linear elastic static analysis of the structure.

EQUIVALENT LATERAL FORCE PROCEDURE KTP 2-89 VS. ASCE 7-02

Equivalent Lateral Force Procedure based on KTP 2-89[5]

The horizontal seismic force E_{ki}, acting at the point(floor) 'k' and corresponding to the 'i'-th mode of vibrations, is obtained from the formula:

$$E_{ki} = k_E\, k_r\, \psi\, \beta_i\, \eta_{ki}\, Q_k$$

Where:

k_E – seismic coefficient, which represents the ratio of the ground acceleration to gravity acceleration, g. This coefficient correlates the seismic intensity of the site and the category of soil.

Table 2 Seismic Coefficient k_E

Category of Soil	Seismic Intensity (MKS-64)		
	VII	VIII	IX
I	0.08	0.16	0.27
II	0.11	0.22	0.36
III	0.14	0.26	0.42

k_r –building importance coefficient, represented as table 5 in KTP 2-89, takes the values from 0.5 to 4. For residential buildings k_r is taken as 1.0.

ψ- structural coefficient, values of which are taken from table 4 in KTP 2-89. For RC structures with brick masonry infilling walls not participating in seismic force resistance:

a) $h/b \le 15$ $\psi=0.25$
b) $h/b \ge 25$ $\psi=0.38$
c) $15 \le h/b \le 25$ *interpolation needed*

Where: h- column height; b- the dimension of the cross section of column, parallel to the direction of seismic force.

β_i - dynamic coefficient corresponding to the i-th mode of vibration, is related with the type of soil on the site and is expressed as a function of the natural period T_i. It takes values within the response spectrum values on the graph represented on KTP 2-89.

1) *Soil category 1-* $0.65 \le \beta_i = 0.7/T_i \le 2.3$
2) *Soil category 2-* $0.65 \le \beta_i = 0.8/T_i \le 2.0$
3) *Soil category 3-* $0.65 \le \beta_i = 1.1/T_i \le 1.7$

η_{ki} –seismic load distribution coefficient, corresponding to each level ''k'':

$$\eta_{ki} = \phi_{ki} \frac{\sum_{j=1}^{n} Q_j \cdot \phi_{ji}}{\sum_{j=1}^{n} Q_j \cdot \phi_{ji}^2}$$

Equivalent Lateral Force Procedure based on ASCE 7-02[4]

1. *The fundamental natural period of a building, T, is the time required for the building to go through one complete cycle of motion. It is depended on mass and stiffness.*

TABLE 1 VALUES OF APPROXIMATE PERIOD PARAMETERS C_t AND x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Eccentrically braced steel frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a] Metric equivalents are shown in parentheses.

$$T_a = C_t h_n^x$$

C_t- building period coefficient
H_n – height of the highest level of the building

2. *Design Spectral acceleration S_{D1} and S_{D2} are determined from seismic maps. They provide the estimate intensities of design earthquakes with T=1 second (S_{D1}) and with T= 0.2 seconds (S_{DS}). The number obtained is a proportion of g.*

3. *The response modification factor accounts for the dynamic characteristics, lateral force resistance, and energy dissipation capacity of the structural system. Its values range 1.25-8, for brittle to ductile structures. For RC frames R=4.*

4. *Importance Factor, I→I=1.0 residential buildings.*

TABLE 3 IMPORTANCE FACTORS

Occupancy Category	I
I or II	1.0
III	1.25
IV	1.5

5. *The effective seismic weight of a building, W.*

W=Dead Load + 25% Live Load + 20% Snow Load

6. *Total static lateral base shear in a given direction is calculated with the formula:*

$$V = \frac{S_{D1}}{T\frac{R}{I}} W$$

This value should be within the minimum and maximum calculated values of shear:

$$V_{min} = 0.0445\, S_{DS} I W \qquad V_{max} = \frac{W S_{DS}}{\frac{R}{I}}$$

For buildings not exceeding 5 stores, with a relatively uniform distribution of mass and stiffness in height, or for residential buildings whose stories height are almost the same, and having a fundamental period of less then 0.4 sec, other formulas presented in the code, can be used. *Q_k- the weight of the lumped mass at point (level) ''K'' which is determined considering the design loads reduced by combination coefficients:* *Q_k=0.9*DL + 0.8 LL + 0.4 Short term LL*	*7. The portion of the base shear V, to be distributed to a particular floor is determined with the following equation:* $F_x = \frac{W_x h_x^k}{\sum_{i=1}^{n} W_i h_i^k} V$ *F_x= lateral seismic load to be applied to be applied* *W_i&W_x- the weight assigned to level level i and x* *n= floor level in question k= distribution exponent* *If $T \leq 0.5$ seconds => k = 1.0* *If $0.5 < T \leq 2.5$ seconds =>* $k = 1 + \frac{T-0.5}{2}$ *If $T > 2.5$ seconds => k = 2.0*

While both codes calculate the seismic load as a percentage of the vertical load of the structure, they use different approaches to fulfill that goal. The main formula upon which the calculations are derived is: $V = S_a*M$, where S_a is the design value of the spectral acceleration, and M is the mass of the structure calculated from the load combination as found in each code. Differences in results between the two codes might be from spectral acceleration, as well as from the mass calculations according each code. The design base shear is determined as a function of the elastic period of the building, subject to certain limitations for very flexible structures.[1]

Table 4 - Soil Categories according to KTP

Soil Category	Description of soils
I	-All kinds of rocks (excluding weathered rocks) -Compact gravel Marl (not weathered)
II	Weathered rocks and marls -Gravel sands, coarse and medium grained sands compact and semi compact -Fine grained sand-compact -Clayey sand and sandy clay stiff, semi-stiff, and stiff-plastic
III	Fine grained sand—semicompact Dusty sand compact and semi compact Clayey sand and sandy clay from medium stiff to soft plastic -Clay from medium stiff to soft plastic

Table 5- Site Classification according to ASCE

Site Class	$\bar{v}_s$
A. Hard rock	>5,000 ft/s
B. Rock	2,500 to 5,000 ft/s
C. Very dense soil and soft rock	1,200 to 2,500 ft/s
D. Stiff soil	600 to 1,200 ft/s
E. Soft clay soil	<600 ft/s
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1

For SI: 1 ft/s = 0.3048 m/s 1 lb/ft^2 = 0.0479 kN/m^2

In the two above tables, there are shown two soil classifications, respectively in Table 4 according to KTP, and table 5 to ASCE. It can be assumed that soil category I from KTP, comprises site class A and B at ASCE classification, while C and D fall under category II. These correlations are important when trying to calculate the Equivalent Lateral Force Procedure for Albanian territory with a foreign code.

REFERENCE BUILDING

A five-story building will be selected as a reference for the case study, reasoning that it is considered as medium raise and that the vast majority of buildings in Albania do not exceed this height. It is assumed to be located in Tirana, on Soil Category II, which in ASCE code it would be compatible with site condition C. As located in Tirana, from the seismic map of Albania we can see that it falls under seismic intensity VIII. The frame of this building consists of a reinforced concrete frame without shear walls, with column dimensions 40x40 cm and beam dimensions 40x30cm. The buildings are regular in configuration with plan dimensions of 20.1 m by 20.1 m with total height of 16m. The assumed occupancy is residence. The roof is considered to be accessible, so live load is calculated for it, too.

For Tirana region, the values of S_{D1} and S_{DS} were taken as 0.173 and 0.595 respectively[6], while for the KTP calculation, the period was calculated from the approximated formula: T=0.1n, where n is the number of stores. In the weight calculation, the snow load for ASCE case and the short term live loads for KTP were neglected. The calculations for lateral forces and overturning moment were done by developing an excel sheet.

Figure 2 – Plan and elevation view of the reference building

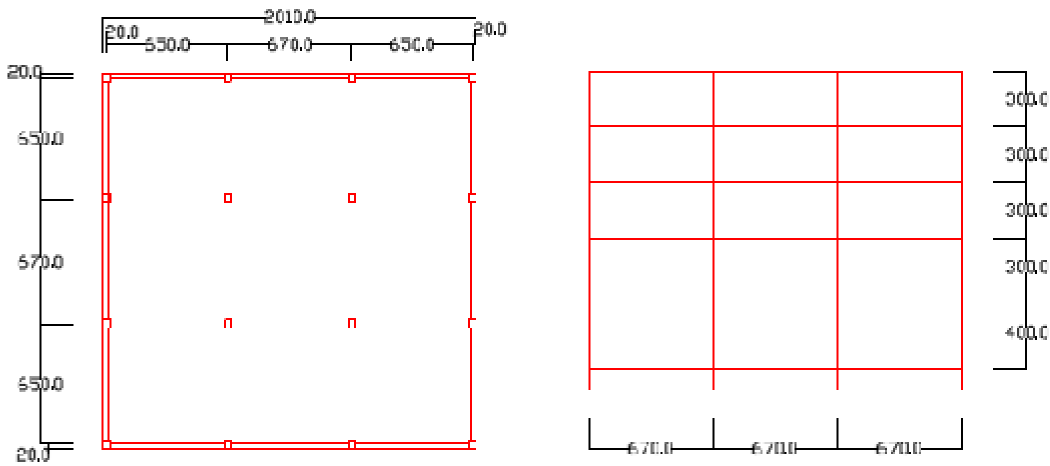


Figure 3 – Spreadsheet calculating base shear and overturning moment based on KTP 2-89

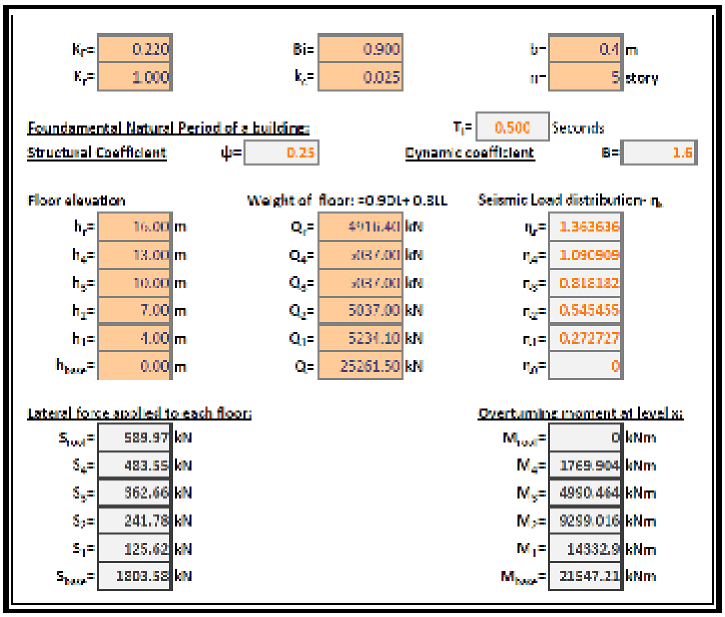
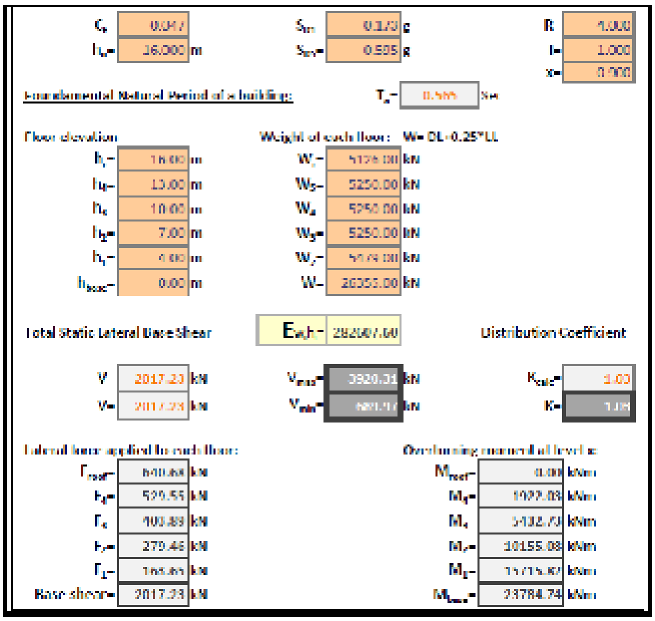
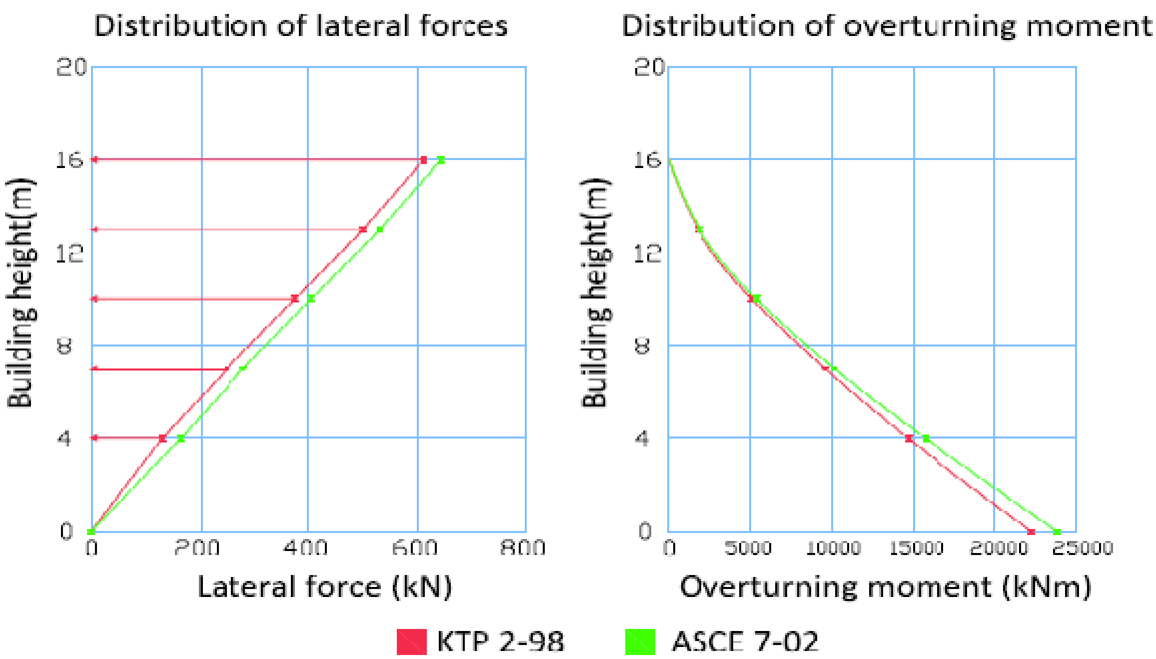


Figure 4 – Spreadsheet calculating base shear and overturning moment based on ASCE 7-02



The above results are also plotted in the graphs in Figure 5. It is clear that ASCE 7-02 is more conservative. The calculations for each code show a difference of 10.6% for the base shear, and 9.3% for the overturning moment at the base. The reason of this difference might be from various reasons, starting from the approximated formula used to calculate the period. One reason of this difference is the fact that the two codes use different load combinations to obtain the gravitational load of the structure, which is then used to calculate the base shear. It is clear from the above example that the calculated load vertical load from KTP is less then the one from ASCE. While KTP 2-89 uses Q = 0.9 * Dead Load + 0.8 * Live Load, ASCE 7-02 calculates it as: W= Dead Load + 0.25 * Live Load. The fact that ASCE indicated the live load for residential buildings as 2 kN/m^2, and KTP as 1.5 kN/m^2 has its weight on the difference in the result. It should be mentioned that in 2005, ASCE 7 was republished with some changes in ELF procedure, increasing the base shear to the maximum value calculated with the formula of V_{max}, and making this code even more conservative.

Figure 5- Distribution of lateral forces and overturning moment along the height of the building



CONCLUSION

The objective of this paper is to describe the Equivalent Lateral Force Procedure based on two different codes, ASCE 7-02 and KTP 2-89. Although the logic of calculations is the same, the codes show large differences especially in the detailing of the information. In the KTP code, the information is limited and there are not many clauses which could categorize different cases. The shown difference is not considered as out of range, but taking into account the situation in Albania for the past twenty years and the rapid urbanization process, this issue raises some concerns. Provisions could be take to increase the percentage of dead load in the weight calculation from 90% to 100%. The process of translation and implementation of Eurocode 8 will surely diminish the actual differences, but problems might be found in the existing buildings.

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