he Leaning Tower of Pisa devi-

ated from the traditional verticality of the average tower, and in order to prevent its destruction

Vertically Challengeo What have they done to fix it?

Gradually, the Leaning Tower of Pisa is tipping its way towards extinction and efforts are continually being put forth to save this historical tower. On any given day, a collapse could be triggered by the slightest interference. (Shrady p. 6) Experts have attempted almost \$30 million worth of ideas, ranging from the foundation to the top of the bell tower, trying to extend the lifetime of this improbable icon. (Shrady p. XV) Besides undertaking several minor renovations such as substituting numerous stones on the tower, experts have pursued major solutions to fix the Leaning Tower of Pisa. In the 1950's, the bells of the famous bell tower were forced to stand silent because of the fear of a potential catastrophe. Then, unthinkably, in 1990, one of Europe's top tourist attractions, the Leaning Tower of Pisa, was forced to close to the public. (Feuerstein) This is probably the most tragic of all. The tower's notoriety has furthered its downfall. However, the tourists still come to see the magnificent tower, which would be just as extraordinary if it wasn't leaning. See Figure 1. Although they aren't allowed to travel the narrow stairways, taking a picture holding up the Leaning Tower of Pisa is reason enough to travel thousands of miles. Today, the tower is open to the public, but limited to small groups of people. (Feuerstein) Then, two years after closing the tower, another step was taken. Twelve plastic-coated metal "tendons" were wrapped tightly around the critical area of the tower, the second story. The purpose of this was to hold the cracks shut to prevent further damage to the tower. (Apsell)

This borderline miraculous tower barely overcame the next two attempts at verticality. The next venture to right the tower included slowly adding 600 tons of lead weights to counter the lean. (Apsell) The weights were stacked near the tower, over a four to five month period, in hopes to hold it upright. See Figure 2. The tilt became under control for the first time in 800 years. (Apsell) However, the magnificent tower was becoming unsightly from the ugly lead weights, ruining the much sought after appearance of the tower. By trying to save the tower, the integrity of the building became compromised. Since the tower has defied all odds up to this point, there's a chance that it will not collapse anytime soon. In that case, the ugly lead weights should no longer be an option. In order to get rid of the hideous weights on the outside of the tower, the latest idea was put to the test. This

and maintain its character, many

why Does it Lean? the sun on the south side of the tower exceeds the heat on the north side, causing the marble exterior to expand. (Apsell) This expansion creates an imbalance, furthering the lean to the south, however, at night, the marble shrinks back to normal. (Apsell) Also, deterioration of the stone used to build the Tower of Pisa is causing parts of the tower to become unstable, resulting in deficiencies. (Apsell) The exterior of the tower is not strong enough to support this large mass and the stress of the lean falls mainly on the thin exterior. (Apsell) The largest stresses are on the south side of the second story near a doorway. (Apsell) This is predicted to be the spot when a collapse would begin, if it happened. (Apsell) This iconic piece of history is worth preserving, and every effort should be put forth to prevent a collapse from happening.

The greatest causalities of the inclination have been attributed to humans and the foundation of the tower. The tower was built in three unconsecutive stages beginning in 1173 and ending in 1370. (Shrady p. XIX-XX) The tilt of the tower became evident around the second stage of construction, when only three of the eight stories had been finished. (Shrady p. XIX) It was actually advantageous for construction to come to halt. If they would have continued work uninterrupted, the tower would almost surely have fallen right away. (Apsell) Luckily, architects noticed the lean and tried to alter the extent of the inclination. For the construction of the fifth, sixth, and seventh stories, the architect tried to correct the tilt by building the next three stories slightly slanted to the north, causing the tower to look similar to a banana. (Shrady p. 76) Before they constructed the bell tower, the builders again tried to adjust for the lean. They added six steps to the south and only four to the north in hopes that the tower would straighten out. ("Leaning Tower") Benito Mussolini has also been blamed for some of the tilt. He felt that the tower did not conform to his Fascist ideas and in 1934, tried to fix the tower by pouring 200 tons of cement into the base, resulting in the tower tilting an extra one-tenth of an inch. ("Leaning Tower") Besides human intervention, the foundation has accounted for a substantial amount of the lean. The tower was built on land that used to be a river estuary and has a consistency "comparable to a beach." (Apsell) The weight of the 14,700 ton tower mixed with the unstable land would almost definitely cause any building to tilt. It's no wonder the architect of this tower is a mystery-I wouldn't want to claim a tower that was built on a beach either. Even though all of the ground is soft, the soil on the south side is a little more compressible than the north side, justifying the tilt towards the south. Although events in history have caused this tower to be a little off-kilter, this extraordinary tower deserves to live for many more years- it is an architectural icon after all.

plan included attaching anchors to the towers and fixing them into the ground all the way down to the bedrock. (Apsell) This would be a permanent solution to help stabilize the tower, not straighten it. (Apsell) However, not surprisingly, the tower lurched one-sixteenth of an inch in one night, quite a substantial amount for a tower. (Apsell) Contractors and experts hastily worked to stabilize it by adding even more lead weights than before. (Apsell) Ironically, while they were trying to take away the unsightly lead weights, they ended up putting up even more to try to fix the mistake of putting them up in the first place. It seems to be inevitable that the tower will lean even more when someone tries to fix it. Every person that has tried to fix the tower has ended up increasing the incline even more. (Apsell) Maybe the tower is trying to tell the world that it does not want to be fixed.

Action Timeline



1992

1995

1999

2001

Action

Construction of tower begins Construction of tower completed Mussolini demands cement to be poured into base Bells silenced Tower closed to public Tendons wrapped around tower Lead weights added to support tower Soil extraction begins Tower re-opened to public



The unsightly lead weights used to hold of the Leaning Tower of Pisa. (Feuerstein)

State & States

Figure 2

Latest Solution

Engineers decided a permanent solution was needed that would keep the integrity of the Leaning Tower of Pisa in tact. The underlying question becomes: to what extent should the tower be fixed? Obviously, they could not possibly straighten the tower completely. What would they name it- Your Normal, Everyday Tower of Pisa? In reality, the tower needs to be reinforced somehow, otherwise the tower will no longer exist. After many years of debate and many diverse engineers' opinions, a solution has been proposed and they like to call it soil extraction. The basic essence of this idea is to remove soil from underneath the north side of the tower. A drill will be inserted under the tower and when it is pulled out, the soil will fill in the cavity, thereby reducing the lean. (Apsell) See Figure 3. This strategy should reduce the inclination by approximately ten percent, or about one half of a degree. (Apsell) According to experts' calculations, this should add at least 300 years to the tower's lifetime. (Apsell) However, it is still very risky and some people are wondering if it is worth it. To take extra precaution, a heavy metal harness would be gently holding the tower in case of any large movements and numerous machines would be monitoring the tower at all times. (Apsell) Thus far, the soil extraction method has been very successful and it is already slowly moving north. (Apsell) This architectural miracle will probably have many surprises to come, but hopefully none of those surprises will be catastrophic. Everyone deserves the opportunity to see this great world wonder.

HE ENGINEERING SOLUTION



drills remove soil

The tower sinks into the cavity

A diagram illustrating the soil extraction method. (Mulvey)

Noteworthy Numbers

- Everyday the tower sways in a tiny circle not more than 1/100 of an inch in diameter. (Apsell)
- The top of the tower has, at one point, leaned 15 feet over the base. (Shrady p. 2)
- The tower once sloped at a 5.5 degree angle. (Apsell)
- The angle of inclination used to increase 1.2 mm per year. (Feuerstein)

The only real fault of this tower is the fact that you get neck cramps from looking at. It's easy to find your head tilted to the side because the magnificence of the architecture leaves you too stunned to notice...

An example of the extraordinary marble used on the tower. As you can see, even if the tower was not leaning, it would still be a tower worth seeing. (Pisa)

Figure 1