The Leaning Tower of Pisa

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The Leaning Tower

- Construction of Tower began in 1173 under supervision of architect Bonanno Pisano
- Bell tower was built as manifestation of city’s pride and was meant to reflect rich city of Pisa

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
Construction of The Tower

- Work on Tower ceased in 1178 for reasons unknown; studies have shown that soil on which Tower was built would not have been able to withstand more construction at that time.

- Construction began again, but ceased in 1278.

- Had Tower been completed at this time, would have collapsed because of the stress on soil.

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.costruzioni.net/images/pisa.h4.jpg
Construction of The Tower

• During actual construction of Tower in 1100’s, Tower originally leaned north
  – Masonry blocks placed on each level to correct lean of axis

• By end of its construction, the Tower leaned significantly to the South

• Tower was finally completed in 1370; height is 53 m
The Leaning Tower Today

- From early 1990 until December 2001, Tower was closed to public because of safety issues
- Italian engineers implemented complex $25 million rescue plan in order to stabilize Tower
- Although Tower looks as if it might collapse at any moment, in reality, it is more stable now than at any time in past few centuries

http://www.pubs.asce.org/ceonline/art/art02/0302feat1.jpg
Alternatives to Restoration

- In 1838, architect Alessendro della Gherardesca constructed a walkway around Tower base

- Water filled the walkway area after the excavation extended below water table

- Plan increased tilt of Tower by over one quarter of a degree

- Gherardesco placed 0.7 meter thick ring of concrete around walkway to help stabilize Tower, but excavation nearly caused its downfall
Alternatives to Restoration

• In 1934, engineers used grout injection to stabilize the foundation of Tower

• This process led to a displacement of Tower

• The tip of Tower tilted 10 mm more to South

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
Alternatives to Restoration

- In 1993, 600 Mg of lead weights were added to north side of Tower, attached by a removable concrete ring placed around base of Tower
  - Reduced leaning by nearly one minute of an arc
  - Reduced moment that pulled on Tower by 10%

- Load was increased in 1995 to 900 Mg while engineers attempted to replace lead weights with ground anchors

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
Alternatives to Restoration

• One unique idea was to drill 10,000 holes in Tower to significantly reduce its weight

• Replica was to be placed next to Tower leaning in opposite direction to hold original tower in place

http://news.bbc.co.uk/2/hi/europe/1391476.stm
http://www.stilepisano.it/immagini13/
Restoration of The Tower

• A new restoration idea was presented in the 1990s
  – Known as soil extraction, or soil subsidence
  – Its goal was to excavate earth from beneath Tower’s foundation on its northern side so that Tower would tilt back toward perpendicular

• Idea was put into motion after various tests on Tower itself and on soil underneath its foundation

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://torre.duomo.pisa.it/towersposters/english_version/2/sezione.gif
Restoration of The Tower

- Temporary cables attached to 3rd level of Tower
  - Would support Tower if anything went wrong during soil extraction
- Lead weights were attached to ends of cables to ensure that Tower would remain steady

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://news.bbc.co.uk/olmedia/790000/images/_793432_pisa2_300gra.gif
Restoration of The Tower

• First soil extraction occurred on February 9, 1999
  – Extracted by means of corkscrew drills

• At first, Tower showed no sign of rotation, but then rotated toward the North

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://torre.duomo.pisa.it/towersposters/english_version/10/perforazioni.gif
Restoration of The Tower

- Tower had rotated seven seconds of an arc toward the North by February 23, 1999, but then it rotated back toward the South
  - Occurred as a result of strong, cold winds from the North
  - Tower soon began to rotate back toward the North after winds had diminished

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
Restoration of The Tower

- Soil extraction was stopped after Tower had rotated a total of eighty seconds of an arc by June 1999
- Three of the lead weights were removed in July 1999, and this resulted in a discontinuation of rotation

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.waidev2.com/php/IMAGES/HC_ThisDayInHistory/58---Image_large.jpg
Restoration of The Tower

- Main soil extraction began in the year 2000, after preliminary extractions had shown vast improvement.
- Tower had a tendency to rotate to the East throughout the process, so soil also had to be extracted from foundation’s west side.
- Tower continued to move northward, and slowly the lead was removed from the structure.

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
Restoration of The Tower

- Restoration process was finished on June 6, 2001
- Tower had returned to position it was in before 1838
- Restoration process moved Tower 1,830 seconds of an arc

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.rod.beavon.clara.net/pisa.htm
Problems and Costs of Implementing

- Design process cost the Italian taxpayers $25 million
- Design process was complicated by decree made by Italian Government that needed to be approved regularly by Italian Parliament
  - Delayed restoration process
  - Work was halted for long periods of time

http://news.bbc.co.uk/2/hi/europe/1391476.stm
http://news.bbc.co.uk/2/hi/europe/793432.stm
http://www.answers.com/topic/leaning-tower-of-pisa
Problems and Costs of Implementing

- Restoration process was halted when harsh winds caused Tower to rotate toward the South
- Throughout restoration process, Tower had to be closed to tourists
  - Tourists had been able to pay a fee so they could climb Tower
  - Now, Pisa would lose revenue (about $2 million/yr)

Problems and Costs of Implementing

- Stabilization of Leaning Tower provided difficulties of its own
  - Tower was originally constructed on weak, compressible soil, which increased instability of Tower
  - Ground on south side of Tower had to be treated with delicacy because any disturbance could result in falling of Tower
  - Original design of Tower had to be respected throughout the process to conserve monument’s character

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.endex.com/gf/buildings/ltpisa/ltpgallery/22nov02/ltp3064rx.jpg
Other Items of Interest

• There are 294 stairs to top of Tower
• Leaning Tower weighs about 14,700 metric tons
• About three million people visit Tower annually
• There are seven bells on Tower, largest of which weighs 3.5 tons

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.endex.com/gf/buildings/ltpisa/ltpinfo.htm
http://www.endex.com/gf/buildings/ltpisa/ltpgallery/22nov02/ltp3096rx.jpg
Conclusion

- Restoration process was very difficult to execute
  - Soil on which Tower was built was very unstable
  - Tower’s original design had to be maintained

- Soil extraction was a successful process that saved Tower from collapse
The Future of The Leaning Tower

• Speculation on whether restoration process will be beneficial in future
  – Professor Burland, who oversaw the restoration process, believes Tower may stay in its current condition
  – Professor Burland speculates that Tower may begin rotating again, and in 300 years, Tower will be where it was in 1990s

• Leaning Tower was reopened to public on December 15, 2001

http://www.pubs.asce.org/ceonline/ceonline02/0302feat.html
http://www.funnypictures.net.au/userimages/user1680_1165895778.JPG
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