Energy Mapping for Seismic Design of Structures

Elie Hasso, Civil Engineering

Mentor: Dr. Giuseppe Lomiento

Kellogg Honors College Capstone Project

INTRODUCTION

Energy-Based Design (EBD) is a recent alternative to traditional force-based and displacement-based design. The use of energy analysis overcomes the unavoidable simplifying assumptions made in traditional methods, which result in inaccurate estimations of the nonlinear, cyclical seismic forces that structures are subjected to. By utilizing energy as the basis for design, structural elements may be sized to redistribute energy within the structure, thus preventing undesired damages from occurring during major seismic events. State-of-the-art energy methods rely on iterative procedures for the sizing of structural elements.

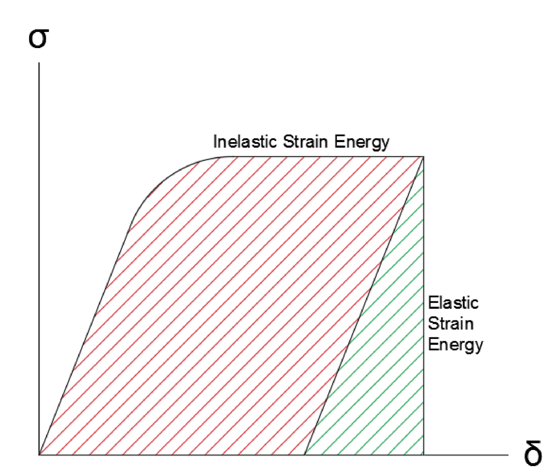
Traditional Design Methodologies

Force Based Design (FBD)

- Applies simplified static forces in an attempt to mimic seismic forces.
- Considers the elastic behavior/strength of structural components
- Considers displacement subsequent to strength

Displacement Based Design (DBD)

- Estimates initial displacements in structural components
- Sets limits to acceptable plastic behavior
- Strength requirements are met once ductility and stiffness demands have been established



Strain Energy

- Work done by an externally applied force is distributed throughout an element by means of strain energy.
- **Elastic Strain Energy** is stored within the element and is recoverable.
- **Inelastic Strain Energy** is dissipated within an element by means of permanent deformations and damages.
- Upon entering the inelastic phase, structural elements within the same system redistribute energy to those with a higher relative stiffness

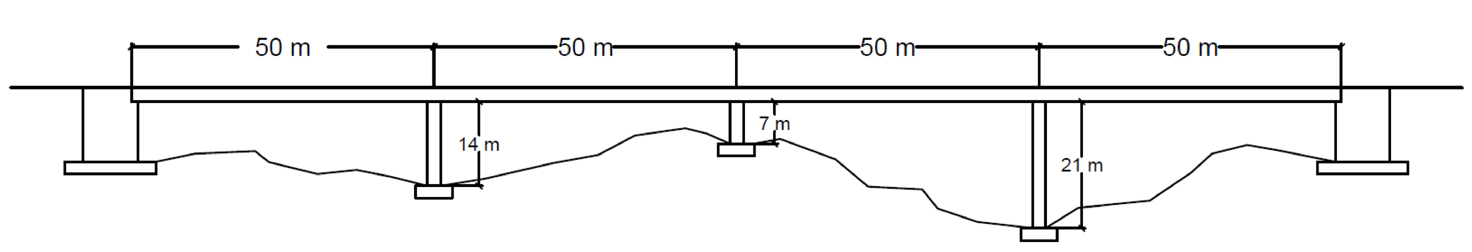
OBJECTIVE

Goal: The development of a supplemental tool to aid in the iterative nature of energy-based design by which the flow of energy throughout a structure during seismic activity is displayed clearly and concisely.

Method: SAP 2000 is utilized to perform nonlinear structural analysis on two variations of a highway bridge monitoring the transition of energy within a structure as a result of seismic isolators and the lack thereof.

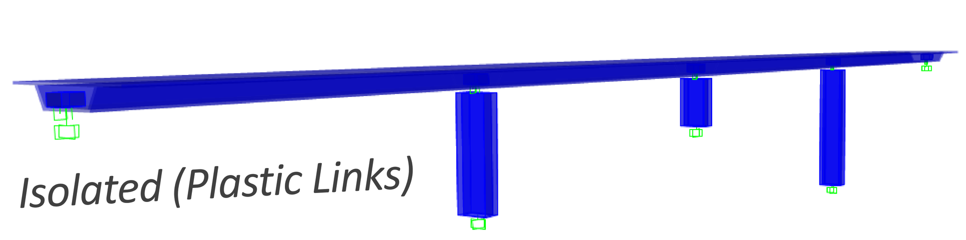
Outcomes: The resulting "Energy Map" greatly aids in the visual representation of the flow of energy within a structure as certain components become increasingly inelastic as dependent on global structural displacement. It is further employed in the examination of structural systems through sensitivity analysis, a means of comparing the global effects of the stiffnesses and strengths of individual structural members.

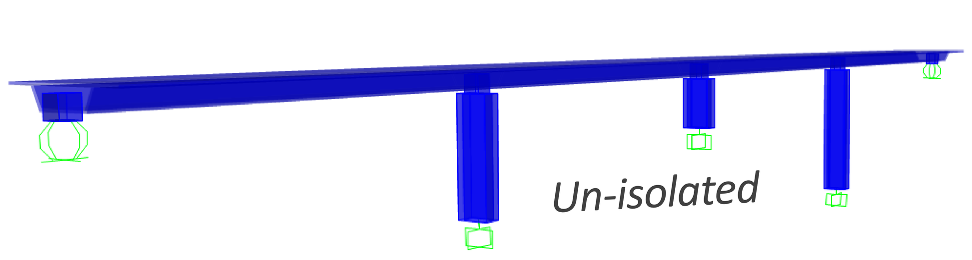
OVERVIEW



- Reinforced concrete box girder bridge.
- Deck spans are 50m in length.
- Column heights are 14m, 7m, and 21m.
- Flexural moment capacities are 34790 kN-m, 17395 kN-m, and 52185 kN-m, respectively.
- All columns have the same moment of inertia of 2.818 m^4

Isolated variation with lead-rubber isolators atop columns and abutments. It is assumed for the sake of this study, that they are bilinear in nature.



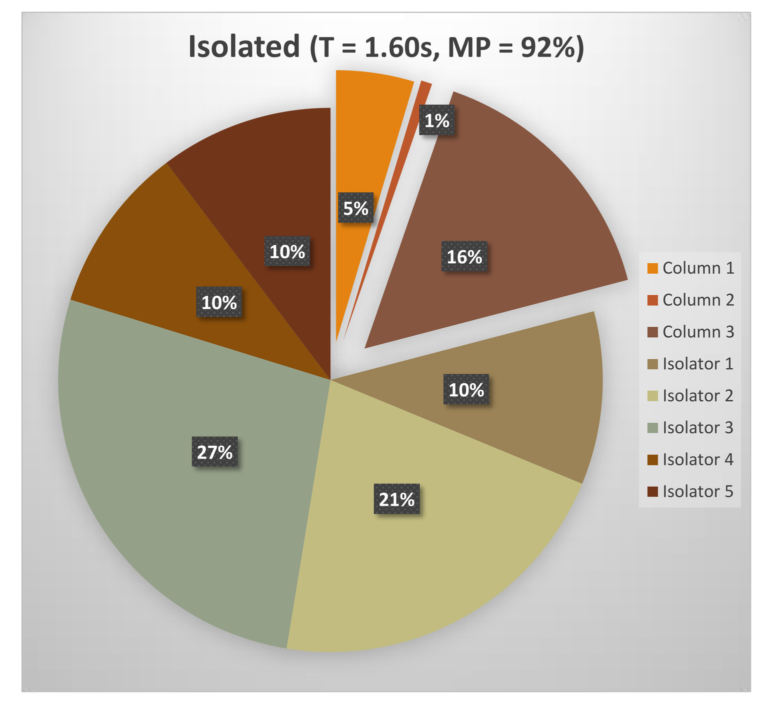


Un-isolated variation with fixed connections between deck and columns. The tops and bottoms of columns will be considered for plastic hinge analysis.

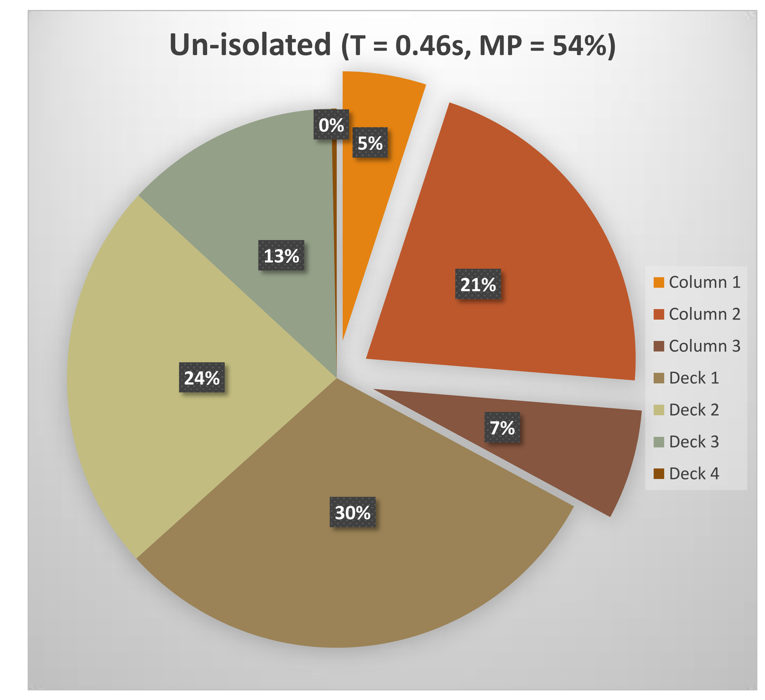
- ❖ The un-isolated variation will be the focus of this poster
- ❖ The analysis of the isolated variation is mentioned in the discussion

RESULTS

Initial Energy Distribution Based on Modal Participation



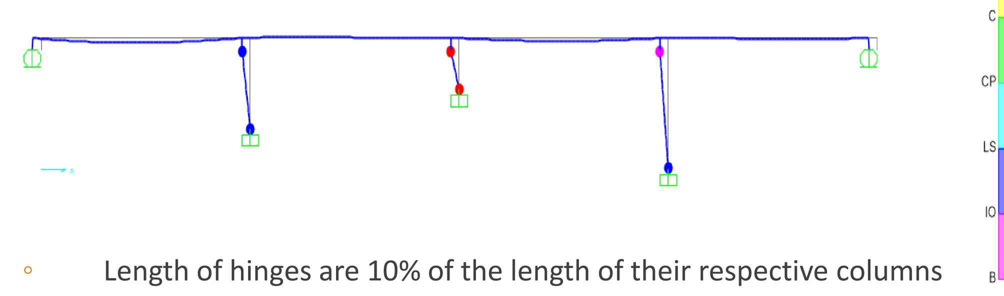
The use of isolation results in inelastic behavior of the lead-rubber isolators while allowing the columns and deck to remain within the range of desirable elastic behavior. The energy absorption of the isolated deck is negligible.



The un-isolated variation utilizes the energy capacity of the columns and deck to dissipate the energy created by ground motion; effectively yielding the critical structural members at localized points and crippling their initial energy capacity.

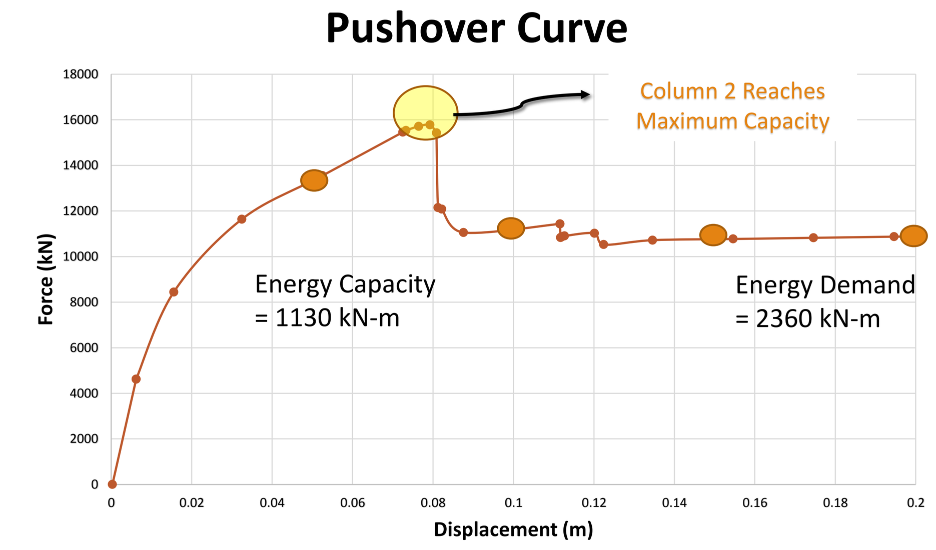
Pushover Analysis

- A nonlinear static application of acceleration to sources of mass
- Plastic hinges at the tops and bottoms of each column

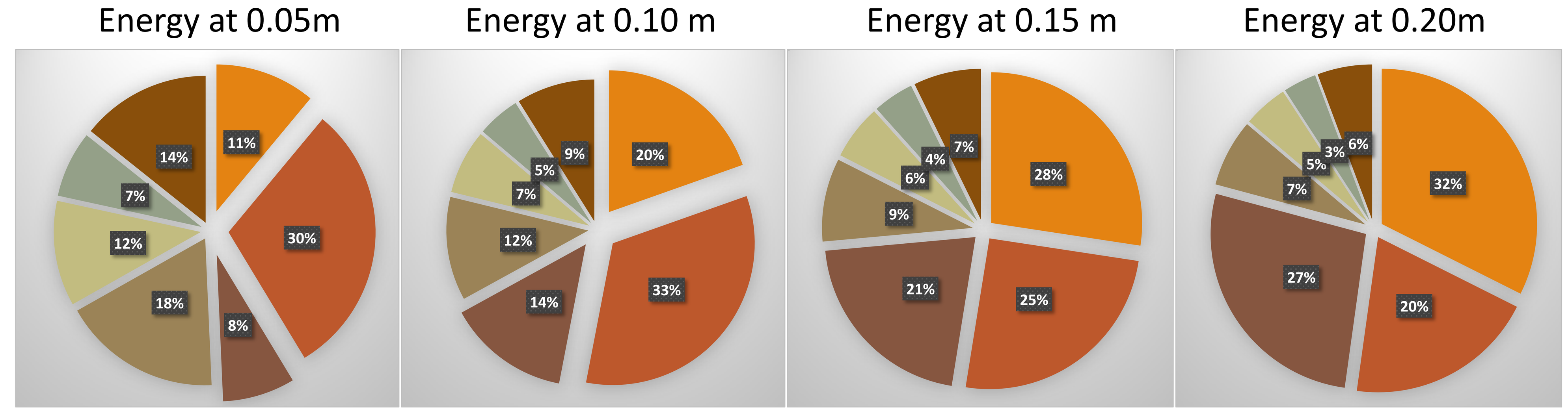


- Length of hinges are 10% of the length of their respective columns
- Flexural capacities at hinges are equal to those of respective columns

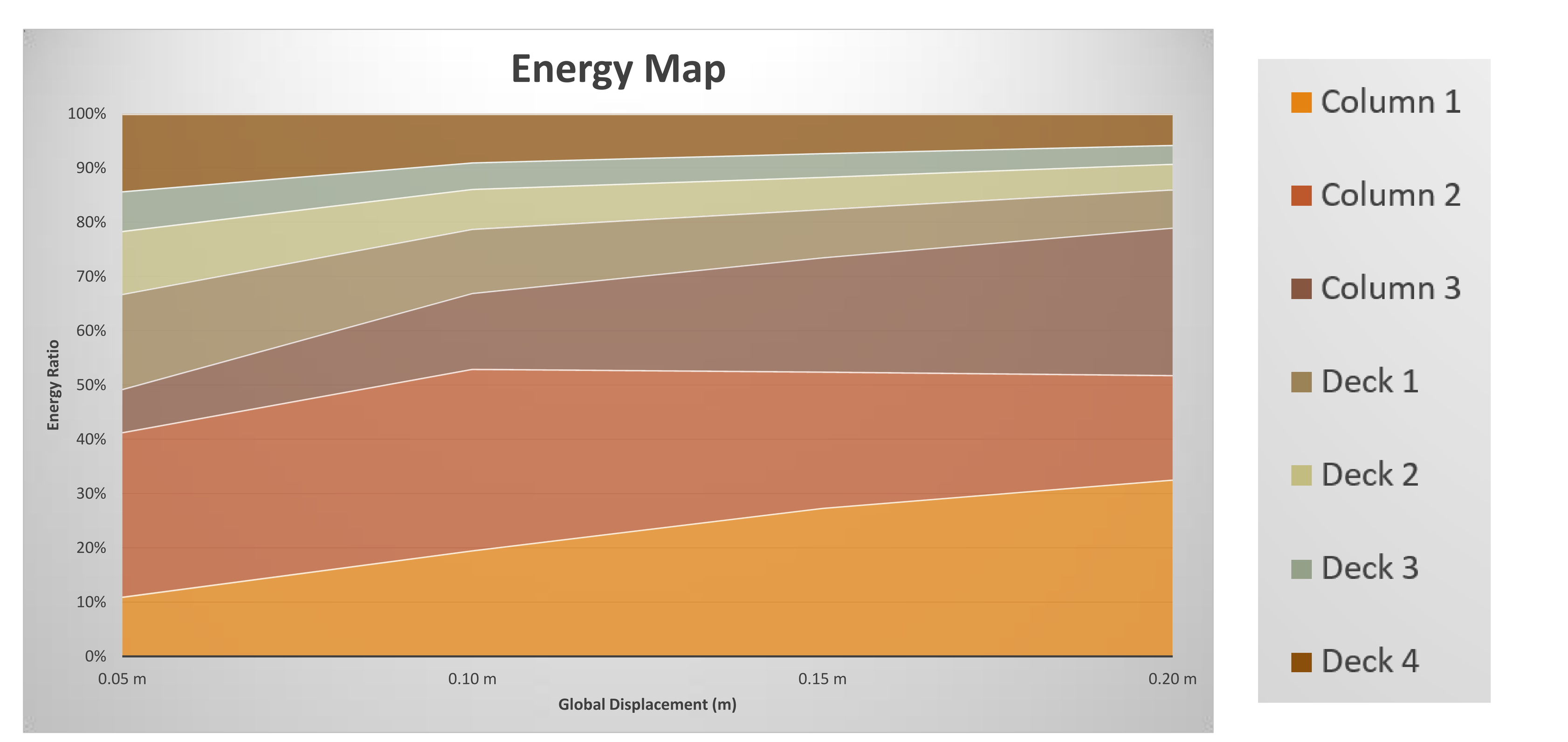
Pushover Curve



- The total energy capacity of the un-isolated variation is roughly 1100 kN-m
- The demand is 2300 kN-m at a total 0.2m displacement of the deck



CONCLUSION



Final Thoughts:

The energy map displays the total energy distribution at different values of global displacement. The second column initially absorbs the majority of the energy due to its higher relative stiffness in comparison to the other, more ductile columns. However, as it reaches its capacity and becomes increasingly inelastic, the energy is distributed to the other two columns.

The benefit to energy mapping is noticed when attempting to perform sensitivity analysis.

In the case of the isolated bridge, the capacity of the isolators determines the capacity of the entire structure. Thus, the capacity of the structure could be greatly increased by using isolators with greater flexibility.

For the un-isolated bridge, individual columns could be targeted for modifications to strength and ductility. To mitigate for the quick failure of column 2, several alternative analyses were conducted. Utilizing a more ductile column geometry for column 2 leads to a greater distribution of initial energy to the other two columns. Increasing flexural capacity of the column similarly allows for a greater overall capacity of the structure.

In an alternative analysis, the total energy capacity of the structure increased to 1350 kN-m by simply reducing the width of the second column, making it more ductile and attracting a greater portion of the initial seismic energy to the other two columns, delaying the failure of the second column.

❖ References

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