Experimental Damage Diagnosis of a Model Three-Story Spatial Frame

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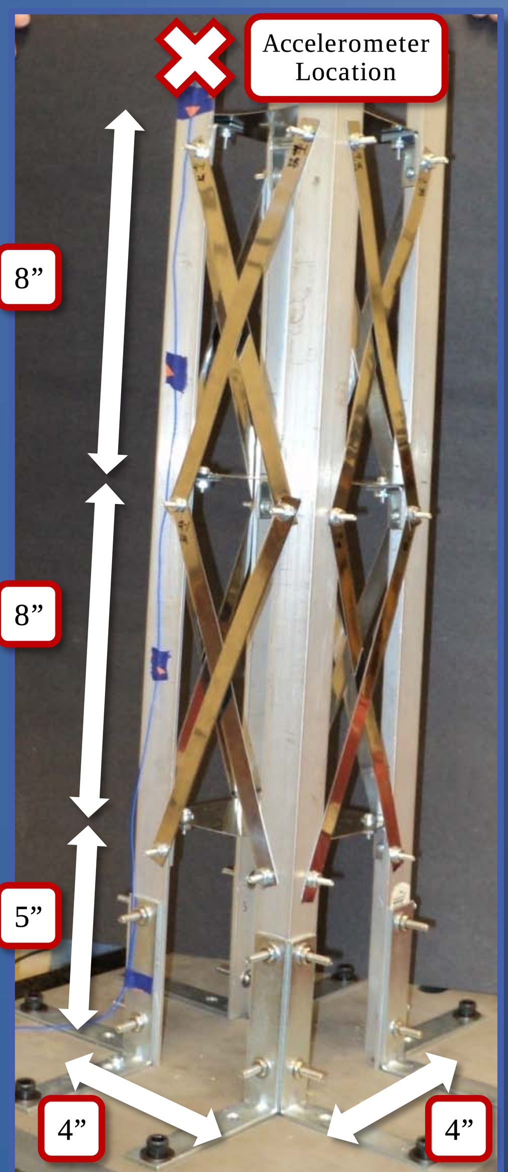
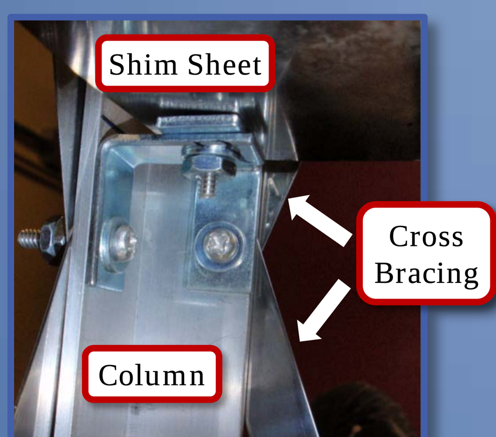
Introduction

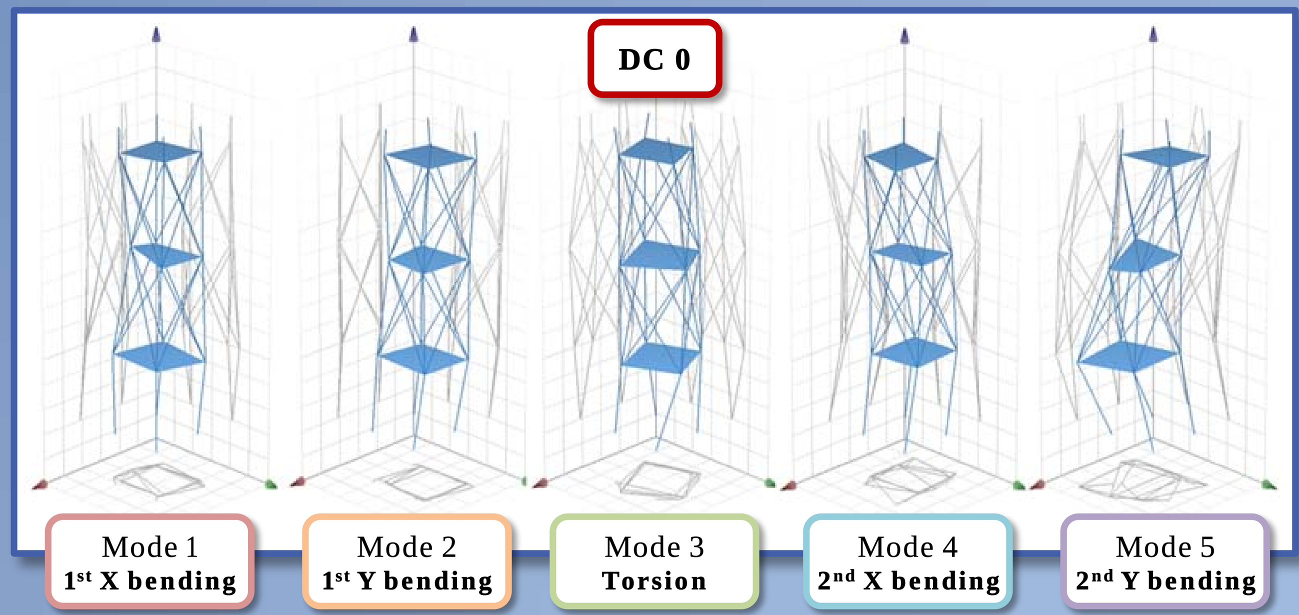
In order to improve the overall safety and reliability of infrastructure and detect structural weakness before failure occurs, a **health monitoring and evaluation** system could be implemented that periodically collects dynamic data on a particular building or bridge. This data is processed, the appropriate features are extracted, and mathematical damage indicators are calculated. If the system is identified as damaged, the appropriate measures can then be taken in order to retrofit, rehabilitate, or decommission the structure. With the aid of various sensors, including accelerometers, strain gauges, and displacement transducers, engineers may instrument buildings, bridges, and other infrastructure in order to collect structural dynamic data. The main **goal** is to detect changes in the structure's dynamic properties that are produced by physical (usually not visible) damage. The **aim** is to detect cracks and minor damage before propagation or structural failure occurs. Ultimately, identifying and locating damage within a structure before failure happens could save both lives and money.





Objectives

- Develop and construct a model building
- Evaluate the test structure's undamaged health state
- Induce 10 different structural damage scenarios by removing various combinations of cross-bracing members
- Perform tap tests on all 11 configurations with a modally tuned impact hammer and one tri-axial accelerometer
- Process acceleration data and calculate modal parameters required for damage detection techniques
- Assess the effectiveness of various damage indicators

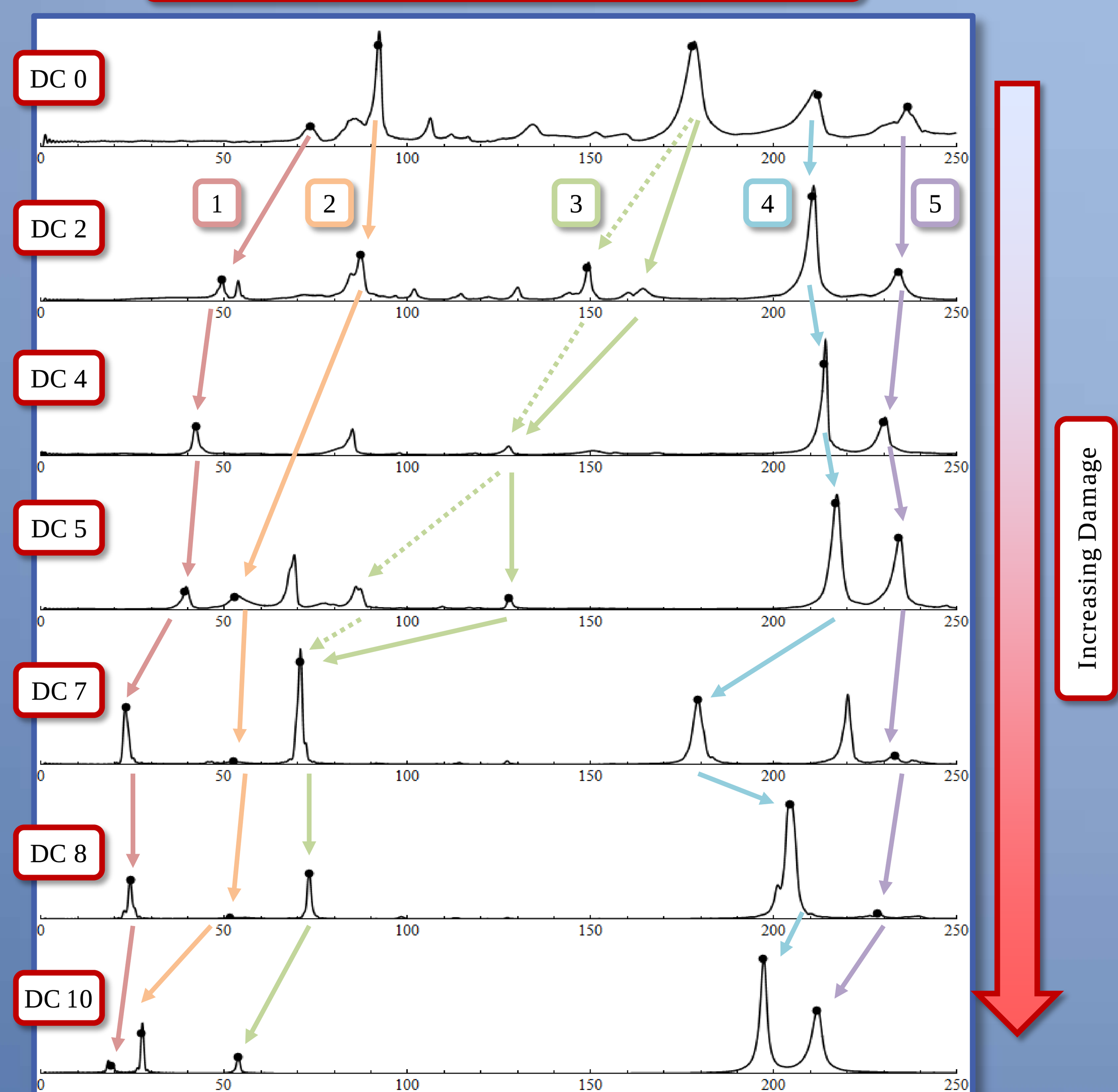


Materials and Methods

In order to evaluate the effectiveness of potential damage indicators, an experimental study of a three-story spatial frame structure model was conducted in the Multi-Function Dynamics Laboratory at the University of Mississippi.

- Single and multiple damage
- Symmetric and asymmetric damage
- Impact hammer modally excites while tri-axial accelerometer captures response signals
- NI Labview (time histories) → Matlab (frequency response functions) → Star Modal (natural frequencies and mode shapes)

Modal Peaks for All Symmetrically Damaged Cases



Damage Indicators

Several damage detection techniques were then employed by mathematically manipulating the experimentally obtained mode shapes and natural frequencies for each damage case. Specifically, two damage indicators were analyzed and compared: modal assurance criterion (MAC) and coordinate modal assurance criterion (COMAC). MAC quantifies the correlation between experimental mode shapes obtained for the baseline and damaged structure.

$$MAC_i = \frac{|\phi_i \phi_i^*|^2}{(\phi_i \phi_i^T)(\phi_i^{*T} \phi_i^*)}$$

$*$: damaged structure
ϕ_i : i^{th} mode shape vector
ϕ_{ij} : i^{th} mode shape value at the j^{th} coordinate

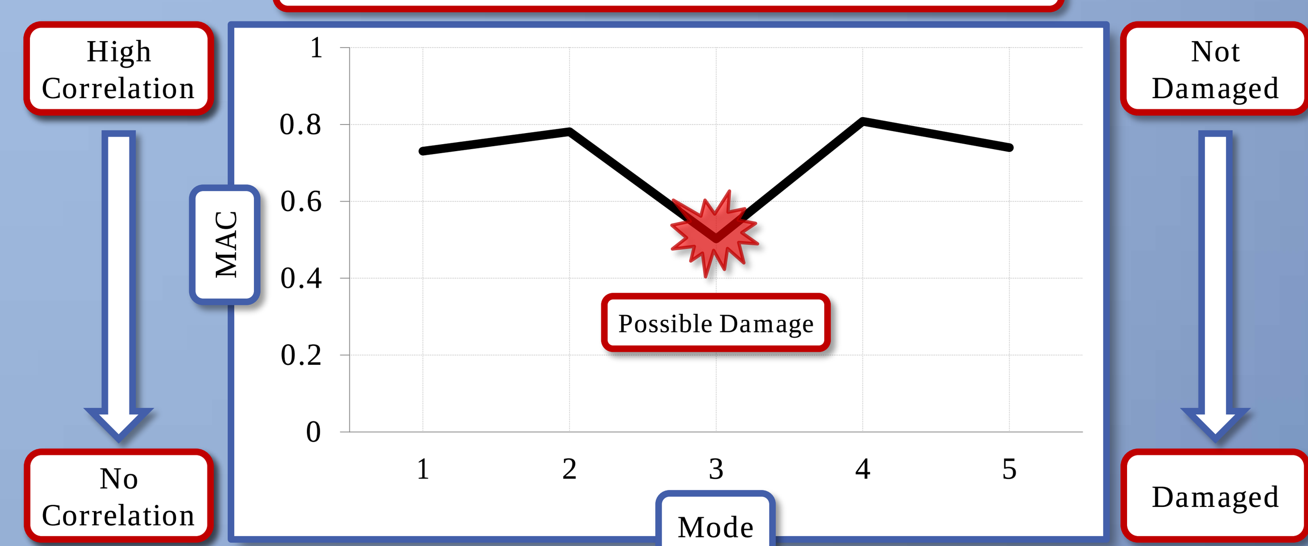
This damage detection technique allows engineers to determine if there is **global damage** within the structure.

Similarly, COMAC determines the correlation between mode shape sets at specific points or coordinates on a structure.

$$COMAC_j = \frac{\left(\sum_{i=1}^{m} |\phi_{ij} \cdot \phi_{ij}^*|\right)^2}{\sum_{i=1}^{m} \phi_{ij}^2 \cdot \sum_{i=1}^{m} \phi_{ij}^{*2}}$$

Unlike MAC, COMAC can **identify and locate damaged elements** within a structure. MAC and COMAC were carried out for both **sequential** (incremental damage) and **cumulative** (large amount of damage) damage. The results of these algorithms are analyzed and compared in order to assess their effectiveness in identifying and locating damage within the test structure.

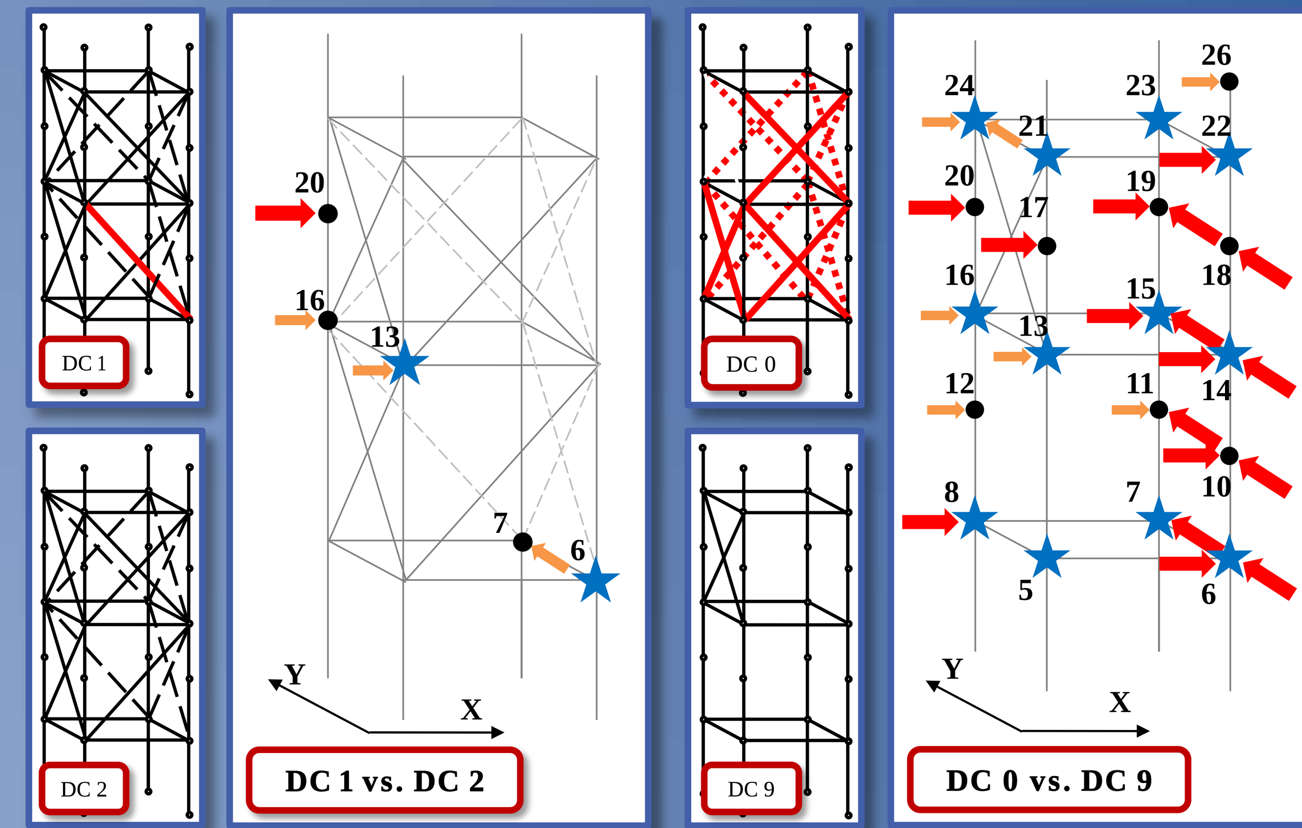
MAC for DC 5 vs. DC 6 (Sequential Damage)



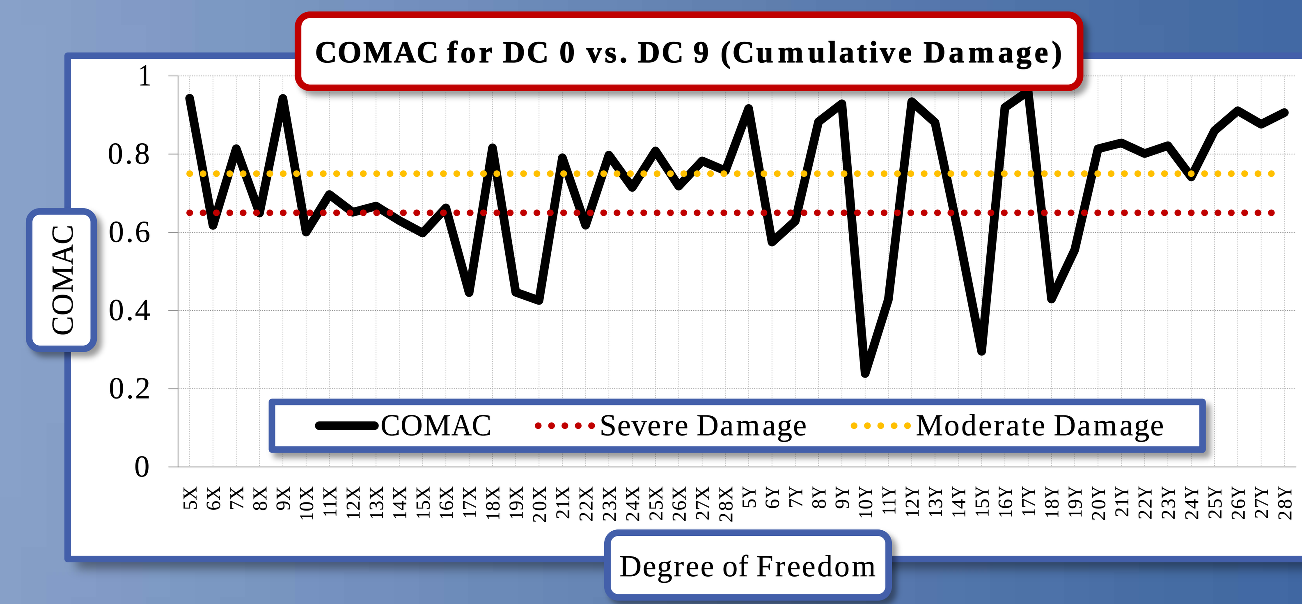
Results

MAC

- Answers the question "Is the structure damaged?" with a yes or no (global damage)
- Calculated MAC results agree with Star Modal
- 1^{st} order modes indicate multiple story damage
- 2^{nd} order modes are most sensitive to single story damage
- The torsion mode is affected when the baseline structure is symmetric and the damaged structure is asymmetric (or vice-versa)



COMAC for DC 0 vs. DC 9 (Cumulative Damage)



COMAC

- Answers the question "Is the structure damaged?" with a yes or no **and** possible damaged locations
- Calculated COMAC results agree with Star Modal
- Effectively locates general area of damage
- More locations were identified as damaged in the cumulative damage scenario than in each sequential damage scenario

Conclusions

- COMAC is more precise in detecting damage location than MAC, which only indicates affected modes of vibration
- Non-destructive, vibration-based damage diagnosis methods can locate and quantify structural weakness within the test structure
- Sensitivity of other damage indicators, such as modal curvature and flexibility methods based methods, are also being evaluated

Acknowledgements

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