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EQUIVALENT STATIC LOADS TO ENVELOPE DYNAMIC TIME HISTORY ANALYSIS RESULTS

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ABSTRACT

In seismic design of structures, especially when there are extreme forms of irregularities, time history dynamic analysis is used with multiple input acceleration records. This dynamic analysis could be linear or nonlinear. However, using the prodigious amount of results created by time history analysis makes it very difficult, if not impossible, to design every structural component for the maximum seismic demands. In this paper a procedure is introduced to determine the peak structural responses for any structural member from a time history dynamic analysis without doing the extremely tedious post processing. In this method a set of static loads are calculated that are equivalent to the envelope of the time history analysis results. In this method, a few section cuts along the height of the structure are defined (for building structures, it would be one section cut for each floor). For each section cut, the maximum resulting forces and moments (six components for 3D analysis or three components for 2D analysis) are obtained from the entire time history record(s). The next step is to back-calculate the equivalent static lateral forces that will create enveloping section cut forces and moments. Now, if the structure is analysed under these calculated static forces, seismic demand for each structural component would be the maximum of what they would have experienced from the time history dynamic analysis run(s).

Numerical examples are provided to show the accuracy and time savings of the approach.

INTRODUCTION

In many structural engineering projects with either complicated or irregular geometries or due to significance of the structure, the engineers have to use a dynamic time history analysis for the seismic analysis of the structure. Even though the CPU time for finite element software can be very long for such an analysis, the main problem starts when the engineer needs to do the post processing to get the most critical seismic demands in every structural component. This is simply due to the fact that, unlike a static analysis load case that would only create a unique set of structural results, a time history analysis contains several thousand sets of results for every structural element. The size of the output is usually so large that even spreadsheets can't be used for post processing and some form of computer programming needs to be used to scan through the results.

METHODOLOGY

In this paper a methodology is introduced that aims at cutting the post-processing efforts significantly. In this approach, the maximum global response of the structure, during the entire time history analysis record, is determined at a few section cuts along the height of the structure. Then these section cut forces, story shear, and story overturning moments, are used to back-calculate a set of static forces that would yield the

same enveloping results. If the structure is analysed under this set of static loads, the structural response would be approximately the same as the maximum of the dynamic time history analysis. These steps are explained in the following example:

For example, consider a 2D frame, as shown below, subjected to ground accelerations $\ddot{U}_g(t)$ in the horizontal direction.

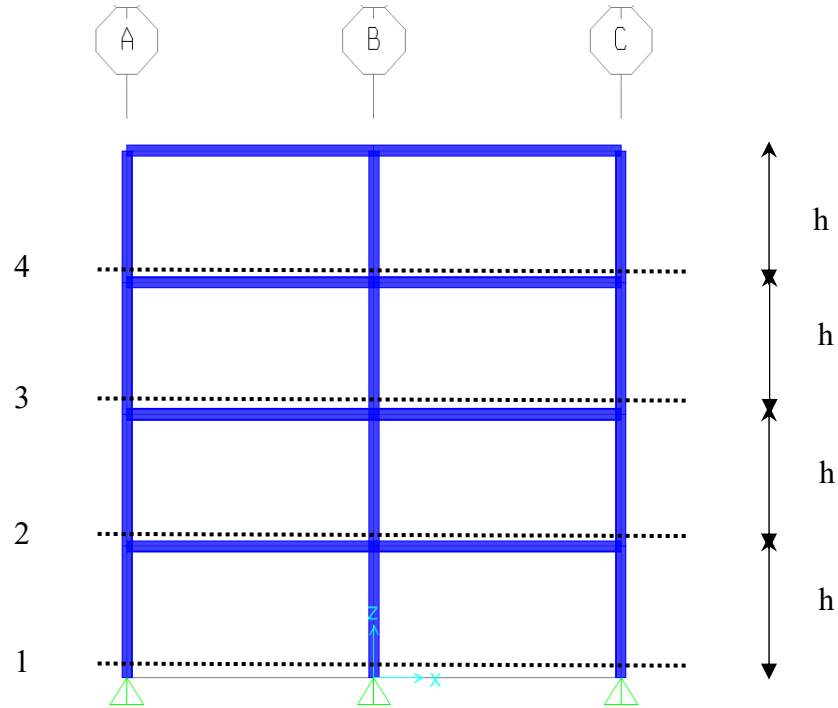


Figure 1. Section Cuts for a 2D Frame Example

At each section cut, the maximum story shear and overturning moment are calculated (total axial forces are zero for a horizontal base acceleration). They are $V_1...V_4$ and $M_1...M_4$. The equivalent lateral story forces that would create the same story shears are shown below:

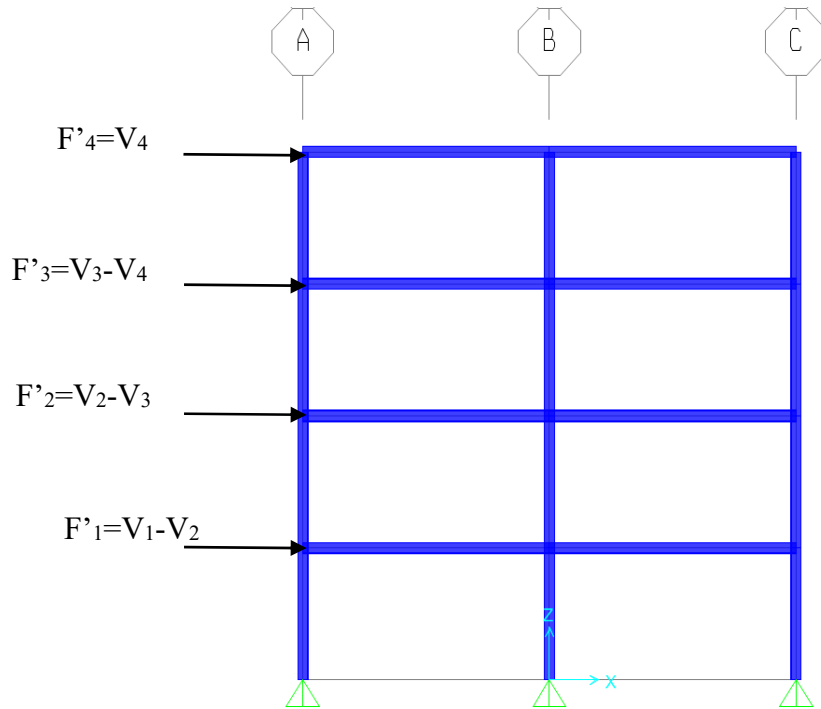


Figure 2. Lateral Story Forces

These story forces, F'_i , will be distributed onto the i^{th} floor as equivalent nodal accelerations to create the same total inertia forces, F'_i . Even though these static forces have equivalent story shears, they will not create the same story overturning moments. To adjust for this imbalance, balancing overturning moments are applied. These overturning moments can be distributed on the columns or shear walls as axial tension/compression forces. Similar to the story forces, these axial tension/compression forces will be applied as nodal accelerations.

Now, the static lateral forces ($F'_1 \dots F'_4$) and overturning moments ($M'_1 \dots M'_4$) are applied as a static load case to the structure and the results, for all structural elements, will be enveloping values in the time history dynamic analysis. In this paper, some numerical examples will be provided to show the accuracy as well as time savings of the approach.

NUMERICAL EXAMPLES

To show the implementation of the methodology explained above, a few examples are presented here.

2D Frame Analysis

A 2D frame is shown below with moment frames subjected to ground acceleration in the horizontal direction. The bays are 24' and floors are 12'. Beams and columns are steel section.

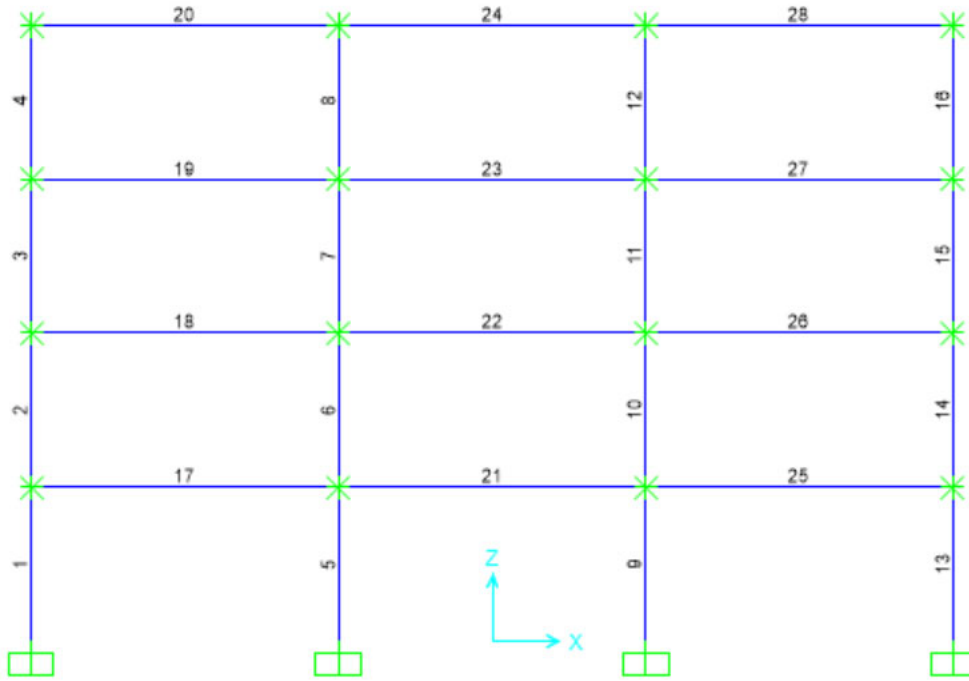


Figure 3. 2D Frame Example

The section cuts are defined right above each floor. The equivalent static forces are calculated as explained above and applied to the model as a static load case. Figures and tables below show the comparison of different structural results between the time history dynamic analysis and the equivalent static analysis.

Table 1: Internal Forces Comparison for the First Floor Column 1

| | T.H. Analysis | Static Analysis | Difference |
|---------------------------------|----------------------|------------------------|-------------------|
| Axial Force (kips) | 8.17 | 8.14 | 0.31% |
| Shear Force (kips) | 4.72 | 4.73 | 0.08% |
| Bending Moment (kips-in) | 499.28 | 498.79 | 0.10% |

Table 2: Internal Forces Comparison for the First Floor Beam 17

| | T.H. Analysis | Static Analysis | Difference |
|---------------------------------|----------------------|------------------------|-------------------|
| Shear Force (kips) | 3.16 | 2.85 | 9.66% |
| Bending Moment (kips-in) | 474.70 | 428.82 | 9.67% |

Table 3: Floor Lateral Displacements Comparison in the X Direction

| Floor | T.H. Analysis | Static Analysis | Difference |
|-----------------|---------------|-----------------|------------|
| 4 th | 2.85" | 2.64" | 7.31% |
| 3 rd | 2.45" | 2.25" | 8.32% |
| 2 nd | 1.70" | 1.54" | 9.40% |
| 1 st | 0.71" | 0.64" | 9.94% |

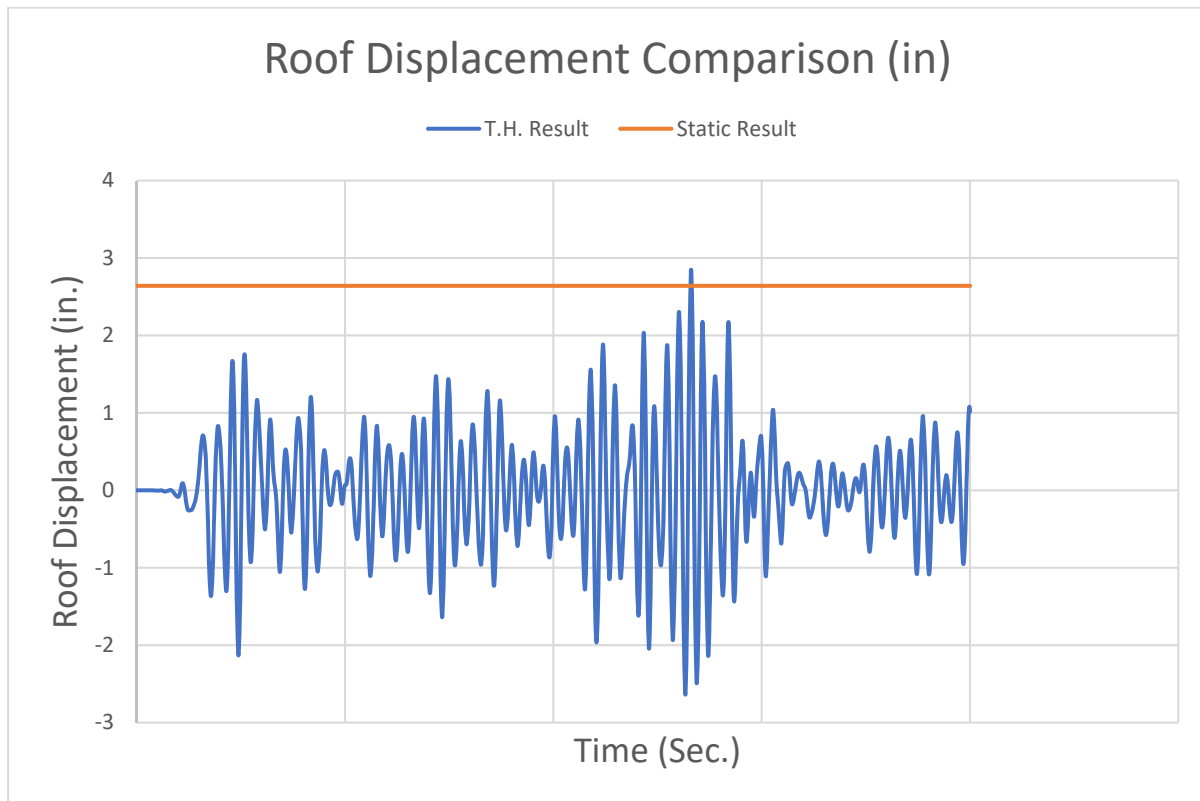


Figure 4. Comparison of the Roof Lateral Displacement

3D Building Analysis

A 5 story reinforced concrete structure with dual lateral system (combined moment frames and shear walls system) and diaphragm is subjected to base acceleration in the X direction. The bays are 24' in the X direction, 26'-7" in the Y direction. Each floor is 15' high.

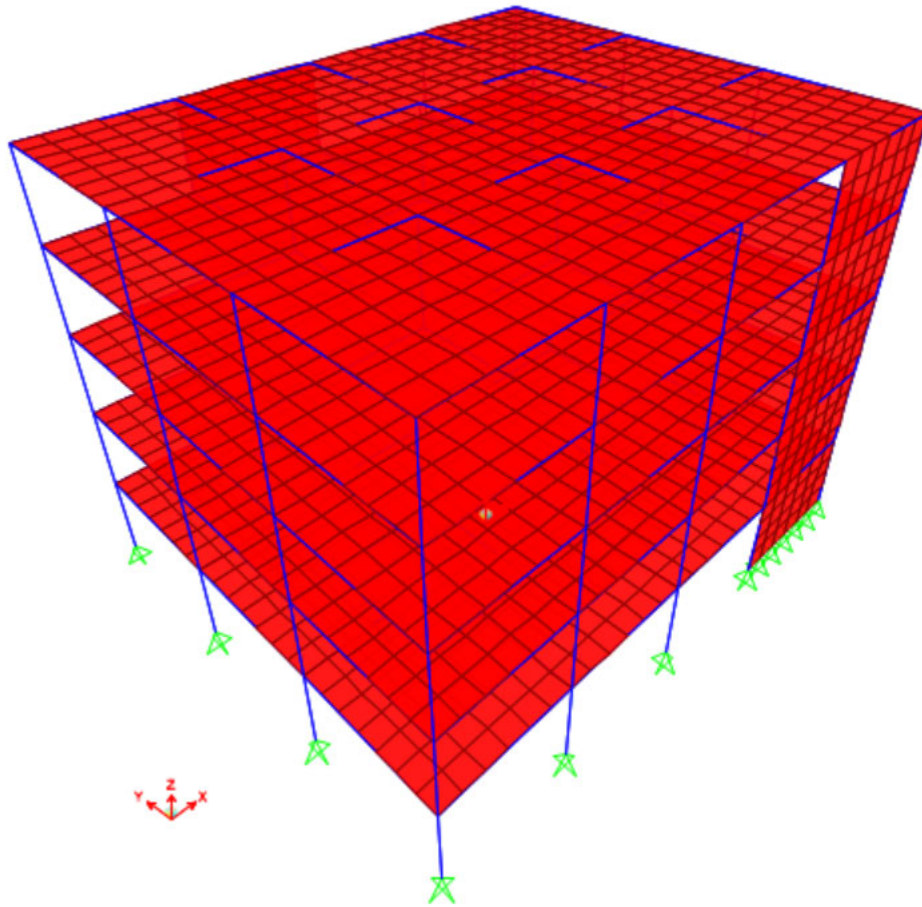


Figure 5. 3D Building Example

The section cuts are defined right above each floor. The equivalent static forces are calculated as explained above and applied to the model as a static load case. Figures and tables below show the comparison of different structural results between the time history dynamic analysis and the equivalent static analysis.

Table 4: Floor Lateral Displacements' Comparison in the X Direction

| Floor | T.H. Analysis | Static Analysis | Difference |
|-----------------|---------------|-----------------|------------|
| 5 th | 4.45" | 4.53" | 1.81% |
| 4 th | 3.34" | 3.44" | 3.07% |
| 3 rd | 2.221 | 2.32" | 5.22% |
| 2 nd | 1.19" | 1.29" | 8.29% |
| 1 st | 0.41" | 0.46" | 12.09% |

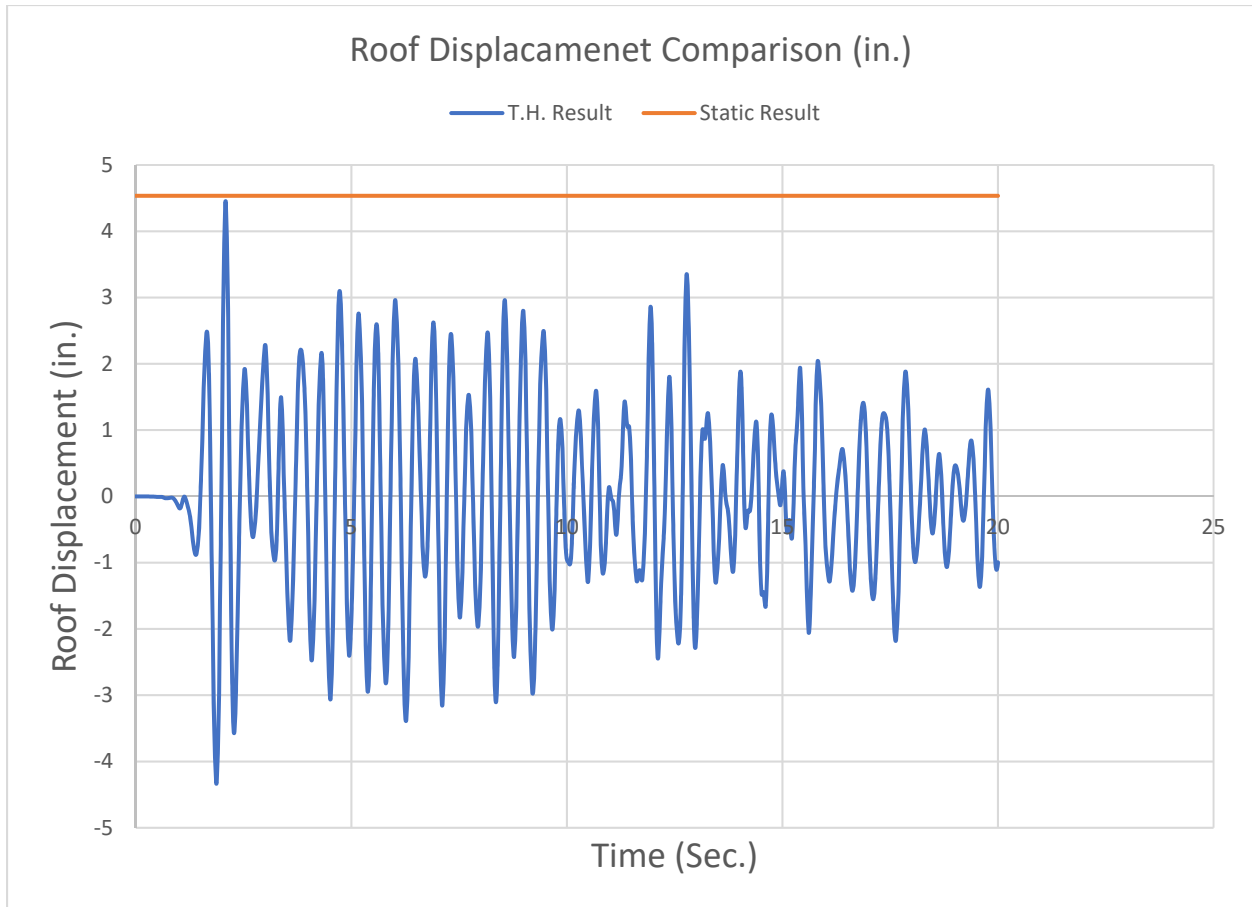


Figure 6. Comparison of the Roof Lateral Displacement

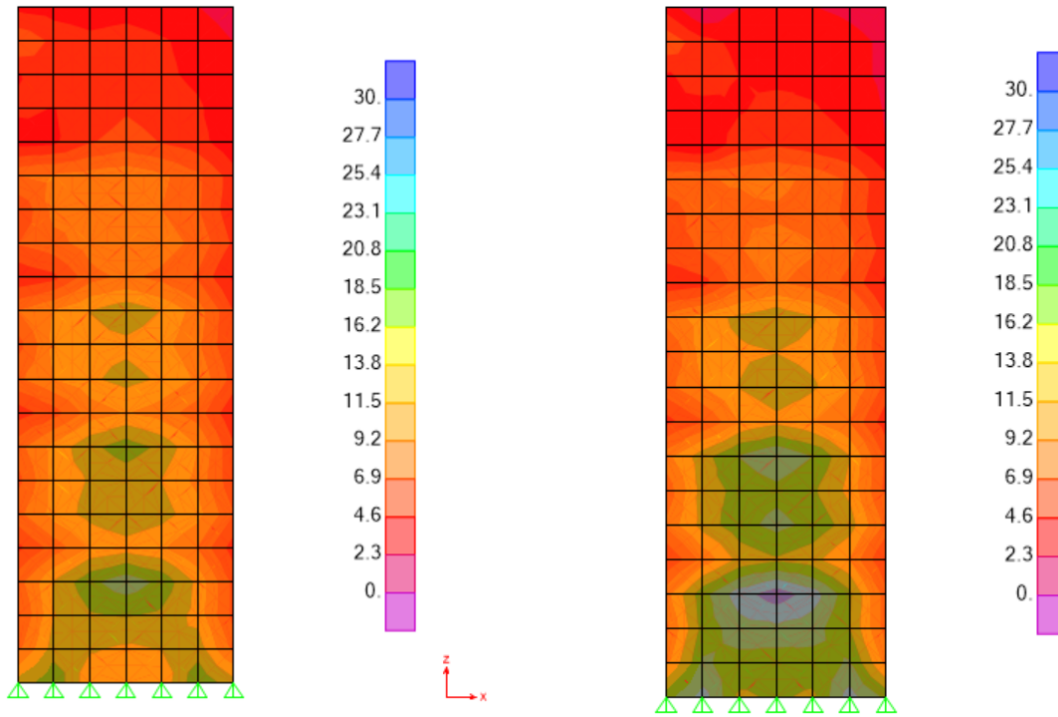


Figure 7. Comparison of the Shear Walls for In Plane Shear Forces (kips/in).
Left: T.H. Analysis, Right: Static Analysis

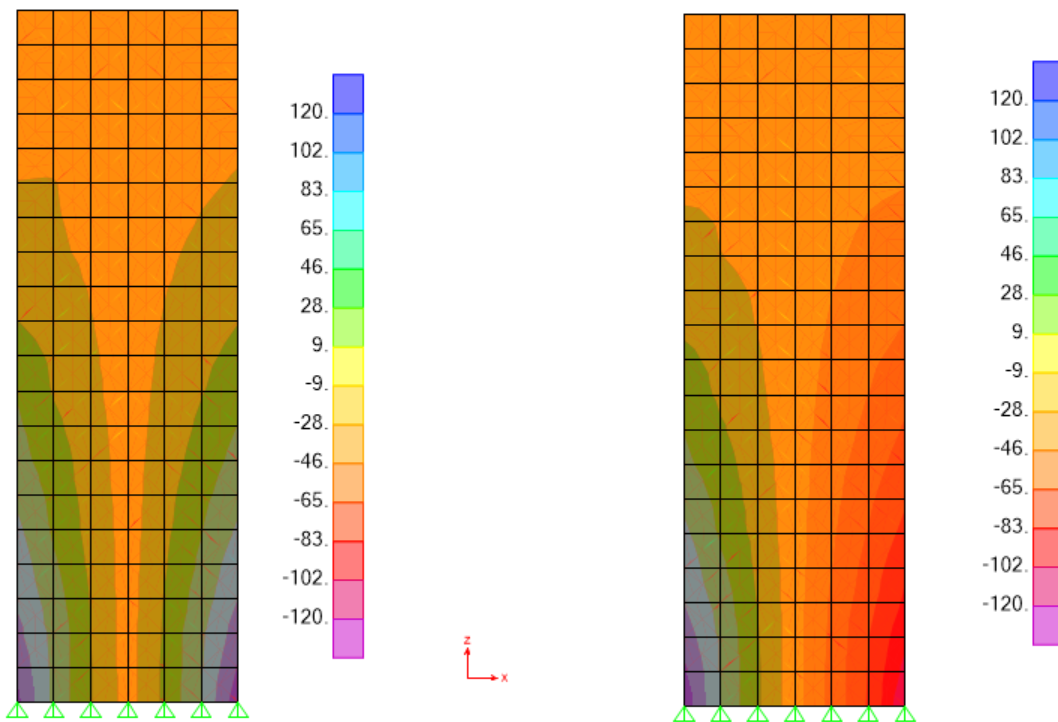


Figure 8. Comparison of the Shear Walls for Axial Forces (kips/in).
Left: T.H. Analysis, Right: Static Analysis

In the last two figures the in plane shear and axial forces distributions in the shear walls are compared.

CONCLUSION

A methodology is presented to determine peak structural responses in a time history dynamic analysis using an equivalent set of static forces. The equivalent set of static forces are calculated using section cuts at different elevations and back-calculating the forces to create the same story forces and moments. Two examples are presented and the results are compared to show the accuracy of the method.

REFERENCES

Chopra, A. K (2015). *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, Pearson Education Limited.
Computers and Structures Inc. "SAP2000 Analysis Reference Manual".