DEPARTMENT OF MECHANICAL ENGINEERING

COLLEGE OF E&ME, NUST, RAWALPINDI

PBL Semester Project: ME-210 Mechanics of Materials I

Analysis of a machine/structural component

Project Title: Project Serene – Structural Failure Case Study (Citicorp Center)

Sr. No.	Student Name	Syndicate	Registration No.
1	Rao Talha Afzal	46-ME-B	533325
2	Fasih Ullah Kiyani	46-ME-B	514589
3	Muhammad Ahsan	46-ME-B	521116
4	Hashim Shujjah Satti	46-ME-B	525289

Introduction

The structural integrity of high-rise buildings depends not only on accurate engineering analysis but also on strict adherence to design specifications during construction. The Citicorp Center in New York City is one of the most well-known cases in structural engineering where a seemingly minor design modification created a major safety risk. Originally designed with welded joints in its diagonal bracing system, the use of bolted connections introduced vulnerabilities that were not fully understood until after construction was completed. When quartering wind effects were re-evaluated, it became clear that the bolted joints were subjected to dangerously high stresses, compromising the building's lateral load-resisting capacity.

This report examines the structural behavior of a typical diagonal brace and its bolted connection underestimated quartering wind forces. By analyzing axial stresses in the bracing member, shear stresses in the bolts, allowable limits, and factors of safety, the study demonstrates that the connection as constructed did not meet essential safety requirements. The case serves as a powerful reminder of the importance of rigorous verification when design changes occur, the need for conservative safety margins, and the ethical responsibility engineers hold in safeguarding the public.

Abstract

This project analyzes the structural safety issues discovered in the Citicorp Center building in New York. During construction, a major design change replaced the originally specified welded joints in the diagonal braces with bolted joints. When quartering wind loads acting on the building were re-evaluated, the bolted joints were found to be critically overstressed. In this study, a typical diagonal brace and its bolted connection are examined underestimated wind loading. The axial stress in the braces, shear stress in the bolts, allowable limits, and factors of safety are calculated. The results show that the bolts experience stresses far above safe limits and the factor of safety is dangerously low. The analysis confirms that the connection was unsafe and required immediate reinforcement. This case highlights the importance of checking design changes carefully and ensuring proper safety margins in structural engineering.

Problem Description

The component selected for this project is the **diagonal bracing element** of the Citicorp Center tower and its **bolted joint connection**. These braces form an essential part of the building's lateral load-resisting system.

Function of the Component:

- Carries wind-induced forces
- Transfers loads to the structural core
- Protects the building from swaying and collapse
- Maintains stability during storms and hurricanes

Original Design:

- The diagonal braces were meant to be **welded** at their joints.
- Welds provide high strength and excellent performance under changing wind loads.

Construction Error:

- The contractor replaced welded joints with **bolted joints** to save cost and time.
- Bolts provide adequate strength for simple shear but are **weaker under combined shear and tension**, especially during repeated wind cycles.
- The building's structural engineer, William LeMessurier, later discovered that the building was unsafe under **quartering winds** (winds blowing at a 45° angle), which increased loads by 30–40%.

Assumed Material Properties:

These are reasonable engineering values:

Diagonal Brace (Steel Plate):

- Yield Strength (σ_Y): 250 MPa
- Elastic Modulus (E): 200 GPa
- Dimensions: 300 mm width, 15 mm thickness

Bolts (High-Strength Steel A325 Type):

- Tensile Strength: 620 MPa
- Allowable Shear Strength: $0.6 \times 620 = 372$ MPa
- Diameter: 20 mm
- Number of bolts installed: 2 per joint

Estimated Loading:

A typical diagonal brace is assumed to carry axial force of:

$$\mathbf{F = 500\ kN}$$

This value represents wind loading under strong quartering-wind conditions.

Analysis

Axial Stress in the Diagonal Brace:

Cross-sectional Area:

$A = \text{width} \times \text{thickness}$

$A = 300\ \text{mm} \times 15\ \text{mm}$

$A = 4500\ \text{mm}^2$

$A = 4.5 \times 10^{-3}\ \text{m}^2$

Axial stress:

$$\sigma = F / A$$

$$\sigma = 500{,}000\ \text{N} / (4.5 \times 10^{-3}\ \text{m}^2)$$

$$\sigma \approx 111\ \text{MPa}$$

Comparison with yield strength:

- Axial stress = 111 MPa
- Yield strength = 250 MPa

Conclusion:

The brace material is safe in axial loading.

Shear Stress on Bolts:

Load per bolt:

$F(\text{bolt}) = F / 2$

$F(\text{bolt}) = 500\ \text{kN} / 2$

$F(\text{bolt}) = 250\ \text{kN}$

$F(\text{bolt}) = 250{,}000\ \text{N}$

Bolt shear area:

$A(\text{bolt}) = (\pi \times d^2) / 4$

$A(\text{bolt}) = (3.14 \times 20^2) / 4$

$A(\text{bolt}) = 314\ \text{mm}^2$

$A(\text{bolt}) = 3.14 \times 10^{-4}\ \text{m}^2$

Shear stress per bolt:

$\tau = F(\text{bolt}) / A(\text{bolt})$

$\tau = 250{,}000\ \text{N} / (3.14 \times 10^{-4}\ \text{m}^2)$

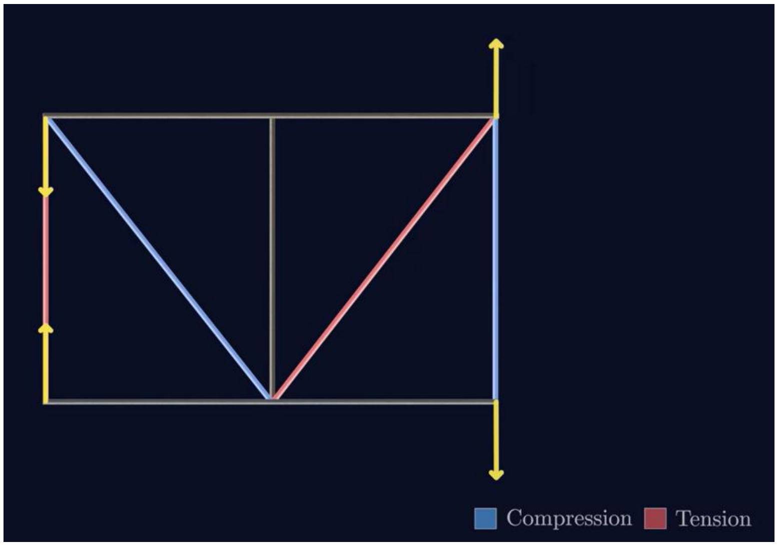
$\tau \approx 796\ \text{MPa}$

Comparison With Allowable Shear Strength:

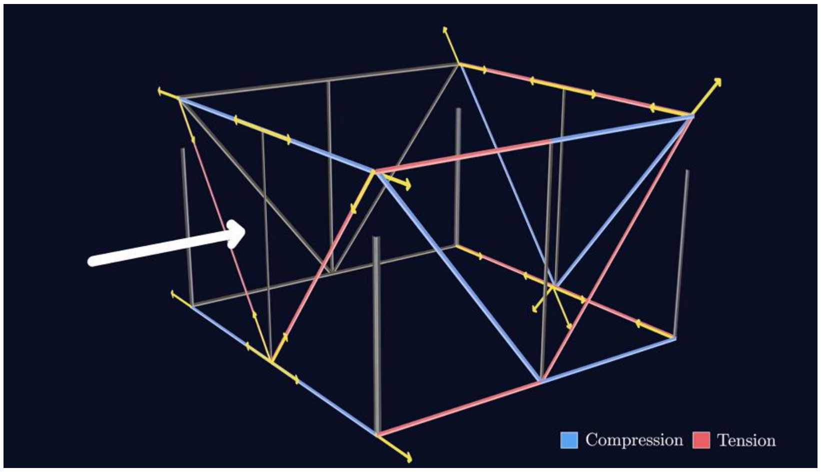
Allowable bolt shear = 372 MPa

Actual shear stress = 796 MPa

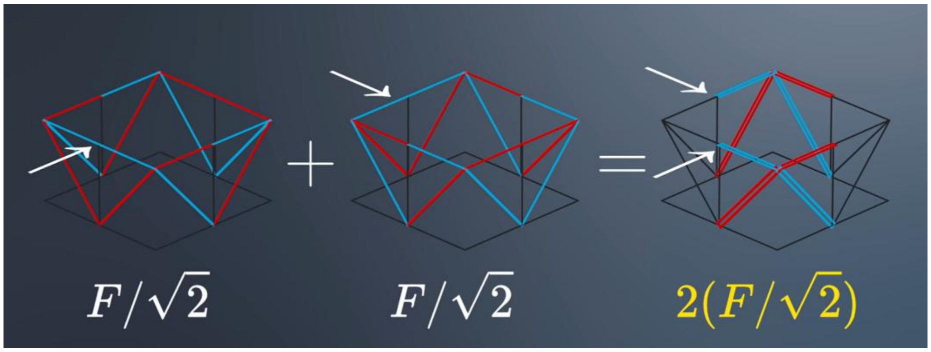
Corner wind Analysis:



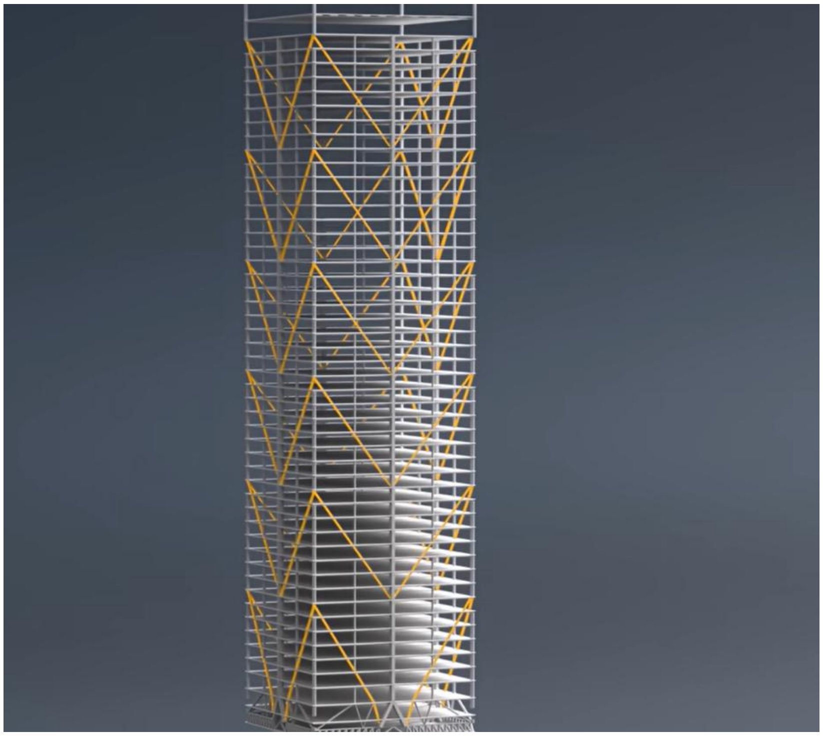
3D Wind analysis:



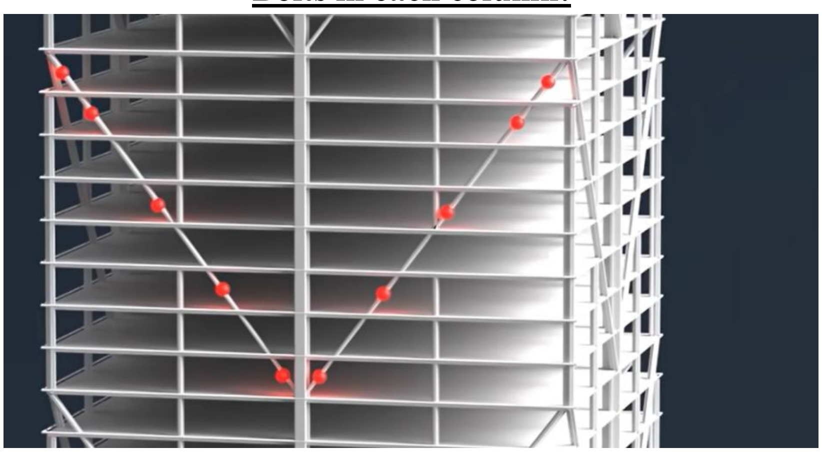
Normal Analysis:



Building loading:



Bolts in each column:



Conclusion:

Bolt shear stress is more than **double** the allowable limit.

Bolts will **fail** during strong wind loading.

Factor of Safety:

FS = Allowable shear stress / Actual shear stress

FS = 372 MPa / 796 MPa

FS ≈ 0.47

Safe design requires:
$FS \geq 2$

Conclusion:
Hence factor of safety is 0.47 which is extremely unsafe. That explains the reason why emergency welding repairs were necessary.

Findings and Engineering Insights:

• The brace member is safe, but the bolted joint is the critical weak point.
• Using only 2 bolts instead of 4 concentrated shear forces dangerously.
• The design change (bolts instead of welds) reduced structural safety significantly.
• Quartering wind (diagonal wind) was not originally checked and increased loads by ~40%.
• This case highlights the importance of correct assumptions, load combinations, and strict construction quality control.

Conclusion

- The analysis confirms that the diagonal brace in the Citicorp Center building was not the main issue.
- The real problem was the bolted joint, which was critically under-designed.
- Each bolt carried a shear stress of **796 MPa**, far exceeding the allowable limit of **372 MPa**.
- This resulted in a very low **factor of safety (0.47)**, indicating a high chance of failure during strong winds.
- The case highlights the importance of:
    - Accurate load and wind estimation,
    - Re-checking designs after any modification,
    - Choosing proper and safe connection types.
- The Citicorp Center incident remains an important lesson in structural engineering ethics, responsibility, and public safety.

Citations:

Veritasium. (2021, July 10). *The skyscraper that almost toppled*. YouTube.
New York City Department of Buildings. (2014). *New York City Building Code.* NYC Department of Buildings.
Feld, J., & Carper, K. L. (1997). *Construction Failure* (2nd ed.). Wiley.
ASCE. (2010). *Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10)*. American Society of Civil Engineers.

Group Members Contribution:

1. Rao Talha Afzal — Calculations Lead

- Performed all structural calculations related to axial stress, shear stress, bolt capacity, and factor of safety.
- Verified material properties, loading assumptions, and numerical accuracy.
- Ensured that the engineering methodology followed standard analytical procedures.

2. Fasih Ullah — Graphing and Analysis Specialist

- Created graphs, charts, and visual representations of stress behavior and load distribution.
- Interpreted analytical results and assisted in deriving conclusions regarding joint safety and wind-load performance.
- Supported the team by validating trends and illustrating structural risks.

3. Ahsan — Report Writer & Editor

- Compiled the full research report and structured all sections including introduction, abstract, analysis, findings, and conclusion.
- Ensured clarity, academic writing standards, and correct citation format.
- Integrated contributions from all team members into a cohesive final document.

4. Hashim — Data Collection & Research Coordinator

- Gathered all necessary technical data, material properties, historical information, and reference sources.
- Researched relevant case studies including the Citicorp Center incident and NYC building code requirements.
- Provided supporting documents and background content for analysis and reporting.