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Continuity Briefs

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The Effect of Unforeseen Disasters on Structural Stability

by Dr. Ajit S. Gill

Highlights:

- planners who have been charged with the task of sourcing redundant facilities need to make site decisions based on a wide range of criteria including structural and geological factors
- subject of unforeseen disasters can have a pronounced effect on the stability of not only buildings, but the key transportation arteries (i.e. roads and bridges) that provide access to these facilities
- Flooding can be caused by naturally-occurring phenomena or human activity; Excessive rainfall might result in excessive surface water flows that can result in the bursting of dams or canals; recent California mudslides illustrate how excessive surface flows can result in soil erosion
- In worst case scenarios, soils are scoured by fast flowing waters, which can compromise shallow foundations of structures such as bridges and buildings – a situation that can lead to collapse
- Planners can implement a number of key measuring criteria that might be implemented to reduce the risk of damage to foundations resulting from floods
- Degree of damage from fire can vary from negligible to complete destruction; variation can result from types of construction materials used
- Materials include steel, concrete, wood; steel framing with inadequate insulation & fire retardants identified in primary cause of WTC collapse
- Earthquakes can impact structures as well as composition of soil; therefore geological factors play important role in site analysis
- Very important to audit not only particular building's adherence to code, but how changing codes have evolved

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Introduction

Over the past several weeks, we have witnessed a cascade of natural disasters that have exacted a heavy toll on life and property. The most visible of these has clearly been the earthquake in ancient city of Bam, Iran where it is now estimated that more than half the city's population of 80,000 has perished. The primary cause of death and destruction has been the poor construction standards of buildings that in many cases were hundreds of years old. The importance of construction standards cannot be overemphasized. Just two weeks prior to the Bam earthquake, an earthquake of the same magnitude (6.5 on the Richter scale) hit the coastal region of California between Los Angeles and San Francisco where loss of life and property damage were held to a minimum.

In the late 2003, we heard daily reports about the wildfires that were ravaging California. Just two weeks, the same area experienced uncontrollable mudslides (mudslides that may have been prevented if so many trees had not been damaged in the earlier fires). Inevitably, planners who have been charged with the task of sourcing redundant facilities need to make site decisions based on a wide range of criteria including structural and geological factors.

Indeed, the subject of unforeseen disasters can have a pronounced effect on the stability of not only buildings, but the key transportation arteries (i.e. roads and bridges) that provide access to these facilities. As construction standards become an increasingly important component in site selection, we use this brief to provide a general commentary on the subject which in itself is an extremely vast subject to deal with. In this brief, we will limit our focus to the effects of flooding, fire and Earthquakes on structures. Ideally, this should provide a quick reference to some of the structural and geological factors that must be considered optimizing a redundant facility selection.

Environmental Risk Factors:

1.0 FLOODING

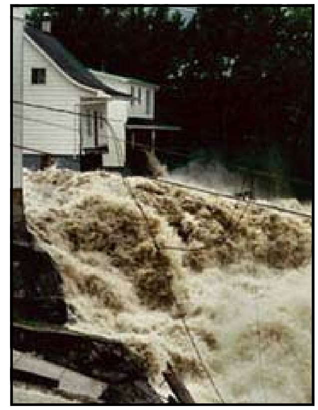
Flooding can be caused by either naturally-occurring phenomena or human activity. Excessive rainfall for instance, might result in excessive surface water flows (such as river swelling) that can sometimes result in the bursting of dams or canals. Likewise, flooding might be induced by human activities (i.e. "anthropogenic") such as terrorist attacks, or massive deforestation resulting from human activity. The recent California mudslides compellingly illustrate how excessive surface flows can result in soil erosion. In worst case scenarios, soils are actually scoured by fast flowing waters, and this can seriously compromise the shallow foundations of structures such as bridges and buildings – a situation that can ultimately lead to the collapse of the supported structure.

A second factor that can cause the failure of foundations by floodwaters is the reduction of the bearing capacity of soil by floodwaters that do not withdraw rapidly. As a rule of thumb, the bearing capacity of a soil is cut in half by a rise in ground water level above the base of the footings (when under normal conditions the ground water level exists well below the base of the footing).

Therefore, when assessing the viability of a particular site, planners can implement a number of key measuring criteria that might be implemented to reduce the risk of damage to foundations resulting from floods. There are a number of simple things to look for in conducting such an analysis. For instance, the structure should have an infrastructure that diverts floodwaters away from the foundations – a task easily accomplished by suitable drainage systems to ensure rapid flow of floodwaters away from the foundation.

Another technique that is sometimes implemented is driving sheet piles around the foundations of important structures. It should be noted that this is an expensive measure, and as an option, it must be subjected to a thorough cost-benefit analysis, as the cost of this project can only be justified by the importance of the structure as well as the degree of risk to its being affected by floodwaters.

Civil Engineering Terminology:
Bearing Capacity of Soil
If a load is applied on a limited area on or below the surface of the soil, the loaded area settles. The area covered by the load is called the bearing area. The load required to produce the failure of the soil support is called the critical load or the total bearing capacity.



The Saguenay River Valley flood in Canada's Quebec province in 1996; in the span of 36 hours 290 mm of rainfall caused massive flash floods resulting in $1.598 (Cdn.) billion in damage

Civil Engineering Terminology: Footings

Footings are structural members that are used to support columns and walls and to transmit and distribute their loads to the soil in such a way that the load bearing capacity of the soil is not exceeded, excessive settlement, differential settlement, or rotation are prevented and adequate safety against overturning or sliding is maintained. Some common types of footings include wall footings, isolated/single footings, combined footings and strap footings.

Civil Engineering Terminology: Sheet Piles

Steel sheet pile walls are generally constructed by driving steel sheets into a slope or excavation. They are considered to be the most economical where retention of higher earth pressures of soft soils is required. Their primary advantage is their ability to be driven to depths below the excavation bottom thereby providing a control to heaving in soft clays. Sheet piles are more expensive and less adaptable to hard driving conditions particularly where boulders or irregular rock surfaces occur.

2.0 FIRE

Whether a fire is the result of a natural phenomenon such as lightning or an anthropogenic event such as arson, its effect generally has the same result. The degree of damage can vary from negligible damage to complete destruction. As structures are made from a wide range of construction materials, these materials often play an important role in determining the extent of damage.

2.1 Steel Structures

For many years steel has been an extremely popular material for constructing multi-story buildings because of its high tensile and compressive strength. Additionally it is readily availability in different structural shapes, thus contributing to ease of assembly.

In order to protect steel supported structures from the effects of fire it is necessary that sufficient amounts of non-combustible insulation are provided around steel structural members. This is a necessary in order to prevent an excessive rise of temperatures of the steel. It has been established that the collapse of the World Trade Center was directly attributable to insufficient amounts of insulation around steel supporting members of the towers. The Trade Center towers were the first supertall buildings constructed without masonry, as the engineers employed an innovative structural model: a rigid “hollow tube” of closely spaced steel columns. When the heat generated by burning aircraft fuel dramatically increased the temperature of the steel, it softened the steel thereby lowering its strength to the point where the steel frames could no longer support the loads imposed upon them by the weight of upper floors.

In order to improve the fire resistance of a steel structure it is recommended that planners carefully analyze the degree to which extra insulation has been provided around all critical load carrying members.

2.2 Concrete

Buildings of reinforced concrete provided they adhere to modern building codes are reasonably well protected from effects of fire.

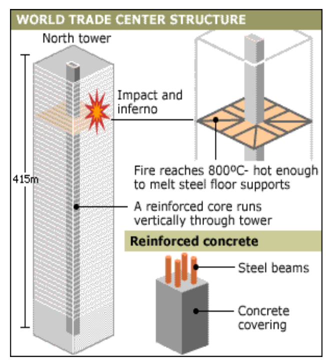
2.3 Timber

Although timber is considered to be a readily flammable material, it actually offers some advantages over steel supported buildings. One particular feature of this material is that unless it is exposed to direct flames, timber maintains its resilience, as it does not collapse entirely. Furthermore, its low degree of conductivity makes fire much easier to extinguish in parts of a building that might be unaffected by direct flames.

3.0 EARTHQUAKES

These are vibrations of the earth’s surfaces that are induced by waves that originate from a source of disturbance in the earth’s mass. They can be caused by volcanic eruptions or when slipping of the earth’s mass occurs. In extreme instances, they can be caused by human actions, such as the release of a nuclear bomb. It is interesting to compare the energy of an earthquake with that of a nuclear explosion. The energy released by a Hiroshima-type atomic bomb for instance, is equivalent to that of an earthquake

Sheet pile template; these horizontal beams provides inside and outside support near ground level
(Source: Pile Branch® Inc.)



This illustration demonstrates the sequence of events leading to the collapse of the WTC
(Source: BBC)

with a magnitude of 6.33 on the Richter scale. The "amplitude" that results from these vibrations determines the extent of likely damage to a structure.

Designated zones in various parts of most countries have been identified by geological surveys as prone to a particular degree of seismic activity. This can range from extensive to trace - such information is readily available. Based on the designation given to a particular district (and the probability of an earthquake occurring in that zone), building codes are generally established for the area. When evaluating facilities in earthquake-prone areas, it is particularly important to find out the particulars of the code, and determine how closely building particulars adhere to that code. As codes can continually change, the age of the building should be known, and planners should see the extent to which code may have changed in the time that has elapsed since a particular facility was opened. How well a structure has incorporated the nuances of code greatly assists when assessing the likelihood of damage to buildings by seismic activity.

Apart from structural damage that can result from earthquakes, it is important to understand the effect of seismic activity on soil. There are various types of soils that may encounter a severe reduction in their bearing capacity if they are subjected to severe vibrations. An example of this type of soil is the sensitive clays that were originally deposited under sea water and subsequently drained and leached by geological activity. This type of soil can actually turn to a virtually liquid state if it is subjected to extreme vibrations.

When sensitive clays lose their sheer strength the results can be dramatic: extensive land slides are a common result. This suggests that damage to buildings and infrastructure is not merely a result exclusively attributable to the dynamics of plate tectonics, but to soil characteristics. Therefore, the danger areas can extend to areas beyond the ones we commonly associate with earthquakes (e.g. the North American West Coast). For instance, Ottawa in Canada's national capital region, as well as the Chicoutimi region of Quebec possess the types of underlying clays in which severe ground vibrations could theoretically induce disastrous loss of life and property.

Silty soils are also susceptible to soil liquefaction when exposed to extreme vibrations. Again, from a preventative standpoint, it is very important to have a soil specialist thoroughly investigate soil quality as well as existing records that assess the stability of foundations of not only buildings, but the underlying characteristics of bridges, roads or even airport runways.

Civil Engineering Terminology: Liquefaction

The phenomena in which saturated soils (usually loose sands) lose their bearing capacity and become fluid like "quick sand" during severe ground shaking. Structures built on liquefiable soils "sink" in and may even topple over.

Our next Continuity Brief will focus on other sources of disasters which will include hurricanes, ice storms, excessive snowstorms, and hail.

Liquefaction in action; this photo shows sand being ejected through a crack subsequently forming a chain of sand boils in Olympia Washington
(Source: U.S. Department of the Interior, U.S. Geological Survey)

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