



Effect of Shape Variation on Centroid Location

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Abstract- The centroid is an important geometrical property widely used in mechanical, civil, aerospace, and structural engineering applications. It represents the geometric center of a body and plays a significant role in balancing, structural stability, stress analysis, and machine component design. This research paper investigates the effect of shape variation on centroid location for different geometrical sections including rectangular, triangular, circular, trapezoidal, and composite bodies. The study focuses on understanding how changes in dimensions and geometrical configurations influence the movement of the centroid. Analytical calculations and computational methods are utilized to determine centroid coordinates for varying shapes. The research also discusses applications of centroid analysis in modern engineering systems such as robotics, CAD modeling, structural analysis, and manufacturing industries. The results demonstrate that even small dimensional variations can significantly affect centroid position, thereby influencing structural behavior and stability.

Keywords: Centroid, Shape Variation, Composite Sections, Structural Stability, Mechanical Engineering, CAD Modeling, Geometrical Analysis..

Shape variation may occur due to:

- Changes in dimensions
- Addition or removal of material
- Manufacturing modifications
- Structural optimization
- Weight reduction techniques
- Design improvements

The centroid location directly influences:

- Structural equilibrium
- Beam bending behavior
- Rotational balance
- Stability of vehicles and machines
- Vibration characteristics
- Dynamic motion of systems

This research investigates centroid movement due to geometrical variation and evaluates its engineering significance.

I. Introduction

The centroid is defined as the geometric center of a plane figure or solid body. It is the point where the entire area or volume of a body can be considered concentrated. In engineering mechanics, centroid analysis is highly important because it affects load distribution, stability, balancing, and structural performance.

In practical engineering applications, components rarely maintain simple geometrical forms. Most machine parts, structural sections, and industrial components are combinations of different shapes. Therefore, understanding how shape variation affects centroid location is essential for designing safe and efficient engineering systems.



II. Literature Review

Several researchers have studied centroid determination for standard and composite sections. Traditional engineering textbooks mainly focus on analytical solutions for regular geometrical shapes. However, modern engineering structures involve irregular and continuously changing geometries. Previous studies indicate that centroid location changes significantly with dimensional modification. Computational tools such as CAD software and finite element methods have improved centroid analysis for complex structures.

Research findings from various studies show:

- i. Composite bodies produce non-uniform centroid shifts.
- ii. Irregular sections require numerical methods for accurate centroid determination.
- iii. CAD-based centroid analysis provides higher accuracy compared to manual calculations.
- iv. Structural stability strongly depends on centroid location.
- v. Lightweight designs often involve centroid optimization.

Despite extensive work on centroid calculations, limited research is available regarding systematic analysis of centroid movement caused by gradual shape variation.

III. Objectives of the Research

The major objectives of this research are:

- i. To study the concept and importance of centroid in engineering systems.
- ii. To analyze centroid locations for various geometrical shapes.
- iii. To investigate the effect of dimensional variation on centroid movement.
- iv. To compare centroid shifts in regular and irregular sections.
- v. To evaluate analytical and computational methods for centroid determination.
- vi. To understand engineering applications of centroid analysis.
- vii. To study centroid behavior in composite structures.
- viii. To examine the relationship between geometry and structural stability.

IV. Theory of Centroid

The centroid of a body depends on its geometry. For symmetrical bodies, the centroid lies along the axis

of symmetry. For irregular and composite bodies, centroid coordinates are determined using area-weighted averages.

Centroid of Simple Geometrical Shapes

Rectangle

For a rectangle of width (b) and height (h):

$$\bar{x} = \frac{b}{2} \quad \bar{y} = \frac{h}{2}$$

Triangle

$$\bar{x} = \frac{b}{3} \quad \bar{y} = \frac{h}{3}$$

Circle

$$\bar{x} = 0 \quad \bar{y} = 0$$

The centroid lies at the center of the circle.

V. Mathematical Formulation

For composite sections, centroid coordinates are determined by:

$$\bar{x} = \frac{\sum(A_i x_i)}{\sum A_i}$$

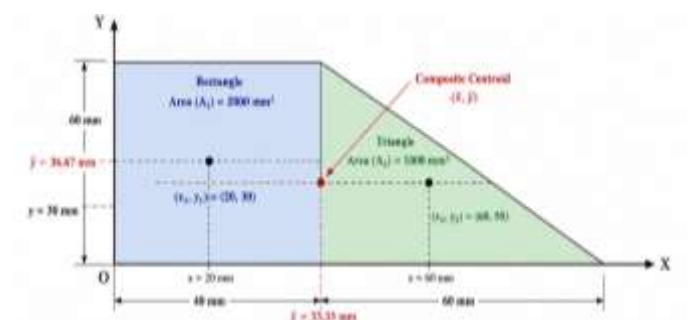
$$\bar{y} = \frac{\sum(A_i y_i)}{\sum A_i}$$

- (A_i) = Area of each component
- (x_i) = x-coordinate of centroid of each component
- (y_i) = y-coordinate of centroid of each component

Example Calculation

Consider a composite section formed by:

- Rectangle area = 2000 mm²
- Triangle area = 1000 mm²



Coordinates:

- Rectangle centroid = (20, 30)
- Triangle centroid = (60, 50)

Then:

$$\bar{x} = \frac{(2000 \times 20) + (1000 \times 60)}{3000} = 33.33 \text{ mm}$$

Similarly:

$$\bar{y} = \frac{(2000 \times 30) + (1000 \times 50)}{3000} = 36.67 \text{ mm}$$



This demonstrates centroid movement due to shape combination.

VI. Shape Variation Analysis

Shape variation changes centroid position because the distribution of area changes relative to reference axes.

Rectangular Section Variation

When width increases while height remains constant:

- Centroid shifts horizontally.
- Structural balance changes.
- Load distribution becomes non-uniform.

Triangular Shape Variation

Changing triangle orientation causes centroid movement toward the larger area concentration.

Circular Section with Hole

When a circular hole is introduced:

- Material removal shifts centroid away from the hole.
- The section becomes asymmetrical.

Composite Shape Variation

Adding multiple geometrical sections creates complex centroid movement.

Examples include:

- T-sections
- I-sections
- L-sections
- Channel sections

These sections are widely used in structural engineering.

VII. Computational Analysis

Modern computational tools simplify centroid analysis for complex geometries.

CAD-Based Analysis

CAD software allows:

- Automatic centroid determination
- 3D visualization
- Accurate geometrical modeling
- Fast calculations

Popular software includes:

- AutoCAD
- SolidWorks
- CATIA
- ANSYS

Finite Element Method

Finite element analysis helps in:

- Structural simulation
- Dynamic analysis

- Stress distribution evaluation
- Stability prediction

The FEM approach is useful for irregular and non-uniform structures.

VIII. Experimental Methodology

The experimental procedure adopted for this research includes:

- i. Selection of geometrical shapes.
- ii. Preparation of CAD models.
- iii. Analytical centroid calculation.
- iv. Dimensional modification.
- v. Computational verification.
- vi. Comparative analysis.
- vii. Graph plotting of centroid movement.

Materials Used

- Graph sheets
- CAD software
- Measuring instruments
- Aluminum and acrylic sheets
- Computational tools

Procedure

Step i: Draw geometrical shapes.
Step ii: Divide complex sections into simpler parts.
Step iii: Calculate areas and centroid coordinates.
Step iv: Modify dimensions systematically.
Step v: Observe centroid movement.
Step vi: Compare analytical and computational results.

IX. Results and Discussion

The obtained results indicate that centroid location strongly depends on shape geometry and area distribution.

Observations

- i. Symmetrical shapes maintain centroid along symmetry axes.
- ii. Asymmetrical modifications cause significant centroid shifts.
- iii. Larger area additions dominate centroid movement.
- iv. Material removal changes balance characteristics.
- v. Composite structures exhibit complex centroid behavior.

Graphical Interpretation

The centroid movement graph shows:

- Linear variation for regular shapes
- Nonlinear variation for irregular sections
- Sudden shifts due to asymmetrical additions



Comparative Analysis

Shape Type	Centroid Behavior	Stability Effect
Rectangle	Uniform shift	Moderate
Triangle	Directional shift	Moderate
Circle with Hole	Asymmetrical shift	High
Composite Section	Complex movement	Significant

X. Engineering Applications

Centroid analysis has wide applications in engineering and industrial systems.

Structural Engineering

Centroid determination is essential for:

- Beam design
- Column analysis
- Bridge structures
- Truss systems

Mechanical Engineering

Applications include:

- Machine balancing
- Rotating shafts
- Flywheel systems
- Automotive components

Aerospace Engineering

Aircraft stability depends on centroid and center of gravity alignment.

Robotics

Robotic arm balancing and movement control require accurate centroid analysis.

Manufacturing Industry

Centroid positioning improves:

- Product stability
- Handling systems
- Packaging design
- Material optimization

XI. Advantages of Centroid Analysis

- Improves structural stability.
- Enhances machine balancing.
- Reduces vibration.
- Helps in efficient material usage.
- Supports lightweight design optimization.
- Improves safety and reliability.
- Enables accurate structural analysis.

XII. Limitations

- Complex shapes require numerical methods.
- Manual calculations become difficult for irregular bodies.
- Computational methods require software expertise.
- Experimental analysis may involve measurement errors.

XIII. Future Scope

Future research may include:

- AI-based centroid prediction systems.
- Machine learning applications in geometrical analysis.
- Real-time centroid monitoring.
- Smart CAD-integrated centroid optimization.
- Advanced 3D modeling techniques.
- Robotics-based centroid balancing systems.
- Centroid analysis in nano-material structures.

XIV. Conclusion

This research paper analyzed the effect of shape variation on centroid location for different geometrical sections. The study revealed that centroid position changes significantly with dimensional modifications and area redistribution. Composite and irregular sections exhibit complex centroid movement compared to regular geometrical shapes.

Analytical calculations and computational methods provide accurate centroid determination for engineering applications. The results emphasize the importance of centroid analysis in structural stability, machine balancing, aerospace systems, and manufacturing industries.

Understanding centroid behavior helps engineers design safer, lighter, and more efficient systems. Future developments involving AI and computational intelligence can further improve centroid prediction and optimization techniques.

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