Leonardo’s Lintel: Analysis with 21st Century Tools

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Project Objectives and Goals
Analyze Leonardo’s lintel using modern engineering tools and methods.

Discover how the mechanics of Leonardo’s lintel differ from that of an Euler Bernoulli beam.

The tools and methods used are:
• CAD tools to visualize the structure
• 3D printing for structural realization
• Three point bend experiments
• Photoelastic experiments
• Finite element analysis

Background
Leonardo’s lintel is constructed using a series of interlocking blocks to replace beams [1].

Hypothesize that Leonardo’s lintel deforms by compression processes only. Therefore, the response would be similar to that of a van Mises truss.

The van Mises truss would span from the support points to the load point.

The force v. displacement response possesses a peak load at a displacement equal to the half lintel height and fail to zero load at a displacement equal to the lintel height.

Lintel stiffness, maximum force and toughness would be linearly dependent on lintel length.

Leonardo’s lintel is a one dimensional topologically interlocking structure. This work expands concurrent research on planar interlocking systems that replace plates [2, 3].

Three Point Bend Experiments:
For three point bend experiments, 8 mm tall lintel pieces were 3D printed. The pieces were arranged into lintels ranging from 7 to 11 pieces. Lintels were placed under a wedge at the lintel center. A force sensor and a displacement sensor were used to collect force and displacement data.

Photoelastic Experiments:
For photoelastic measurements, 16 mm tall translucent pieces were 3D printed, arranged into a lintel, and placed under a wedge, bisecting the lintel. Images were taken throughout the loading process.

Finite Element Model:
Finite element models were made using ABAQUS for lintels ranging from 6 to 10 pieces. Models were used to compute the force v. displacement response and the stress distribution.

Data and Results
Three Point Bend Experiments:
Figure 2: The three point bend experiment set up

Figure 6: Sample force v. displacement curve

Figure 7: The average peak load, stiffness, and toughness of each lintel

Photoelastic Experiments:
Figure 4: The photoelastic set up with two polarized filter sheets

Figure 8: Photoelastic images of a ten piece lintel in deformation

Finite Element Model:
Figure 8: The nine piece lintel

Figure 10: Distribution of compressive principal stress vectors for the seven piece lintel

Three Point Bend Experiments:

There is a significant difference in the force v. displacement response of the lintel compared with that of an Euler Bernoulli beam.

This behavior is in significant contrast to the Euler-Bernoulli beam, which sees tension and compression stresses, possesses a nonlinear dependence on beam length, and generally fails brittle.

Conclusions
Experiments and analysis confirm the initial hypothesis that the load-deflection response of Leonardo’s lintel resembles the van Mises truss.

Leonardo’s lintel is a compression only structure. Stiffness, strength and toughness emerge as linear dependent on lintel length. The lintel exhibits a gradual failure response.

This behavior is in significant contrast to the Euler-Bernoulli beam, which sees tension and compression stresses, possesses a nonlinear dependence on beam length, and generally fails brittle.

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References

REU Experience and Highlights
During this research experience I learned:
• How to perform finite element analysis via ABAQUS
• How to perform photoelastic analysis of a structure or member
• How to experimentally determine the force v. displacement response of a structure
• How to redesign an experiment when the original plan for an experiment does not work
• The value of using history to inform design of new technologies

Conclusions
Experiments and analysis confirm the initial hypothesis that the load-deflection response of Leonardo’s lintel resembles the van Mises truss.

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