Kevin K Goudarzi, PE

Project Manager
KGS Construction Services Inc
Email: Kgoudarzi@kgsconstruction.com
Cell: 703-853-0092

Seismic Retrofitting of a 28 story hotel

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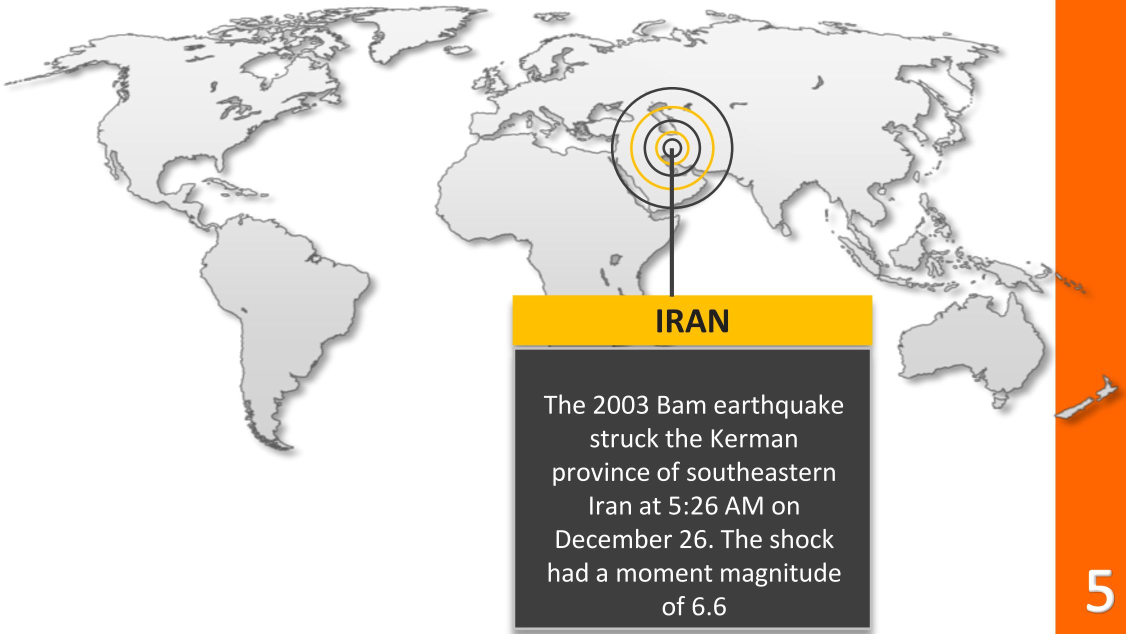
1. Introduction

Bam earthquake

The 2003 **Bam earthquake** struck the Kerman province of southeastern Iran at 5:26 AM on December 26. The shock had a moment magnitude of 6.6 . The earthquake was particularly destructive in Bam, with the death toll amounting to at least 26,271 people and injuring up to 30,000. The effects of the earthquake were exacerbated by the use of mud brick as the standard construction medium; many of the area's structures did not comply with earthquake regulations set in 1989.



Earthquake damage to the city

Bam Citadel before earthquake

- It was built 2500 years ago and
- It is the largest Adobe in the world
- It was almost completely destroyed by the earthquake On December 26, 2003.

Bam Citadel after earthquake

1.A- Seismic Retrofitting of a 28 Story Hotel

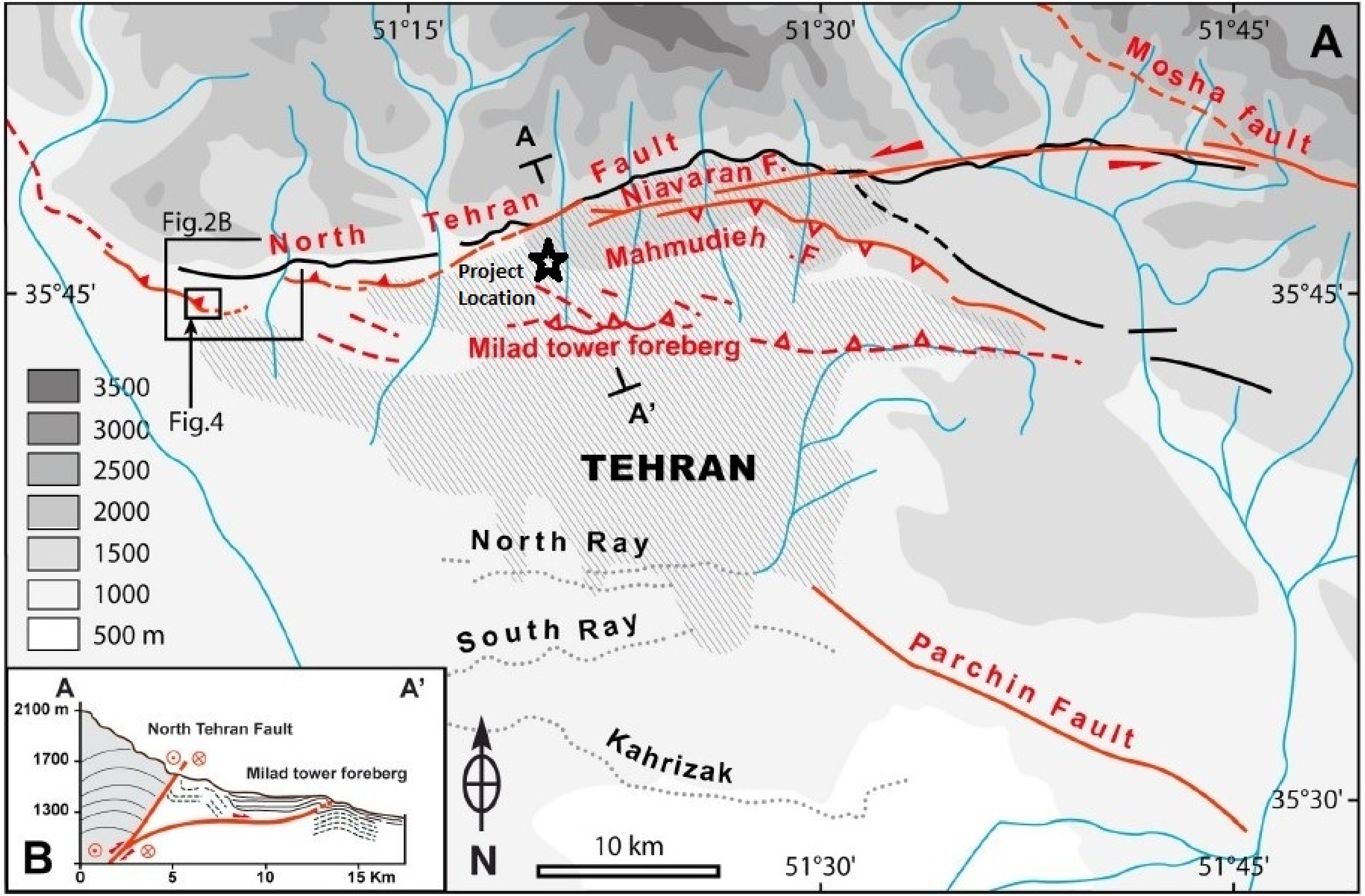
- The 28 story Azadi Hotel was built during the 1970's by a German engineering company.
- The building is made of concrete and has continuous walls from the 2nd floor to the 28th floor.
- These walls partition the rooms and are made of reinforced concrete and they work as the preliminary resisting elements for the seismic.
- The major deficiency was the existence of a soft story in the lobby, including poor quality concrete columns of up to 36 feet high.

The building before improvement

The building after renovation

2. Earthquake hazard zone

The Fault map in project Location



Fault line near to project location

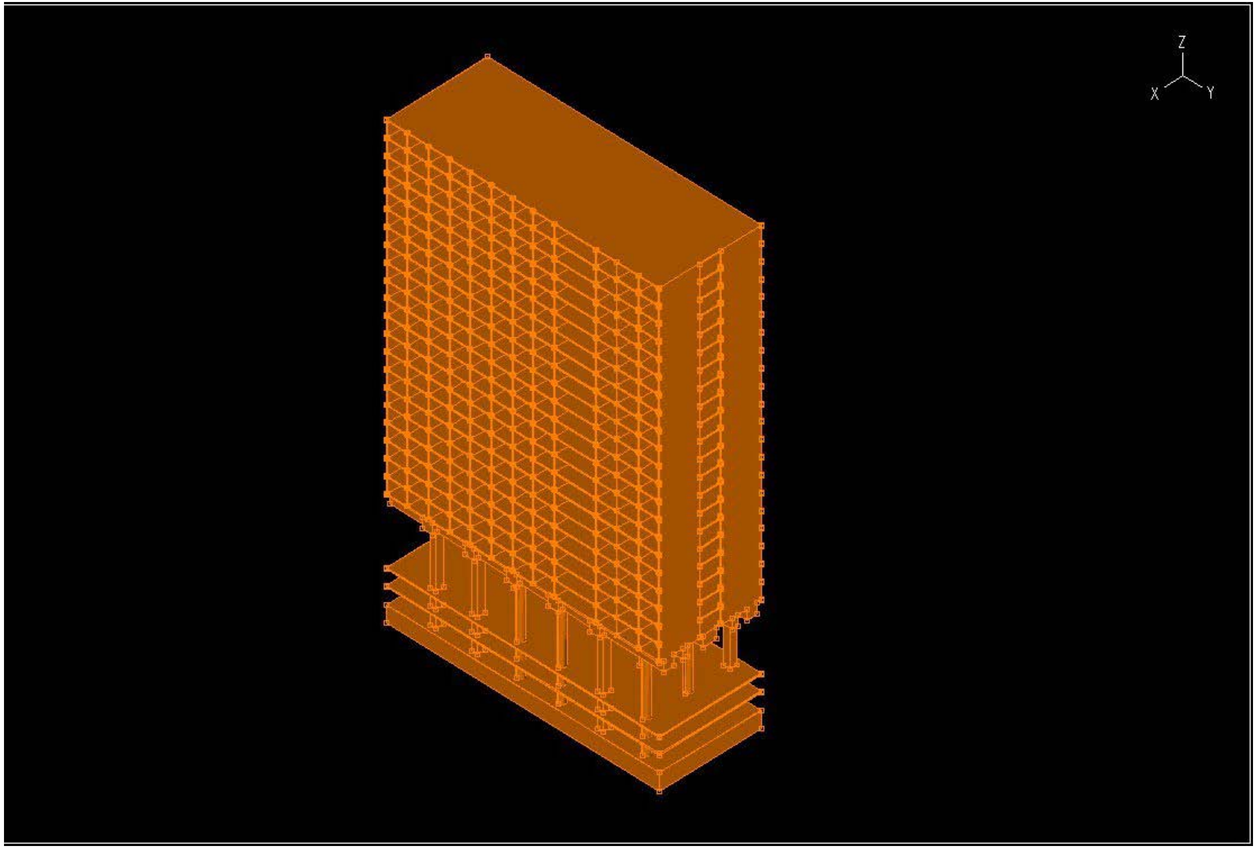
3. Existing Condition

The existing column with poor concrete and no lateral reinforcement at the bottom of the column

Huge beams over columns at lobby

4. Structural analysis

3D Modeling of the structure



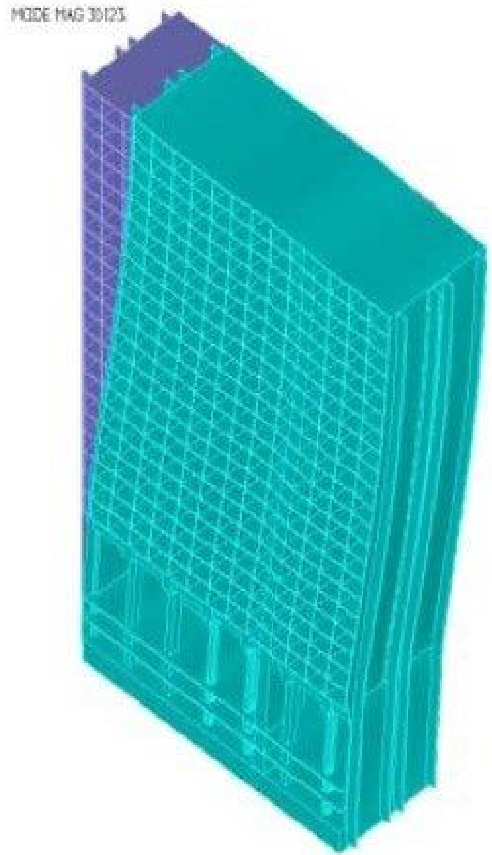
Structural Analysis

- The building is made of concrete and has continuous walls from the 2nd floor to the 28th floor.
- These walls partition the rooms and are made of reinforced concrete and they work as the preliminary resisting elements for the seismic. This is advantageous during an earthquake.
- The columns in the lobby, which were introduced to create a commercial space in the first story, are highly critical. These columns have very little stirrups and consist of poor quality concrete with average concrete compressive strength of 2900 psi.
- the walls stop at ground level, introducing a discontinuity to the lateral load resisting system. This results in a structure with a soft story floor.

Studies, Design and Supervision

- SMTeam GmbH Co. from Switzerland was the authorized company for design and supervision of seismic rehabilitation project.
- Radyab Co was the local engineering consultant in charge for local design and supervision.
- EMPA Institute from Switzerland as the consultant was responsible for quality control of the materials and equipment.

Displacement of structure under lateral loads



Local Seismic code

- Soft Story: The story in which, lateral stiffness is less than 70 percent of that of the story above or less than 80 percent of the average stiffness of the three above stories.

- Building Classification according to Importance:

❖ Group1- Buildings with “Very High Importance”

This group includes buildings that their post-continuous earthquake operation is of special importance and any discontinuity in this regard leads to an indirect increase in casualties and damages. Hospitals, clinics, fire stations, police stations, etc.

Building Classification according to Importance:

❖ Group2- Buildings with “High Importance”

a- Buildings whose damage results in great loss of life such as: schools, mosques, stadiums, cinemas and movie theatres, etc.

b- Buildings whose damage results in loss of national heritage. These include: museums, libraries and other places where national documents and valuable items are preserved.

c- Industrial buildings and facilities whose failure, may result in environmental pollution or widespread fire, such as refineries, fuel storage tanks and gas supply centers.

Building Classification according to Importance:

- Group3- Buildings with "Moderate Importance"

All buildings that are within the scope of this Code, except those included in other categories, fall in this group. These include: residential, office and commercial buildings, hotels, etc.

- Group4- "Buildings with Low Importance"

a- Buildings with low risk of damage and loss of life due to their failure such as agricultural warehouses and poultry farms.

b- Temporary buildings with an operational life of less than two years.

Earthquake base shear load

Base Shear, V

The minimum base shear or the sum of the horizontal seismic loads, in each direction of the structure, shall be determined from:

V=CW

Where:

V= The shear force at base level.

W= The total seismic weight of building, that is equal to the total dead load plus, a percentage of live and snow loads

C= The seismic coefficient, that is determined from the following

C Factor in base shear force

C = ABI/R

- A= Design base acceleration ratio (ratio of seismic acceleration to gravity acceleration, g)
- B= Building response factor determined from the design response spectrum,
- I= Importance factor
- R= Building behavior factor,

Percentage of live and snow loads in the seismic weight of the building

Location	Percentage of live load
Sloped roofs with a slope equal to or greater than 20%(1)	----
Flat roofs or roofs with a slope less than 20%	20
Residential buildings, Offices, **hotels** and garages	20
Hospitals, schools, shopping centers and public buildings	40
Storages and Libraries	60
Water tanks and other liquid storage tanks and silos	100

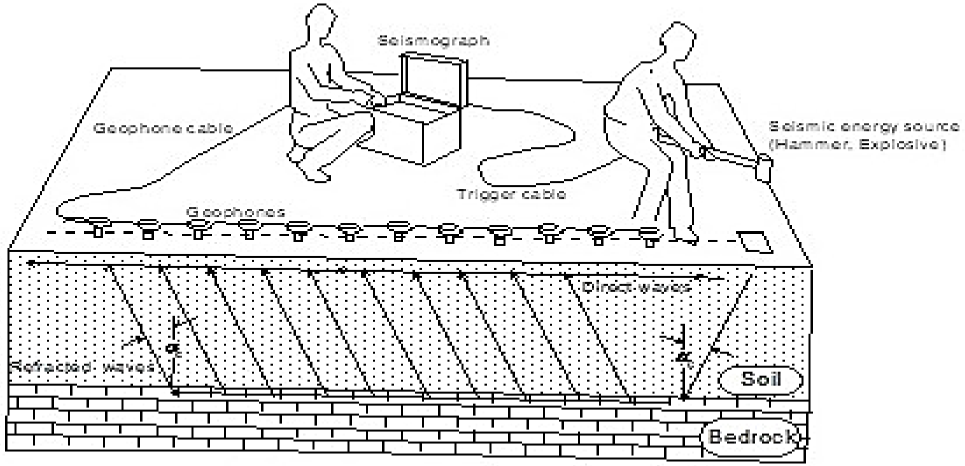
Design base acceleration ratio for various seismic zones

Zone	Description	Design base acceleration
1	**Very high level of relative seismic hazard**	**0.35**
2	High level of relative seismic hazard	0.30
3	Intermediate level of relative seismic hazard	0.25
4	Low level of relative seismic hazard	0.20

Building Importance Factor(I)

Building Classification	Importance Factor
Group 1	1.4
Group 2	1.2
Group 3	**1.0**
Group 4	0.8

The seismicity and seismotectonic study



The seismicity and seismotectonic studies on site

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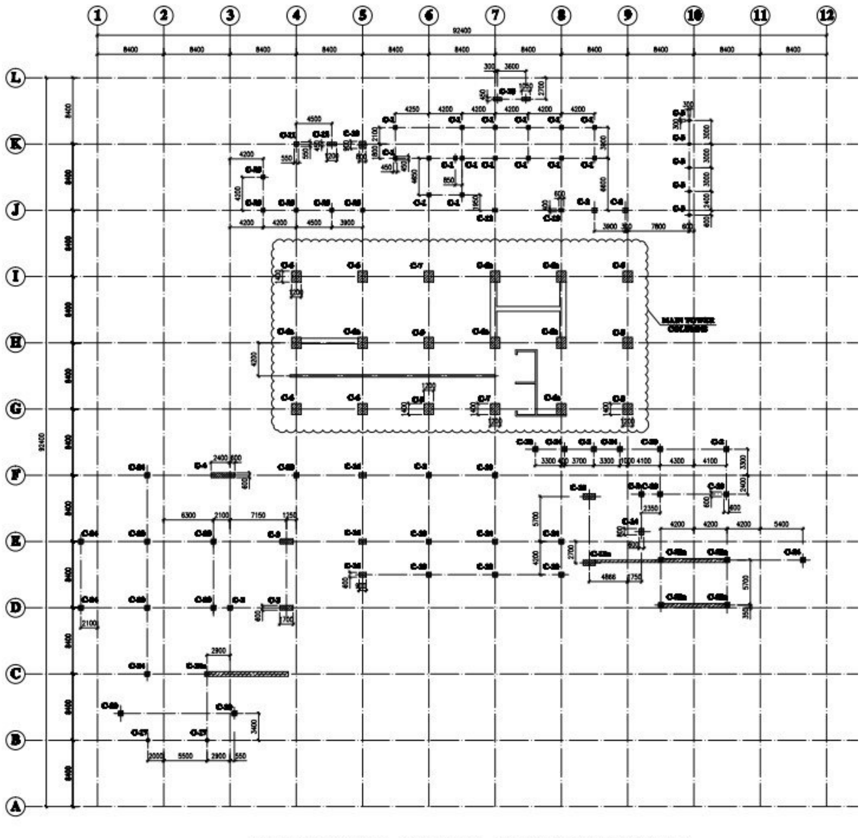
Columns layout



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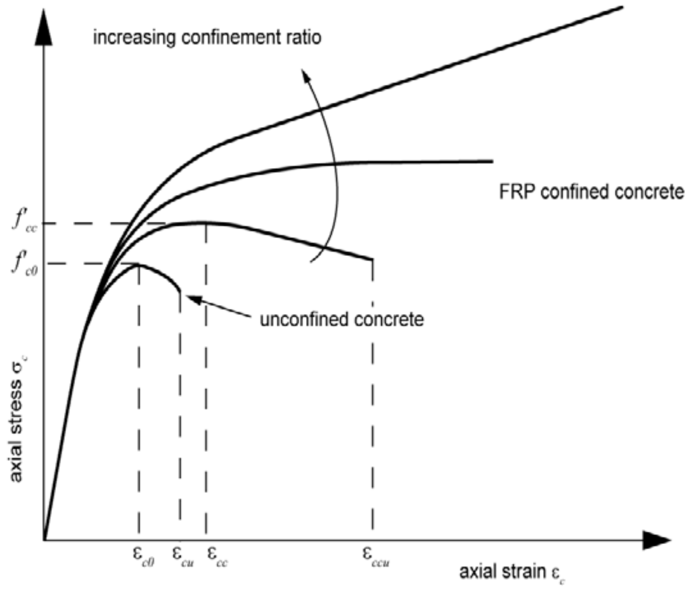
5. Carbon Fiber (CFRP)

Columns Confinement with CFRP

Column Confinement with CFRP:

- Enhancing load carrying capacity
- Increasing deformation capacity usually in the case of seismic upgrading
- Increasing shear capacity



Surface preparation for CFRP installation

Excavating down to the foundation to install CFRP

Carbon Fiber wrapping on the columns

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Carbon Fiber installation on the shear walls

Rectangular columns confined by CFRP, the bottom and top sections of the column has been reprofiled to curvy shape

Attached buildings columns wrapped by CFRP

6. Material Testing

Pull-off test on surface preparation material

Pull-off test on CFRP

Pull-off test on CFRP showing successful bonding, Failure in concrete

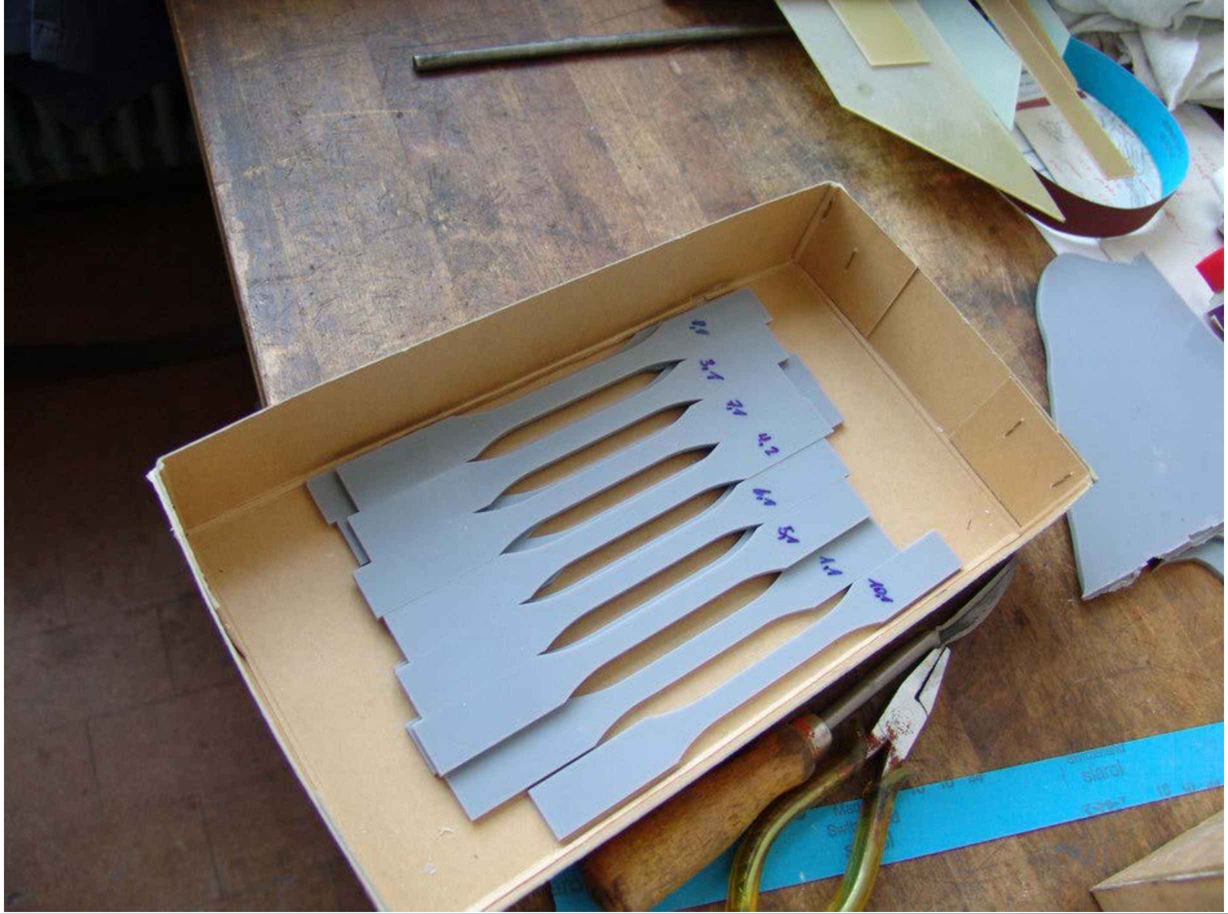
Columns built in lab to simulate the hotel's columns under earthquake load

Scaled columns in lab tested with and without CFRP

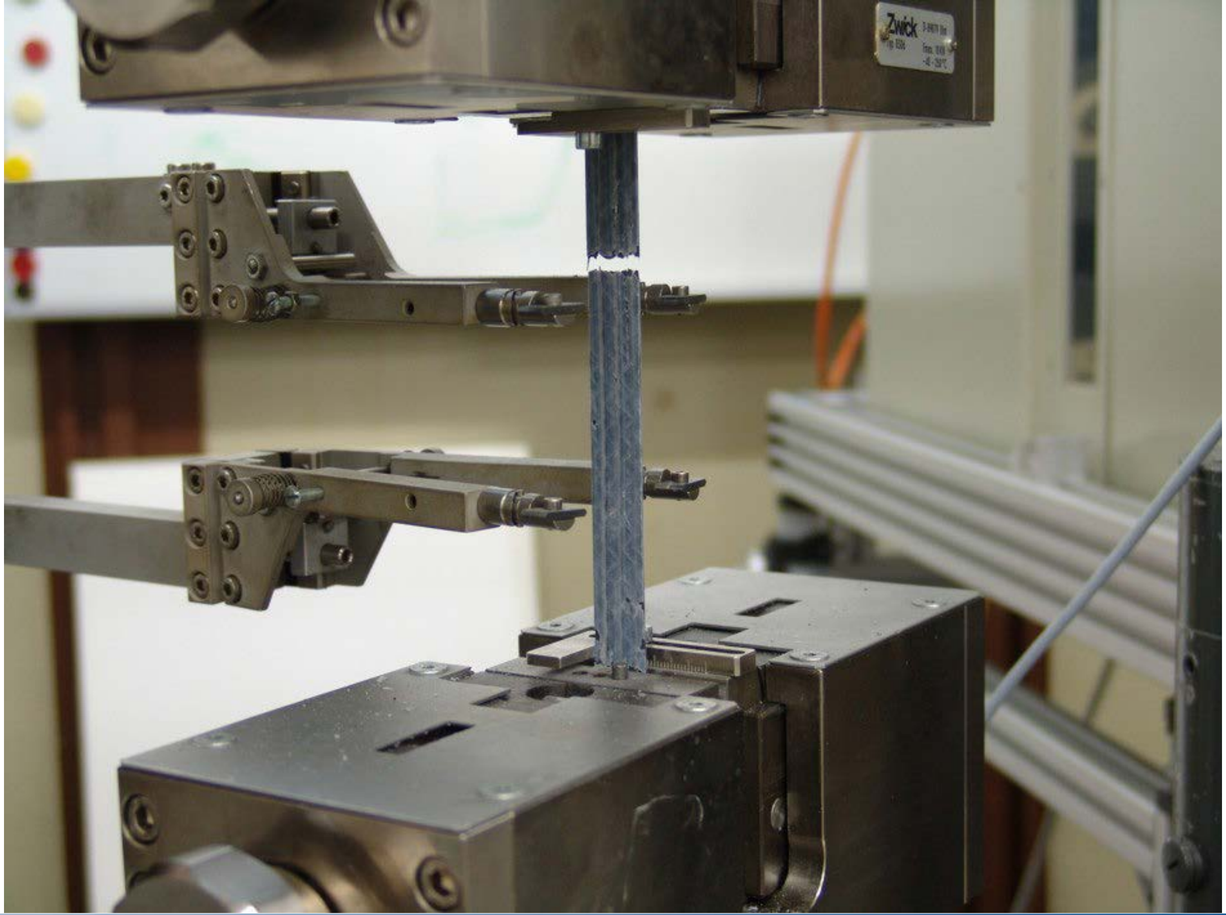
sample preparation for CFRP and epoxy testing

sample preparation for CFRP and epoxy testing

sample preparation for CFRP and epoxy testing



CFRP sample after failed under tensile stress test



Epoxy Testing

- Epoxy Test Result in Laboratory:

1) Tensile strength: **42.1** N/mm2 ± 7.4%
2) Tensile elastic modulus: **4'485** kN/mm2 ± 1.5%

- Specified values in the Product Data Sheet:

1) Tensile strength: **30** N/mm2 (7 days at 23°C)
2) Tensile elastic modulus: **4'500** N/mm2 (7 days at 23°C)

Carbor Fiber Testing

- CFRP Composite Test Result in Laboratory:

1) Ultimate load **387** kN ± 7.6% per 1 m' laminate width
2) Tensile elastic modulus **30.4** kN/mm2 ± 2.8% based on a thickness of 0.9 mm

- Specified values in the CFRP Product Data Sheet:

1) Ultimate load **360** kN per 1 m' laminate width
2) Tensile elastic modulus **25.0** kN/mm2 based on a thickness of 0.9 mm

Material Testing Assessment

- The measured strength (tensile and compression) and the elastic modulus of the using epoxy corresponds well or are even higher than the specified ones.

- The measured strength and elastic modulus of the CFRP composite impregnated with Epoxy corresponds well or are even higher than the specified ones.

7. Dampers

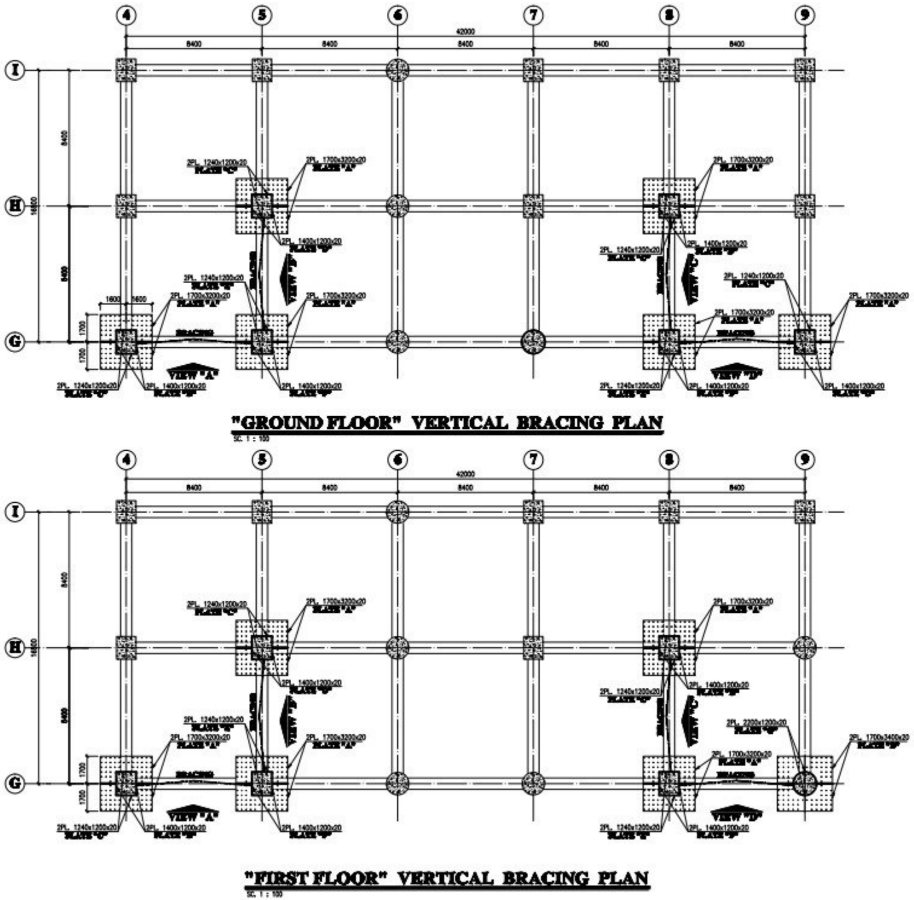
Recommended Damper Specifications

The following specifications were recommended:

- Maximum damper at maximum damper velocity of 1500 kN +/- 15% tolerance.
- Maximum damper stroke: +/- 15 mm for the mitigation of earthquake vibrations
- +/- 5 mm for the compensation of thermal expansion/contraction
- +/- 3 mm for the installing tolerances

==> the maximum recommended stroke is +/- 23 mm

Damper locations plan



Inverted V bracing with dampers

Inverted V bracing with dampers

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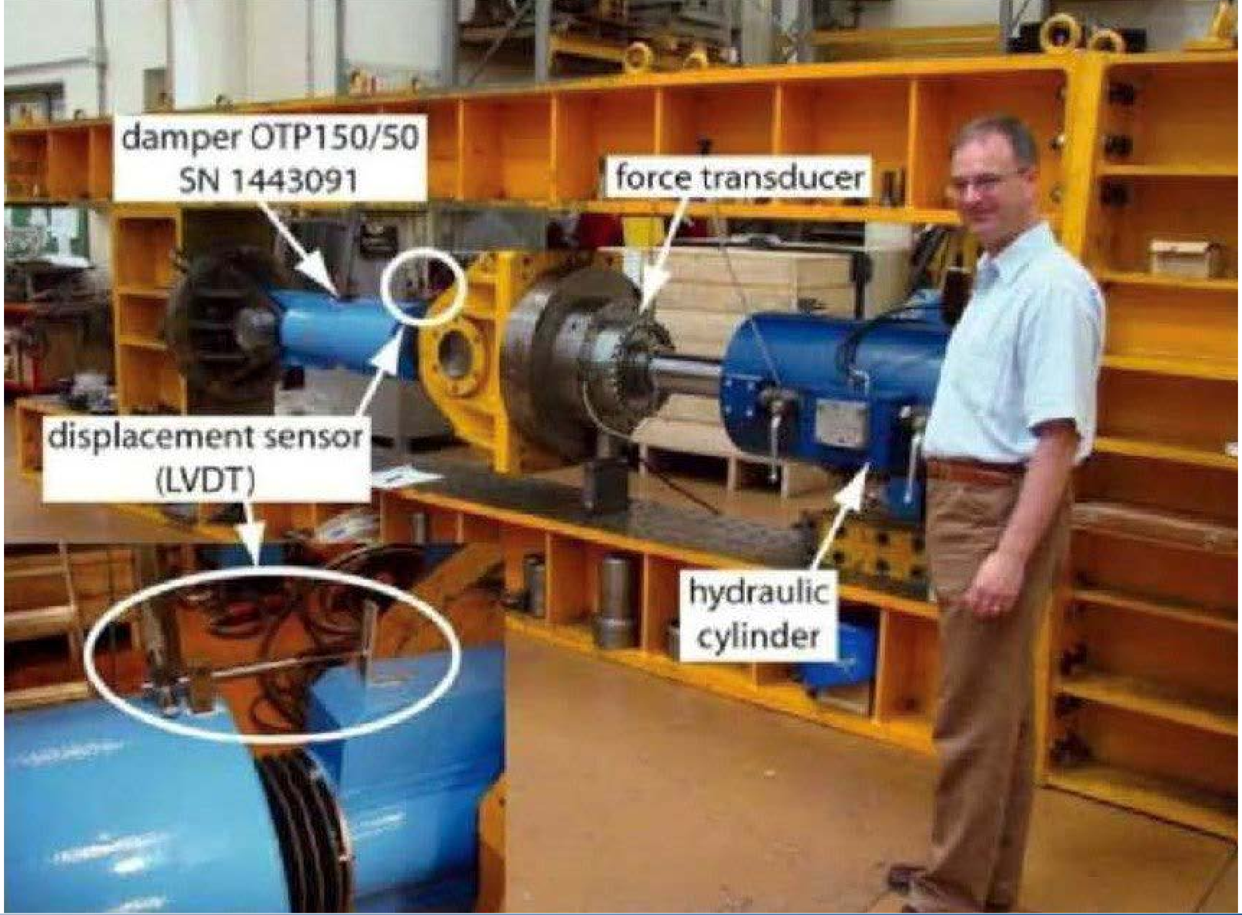
Dampers ready for testing

Hydraulic Dampers in testing setup



8. Summary

Summary

- The preliminary design was to apply FRP to the columns and shear walls at the lobby level and the basement.
- It was clearly demonstrated that applying FRP alone could not be satisfactory.
- The FRP could solve the shear problem of the columns; however, the bending problems of the columns could not satisfactorily be solved.
- The columns drift too much, resulting into high bending moments.
- It was decided to introduce additional bracings with hydraulic dampers in the lobby level and in the first floor.
- In order to prevent overturning of the structure, and reduce moments and shears at the base, 16 hydraulic dampers were utilized in the lobby and first floor.
- More than 215,000 square feet of carbon fiber reinforced polymer was also used to reinforce the columns and the shear walls in the lobby and the two basements floors. The dampers also, were installed with help of inverted V-bracings.

Summary

- Checking the shear forces, moments and axial loads with the allowable shear forces and moment-axial load capacity diagrams shows that the building can undergo the 475year earthquake without major damage.

- The retrofitted solution has following advantages:

1. Reducing of the drift of the lobby that resolved the soft story issue
2. Reduction of the shear and bending stresses
3. The loads in the bracing shall be in order of acceptable levels
4. The dampers allow a seismic health monitoring of the hotel in future

The hotel before improvement

The hotel after improvement

Project Complete

References

References

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Thank You!

Do you have any questions?

Kevin K Goudarzi, PE

Project Manager
KGS Construction Services Inc
Email: Kgoudarzi@kgsconstruction.com
Cell: 703-853-0092