Sample Engineering Case Study
Seismic Structural Retrofitting

Introduction

In an effort to improve the quality of project applications, engineering case studies have been prepared for several common mitigation measures. The engineering cases studies provide focus on the types of information and data needed to ensure completeness of the sections of the project application affecting engineering feasibility. Of particular importance in the engineering review are:

- Scope of Work, including:
  - Problem Description and Proposed Solution;
  - Description of Existing Condition; and,
  - Work Schedule.
- Cost Estimate, including:
  - Conducting the Benefit-Cost Analysis;
  - Anticipated environmental resource remediation or historic property treatment measures;
  - Engineering schematics, detailed engineering drawings, or engineering designs;
  - Other related construction/demolition/relocation costs, such as survey, permitting, site preparation, material disposal; and,
  - Other related acquisition costs, such as appraisals, legal recordation, displacement costs for renters, maintenance.

For each of these sections in the project sub-application, the engineering case studies describe the general type of information that a Sub-applicant should submit. In order to provide additional guidance, the case studies also include sections of a sample project application that present the kind of specific information that the Sub-applicant would need to include in each engineering-related section to support the proposed project. These engineering case studies are not meant to represent complete project applications. Some relevant project information related to historic and environmental impacts, as well as information regarding the project's cost effectiveness may not be included.

The goal of a seismic structural retrofitting (upgrading or rehabilitating) project is to reduce the risk of death, serious injury, and property damage during an earthquake event. This is typically accomplished by modifying a building's structural system to reduce or eliminate known seismic deficiencies. Although new structural elements are sometimes required, in many cases existing elements can be enhanced to achieve a desired level of performance. Performance levels can range from basic life safety to operational after an earthquake.

Some common examples of seismic structural retrofitting project elements are:

- Adding new lateral load resisting elements including concrete shear walls or structural steel braced frames;
- Adding new vertical load resisting elements to prevent floor or roof collapse;
- Providing continuous load paths for lateral load resisting systems;
- Eliminating weak or soft stories by infilling openings or adding moment frames;
- Increasing concrete member ductility with column jackets or steel or fiber wraps;
- Modifying existing steel braced frames with BRBs (buckling restrained/resistant braces) or other;
- Installing base isolation systems or adding damping elements;

- Adding pneumatically applied concrete, weld plates or plywood panels to existing lateral load resisting systems;
- Strengthening roof and floor diaphragms as well as their connections to supporting walls and lateral load resisting systems; and
- Eliminating plan irregularities by modifying floor areas or adding seismic joints; and
- Enhancing detailing of structural elements to improve ductility.

Following is a list of useful references:

- Applicable building code/edition or engineering standard used, including but not limited to International Building Code (IBC), International Existing Building Code (IEBC), and NFPA 5000 Building Construction and Safety Code;
- American Society of Civil Engineers (ASCE) 7-02 *Minimum Design Loads for Buildings and Other Structures*;
- ASCE 31-03, *Seismic Evaluation of Existing* (based on FEMA 310, *Handbook for the Seismic Evaluation of Buildings – a Prestandard*);
- FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE 41 balloting in process); and
- FEMA 450, National Earthquake Hazards Reduction Program (NEHRP) *Recommended Provisions for New Buildings and Other Structures*

ASCE 31-03 and FEMA 356 provide a standardized methodology for identifying seismic deficiencies. ASCE 31-03 use a three-tiered approach intended to channel the investigative effort in an efficient way.

Scope of Work

The Scope of Work (SOW) describes the objectives, methodology, outcomes, timeline, milestones, resources, and deliverables of the proposed hazard mitigation project and documents the benefits, feasibility, and effectiveness of the project. The SOW must contain sufficient detail to evaluate effectiveness in reducing the identified seismic hazards. It must also be detailed enough to develop a reasonably accurate cost estimate. Technical documentation (including sketches and engineering calculations) should be provided with the sub-application to demonstrate that the proposed work will successfully mitigate against future earthquake damage. The project sub-application SOW should include the following as well as applicable references and supporting documentation:

- Proposed schematic or detailed engineering drawings, or engineering design, including calculations demonstrating the effectiveness of the proposed solution in mitigating the seismic hazards.
- Applicable building code/edition or engineering standard used;
- Level of protection provided by the proposed project;
- Any residual risk to the structure from all hazards after project implementation;
- Proposed project details
  - Description of the proposed activity to correct the identified seismic deficiencies including a discussion of any alternative schemes considered;
  - Description of design criteria;
  - Description of vertical and lateral load resisting systems;
  - Design properties of construction materials (f'_c, F_y, f'_m - known or assumed);

- Dimensions, locations and material properties for any modifications to existing and/or new structural elements;
- Details for the connection of mitigating elements to the existing structure;
- Description of any foundation work required by the proposed mitigation; and
- Description of any work required due to compliance with any Federal, state and local laws, regulations, and ordinances, such as historic preservation issues or accessibility requirements.

Sample Scope of Work

The City of Mercalli contracted with XYZ Engineering to perform a seismic evaluation and preliminary retrofit design for their 2-story City Hall Building. Using the procedures defined in ASCE 31-03, XYZ was able to identify several seismic deficiencies in the building's lateral load resisting system. These deficiencies, as well as appropriate mitigation measures, are described in detail in XYZ's report entitled "Seismic Evaluation of Mercalli City Hall", dated July 5, 2005. This report has been attached as backup documentation to this sub-application. Structural design was based on the provisions of the 2003 IBC.

XYZ's preliminary upgrade design corrects this problem in two ways: (1) pneumatically applied concrete will be added to the building's existing shear walls and (2) new shear walls will be added at two other locations to reduce the eccentricity of the seismic loading. As the Mercalli City Building Code *has not yet incorporated MCE criteria, XYZ chose to use the* 2003 International Building Code *for their design. Again, the details of these preliminary calculations including specific code sections used are included in the attached report.*

The scope of work consists of the following items:

1. *At existing shear walls on column lines 2, 5, A and D provide 4"- thick reinforced pneumatically applied concrete. Reinforcing shall be single curtain of horizontal and vertical bars with J-bar ties drilled and grouted into existing concrete. Reinforcement shall also be provided to tie floor slabs to walls.*
2. *On column lines B and E provide new 12"- thick reinforced concrete shear walls for full building height. Reinforcement shall also be provided to tie floor slabs to new walls.*
3. *Provide new reinforced concrete footings at all new shear walls and widen existing concrete footings at shotcreted walls. At widened footings, roughen existing concrete and provide dowels into new concrete.*
4. *Structural work in items 1, 2 and 3 requires the removal and re-installation of interior wall finishes, floor finishes, and acoustical drop ceilings.*
5. *Structural work in item 3 requires the removal and re-installation of the concrete slab on grade and architectural floor finish in basement.*

Note: See attached XYZ Engineering report for more detail including location, dimensions, and preliminary reinforcing for these items of work.

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Problem Description and Proposed Solution

At a minimum, be sure to include the following items:

- Geotechnical conditions;
- Site specific seismic hazard data for the Maximum Considered Earthquake (MCE) spectral response accelerations for periods of 0.2 second (S_S) and/or 1.0 second (S_1);
- Description of any damage sustained in past earthquakes (enter data into Cost Effectiveness Information section (Part 2 of 2));
- Descriptions of all identified seismic deficiencies including overstressed structural elements, soft or weak stories, plan or vertical irregularities, excessive deflections, non-continuous load paths and areas of low ductility; and
- Description of non-structural elements that could interact with the structural elements during an earthquake.

The current engineering practice is to design for a MCE used for collapse prevention. Except in near-fault areas, it is equivalent to the earthquake having a 2 percent chance of occurrence in 50 years. For new construction, it is generally multiplied by a factor of 2/3 to produce life safety level design. Site specific seismic hazard data is required for both evaluation and design. This data consists of the MCE spectral response accelerations for periods of 0.2 second (S_S) and 1.0 second (S_1). Values for these parameters can be obtained from the USGS website http://earthquake.usgs.gov/hazmaps as well as ASCE 7-02. This data is also available in the *2003 IBC* and may be available in the sub-applicant's local building code.

Sample Problem Description and Proposed Solution

The XYZ Engineering report "Seismic Evaluation of Mercalli City Hall", dated July 5, 2005 describes the ASCE 31-03 procedure used to evaluate this building as well as details of the building itself. Note that the report includes sketches and engineering calculations demonstrating the effectiveness of this design are included based on a MCE. Also provided are seismic evaluation and design criteria including site specific MCE spectral response accelerations. Seismic hazard information was obtained from the USGS website using the building's actual latitude and longitude. For details, see the XYZ Engineering report attached as backup to this sub-application.

The most significant deficiency identified was a condition of overstress in the building's concrete shear walls. This condition was partly due to torsional stresses arising from the building's shape and the present location of the lateral load resisting elements. Refer to Section 3 of the XYZ report for discussion.

Site visits indicate the building has been reasonably well maintained with the exception of some water damage to the basement adjacent to the south foundation wall. The building suffered minor damage in the 2003 Diablo Fault Earthquake, consisting mainly of crack damage to interior walls especially around door frames. Several windows were broken and one 3" water line separated near a 2nd floor restroom causing water damage to the floor below. There was also some minor contents damage. No structural damage was noted. Costs for building repair totaled $68,450.

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Description of Existing Conditions

The following information regarding the building should be included in the property description of the application:

- Age of structure (year built) (enter data into Property section (Part 2 of 3) Property Information);
- Date of any upgrades or additions;
- Structure type (ASCE 31-03, Table 2-2) (enter data into Property section (Part 2 of 3) Property Information);
- Site Classification (ASCE 7-02, Table 9.4.1.2);
- Occupancy Category (ASCE 7-02, Table 1-1);
- Seismic Use Group (ASCE 7-02, Table 9.1.3);
- Foundation type (enter data into Property section (Part 2 of 3) Property Information);
- Number of floors, including basement and dimensions including inter-story heights (enter data into Property section (Part 2 of 3) Property Information);
- Floor and roof diaphragm construction (to evaluate flexibility);
- Location of any seismic isolation joints; and
- Description of architectural finishes (floors, walls, and ceilings) and glazing.

Sample Description of Existing Conditions

Mercalli City Hall is a 24,750 SF 2-story plus basement office building, completed in 1978. It is classified as Building Type 6 - S4 Steel Frame with Concrete Shear Walls (Table 2-2 in ASCE 32-02). The building is L-shaped in plan consisting of a 75'- 8" x 100'- 8" east-west rectangular section with a 25'- 4" x 50'- 6" wing at the north-east corner which contains a 2-story high auditorium. Floor to floor heights based on top of slab elevations are 12'- 6" throughout. The façade consists of 8"-thick precast concrete panels with 5'-6" high ribbon window around the 1st and 2nd floors (except for the auditorium area which is unglazed). Interior finishes consist of vinyl tile and carpet floors, gyp board and metal stud walls and acoustical drop ceilings. Lobby finishes are marble. Restroom finishes are ceramic tile for both floors and walls. Various city offices are located throughout the building on Floors 1 and 2. The basement contains a kitchen, food storage area, cafeteria, records storage and several utility rooms. Stairs are located at the north-east and south-west corners with elevators located in the lobby area at the center of the south side.

The building's structural system consists of W18 and W21 steel beams, with W10 steel columns spaced at 25'- 0"o/c in both directions. Floor and roof construction consists of 5-1/2" thick normal weight concrete on metal deck. The basement floor is a 6" concrete slab on grade. Typical foundation elements are 2'- 6" thick 6'- 6" square reinforced concrete footings. Foundation walls are reinforced concrete 12" thick, supported on 2'- 0" wide concrete wall footings. The building's lateral load resisting system consists of 8" thick reinforced concrete shear walls located along column lines 2, 3 and 5 (north-south) and A and D (east-west). Foundations for these walls consist of 2'- 0" reinforced concrete wall footings. Refer to reduced size copies of Architectural Drawings A1 – A6, Structural Drawings S1 - S6 and MEP Drawings M1 - M3 attached to the XYZ Engineering report.

Work Schedule

The sub-application should contain a schedule for accomplishing the proposed mitigation activity. Care should be taken to include any materials testing or preliminary study required in addition to the engineering design. In addition to the actual construction work, the schedule should include time for design review, permitting, bid and award, and contractor mobilization. Compliance with Federal, state, and local laws, regulations, and ordinances, such as required accessibility upgrades, can also have significant impacts on a project's schedule. The following project elements should be included in the Work Schedule:

- Architectural/engineering design including schematic, design development and contract document phases;
- Materials testing or other anticipated studies;
- Advertising, bid, and award of contract(s);
- Permitting;
- Temporary relocation of occupants and contents;
- Contractor mobilization;
- Construction, including milestones; and
- Reoccupy facility.

Sample Work Schedule

XYZ Engineering was also asked to develop the following Work Schedule for their preliminary seismic upgrade of the Mercalli City Hall.

MERCALLI CITY HALL – SEISMIC STRUCTURAL RETROFIT PROJECT

ACTIVITY	***DURATION***
Architectural & Engineering Design	
Schematic Design	*2 weeks*
Design Development	*3 weeks*
Contract Documents	*8 weeks*
Bid Phase	
Advertise, Review Bids and Award Contract	*6 weeks*
Obtain Permits	*2 weeks*
Construction Phase	
Contractor Mobilization	*2 weeks*
Demolition – Walls, Ceilings and Floors	*4 weeks*
Rebar Installation	*4 weeks*
Concrete Placement	*5 weeks*
Restore Architectural Finishes	*4 weeks*
TOTAL	***40 weeks***

Cost Estimate

The Cost Estimate describes all anticipated and potential costs associated with the proposed project activity, and represents the Sub-applicant's best estimate of the total value of the proposed activity. Sufficient detail should be provided regarding various cost items. Back-up documentation for all costs, including the basis for each should be provided (*e.g.*, bids from qualified professionals, nationally published or local cost estimating guides). Also, reference the base year for all cost data used.

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Costs should be provided for the following tasks:

- Architectural/engineering design or other anticipated studies;
- Permits;
- Modification work to existing structural elements;
- Installation of new structural elements;
- Any non-structural work required including the demolition /restoration of architectural finishes as well as work to the building's utility systems;
- Temporary relocation including rental and moving expenses (out and back); and
- Compliance with Federal, state, and local laws, regulations, and ordinances, such as historic preservation issues or required accessibility upgrades.

Sample Cost Estimate

XYZ Engineering was also asked to develop the following Cost Estimate for their preliminary seismic structural retrofit of the Mercalli City Hall.

	DESCRIPTION	***SOURCE***	***QUANTITY***	***UNIT***	***UNIT PRICE***	***COST (Note 1)***
Architectural & Engineering Design						
1	*A&E Fee*	*City Contracts*	*1*	*LS*	*$105,000*	*$105,000*
Contractor General Conditions and Contingency						
2	*Standard Cost*	*City Contracts*	*1*	*LS*	*$142,000*	*$142,000*
Construction						
3	*Demolition*	*Engineer Est (Note 2)*	*1*	*LS*	*$97,000*	*$97,000*
4	*Place Footings*	*RS Means (Note 3)*	*82*	*CY*	*$610*	*$50,020*
5	*Pneumatically applied concrete Ext'g Walls*	*RS Means (Note 3)*	*138*	*CY*	*$910*	*$125,580*
6	*New R/C Shear Walls*	*RS Means (Note 3)*	*194*	*CY*	*$840*	*$162,960*
7	*Remove/ Replace SOG*	*RS Means (Note 3)*	*42*	*CY*	*$510*	*$21,420*
8	*Arch Finishes Bsm't*	*Engineer Est (Note 2)*	*1*	*LS*	*$72,000*	*$72,000*
9	*Arch Finishes 1st Fl*	*Engineer Est (Note 2)*	*1*	*LS*	*$57,000*	*$57,000*
10	*Arch Finishes 2nd Fl*	*Engineer Est (Note 2)*	*1*	*LS*	*$84,000*	*$84,000*
					TOTAL	***$916,980***

Note 1. Costs are based on 2005 construction data.
Note 2. See XYZ Engineering Report for details of lump sum costs.
Note 3. RS Means unit cost has been factored to account for placement of reinforcing.