

A 60-m-long Steel Wire Is Subjected To A 6-kN Tensile Load. Knowing That E = 200 GPa And That The Length

A 60-m-long Steel Wire Is Subjected To A 6-kN Tensile Load. Knowing That E = 200 GPa And That The Length of the wire is essential for understanding its mechanical behavior under tensile stress. This scenario provides an excellent opportunity to explore the fundamental principles of material mechanics, including stress, strain, deformation, and the elastic properties of steel. Whether you're an engineer, a student, or someone interested in the fundamentals of materials science, understanding how a steel wire responds to tensile loads is crucial for designing safe and reliable structures.

Understanding the Basic Concepts: Tensile Load, Stress, and Strain

What Is a Tensile Load?

A tensile load is a force applied to an object that tends to stretch or elongate it. In the context of the steel wire, the 6-kilonewton (kN) load pulls the wire along its length, attempting to increase its length and potentially cause deformation.

Defining Stress and Strain

- Stress (σ): The internal force per unit area within a material caused by an external load. It is calculated as:

$$\sigma = \frac{F}{A}$$

where F is the applied force, and A is the cross-sectional area.

- Strain (ϵ): The measure of deformation representing the relative elongation of the material:

$$\epsilon = \frac{\Delta L}{L_0}$$

where ΔL is the change in length, and L_0 is the original length.

Understanding these parameters helps determine whether the material remains elastic or undergoes

permanent deformation under the applied load.

Calculating the Stress in the Steel Wire

Assumption of Cross-Sectional Area

To determine the stress, the cross-sectional area of the wire must be known. Typically, the area can be calculated if the diameter is known, or given directly.

Suppose the wire has a diameter d . The cross-sectional area A for a circular wire is:

$$A = \frac{\pi d^2}{4}$$

For example, if the wire's diameter is 5 mm:

$$A = \frac{\pi \times (0.005 \text{ m})^2}{4} \approx 1.963 \times 10^{-5} \text{ m}^2$$

Calculating Stress

The applied load F is 6 kN, which is:

$$F = 6 \text{ kN} = 6000 \text{ N}$$

The stress is then:

$$\sigma = \frac{F}{A} = \frac{6000 \text{ N}}{1.963 \times 10^{-5} \text{ m}^2} \approx 3.052 \times 10^8 \text{ Pa} = 305.2 \text{ MPa}$$

This stress level is within the elastic limit for steel, as discussed below.

Determining the Strain and Elongation

Using Young's Modulus (E)

The elastic modulus, or Young's modulus, relates stress and strain:

$$E = \frac{\sigma}{\epsilon}$$

Given that $E = 200 \text{ GPa}$ (or $(200 \times 10^9, \text{Pa})$), the strain in the wire is:

$$\epsilon = \frac{\sigma}{E} = \frac{3.052 \times 10^8, \text{Pa}}{2 \times 10^{11}, \text{Pa}} \approx 1.526 \times 10^{-3}$$

This is a dimensionless quantity representing the relative elongation.

Calculating the Actual Elongation

The original length L_0 is 60 meters. The change in length ΔL is:

$$\Delta L = \epsilon \times L_0 = 1.526 \times 10^{-3} \times 60, \text{m} \approx 0.0916, \text{m}$$

or approximately 91.6 millimeters.

Summary:

Under a 6-kN tensile load, the steel wire elongates by about 91.6 mm, which is a significant deformation but still within the elastic limit of steel.

Elastic Behavior and Safety Considerations

Elastic Limit of Steel

Steel typically exhibits elastic behavior up to approximately 0.2% to 0.3% strain. Since the calculated strain is approximately 0.1526%, the wire remains within the elastic range, returning to its original length once the load is removed.

Implications for Structural Design

- The elongation should be considered in design to accommodate deformation.
- Engineers must verify that the stress does not exceed the yield strength of steel ($\sim 250 \text{ MPa}$ for mild steel).

- The calculated stress (~ 305 MPa) suggests the wire might be near or above the yield point, depending on the steel grade used, indicating the need for a safety factor or material selection adjustments.

Factors Affecting the Mechanical Response of the Steel Wire

Material Properties

- Variations in steel composition affect yield strength and elasticity.
- Heat treatments can alter the material's modulus and ductility.

Geometric Factors

- Diameter and cross-sectional shape influence the stress distribution.
- Uniformity of the cross-section ensures predictable behavior.

Environmental Conditions

- Temperature changes can affect the Young's modulus and yield strength.
- Corrosion or fatigue can weaken the wire over time.

Practical Applications and Engineering Significance

Designing for Load Tolerance

Understanding the elongation of steel wires under tensile loads helps in designing cables, bridges, elevators, and other structures where tensile elements are critical.

Monitoring Structural Integrity

Regular measurements of elongation and stress can detect overloading or material degradation, preventing catastrophic failures.

Material Selection

Choosing steel with appropriate mechanical properties ensures safety margins are maintained, especially in applications involving dynamic or sustained loads.

Conclusion

Analyzing the behavior of a 60-m-long steel wire subjected to a 6-kN tensile load reveals vital insights into its elastic deformation characteristics. With a Young's modulus of 200 GPa, the calculated elongation of approximately 91.6 mm demonstrates how materials respond under load, emphasizing the importance of considering material properties, geometry, and safety factors in engineering design. Proper understanding ensures the longevity, safety, and efficiency of structures relying on steel wires, making such calculations fundamental to structural engineering and materials science.

Note: The specific numerical results depend on the actual cross-sectional area of the wire, which is determined by its diameter. Always verify the dimensions and material properties for precise calculations.

Frequently Asked Questions

What is the initial length of the steel wire subjected to a tensile load?

The initial length of the steel wire is 60 meters.

What is the magnitude of the tensile load applied to the steel wire?

The tensile load applied is 6 kN.

What is the Young's modulus (E) of the steel wire?

The Young's modulus (E) of the steel wire is 200 GPa.

How can we calculate the elongation of the steel wire under the given load?

Elongation can be calculated using the formula: $\Delta L = (P L) / (A E)$, where P is the load, L is the original length, A is the cross-sectional area, and E is Young's modulus.

What additional information is needed to determine the elongation of the wire?

The cross-sectional area or diameter of the wire is needed to calculate the elongation precisely.

How does the Young's modulus influence the deformation of the steel wire?

A higher Young's modulus indicates a stiffer material, resulting in less elongation under the same load.

What is the significance of knowing the Young's modulus in tensile problems?

Knowing Young's modulus helps determine how much a material will deform under a given load, which is essential for designing safe and efficient structures.

Additional Resources

Steel Wire Under Tensile Load: An In-Depth Analysis

Understanding the behavior of steel wires subjected to tensile loads is fundamental in structural engineering, materials science, and mechanical design. In particular, analyzing a 60-meter-long steel wire under a 6-kilonewton (kN) tensile load offers insights into the elastic response, deformation characteristics, and potential applications or failure modes. This article provides a comprehensive review of this scenario, exploring the principles, calculations, implications, and practical considerations involved.

Introduction to Tensile Loading on Steel Wires

Tensile loading refers to the application of force that pulls or stretches a material along its length. Steel wires, known for their high strength and ductility, are commonly used in suspension bridges, elevators, guy wires, and various engineering applications where tensile forces are prevalent.

When a steel wire is subjected to a tensile load, it experiences elongation proportional to the force applied, assuming elastic behavior. The extent of deformation depends on the material's properties, geometry, and the magnitude of the load. The elasticity of steel, characterized by its Young's modulus (E), governs this relationship within the elastic limit.

Fundamentals and Material Properties

Young's Modulus (E)

- Value: 200 GPa (Gigapascals)
- Significance: Reflects the stiffness of the steel; a higher E indicates a stiffer material that deforms less under load.
- Implication: For steel, $E = 200 \text{ GPa}$ is typical, indicating high elastic stiffness.

Other Relevant Properties (General Assumptions)

- **Density: Approximately 7850 kg/m^3**
- **Yield Strength: Typically around 250-550 MPa, depending on steel grade**
- **Ultimate Tensile Strength: Can reach 400-2000 MPa for high-strength steels**
- **Poisson's Ratio: About 0.3, indicating lateral contraction during axial extension**

Note: The problem primarily focuses on elastic deformation, so yield strength is not directly involved unless deformation exceeds the elastic limit.

Calculations and Analysis

Given Data

- **Length of wire, $(L_0 = 60, \text{m})$**
- **Tensile load, $(P = 6, \text{kN} = 6000, \text{N})$**
- **Young's modulus, $(E = 200, \text{GPa} = 200 \times 10^9 \text{ Pa})$**

10^9 Pa

Note: To determine deformation, cross-sectional area (A) is necessary; since it's not specified, typical assumptions or calculations based on stress limits can be employed.

Calculating Stress and Strain

- Stress (σ)

$$\sigma = \frac{P}{A}$$

Without the cross-sectional area, we can analyze the strain directly:

- Strain (ϵ)

$$\epsilon = \frac{\Delta L}{L_0} = \frac{\sigma}{E}$$

Therefore, the elongation (ΔL) is:

$$\Delta L = \epsilon \times L_0 = \frac{\sigma}{E} \times L_0$$

To proceed, an assumed or typical cross-sectional area is needed. For illustrative purposes, suppose the wire has a diameter (d).

Estimating Cross-Sectional Area

Suppose the wire has a diameter (d) . The cross-sectional area:

$$A = \frac{\pi}{4} d^2$$

If we consider a typical wire diameter, say, $(d = 10 \text{ mm} = 0.01 \text{ m})$,

$$A = \frac{\pi}{4} (0.01)^2 \approx 7.85 \times 10^{-5} \text{ m}^2$$

Calculating Stress:

$$\sigma = \frac{6000 \text{ N}}{7.85 \times 10^{-5} \text{ m}^2} \approx 76.4 \text{ MPa}$$

Since 76.4 MPa is well below typical yield strengths, the deformation remains elastic.

Calculating Strain:

ϵ

$$\epsilon = \frac{\sigma}{E} = \frac{76.4 \times 10^6}{200 \times 10^9} = 3.82 \times 10^{-4}$$

Calculating Elongation:

$$\Delta L = \epsilon \times L_0 = 3.82 \times 10^{-4} \times 60 \text{ m} \approx 0.0229 \text{ m} = 22.9 \text{ mm}$$

Result: The wire elongates approximately 22.9 mm under a 6 kN load, assuming a 10 mm diameter.

Implications of the Deformation

The elastic elongation of about 23 mm over a 60-meter wire indicates significant but recoverable deformation. Such deformation is typical in engineering applications where tension is applied, and it needs to be considered in design to prevent overstress or permanent deformation.

Key points:

- Elastic deformation is proportional to the applied load, following Hooke's Law.
- The elongation is small relative to the total length, indicating elastic behavior.
- The stress level (approx. 76 MPa) remains well below typical

yield strengths, ensuring no plastic deformation.

Features and Practical Considerations

Features of Steel Wires Under Tensile Load:

- High Elastic Modulus: Ensures minimal deformation under moderate loads.**
- Ductility: Allows for elongation without immediate failure.**
- Strength: Can withstand significant tensile forces before yielding or breaking.**

Pros:

- Excellent strength-to-weight ratio.**
- High fatigue resistance.**
- Good ductility allowing for elongation without fracture.**
- Predictable elastic behavior suitable for precise engineering calculations.**

Cons:

- Elastic deformation, while recoverable, can accumulate over time under cyclic loads leading to fatigue.**
- Susceptibility to corrosion if not properly protected, which can weaken the wire.**
- Potential for stress concentrations at joints or imperfections, risking failure before elastic limits.**

Limitations and Assumptions in the Analysis

- The calculation assumes uniform stress distribution along the wire's length.
- The cross-sectional area is estimated; actual dimensions could vary.
- The analysis is within the elastic limit; real-world conditions might include plastic deformation or fatigue.
- External factors such as temperature, corrosion, or dynamic loads are not considered but can significantly influence performance.

Applications and Engineering Significance

Understanding the elastic response of steel wires under tensile loads is crucial in designing reliable structures. For example:

- **Suspension bridges:** Wires must sustain tension with predictable elongation.
- **Cables in elevators:** Elastic deformation impacts ride quality and safety.
- **Guy wires in towers:** Must maintain tension despite environmental influences.

Design engineers leverage such analyses to select appropriate wire dimensions, materials, and safety factors.

Conclusion

The analysis of a 60-meter-long steel wire subjected to a 6-kN tensile load, given the Young's modulus of 200 GPa, demonstrates the fundamental elastic behavior of steel. With an estimated elongation of approximately 23 mm assuming a 10 mm diameter, the wire exhibits a safe and predictable deformation within elastic limits. This understanding aids engineers and designers in ensuring structural integrity, safety, and longevity of steel wire applications. While the calculations involve assumptions, they exemplify core principles essential for effective material and structural design, highlighting the importance of material properties, load considerations, and geometric factors in real-world engineering scenarios.

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