# Economic Benefit Cost Analysis: CoreFirst vs. Standard Retrofit

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June 2014

**Introduction**

CoreFirst, llc. (CoreFirst) of Portland, Oregon has developed a new system to protect buildings (actually people in buildings) from earthquakes as well as a number of other natural and man-made disasters. CoreFirst's system is patented and is designed to be integrated into a 1-4 level building to create a safe space for people inside the building.

This economic benefit-cost analysis prepared by Kleinhenz & Associates for CoreFirst is specific to earthquakes and considers a specific case of a four-building elementary school system that is faced with the option of retro-fitting one of the four buildings using the traditional and more costly method or, for the same cost, retrofitting all four buildings using the CoreFirst system. It includes a comparison between the two retrofit options in terms of cost to society, not merely costs to the school system. Three earthquake scenarios are examined: mild, moderate, and severe. All assumptions regarding inputs used in the study are referenced.

The primary assumption is that an earthquake will occur. This simplifies the explanation since we need only compare the traditional retrofit versus the CoreFirst at one point in time. As such, the analysis holds constant probabilities of occurrence, time value of money, net present value, interest rates, future incomes and projected healthcare costs, etc. All of these measures are important when considering a retrofitting approach. However, in this analysis it is assumed the school system wants a retrofit and the decision is to determine what kind of retrofit they desire. It is noted that the CoreFirst option costs approximately 25 percent to 30 percent of the cost of a standard retrofit. This savings allows for four school buildings to be retrofitted using the CoreFirst method versus one school building being retrofitted using the standard retrofit techniques. If an earthquake does not occur, the CoreFirst system remains available to offer building occupants protection in a number of other emergency scenarios. In addition, the CoreFirst system includes educational messages, first aid equipment, communication equipment along with other features while the traditional seismic upgrade does not.

## Results

If a severe earthquake occurred, the CoreFirst system saves society a net of $245 million when compared to the standard retrofit approach as shown in Table 1. This savings is generated by reduced casualties, associated costs of loss of life and medical care and nets out the increased cost in building damages. Key assumptions include 114 deaths and 342 injuries given the standard retrofit approach. Property damages and reconstruction costs are greater under the Corefirst retrofit choice by $3.6 million when compared to the standard retrofit approach.[1]

In the event of a moderate earthquake, a reduced number of casualties results and reduces the benefits of the CoreFirst system. However, the net benefits of using the CoreFirst technique favorably totals $59 million compared to the standard retrofit approach. Given that a mild earthquake scenario assumes no fatalities and only 9 casualties, the CoreFirst approach yields a negative benefit of $0.8 million. This is due to the greater reconstruction costs associated with the CoreFirst approach.

Table 1. CoreFirst vs. Standard Retrofit Societal Costs

| | Mild | | Moderate | | Severe | |
|---|---|---|---|---|---|---|
| Type of Cost | CoreFirst | Standard | CoreFirst | Standard | CoreFirst | Standard |
| **Casualty Loss Damages** | | | | | | |
| Number Uninjured | 1200 | 1191 | 1176 | 1086 | 1104 | 744 |
| Number Injured | 0 | 9 | 18 | 85.5 | 72 | 342 |
| Number Dead | 0 | 0 | 6 | 28.5 | 24 | 114 |
| Total Check | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 |
| Hospital Cost for injured | $ - | $ 35,100 | $ 70,200 | $ 333,450 | $ 280,800 | $ 1,333,800 |
| Value of lost life or severely injured: | $ - | $ - | $ 16,500,000 | $ 78,375,000 | $ 66,000,000 | $ 313,500,000 |
| Total Casualty Cost | $ - | $ 35,100 | $ 16,570,200 | $ 78,708,450 | $ 66,280,800 | $ 314,833,800 |
| **Property Damages** | | | | | | |
| Reconstruction Costs | $ 3,060,000 | $ 2,295,000 | $ 15,300,000 | $ 13,005,000 | $ 27,540,000 | $ 24,480,000 |
| Value of In-building Assets | $ 183,600 | $ 137,700 | $ 918,000 | $ 780,300 | $ 1,652,400 | $ 1,468,800 |
| Total Property Costs | $ 3,243,600 | $ 2,432,700 | $ 16,218,000 | $ 13,785,300 | $ 29,192,400 | $ 25,948,800 |
| **Displacement** | | | | | | |
| Number of reconstructed Buildings | - | - | 2.00 | 1.70 | 3.60 | 3.20 |
| Number o f Modular Classrooms Required | - | - | 24 | 20 | 43 | 38 |
| Mobile Classroom cost | $ - | $ - | $ 1,680,000 | $ 1,428,000 | $ 3,024,000 | $ 2,688,000 |
| Total Casualty, Property, Displacement Cost | $ 3,243,600 | $ 2,467,800 | $ 34,468,200 | $ 93,921,750 | $ 98,497,200 | $ 343,470,600 |

| | Mild | Moderate | Severe |
|---|---|---|---|
| CoreFirst Savings to Society | $ (775,800) | $ 59,453,550 | $ 244,973,400 |

Note: Standard Calculation includes 1 standard retrofit building and 3 nonretrofitted buildings
CoreFirst calculation includes 4 buildings retrofit using the CoreFirst method.

[1] Core First total property cost of $29,192,400 and mobile classroom outlays of $3,024,000 equals $32,216,400. For the Standard scenario, these same expenditures amount $28,636,800. Their difference is $3,579,600.

**Assumptions**

I. Building construction and temporary replacement

Number of Buildings in School system: 4 (assumed)
Number of occupants, students and staff, per building: 300 (assumed)
Number of classrooms per building: 12 (reference #1)
Construction cost of new school building: $170 per square foot (#2)
Size of one school building: 45,000 square feet (#2)
Implied cost of building: $7,650,000 (#2)
Additional cost of furniture, fixtures, and equipment (FFE): 6% of total costs (#3)
Cost of mobile/trailer classroom per year: $70,000 (includes set-up) (#4)

II. Medical cost for survivors and cost of life for casualties

Emergency room cost per visit: $2,100 (#5)
One day hospital cost: $1,800 (#6)
Lifetime medical support cost per severely injured person: $3 million (#7)
Cost of life (NPV of lost income): $2.5 million (#8)

III. Earthquake levels

The U.S. Geological Survey provides a description of the impact on structures for each level of the Mercalli Intensity Scale (reference #9). It is assumed that the "mild" earthquake is described by Mercalli's V,VI, and VII intensity levels. A "moderate" earthquake is described as being of a Mercalli VIII intensity level. A "severe" earthquake is a Mercalli IX or greater. See Table 2.

Table 2. Earthquake Definitions and Assumptions of Mild, Moderate, and Severe

| Benefit-Cost Category | Mercalli Intensity Scale |
|---|---|
| less than mild | **I**. Not felt except by a very few under especially favorable conditions. |
| less than mild | **II**. Felt only by a few persons at rest, especially on upper floors of buildings. |
| less than mild | **III**. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated. |
| less than mild | **IV**. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. |
| Mild | **V**. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. |
| Mild | **VI**. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. |
| Mild | **VII**. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. |
| Moderate | **VIII**. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. |
| Severe | **IX**. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. |
| Severe | **X**. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. |
| Severe | **XI**. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. |
| Severe | **XII**. Damage total. Lines of sight and level are distorted. Objects thrown into the air. |

IV. Degree of Building Damage, Injuries, and Fatalities

Table three on the following page outlines assumptions regarding the degree of building damage, injuries, and fatalities across the types of retrofits as well as by earthquake intensity. In the case of human injury and fatalities it is assumed that buildings retrofitted with either CoreFirst or standard methods yield the same injuries. As noted earlier only one building is to receive the standard retrofit, while all four buildings are to receive the CoreFirst retrofit. For the three non-retrofitted buildings, injuries and fatalities would be greater.

The Oregon Resilience Plan (#10) reports that in the event of a 9.0 magnitude earthquake, half of the public school buildings examined had a “high or very high potential for collapse.” Given this finding, it is assumed that 50 to 90 percent of the school building is damaged in the event of a severe earthquake. Another source agrees with the degree of magnitude of destruction that could result. According to a 2010 hazard report commissioned by San Francisco city officials, a 6.9 quake on the Hayward Fault east of the Bay could cause as many as 120 deaths and 2,300 injuries in the region. A 7.2 quake along a northern section of the San Andreas Fault, an 800-mile-long fracture stretching from the Southern California desert through just south of San Francisco, could kill 300, injure 7,000 and cause $30 billion in property damage.

Information taken from Gutierrez (#11) and the U.S. Geological Survey are adopted in this analysis and provide a possible magnitude of injury and death that might be associated with earthquakes. Gutierrez et al, 2005 found the overall ratio of injuries-to-fatalities to be 550,000/190,000 in the cases where fatalities were reported, approximately 3:1 or three injuries for every one fatality. The U.S. Geological Survey (USGS) reports 332,723 earthquakes of all magnitudes between 2000 and 2012 worldwide. Deaths totaled 813,856, or 2.45 deaths per earthquake. Deaths are not broken out by magnitude of earthquake. We make an estimate of the death-to-injury ratio based upon the Mercalli Intensity Scale[2] indicating that for intensity levels of VI or less, vibrations would be felt but no damages would ensue that cause deaths (K&A interpretation). Based on the USGS, worldwide deaths due to earthquakes could be limited to earthquakes measuring greater than a VI on the Mercalli scale (greater than 5.0 on the Richter scale). Using these figures, 5.1 deaths per earthquake are associated with greater than VI on the Mercalli scale. If the injury-to-fatality ratio of 3-to-1 is accepted, then 15 injuries and 5 fatalities for earthquakes registering greater than or equal to a VI on the Mercalli scale are expected. A mild earthquake as defined by the authors (K&A) is to include Mercalli intensities of V, VI, and VII. Thus, it appears plausible that for moderate and severe earthquakes, as defined by this study, these averages might provide a reasonable starting point for analysis. Given that the earthquake impact area is much larger than a set of four school buildings, the fatalities and injuries to occupants of the four school buildings would, on average, be less.

[2] The Mercalli Intensity Scale measures the intensity of an earthquake by observing its effect on people, the environment and the earth’s surface. The Richter Scale measures the energy released by an earthquake using a seismograph.

In the case of damage to the building shell itself, the CoreFirst method would yield the same result as the three non-retrofitted school buildings. The standard retrofit is assumed to result in less damage to the building than either the CoreFirst or the non-retrofitted buildings.

## V. Displacement or Downtime

It is assumed that with both retrofit options they are carried out without displacement, either due to procedures required or due to the retrofit being performed during the summer months when the buildings are not occupied.

The approximate cost of displacement due to damage to building from an earthquake is assumed to be the cost of modular classrooms needed in the case of school building repairs. The number of modular units needed is calculated based upon the dollar amount of damage to the buildings as a percent of the cost of building new buildings. For example, if the damage to the buildings totaled $16 million that is the equivalent of two new school buildings, implying that during the construction period or reconstruction period, that 24 modular units would be required to house the classes.

Several assumptions were made regarding injuries and fatalities under moderate and severe earthquake scenarios. First, a 3:1 ratio was maintained between injuries and fatalities. Second, given the case of 1200 occupants a 0.5 percent fatality rate is used and equals 6 deaths in the case of a moderate earthquake. Buildings with no retrofits are assumed to have a greater fatality rate of 3 percent or 36 deaths. In the event of a severe earthquake the percentages were multiplied by 4. These assumptions provide a range of results that compares CoreFirst's versus the standard technology, yet they do not appear to stray too far from what could be expected on average from an earthquake occurrence.

Table 3. Earthquake Intensity Scenario Assumptions*

| | Mild | Moderate | Severe |
|---|---|---|---|
| Injuries | | | |
| Corefirst | 0% | 1.5% | 6% |
| Standard | 0% | 1.5% | 6% |
| No Retrofit | 1% | 9% | 36% |
| Fatalities | | | |
| Corefirst | 0 | 0.5% | 2% |
| Standard | 0 | 0.5% | 2% |
| No Retrofit | 0 | 3% | 12% |
| Degree of Building Damage | | | |
| Corefirst | 10% | 50% | 90% |
| Standard | 0% | 20% | 50% |

| | | | |
|---|---|---|---|
| No Retrofit | 10% | 50% | 90% |

*For reference sake, 1% of 1200 school building occupants equals 12 people.
A 3:1 ratio of injuries: fatalities are maintained.
For reference: 1% of building damage equals approximately $75,000.
Moderate Case of building damage follows Mercalli definition: “considerable damage in ordinary substantial buildings with partial collapse. Damage is great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls.”
Severe Case of building damage follows Mercalli definition: “most masonry and frame structures destroyed with foundations.”

**References**

#1 300 occupants divided by 25 occupants per class room equals 12 classrooms. This is conservative since administrators are included as occupants in the classroom, driving the occupancy up and the number of calculated classrooms down.

#2 From RSMeans Data online: Construction Cost Estimates for Elementary School in Los Angeles, California

| Elementary School Construction Cost Assumptions | |
|---|---|
| Location: | Los Angeles, California |
| Stories: | 1 |
| Story Height (L.F.): | 15.00 |
| Floor Area (S.F.): | 45000 |
| Basement Included: | No |
| Data Release: | Year 2013 |

Elementary School Square Foot Cost Assuming Decorative Concrete Block / Bearing Walls

| Cost Estimate (Union Labor) | % of Total | Cost Per SF | Cost |
|---|---|---|---|
| Total | | $131.68 | $5,925,500 |
| Contractor Fees (GC,Overhead,Profit) | 25% | $32.92 | $1,481,400 |
| Architectural Fees | 7% | $11.52 | $518,500 |
| Total Building Cost | | $176.12 | $7,925,300 |

Another project, Big Sandy School District 100J (District), Simla, Colorado, invites your firm to submit a qualification statement for FF&E Planning and Procurement Services. The District is conducting a qualifications based selection/cost proposal process to retain a firm for FF&E services for construction of a new 83,412 SF P_12 facility. The school will have a design capacity for up to 331 students. This would put the cost at $14.7 million for a primary school, double the RSMEANS estimate.

#3 taken from a School Facilities Board Cost Estimate Form (North Carolina)

<u>Furniture, Fixtures & Equipment (FF&E):</u> FF&E budget is 8% to 10% of the base construction cost estimate. The District is required to purchase all desks, tables, chairs, file cabinets, and 10 library books per student with these funds. *NOTE: % @ current CPSF x SFB original approved sf, whichever is less*

a. FF&E of 8.00% -- grades K-6 or <u>6.4% @ cur. CPSF</u>

b. FF&E of 8.25% -- grades K-8 or <u>6.6% @ cur. CPSF</u>
c. FF&E of 8.75% -- grades 6-8 or <u>7 % @ cur. CPSF</u>
d. FF&E of 9.00% -- grades 7-8 or <u>7.2% @ cur. CPSF</u>
e. FF&E of 10.00% -- grades 9-12 or <u>8 % @ cur. CPSF</u>

#4 Belsha, Kalyn, "Some don't like them, but modular classrooms help schools plan for future" The BeaconNews – A Chicago SunTimes Publication June 15, 2013. "purchasing a one-classroom modular unit can range in price from $60,000 to $140,000 — depending on the age and size of the unit, site conditions and installation methods — while leasing the same unit could vary from $25,000 to $80,000 for set-up, plus $5,000 to $14,000 per year in rental costs."

#5 Abrams, Lindsay, How Much Does It Cost to Go to the ER?
The Atlantic, February 28, 2013. (cites an NIH funded study: Citation: Caldwell N, Srebotnjak T, Wang T, Hsia R (2013) "How Much Will I Get Charged for This?" Patient Charges for Top Ten Diagnoses in the Emergency Department. PLoS ONE 8(2): e55491. doi:10.1371/journal.pone.0055491)

"NIH-funded study published today in *PLOS ONE:* The average cost of a visit to the ER for over 8,000 patients across the U.S. was $2,168. "

#6 Oh, Jaimie, Beckers Hospital Review, April 30 2012.
http://www.beckershospitalreview.com/lists/average-cost-per-inpatient-day-across-50-states-in-2010.html

Here are average U.S. costs per inpatient day, according to the latest statistics from Kaiser State Health Facts.

State/local government hospitals — $1,625
Non-profit hospitals — $2,025
For-profit hospitals — $1,629

#7 Lifetime cost estimates of between $1.4 and $4.5 million for spinal injury survivors. Based on University of Alabama study. http://www.christopherreeve.org/site/c.mtKZKgMWKwG/b.5193227/k.AFB/Costs_of_Living_with_Spinal_Cord_Injury.htm

Estimated Lifetime Costs by Age of Injury

| Severity of Injury | 25 Years Old | 50 Years Old |
|---|---|---|
| High Tetraplegia (C1-C4) | $4,530,182 | $2,496,856 |
| Low Tetraplegia (C5-C8) | $3,319,533 | $2,041,809 |
| Paraplegia | $2,221,596 | $1,457,967 |
| Incomplete motor function at any level | $1,517,806 | $1,071,309 |

*Source: National Spinal Cord Injury Statistical Center (NSCISC) located at The UAB Department of Physical Medicine and Rehabilitation, Centers for Disease Control and Prevention*

#8 Cohen, Mark A. and Ted R. Miller, "Willingness to award" nonmonetary damages and the implied value of life from jury awards" International Review of Law and Economics Volume 23, Issue 2, June 2003, Pages 165–181. Authors found a range of $1.4 to $3.8 million.

Other confidential sources found the assumed value of life of an infant girl to range from $1.3 to $2.1 to $3.8 million based upon assumptions of educational attainment and longevity.

#9 US Geological Survey Data
http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php
US Geological Survey Data http://earthquake.usgs.gov/learn/topics/mag_vs_int.php

#10 http://www.oregon.gov/OMD/OEM/osspac/docs/01_ORP_Cascadia.pdf
Oregon Resilience Plan as per Dr. Yumei Wang

Oregon's Infrastructure and Risk section p.13
The estimated impacts of a Cascadia subduction earthquake in Oregon are catastrophic. This is partly due to the sheer size and power of a magnitude 9.0 earthquake, but it is also the result of the inherent vulnerability of our buildings and lifelines. ….. the majority of buildings in Oregon have not been designed to resist the shaking from a magnitude 9.0 Cascadia earthquake. This widespread vulnerability of Oregon's buildings is grimly illustrated in the Statewide Seismic Needs Assessment completed by the Oregon Department of Geology and Mineral Industries (DOGAMI) in 2007. This study surveyed public schools and public safety buildings in Oregon and assessed their potential for collapse in a major earthquake. Almost half of the 2,193 public school buildings examined had a high or very high potential for collapse, as did almost a quarter of the public safety buildings

Another source concurs with the degree of magnitude of destruction that can be caused:
Confidential email passing along WSJ article citing the following:
According to a 2010 hazard report commissioned by San Francisco city officials, a 6.9 quake on the Hayward Fault east of the bay could cause as many as 120 deaths and 2,300 injuries in the region. A 7.2 quake along a northern section of the San Andreas Fault, an 800-mile-long fracture stretching from the Southern California desert through just south of San Francisco, could kill 300, injure 7,000 and cause $30 billion in property damage.

#11 Gutierrez et al., 2006, Am J Epidemiol 2005;161:1151–1158

for the most severe earthquakes (thousands of fatalities),
the ratio of reported injuries to reported fatalities is on the order of 1:1 or less;
for moderate severity earthquakes (hundreds of fatalities), it is approximately 10:1;
and for the most moderate earthquakes, that is, those where tens of fatalities are reported, it is 20:1.

Overall, the number reported injured (~553,000) exceeds that of fatalities (~190,000); "however, in the database constructed herein, numerous examples may be found where more fatalities than injuries are reported."