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Effects of Prestressing Force on Column, Frame Consider Construction and Tensioning Sequence

Abstract: The paper presents the effects of prestressing force on column, frame in prestressed concrete structures associated with construction and tensioning sequence. By expanding basic equations of presstressed concrete structure explain the dependence of internal force on construction and tensioning sequence is also established in this paper. Subsequently, two ways to analyze the tendons are normal and nonlinear staged construction in Etabs software is intended for verifying the accuracy of expanded equations. Besides, the paper introduces the way to analyze the tendons in global model Etabs (nonlinear staged construction) for gaining a reasonable result in accordance with construction and tensioning sequence in practical design. The nonlinear staged construction analysis to consider effects of construction and tensioning sequence to distribute internal forces on slabs, columns and frames associated with construction sequence. The behaviors of the column include bending, shear, tension (compression) due to prestressing force easily determine before combination with other actions in design.

Contact: ***Phạm Thành Công****, Independent research and Director at Việt Thành Công Consulting Construction Company 43/32 Trần Thị Do street, Hiệp Thành Ward, 12 District, Hồ Chí Minh City, VietNam.*
Email: *cong.iso.nolimit@gmail.com*

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INTRODUCTION

In prestressed concrete structures, to determine effects of presstressing force on structures T. Y. Lin [1] introduces load balancing method. In load balancing method, the interaction between tendons and concretes replace it with the forces the tendon exerts on the structure when in place as well as a constant compression force. The replaced forces are comprised of upward and downward forces resulting from tendon profile, called equivalent load or balanced load. The next, the primary moment concept $M_p = Py$ (1) due to eccentricity y of the prestressing force P at any location, secondary moment $M_{sec} = \Sigma R_i x_i$ (2) due to reactions at any location, balance moment $M_b = M_{sec} + M_p$ (3) is sum of primary and secondary moment are completed by Aalami BO [2],[3],[4]help the engineers to approach to prestressed concrete structures easily. In this theory, balance moment is determined through appling to the system a balanced force and compression force, and then directly secondary moment is determined through reactions or balance moment subtract primary moment. Initial researches made foundation to develop prestressed concrete industry, a optimized solution, wide applied range in construction. The tendons are arranged in horizon element such as beams, slab to reduce tension stress, reduce deflection and crack. Vertical elements is not because inherently they are subjected to compression. Therefore, the engineer's main concern is the effects of prestressing force on beams, slabs and their effects on column are usually ignored. Besides, these theoris present the effects on beams, slabs only without on columns. Furthermore, most current standards in over the world as American Standard ACI-318 [5], European Standard EN 1992-1-1 [6] or Vietnam Standard TCVN 5574-2018 [7]…not refer to the effects of prestressed force on columns. Thus, the consideration for the effects of prestressed force on columns are depend on the engineers and are usually disregarded. In practical designs, the balanced load is in the opposite direction and equal to (0.8-1)self-weigh, this mean that there is no bending moment or there is a litle bit on the column. It is significant for exact determination of effects of presstresing force on column.

Recent researches investigated the effects of prestressing force on column based on relation between the horizontal equivalent stiffness of column and beam what was conducted by Wang Li and associates [8]help distribute secondary moment from beams to columns; besides, it indicate the impact of construction and tensioning sequence on internal forces. However, firstly the distribution of balance moment to column dose not refer; secondly a theory or a mathematical model to explain the impact of construction and tensioning sequence on internal forces dose not establish on the other hand it found out phenomenon but cause.

The paper makes mathematical model clear to consider the effects of prestressing force on columns clear based on the equilibrium of the column, beam associated with construction sequence; besides, the paper presents the way to make and analysis model with the tendons element in Etabs in practice design.

THE EFFECTS OF PRESTRESSING FORCE ON COLUMN IN TENSIONING TIME

Considering a prestressed frame as Figure 1 and tensioning, the effects of prestressing force are carried out as follows:

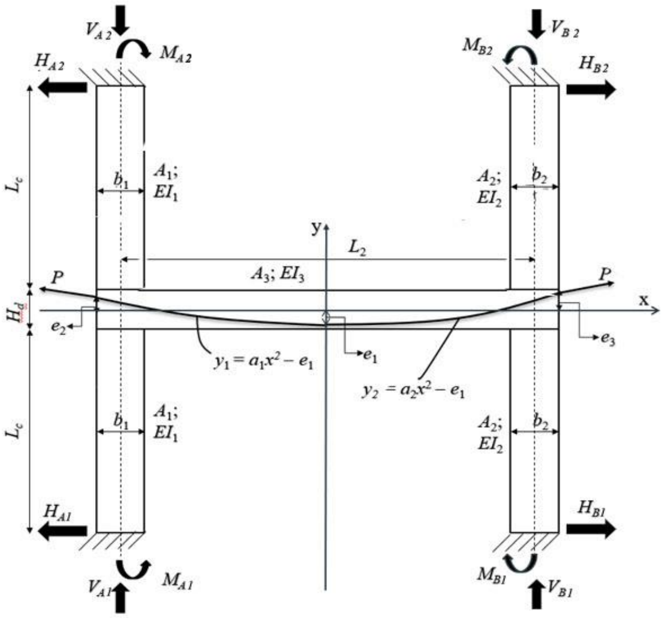

Figure 1. The one-span prestressed frame

At the location *x* on beam as Figure 2

Phạm Thành Công

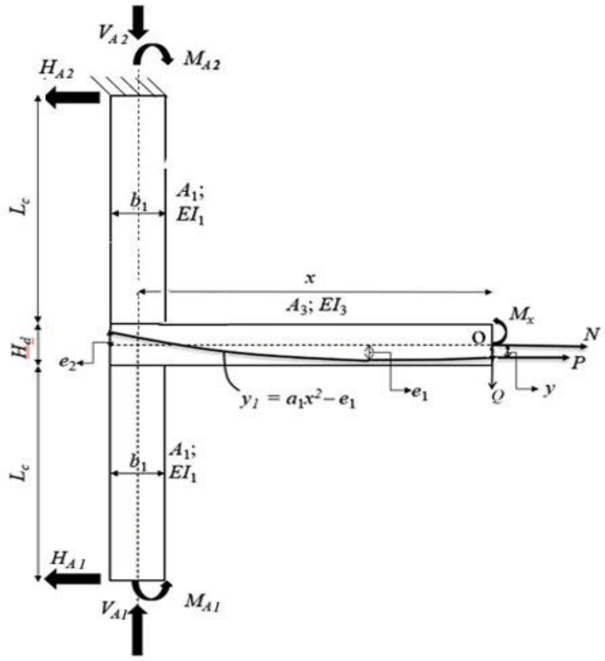

Figure 2. The equilibrium at location *x* on beam

The balance moment M_x which is sum of moment due to reactions and moment due to eccentricity of prestressing force at location *x* figure out in sum of moment about point O, rewrite according to definition of equation (3):

$$\begin{aligned} \Sigma M &= M_{A1} - M_{A2} + H_{A2}L_1 - H_{A1}L_1 + V_{A2}x - V_{A1}x + M_x + P\left|y\right| = 0 \\ \Rightarrow M_x &= -M_{A1} + M_{A2} - H_{A2}L_1 + H_{A1}L_1 - V_{A2}x + V_{A1}x + Py \end{aligned} \quad (4)$$

where L_1 is distance from axial beam to bottom column.
M_{A1}, H_{A1}, V_{A1} are reactions of the bottom of below column at tensioning time t_1.
M_{A2}, H_{A2}, V_{A2} are reactions of the top of above column at tensioning time t_1.
If taking moment due to reations only in equation (4), the engineers obtain secondary moment M_{sec} according to definition of equation (2):

$$M_{\text{sec}} = -M_{A1} + M_{A2} - H_{A2}L_1 + H_{A1}L_1 - V_{A2}x + V_{A1}x \quad (5)$$

Similarly, the equilibirum of column in Figure 3

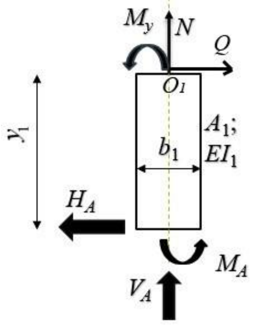

Figure 3. The equilibrium at location *y* on column

Phạm Thành Công

Because there is not prestressing force in column, both balance and secondary moment determine according to definition of equation (2) and (3):

$$\begin{aligned} &\Sigma M = M_{A1} - H_{A1}y + M_y = 0 \\ &\Rightarrow M_y = -M_{A1} + H_{A1}y_1 \end{aligned} \tag{6}$$

Equation (6) makes the bending moment of prestressing force to column clear, the other effects including shear, tension (compression) also make clear through the other equilibrium. These effects only depend on reactions due to prestressing force acting to support. Therefore, it can be applied for every situation.

At earlier time t_2 of tensioning (not yet above columns), making in the same as manner, the equilibriums in equations (4) – (6) are maintained other than different reactions. The difference of reactions induce variable moments in equations (4) – (6), becomes:

$$\begin{aligned} &\Sigma M = M_{A1}* - H_{A1}*L_1 - V_{A1}*x + M_x + P|y| = 0 \\ &\Rightarrow M_x = -M_{A1}* + H_{A1}*L_1 + V_{A1}*x + Py \end{aligned} \tag{7}$$

$$M_{\sec} = -M_{A1}* + H_{A1}*L_1 + V_{A1}*x \tag{8}$$

$$\begin{aligned} &\Sigma M = M_{A1}* - H_{A1}*y + M_y = 0 \\ &\Rightarrow M_y = -M_{A1}* + H_{A1}*y_1 \end{aligned} \tag{9}$$

where $M_{A1}*$, $H_{A1}*$, $V_{A1}*$ are reactions of the bottom of below column at tensioning time t_2.

Example: in Figure 1 (t_1 time) let:

Frame: L_c = 2.70 m; L_1 = 3.00 m; L_2 = 7.60 m.

Column A: b_1 = 0.40 m; h_1 = 0.40 m; I_1 = 0.00213 m^4; A_1 = 0.16 m^2.

Column B: b_2 = 0.40 m; h_2 = 0.60 m; I_2 = 0.00320 m^4; A_2 = 0.24 m^2.

Beam: b_d = 0.30 m; h_d = 0.60 m; I_3 = 0.00540 m^4; A_3 = 0.18 m^2.

Tendon: e_1 = 0.20 m; e_2 = 0.10 m; e_3 = 0.20 m; a_1 = 0.0188; a_2 = 0.0250; P = 146 N.

determine balance and secondary moment.

Results show in Figure 4

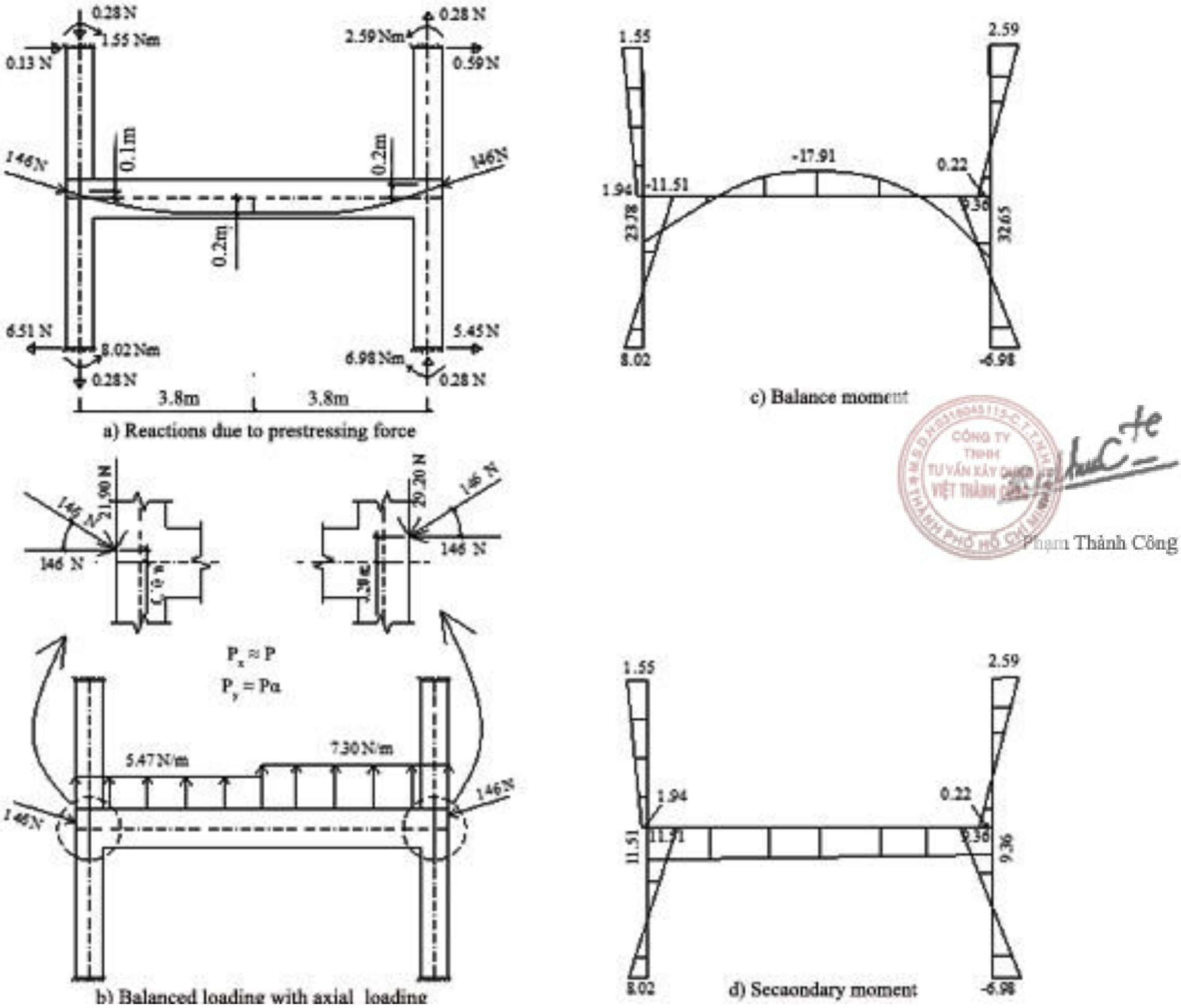

Figure 4. The internal force in one-span prestressed frame (t_1 time)

This frame also, at the earlier time (t_2 time) of tensioning in no above columns, the effects of prestressing force on column show in Figure 5.

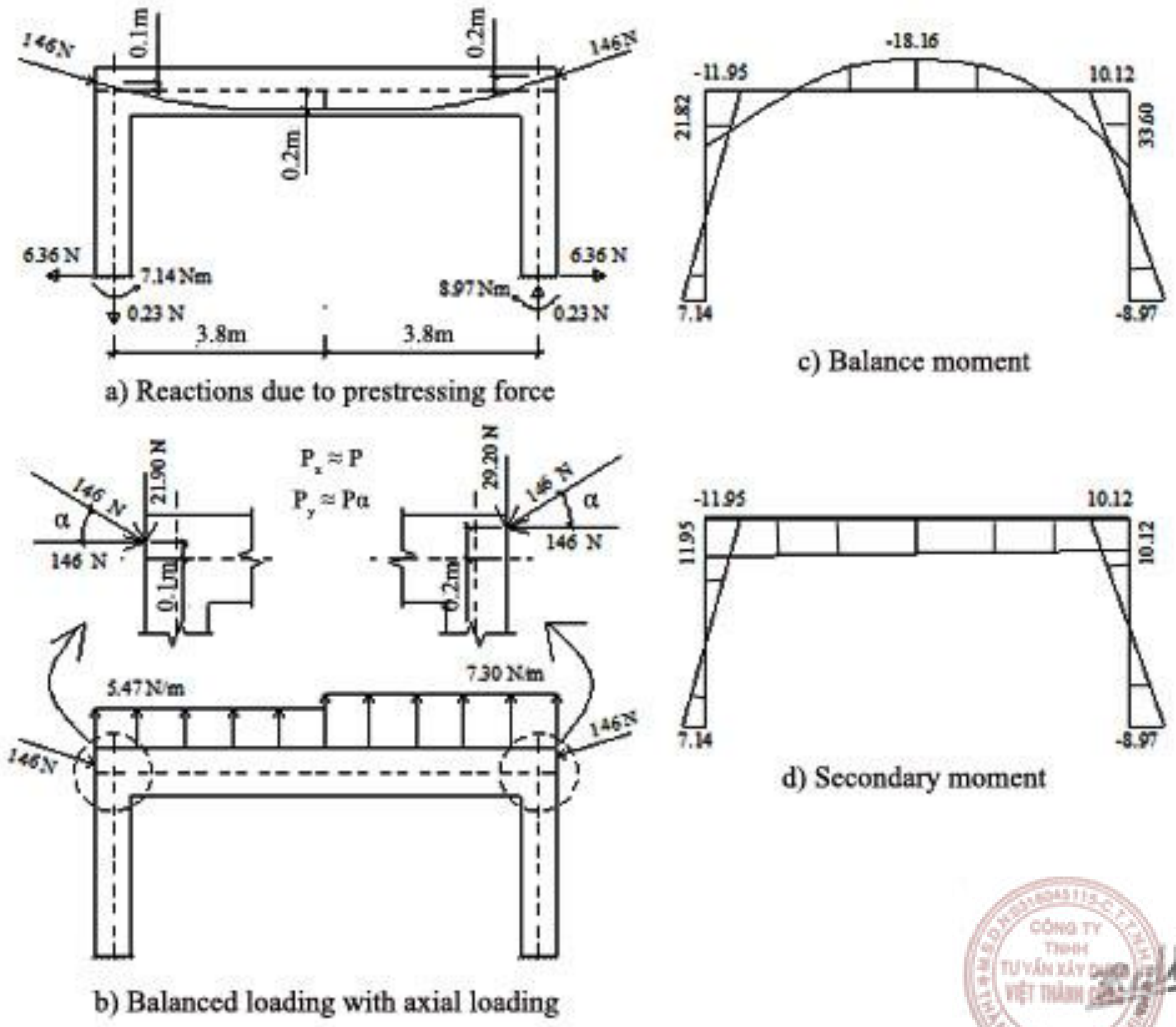

Figure 5.The internal force in one-span prestressed frame (*t_2* time)

Figure 4 and Figure 5: the below columns are different from +10% to -28%, the above columns are absolutely different. These differences indicate the effects of construction, tentioning sequence on the distribution of reactions and internal forces. Where the tendons model as Figure 5 is more appropriate because in reality the tensioning time is realized after concrete is enough strength and before concreting the next story, therefore the reactions do not produce at top of above columns.

APPLICATION TO ETABS SOFTWARE TO DETERMINE THE EFFECT OF PRESTRESSING FORCE ON COLUMN

Simulation of tendons on Etabs software

From Etabs 2018 version onwards, the application allows to simulate the tendons element in to global model. The engineers determine the effects of prestressing force on columns easily; and subsequently, combine with other loads before design. The eigh-story building uses prestressed concrete floor (average span 8m, slab thick 300mm, tendons 12.7mm parabola profile) taken an example in Figure 6. The effect of prestressing force of column in 2-axial frame has result which show in Figure 7.

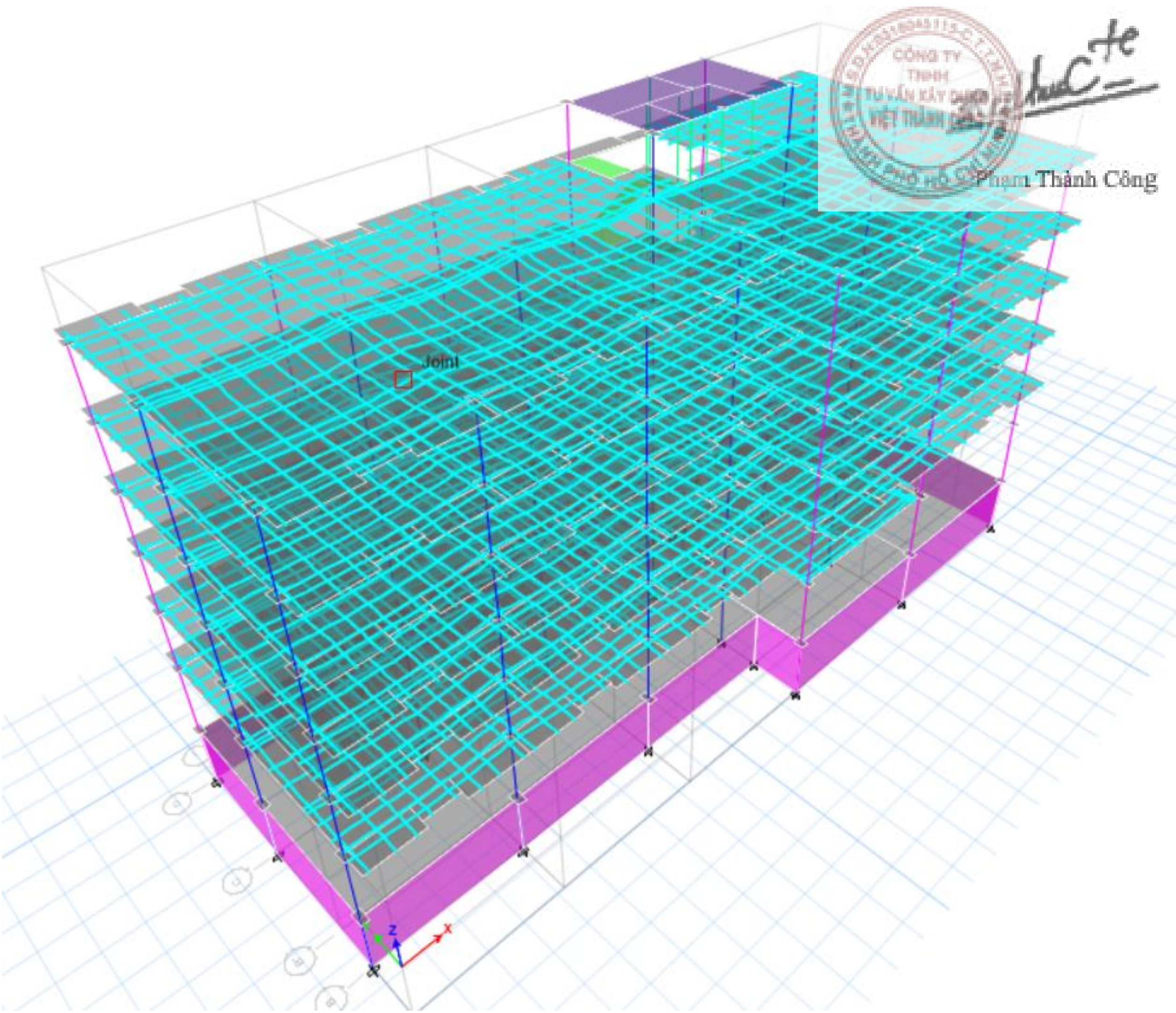

Figure 6. Simulation of tendons in global Etabs

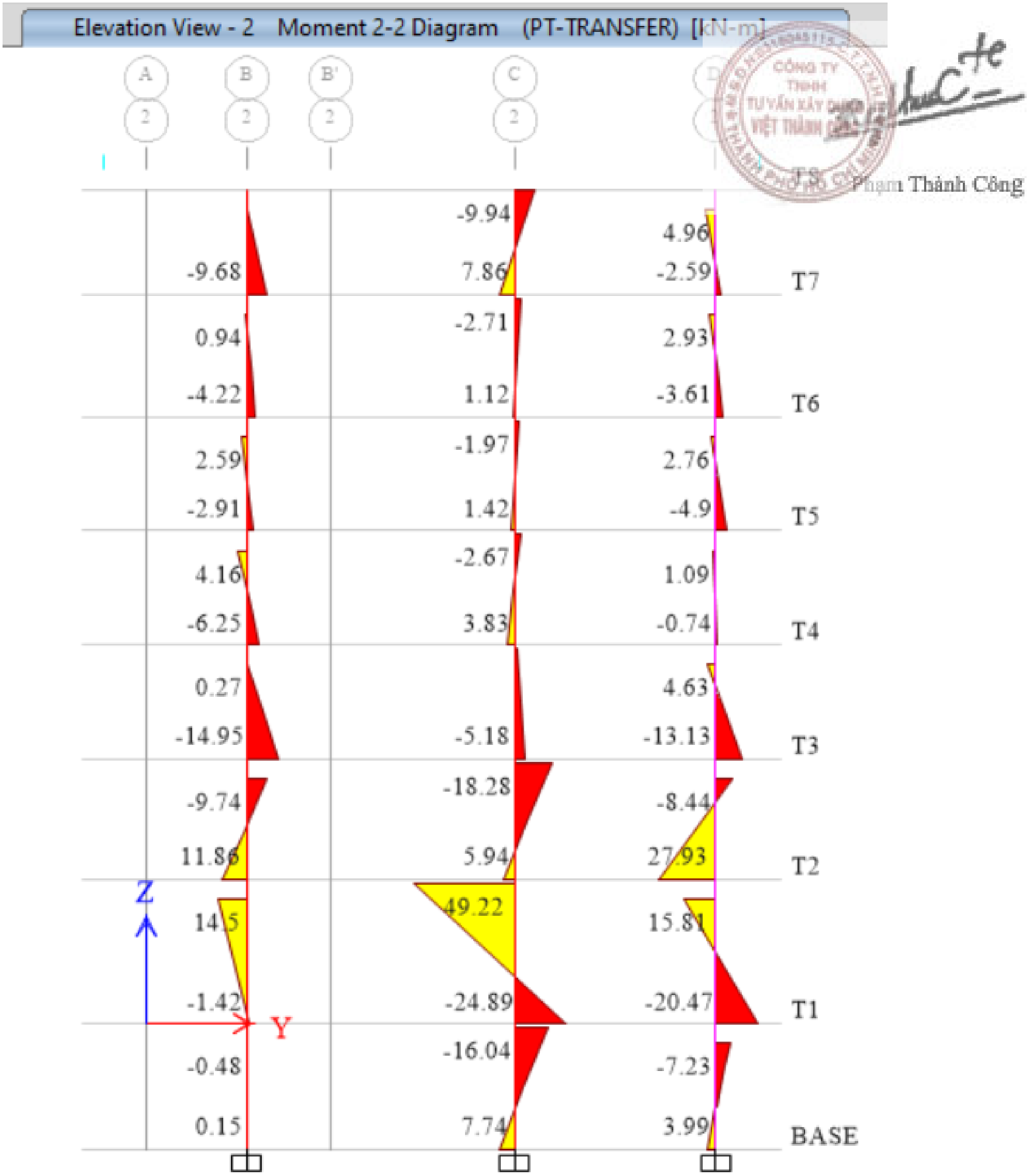

Figure 7. Bending moment in 2-axial frame due to prestressing force (normal analysis)

Nonlinear staged construction analysis

The effect of prestressing force on column show clearly in Figure 7. However, this result is determined by Etabs based on the assumption that the integral casting and one-time tensioning model. In reality, the tensioning is realized after concrete is enough strength and before concreting the next story. The assumption is tensioning in four story in progress (the assumption does not affect result providing that it is not final story). Structural shape and construction order at four story is described in Figure 8.

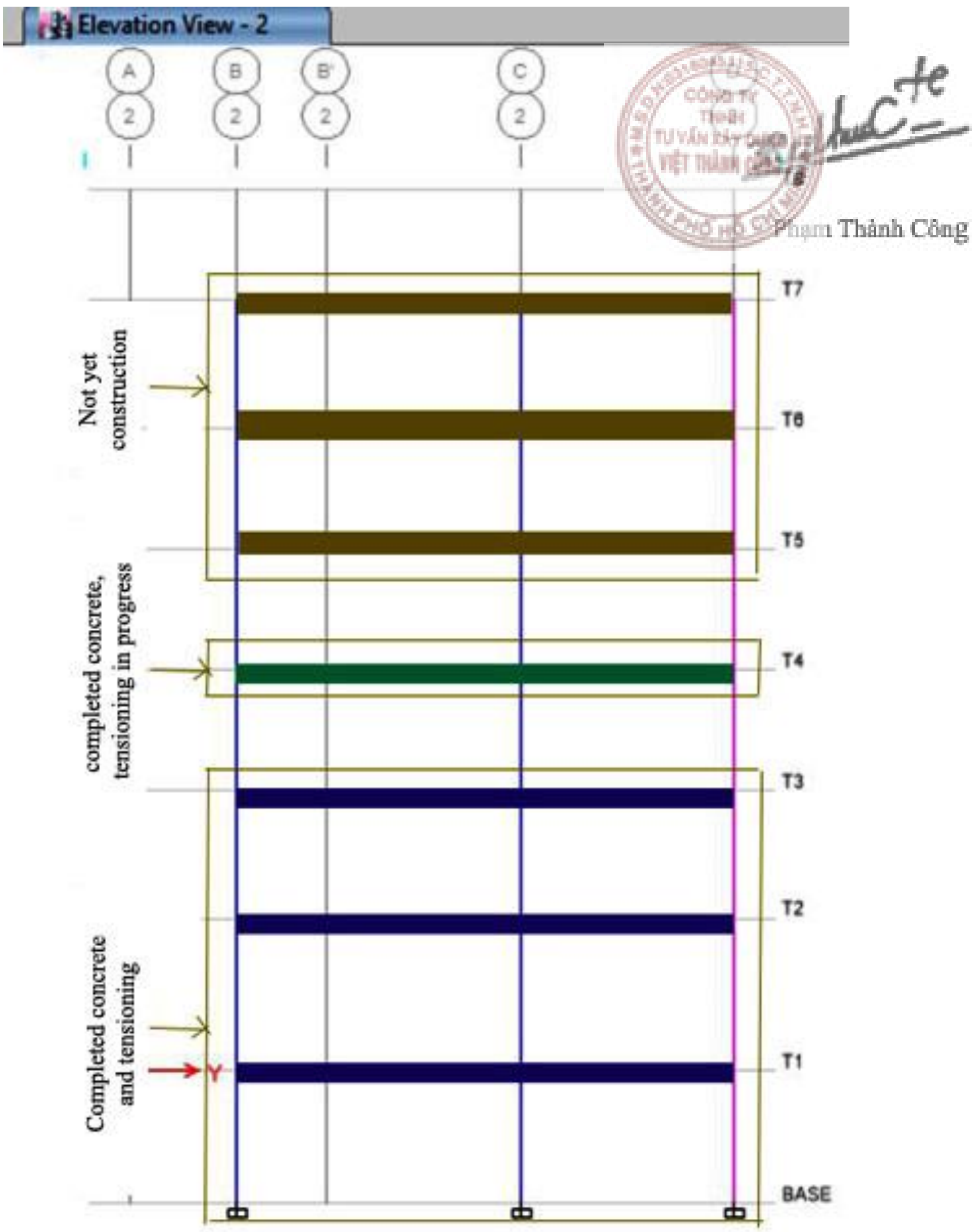

Figure 8. Structural shape in tensioning at the four story

However, the bending moment is unreasonable in Figure 7 show in Figure 9.

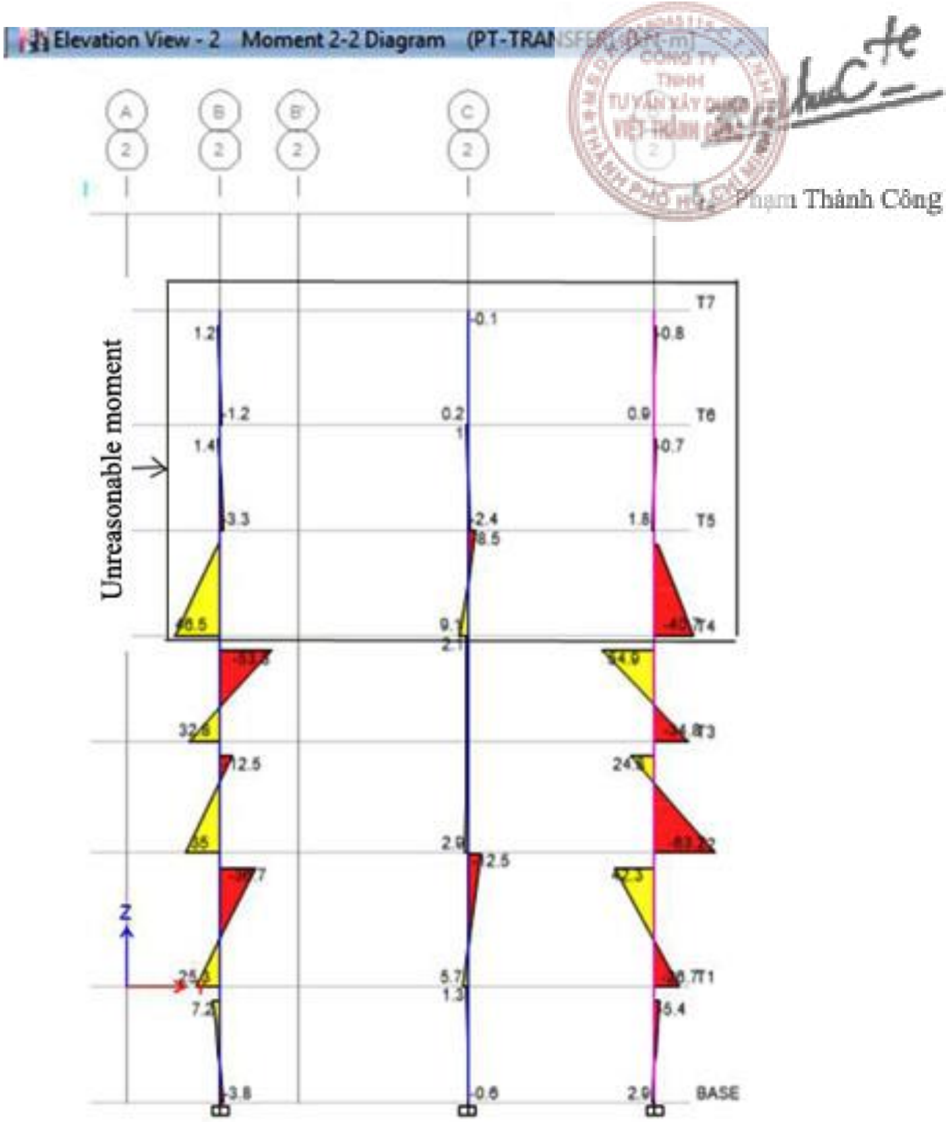

Figure 9. The unreasonable bending moment in tensoning four story (normal analysis)

The bending moment due to prestressing force distributes to the above column from four story is unreasonable because these above columns have not casted or if they have casted, the top of these columns are free therefore they do not take part in distributing moments. To solve this problem, Etabs provides nonlinear staged construction analysis according to Computer & Structure, Inc [9]and Fintel M, Ghosh SK [10]. Nonlinear staged construction analysis includes: nonlinear structural shape considers the formation of a new story which change structural shape; nonlinear geometry considers axial effects of prestressing force which pull the top of columns and make they inclined (especially, edge columns) and thus P-Δ effect is produced, induces to increase the internal force in structure; nonlinear load considers to increase weight and prestressing force step by step. In this analysis, the bending moment due to prestressing force only distributes to below columns and slabs in accordance with actual construction.

In construction sequence, concreting first after tensioning, thus loads in construction sequence include: firtly, sum of self-weight and prestressing force-immediate losses according to Kelley GS

[11] and all losses according to Kelley GS [11] called PT-final. The analysis divides many steps, every step is a story and load defines in Figure 10 and Figure 11 as follows:

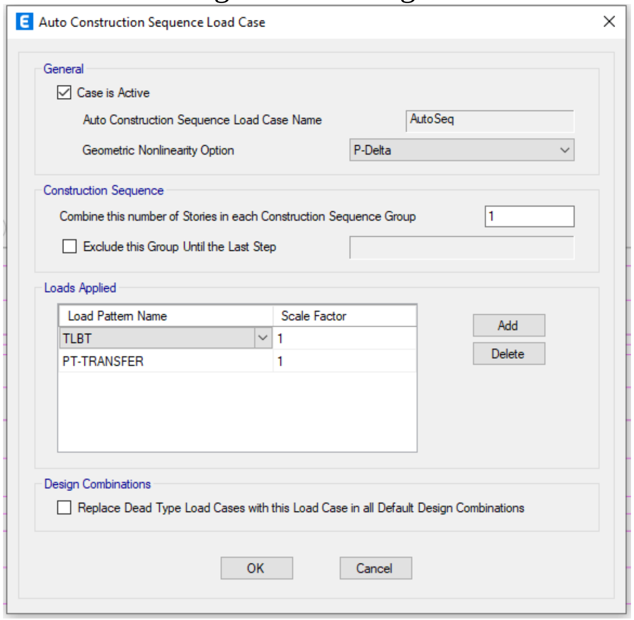

Figure 10. Loads in Nonlinear staged construction analysis (PT-transfer time)

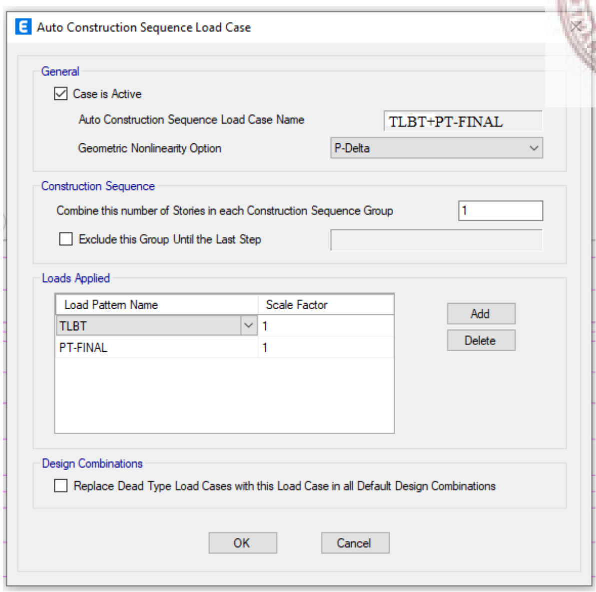

Figure 11. Loads in Nonlinear staged construction analysis (PT-final time)

Selecting loads in nonlinear stage construction analysis depend on sequence of structural shape formation and appeared load respectively. In particular, when four story is under construction has self-weight and prestressing force (PT- transfer and PT-final) only, therefore the engineers consider these one. The other loads as wall load, finishing load, live load and wind load, seismic load (if any) distribute to whole building when the building is completed therefore the paper dose not consider them in stage construction analysis.

Results of internal force analysis

Dependence on intended use, the engineers consider loads in design are at tensioning time (initial time) or final time. When slab design in tensioning time need to consider sum of self-weight and PT-transfer. When slab, column design in final time need to consider sum of self-weight and PT-final before combining with other loads.

a) Tensioning time (initial time)

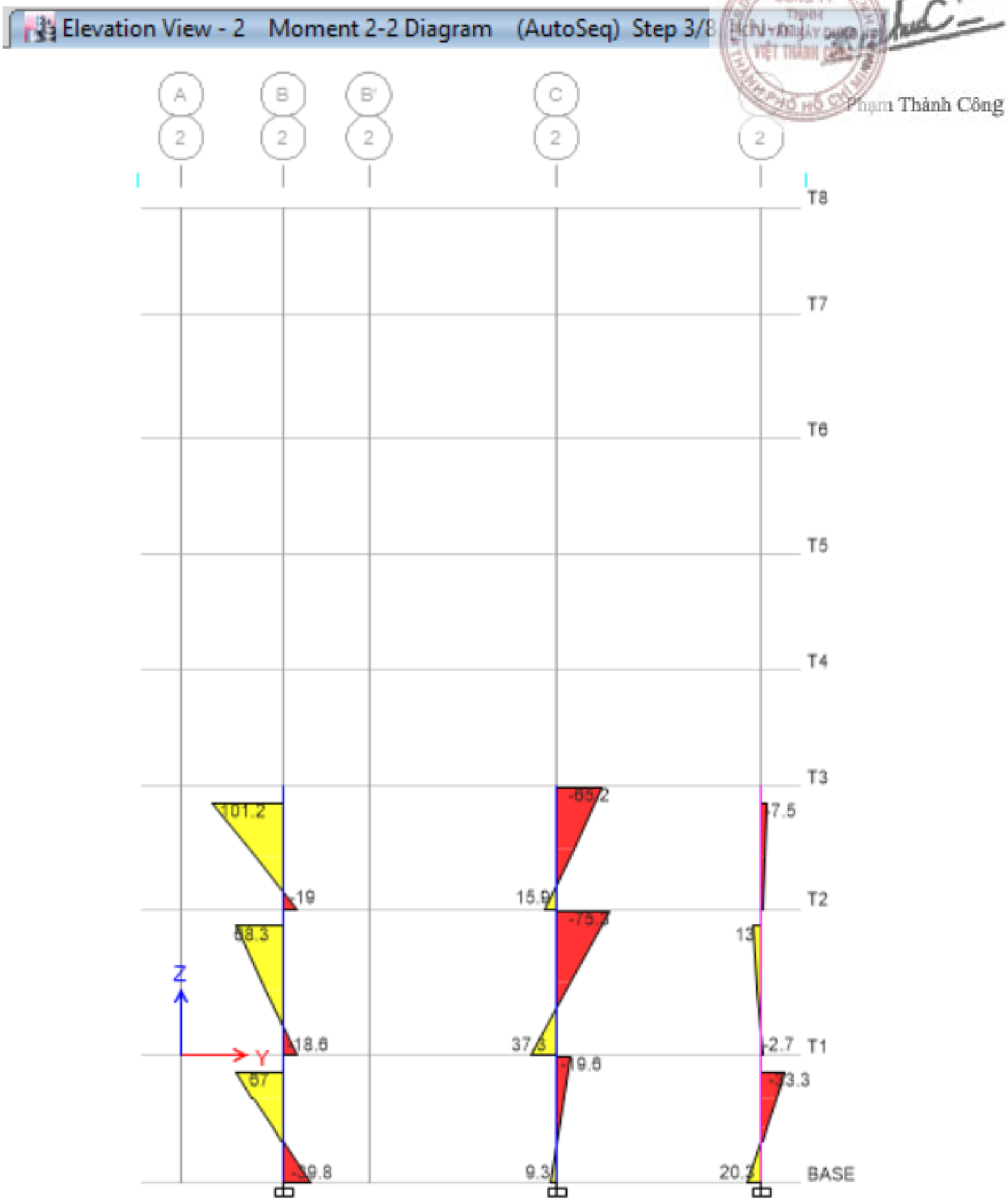

Figure 12. Three-story bending moment at tensioning time (Nonlinear staged construction analysis PT-transfer time)

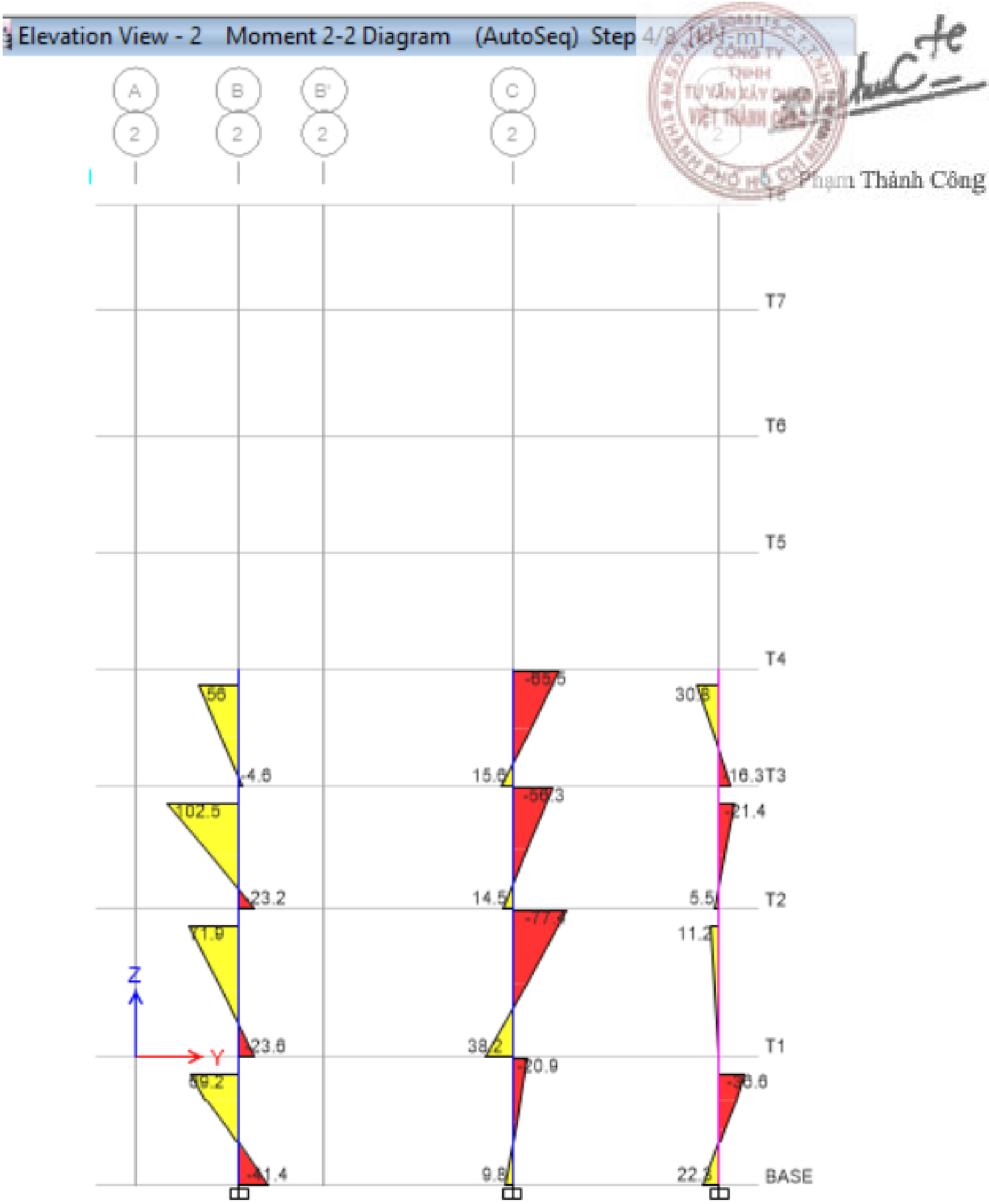

Figure 13. Four-story bending moment at tensioning time (Nonlinear staged construction analysis PT-transfer time)

Figure 12 and Figure 13 are the results of typical analysis step 3 and step 4 in actual construction respectively. Similarly, the effects of prestressing force can find any time. With respect to tensioning time, the engineers take this internal force in every step to calculate, design.

b) Final time

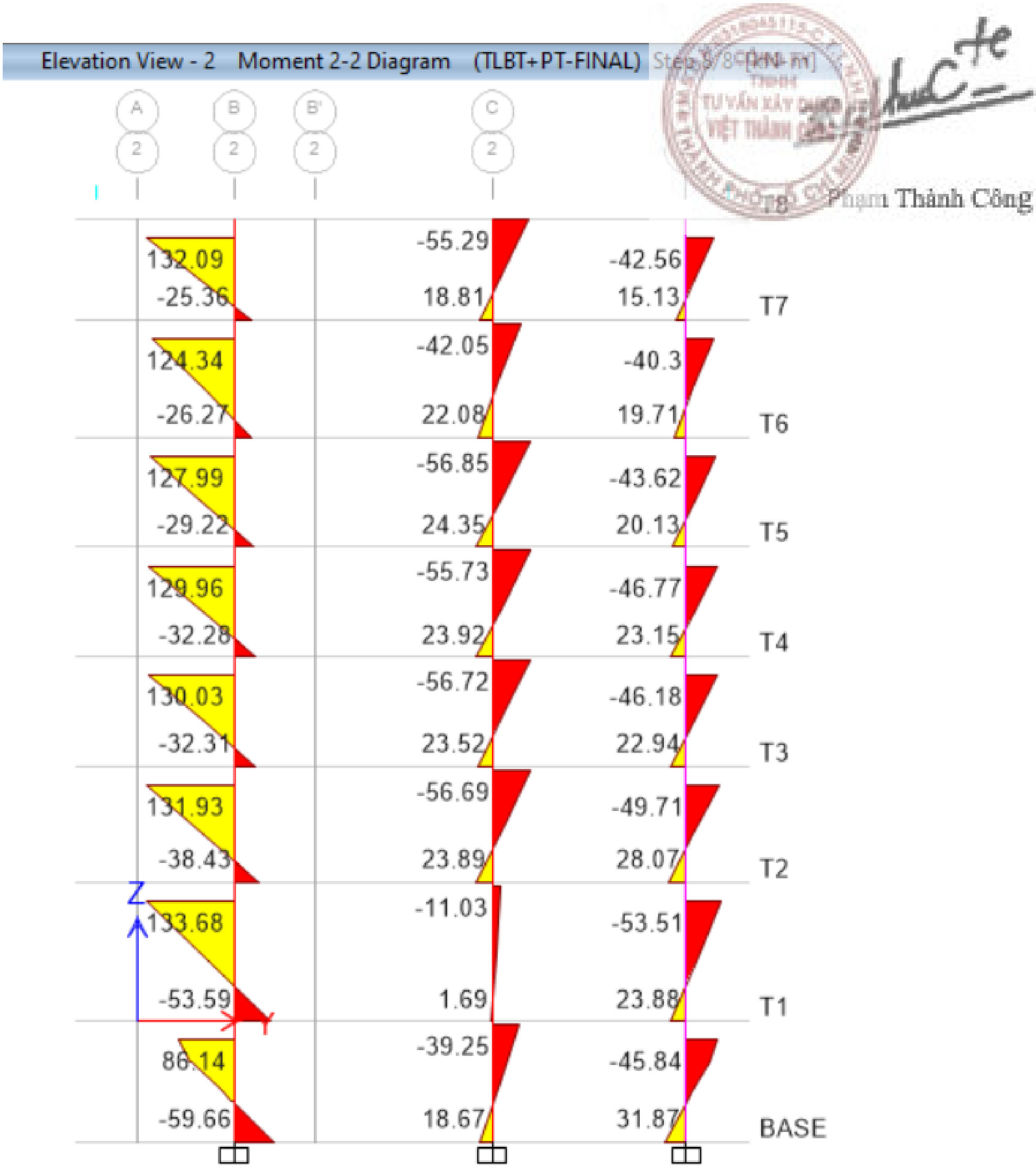

Figure 14. Bending moment at final time (Nonlinear staged construction analysis -PT-final time)

Figure 14 is result of analysis after all loss stress, this result shows total effect of prestressing force from all above story on its below, when the engineers design for ultimate stage must be taken this result into account.

CONCLUSIONS

By expanding the basis equations of presstressed concrete structure for global model, some conclution is drawn:

The paper makes the internal forces in column due to prestressing force clear associated with balance moment and secondary moment.

Because of absence of prestressing force in columns, balance moment and secondary moment are one value. These moments depend on construction and tensioning sequence, a mathematical equation is established to make clear this dependence.

The paper introduces the application for design prestressed concrete structure in global model; finding out the effect of prestressing force on column, frame what are usually ignore or have to export from the separate calculated slab application and then import to global model. In a global model, the engineers find out both the effect of prestressing force on column, frame and its effect on floor to help the design more comprehensive.

Considering the effect of prestressing force on column must be taken construction and tensioning sequence into account. Nonlinear staged construction analysis is very usefull, approprate to rule of prestressed concreate construction: concreting → tensioning → concreting next story.

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Phạm Thành Công