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PORTLAND STATE UNIVERSITY ONDINE RESIDENCE HALL SEISMIC REHABILITATION DEMONSTRATION PROJECT

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EXECUTIVE SUMMARY

This case history summarizes the successful seismic upgrade project of the 15-story Ondine Residence Hall at Portland State University (PSU) in Portland, Oregon. Ondine Hall, built in 1966, provides student housing as well as other limited student services, such as classrooms, a theatre, and a laboratory. In 1996, this building was evaluated by structural engineers using the Federal Emergency Management Agency (FEMA) 178 methodology (*National Earthquake Hazard Reduction Program Handbook for the Seismic Evaluation of Existing Buildings, FEMA 178*, 1992). Many serious structural seismic deficiencies were found to pose a serious life-safety threat to hundreds of students. Corrective action was recommended, and in 2003 a proposal was submitted to the U. S. Department of Homeland Security FEMA.

In April 2004, the Oregon Department of Geology and Mineral Industries (DOGAMI) was provided with $3.8 million by the FEMA Predisaster Mitigation Program (PDM). Of this, $2.3 million was allocated to conduct a partial seismic upgrade to Ondine Hall. Oregon Emergency Management (OEM), which administers FEMA PDM grants for the state, provided administrative contract assistance between DOGAMI and FEMA. The FEMA grant provided 75% of the mitigation cost; the remaining 25% was funded by the Oregon University System (OUS) and PSU.

Although stakeholders planned extensively prior to construction and carefully managed logistics during construction, actual costs for seismic rehabilitation were higher than the estimated $2.3 million budget. This was due to several factors, including higher material and labor costs caused by economic fluctuations and significant, unidentified shortcomings in the original construction. Final mitigation costs were approximately $3 million; the state provided the additional $700,000 rehabilitation funds. Seismic rehabilitation was completed in November 2005.

The rehabilitation design mitigated the inadequate shear wall thickness, the inadequate bracing on the first and second floors (which are considered to be soft stories), and the lack of vertical continuity in the rebar located in the concrete columns. These upgrades are intended to improve the building to a life-safety performance level and to minimize potential for a soft story collapse of the first and second floors.

The Ondine Hall upgrade was a high-visibility demonstration project. The project raised earthquake hazard awareness on campus, in the community, and among state leaders. The awareness that this project promoted has helped establish a foundation for more seismic mitigation of high-risk educational facilities.

INTRODUCTION

Oregon is characterized by a beautiful and geographically diverse landscape. However, this intriguing landscape is associated with a variety of natural hazards. Earthquake hazards are a significant threat for the entire state but especially in the western portion. While seismic risk in California is considerably higher than in Oregon, actual life-safety risk is higher in Oregon due to the percentage of structures that are not earthquake resistant.

Portland is located approximately 100 miles east of the Cascadia Subduction Zone fault, which has the potential of producing an earthquake similar to the magnitude 9.1, December 26, 2004, Sumatra earthquake and Indian Ocean tsunami. Furthermore, the active Portland Hills fault is a threat because it is very near the Portland State University (PSU) campus. The U.S. Geological Survey (USGS) projects for the Portland region a 2% chance in the next 50 years that bedrock ground shaking levels will be on the order of 0.4 g, where g is acceleration due to the force of gravity (981 cm/s/s) (USGS, 2003).

Because Oregon faces a serious statewide threat from earthquakes, federal, state, and local governments and private organizations support earthquake risk reduction. Oregon has made strides in reducing the adverse impacts of earthquakes on Oregon schools that led to successful mitigation of a number of Oregon's seismically deficient school buildings.

The seismic rehabilitation of Ondine Residence Hall (see Figure 1) at PSU is an example of a successful mitigation project.

Figure 1. Ondine Residence Hall, Portland State University. This view from the southwest shows the lower, soft stories that are vulnerable to collapse prior to mitigation.

EARTHQUAKE AWARENESS FOR OREGON UNIVERSITY BUILDINGS

Oregon leaders recognize the importance of seismic safety in public school buildings. In 2001, the Oregon legislature passed a state law (Oregon Revised Statute 455.400; http://www.leg.state.or.us/ors/455.html) that requires public school buildings with 250 or more occupants meet life-safety standards. In 2002, Oregon citizens voted statewide to amend the Oregon constitution to allow the legislature to establish general obligation bonds to provide funds to rehabilitate school buildings, including university buildings.

The Oregon University System (OUS) is committed to rehabilitating seismically deficient university buildings. DOGAMI has been working with OUS since 2002 to complete a seismic risk study on all facilities at the state's seven public university campuses. In 2002-2003, DOGAMI and OUS assessed the seismic needs of approximately 1,000 OUS buildings and developed a strategy for long-term seismic rehabilitation planning (Simonton and others, 2004).

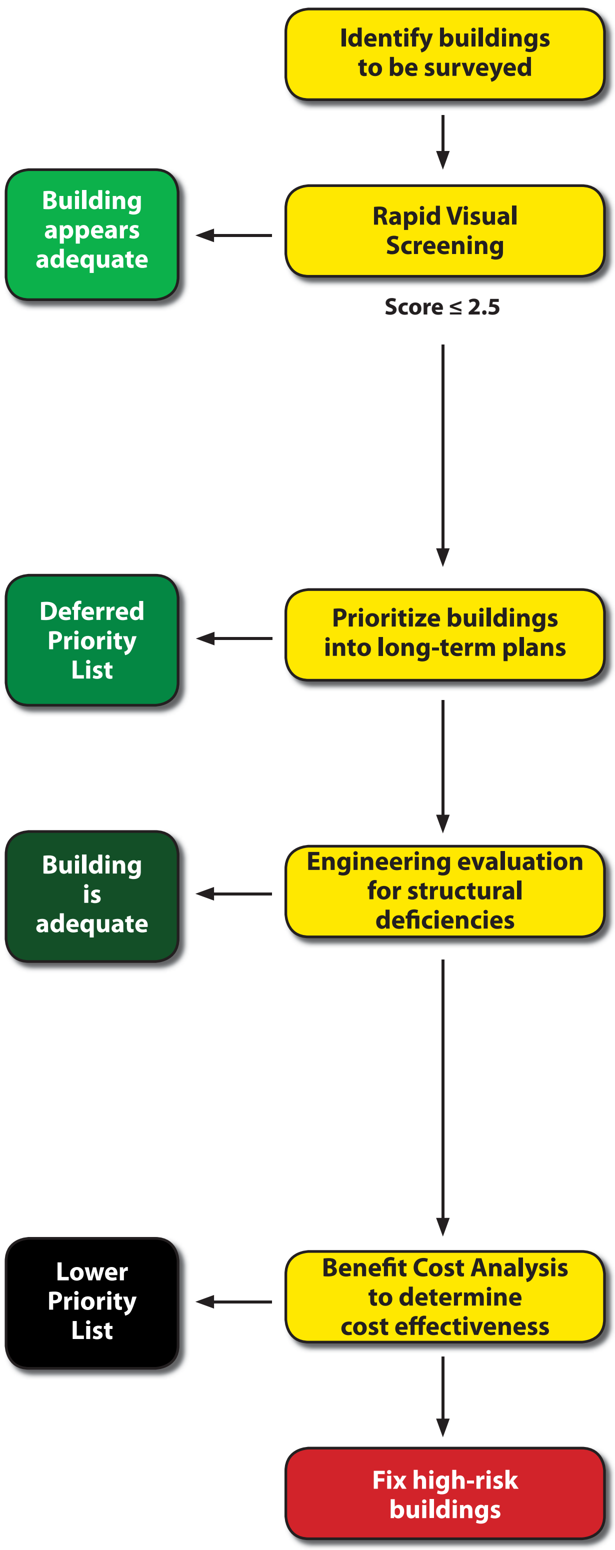
During this assessment, DOGAMI developed for OUS a six-step method for evaluating high-risk buildings, which is part of the long-term mitigation plan (Figure 2) (Wang, 2004). The six-step method incorporates a rapid visual screening (RVS) method, structural engineering and benefit-cost analyses, deferred maintenance and energy efficiency needs, as well as other considerations. In 2005 and 2006, DOGAMI codeveloped with Goettel and Associates a preliminary enhanced RVS method, which was funded by and continues to be used by OUS.

FEMA GRANT AWARD

Of the 1,000 university buildings assessed for seismic needs, OUS and DOGAMI identified Ondine Hall along with PSU's Montgomery Court and the Oregon Institute of Technology's (OIT) Snell Hall as the top candidates for seismic rehabilitation.[1] DOGAMI and OUS then worked together to complete a nationally competitive FEMA pre-disaster mitigation grant (PDM) application. For the Ondine Hall assessment portion of the grant, DOGAMI collaborated with Portland State University personnel Michael Irish, Director of Facilities; Richard Piekenbrock, Campus Architect; and Carol Hasenberg, structural engineering instructor. The grant application included engineering evaluations, benefit-cost analyses, and stakeholder support. The grant was submitted with letters of support from structural engineers at PSU and at the Oregon Seismic Safety Policy Advisory Commission (OSSPAC).

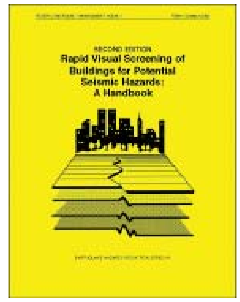
In April 2004 FEMA awarded DOGAMI a $3.8 million award, described as an Earthquake Building Rehabilitation grant, to complete seismic readiness work on the three selected buildings. Of this $2.3 million was allocated for Ondine Hall. FEMA funding provided 75% of the total project costs. OUS committed to the 25% match amount (almost $950,000) required by FEMA to receive the grant. The funds were to be used to upgrade the buildings as demonstration projects, as described in the "Demonstration Projects at Oregon Universities" section, below. Oregon Emergency Management (OEM) provided administrative assistance to DOGAMI and to the overall project.

1. Many other Oregon university buildings that were not selected for this initial grant application have serious seismic deficiencies.



Step 1. Planning Stage
Identify buildings to be surveyed. Buildings with 24/7 or high-capacity occupancy (Oregon Revised Statute 455.400) hazardous materials, critical operations, and special concerns.

Step 2. Rapid Visual Screening (RVS)
Conduct FEMA 154 screenings to develop preliminary scores (e.g., earthquake performance) and preliminary funding needs.



Federal Emergency Management Agency (FEMA) 154 — Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook

Step 3. Prioritization
Prioritize buildings that warrant detailed engineering studies. If building scores ≤ 2.5 AND requires additional upgrades, then engineering evaluations are recommended. Prioritization factors involve: seismicity, occupancy load, energy efficiency, deferred maintenance needs, Americans with Disabilities Act regulations, fire safety, environmental condition, modernization, and special circumstances (e.g., historic, shelter, future demolition).

Step 4. Engineering Evaluation
Conduct ASCE 31 engineering evaluations to determine any specific seismic deficiencies and mitigation concepts.

American Society of Civil Engineers (ASCE) 31 — Seismic Evaluation of Existing Buildings

Step 5. Benefit Cost Analysis (BCA)
Conduct BCA to determine cost effectiveness of mitigation. If the benefit cost ratio (BCR) exceeds 1, then mitigation is recommended.

Step 6. Earthquake Mitigation
Mitigate high-risk buildings with BCR > 1 to improve life-safety, liability, and sustainability. Level of upgrades varies. Use FEMA 356 method or other appropriate method.

Figure 2. Six-step evaluation method for high-risk buildings developed by the Oregon Department of Geology and Mineral Industries for the Oregon University System.

ONDINE RESIDENCE HALL

Ondine Hall is a 15-story residence building located at 1912 SW 6th Avenue in Portland, Oregon, which was purchased by the university in 1976. The building includes residential space as well as first-floor commercial space, auditoriums, lobby, cafeteria, and a mechanical testing laboratory. The building has a basement and a subbasement that contains the mechanical and electrical systems. A three-level parking structure is attached to the east side of the building. The 15-story tower section is approximately 160,000 sq ft and the parking section is approximately 40,000 sq ft. The middle level of the parking structure was remodeled for commercial use in the 1970s. The top level of the parking garage aligns with the second floor of the residential tower, and the lowest floor of the parking garage aligns with the basement of the tower.

Ondine Hall was known by PSU to have serious deficiencies and the potential for catastrophic collapse in a major earthquake. Furthermore, Ondine Hall was previously identified by PSU as a high-priority building for rehabilitation on the basis of continuous student occupancy and deferred maintenance. This building is an integral and critical part of the PSU community because it is a public service building and home for PSU students. If this building were damaged and dysfunctional following a seismic event, the entire campus community would be negatively impacted.

The structural elements of the building consist of cast-in-place, reinforced concrete shear walls, columns, beams, joists, and reinforced concrete slabs. The shear walls comprise the primary lateral force resisting system (LFRS). The walls vary from 8 in to 12 in thick and are reinforced in both vertical and horizontal directions. This building was constructed in 1966 under the City of Portland Building Code, prior to adoption of the first statewide seismic code. In 1974, the State of Oregon ratified the 1973 Uniform Building Code. Prior to the seismic upgrade of the lower floors done for this project, the structure was considered to be seismically deficient according to the standards of both the State of Oregon and the City of Portland building codes.

DEMONSTRATION PROJECTS AT OREGON UNIVERSITIES

Researchers (NIBS, 2005) have found that supporting seismic mitigation activities increases the resilience of communities by increasing knowledge and promoting institutional commitments to mitigation at the local level. Mitigation is most effective when it is carried out on a comprehensive, community-wide, long-term basis. Single projects help, but a series of coordinated mitigation activities over time is the best way to ensure that communities will be physically, socially, and economically resilient in managing earthquake damage (NIBS, 2005).

Mitigation activities can be divided into two types: project and process. Project mitigation includes physical measures to avoid or to reduce damage from earthquakes; process mitigation includes activities that lead to policies, practices, and projects that reduce risk and loss. Typical process mitigation activities include conducting vulnerability and risk studies; increasing awareness by decision makers; building constituencies; and fostering adoption of mitigation strategies, building codes on existing buildings, and synergistic activities (NIBS, 2005).

Oregon's three university building demonstration projects (Ondine Hall, Montgomery Court, and Snell Hall)) include typical project mitigation benefits but also include a strong component of process mitigation. Project mitigation benefits are due to avoiding losses relating to:

- Reduced direct property damage, including the building itself and nearby buildings, contents, and the building's lifeline services connecting to adjacent facilities
- Reduced direct business interruption loss, including campus operations, class sessions, and research activities
- Reduced human losses, including deaths, injuries, and homelessness (for residence halls)

Oregon's demonstration projects have led to process mitigation activities including:

- Societal impacts, such as increased awareness among decision makers and peace of mind within the community at large
- Synergistic impacts, such as future project mitigation

and will lead to:

- Reduced cost of emergency response, such as ambulance service, fire protection, and environmental cleanup
- Reduced indirect business interruption loss, including ripple effects such as loss of housing income, enrollment, or research status

According to Robert Simonton, OUS Director of Capital Construction Planning and Budget, the 2004 FEMA grant has allowed OUS to increase the safety of campus facilities by increasing earthquake awareness among decision makers and university facilities staff. OUS campuses make up half of all state-owned facilities in Oregon and have a decade-plus deferred maintenance backlog of approximately $600 million. In 2005, the Oregon legislature approved a spending limitation of $410 million for capital repair, maintenance, and new construction. During this same period, because of the mitigation assessment and resulting FEMA grant, OUS was allocated $8 million in state funds as the first systematic allocation for university seismic needs by the state. Therefore, OUS has made significant progress in addressing seismic upgrades to improve campus safety.

When FEMA grants lead to additional non-federally funded mitigation activities and help institutionalize seismic mitigation programs, the benefit-cost impacts are substantial and highly cost effective for the state. The three university demonstration projects will result in future savings from averting not just casualties but also direct financial losses from building damage, continuity of university operations, and campus preparedness. Moreover, long-term mitigation strategies are being considered or are being improved on the campuses.

Oregon's long-range goal is to upgrade all public school buildings, including university buildings, to life-safety standards as mandated by Oregon Revised Statute 455.400. These three university seismic upgrades serve as demonstration projects not only for the campuses and surrounding communities but for Oregon government and legislators. These projects have been strongly supported by various earthquake policy and engineering organizations, including the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) and the Oregon Department of Emergency Management (OEM).

ONDINE HALL DEMONSTRATION PROJECT — MEDIA ATTENTION AND PUBLIC AWARENESS

The rehabilitation of Ondine Hall has served as a demonstration project for awareness of seismic safety for Oregon's school buildings through media attention, on-site tours, and a permanent public display. Because of the university setting in a major population center, the project has had high visibility. An integral goal of the demonstration project was garnering media coverage. Campus newspapers, radio stations, and web news increased awareness of this project. Community television, radio, and newspaper press have also publicized the project.

Representatives from FEMA and from other agencies and organizations were invited to tour the building during the construction phase in August 2005. High-ranking officials as well as community and project team members participated in the tour (Figure 3). Smaller tours for other interested parties were also conducted.

It is important to provide awareness of demonstration projects not only during the planning and construction phases but also long after construction is complete. Therefore, all three university demonstration projects include (or will include) a permanent public display to promote earthquake safety awareness. At Ondine Hall, a wall of structural steel plates used in mitigation was exposed for permanent display in the cafeteria area on the first floor, which was remodeled during the seismic rehabilitation. In addition, a commemorative plaque was erected at the main building entrance to serve as a reminder of the recent seismic upgrades. The plaque is shown in Figure 4.

Figure 3. Portland State University (PSU) August 2005 seismic mitigation tour. Participants included Portland State University (PSU) President Dan Bernstine; PSU Facilities and Planning Director Robyn Pierce; Federal Emergency Management Agency (FEMA) Region X representative Sharon Loper; Oregon Emergency Management (OEM) representative Abby Kershaw; Robert Simonton, Oregon University System (OUS) Director of Capital Construction Planning and Budget; and James Doane, chairman of the State Earthquake Commission. Also present are Oregon Emergency Management staff, PSU facilities and housing departments staff, PSU Civil and Environmental Engineering department faculty, Oregon Department of Geology and Mineral Industries staff, community leaders, and project team leaders (architect, construction manager, and general contractor).

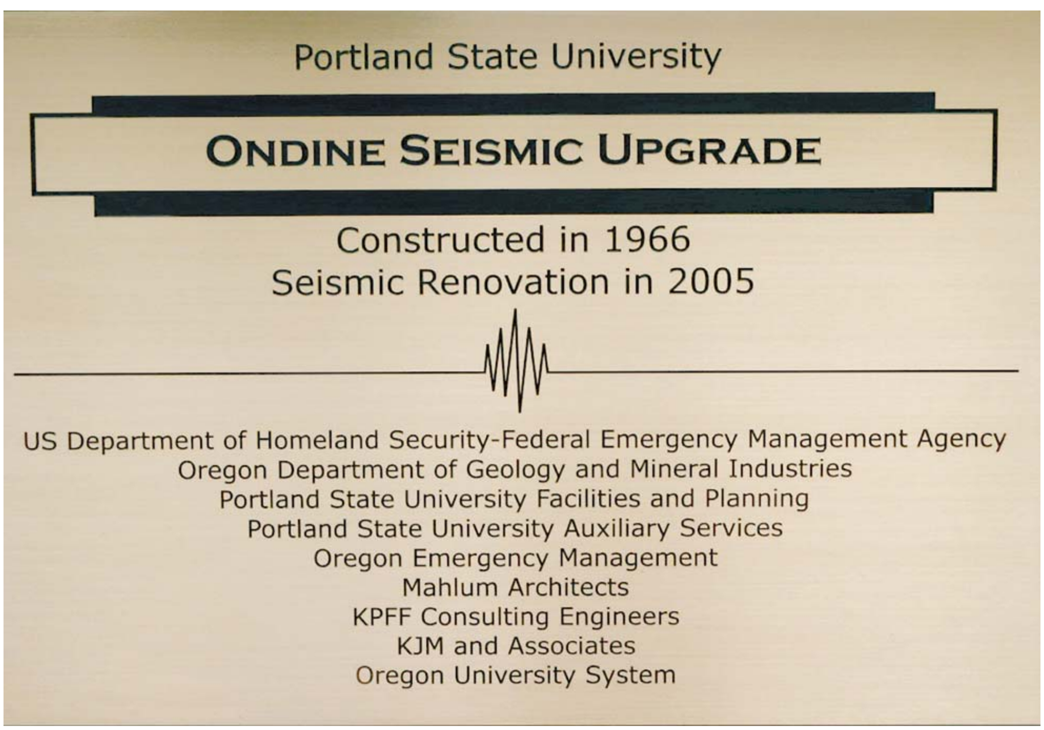


Figure 4. Demonstration project plaque for the Ondine Hall seismic rehabilitation, permanently displayed at the main building entrance to increase seismic safety awareness.

PREVIOUS SEISMIC EVALUATION

In 1996, KPFF Consulting Engineers was retained by Michael & Kuhns Architects to conduct a structural seismic evaluation of Ondine Hall using FEMA 178 methodology (BSSC, 1992). The scope of KPFF's review was limited to structural elements resisting lateral forces. Evaluation of nonstructural inventory and deficiencies was not included in the scope. KPFF compared existing Ondine Hall structural elements resisting lateral forces to requirements indicated in the Uniform Building Code, 1994 edition (UBC 1994).

The evaluation included a site visit on February 28, 1996, where representatives from KPFF walked through the building and reviewed the structure. The evaluation included observations of the general condition of the building, a review of available design drawings, and an assessment of the most significant structural deficiencies.

KPFF found that lateral earthquake forces would be resisted by concrete shear walls in the building. Floor diaphragms were connected to the shear walls and would transfer lateral forces to them. The drawings indicated that joist reinforcement extended and hooked into the walls, which would assist in transfer of lateral forces between the floor diaphragms and walls.

KPFF also determined that the lack of shear walls on the second floor along the west face of the building should be considered a vertical irregularity. At this floor, forces resisted by the shear wall above the second floor must be transferred through the floor diaphragm to other shear walls. This severely degrades the building's performance. It increases the load on the diaphragm and on other shear walls within the building by causing the building to twist and rotate during earthquake shaking.

The panels on the east and west faces of the building were analyzed as complete walls with punched window openings. The weak link in these walls was determined to be the coupling beams between the panels. The walls were found to have inadequate shear capacity at the 11th floor and below for the FEMA 178 load level, and at the 12th floor and below for the UBC 1994 load level. All other shear walls were found to be inadequate for FEMA 178 requirements and UBC 1994 loads for the majority of the height of the building. The one exception was the parking garage, where shear walls were found to have demand-to-capacity ratios much less than 1.0 (KPFF, 1996).

SEISMIC MITIGATION DESIGN

No additional work or studies were completed on the building for approximately eight years. Upon approval of the FEMA PDM grant funding, Mahlum Architects was hired and KPFF was rehired to analyze the building and to propose a seismic mitigation design. The targeted rehabilitation objective is to meet life-safety at the basic safety earthquake-1 (BSE-1) level according to FEMA 356 methods (FEMA, 2000). Analyses show that the Ondine building, without a seismic upgrade, would be damaged and might experience a partial collapse under a BSE-1 level earthquake, which is commonly known as the design basis earthquake, or DBE (KPFF, 2004).

On the basis of field tests and linear dynamic analyses, per FEMA 356 guidelines, KPFF proposed a four-part mitigation: (1) strengthening of existing column reinforcement, (2) addition of exterior concrete along the south elevation and strengthening end-of-wall reinforcing at existing concrete shear walls, (3) addition of 3/8-inch steel plates to the interior wall along the north and south elevations, and (4) new cross-bracing along the west elevation. Each part of the seismic mitigation design is shown in Figure 5 and is discussed in this report. The proposed upgrade would allow the building to remain close to elastic in the BSE-1 event. The existing building systems that would not be upgraded would benefit due to reduced building drifts and improved lateral load path (KPFF, 2004).

The mitigation design proposed by KPFF was based on FEMA 356 methodology and therefore did not consider the detailing requirement necessary to meet the full requirements of International Building Code (IBC) 2003, the current code. Forces generated in the analysis using FEMA 356 methodology are actually higher than IBC 2003 levels. This is an intentional difference between the codes—

Figure 5. Solutions recommended by structural engineers for seismic improvement: (A) existing rebar joint, which was mitigated by welding rebar together, (B) new concrete shear wall on the south side of the building, (C) new steel cross bracing, and (D) steel plate installation in progress.

it allows the FEMA 356 procedure to omit certain detailing requirements of the IBC 2003 and is more appropriate for existing buildings.

The proposed mitigation was intended to provide general improvements to most serious deficiencies, which were located on the lower floors, in order to achieve a life-safety performance level and to minimize potential for collapse during a seismic event. After intense negotiations with the City of Portland, the city eventually allowed PSU to maintain the original scope outlined in the FEMA grant proposal, which includes mitigation of only four floors (subbasement, basement, first floor, and second floor).

CONSTRUCTION FEASIBILITY CONSIDERATIONS AND MITIGATION COSTS

Considerations of the preliminary conceptual design included the cost, construction feasibility, and effectiveness of different types of mitigation that would provide viable solutions for the major deficiencies.

Three options were considered to provide additional strength to the inadequate shear walls. The first, and relatively inexpensive, option was to provide additional shear wall thickness by simply adding more concrete shear wall to the existing walls. However, concrete walls would result in a significant increase in load on footings and piles. In this case, the addition of exterior concrete walls was not feasible due to the excavation that would be required for the basement and subbasement stories and associated costs. Also, the use of concrete on interior walls would result in loss of the already limited interior space. Furthermore, adding concrete walls was considered to be unworkable in locations where there were conflicts with obstacles, such as the exterior stairwell shown in Figure 6. A second option of reinforcing with composite fibers was ruled out due to high cost.

Therefore, the option of adding lighter steel plates rather than heavy concrete was adopted in most cases. The one exception where concrete was determined to be the most inexpensive yet feasible solution was the first and second floors of the exterior south side of the building.

Epoxy-coated anchor bolts were to be used to attach the steel plates to the existing concrete walls. Two main criteria involving the location of the anchor bolts affected the approach to attaching the plates: (1) the architect wanted consistent spacing of the bolts for aesthetic reasons, and (2) KPFF would not permit damage to in-situ rebar in the existing concrete walls.

Many methods were considered to satisfy both criteria. One option was simply to drill two holes close together so that in the event that the rebar was hit in one hole, there would be another hole available. However, excessive fabrication work would be required to drill all the unused holes, and the architect did not want more holes in the plate than necessary. Another option was to locate the rebar during installation and then field drill the holes to match. This option would have slowed construction to an unacceptable rate. It became evident that drilling holes during installation was not feasible. This activity had to be done in the shop.

Ultimately, it was decided that existing rebar locations in the walls needed to be determined before installation of the steel plates. Nondestructive testing was conducted to locate and mark all the rebar in the walls. The fabricator then field measured this “rebar map” and transferred the pattern to shop drawings. The holes were then placed to avoid the rebar. Figure 7 shows a sample of the rebar maps that were developed to determine drill hole placement in the steel plates. As a consequence, each plate had to be detailed and fabricated for a specific wall location.

The addition of the braced frames at the soft story of the west face dramatically improved the building’s response to seismic excitations. The braced frames reduce load demands on the other walls and floor diaphragms resulting in less overall required reinforcing as well as lower mitigation costs.

A major problem discovered during the investigation phase of design was that the concrete columns were not positively connected to each other with vertical rebar. At this point, several options were considered. Because the upper floors of the building were to remain occupied during construction, safety of occupants was a major concern when the columns were being reinforced. The first option of adding concrete and reinforcing around the existing column was ruled out due to high cost and loss of interior space. The

Figure 6. Obstacles such as the exterior stairwell prevented use of additional exterior concrete shear walls.

Figure 7. Map of existing rebar to determine locations for drill hole anchors needed for steel plate mitigation.

second option of steel plating was also ruled out for cost reasons. These limitations narrowed the options to fixing the splices directly, which required laborious and accurate chipping of existing concrete columns to expose rebar splices.

Large, mechanical couplers were considered. However, #18 rebar is so big (about 2¼ in diameter) that using large couplers would require removing an unacceptable amount of concrete at each column simply to install the couplers. Large couplers are also expensive. Due to these economic and feasibility constraints, using a welded splice became the most viable option. This option is further discussed later in this report (see Mitigation 1 subsection).

Table 1 shows a summary of construction and soft costs for the project. The estimated FEMA grant budget was $2.3 million for Ondine Hall, but final cost after construction was about $3.0 million — $700,000 over the original estimate. The local economy improved raising construction costs for both labor and material and added approximately $100,000 to the total project costs. The rebar problem added approximately $600,000 to the project costs.

Table 1. Portland Sate University Ondine Hall mitigation project costs.

Amount	Category
	Construction Costs
$2,360,000	rebar coupler repair ($600,000)
	concrete shear wall
	steel plates
	steel cross bracing
	Soft Costs
$640,000	architect and engineering
	project and construction management
	bids, permits, relocation, drawings
	special inspection and testing
	quality assurance/quality control monitoring
	DOGAMI, OUS, and PSU oversight
$3,000,000	Total

SEISMIC MITIGATION CONSTRUCTION

Project Team

The project team was developed by PSU with KPFF Consulting Engineers; Mahlum Architects; Skanska USA Building, Inc. as the general contractor; and KJM & Associates as construction management. OUS and DOGAMI facilitated and provided oversight for the project, and Oregon Emergency Management (OEM) provided administrative assistance with FEMA. The main project team members and their project roles are summarized in Table 2.

Project Schedule

The project schedule and time line of major events are summarized in Table 3. Like many older buildings, Ondine Hall was not constructed to today's seismic standards. Recognizing life-safety issues, obtaining funds, identifying specific deficiencies and solutions, and mitigating the deficiencies can be a lengthy, complex process. In this case, the planning and mitigation process took well over two years. Final construction completed in late 2005.

Before performing construction on the fully occupied building, it was necessary to consider all adverse effects caused by construction activities to the occupants. KJM & Associates, the construction management contractor, considered the PSU academic schedule, building occupant suggestions, and many other logistics in developing the project schedule. A system was devised to notify residents and tenants directly impacted by the construction. In addition, notices were posted two weeks in advance for areas of the building likely to be affected by noise and other disturbances. Most of the construction took place during the summer months when fewer students were in the building during daytime hours.

Table 2. Ondine Hall seismic rehabilitation project team.

Project Role	Project Team Member	Location
Owner	Portland State University	Portland, OR
Operator	College Housing Northwest at Portland State University	Portland, OR
Construction Management	KJM & Associates	Portland, OR
Architect	Mahlum Architects	Portland, OR
Structural Engineer	KPFF Consulting Engineers	Portland, OR
Builder	Skanska USA Building, Inc.	Portland, OR
Project Funding	U.S. Department of Homeland Security - Federal Emergency Management Agency	Washington, DC
	Oregon University System	Oregon
	Portland Sate University Facilities and Planning	Portland, OR
	College Housing Northwest	Portland, OR
Project Facilitator/Oversight	Oregon Department of Geology and Mineral Industries	Oregon
Administrative Assistance	Oregon Emergency Management	Oregon

Four-Part Mitigation

The four-part seismic mitigation included (1) strengthening existing column reinforcement, (2) adding exterior concrete shear wall along the south elevation, (3) adding 3/8-inch steel plates to the interior walls along the north and south elevations, and (4) adding cross-bracing along the west elevation. Each part of the seismic mitigation is discussed below.

Mitigation 1: Strengthen existing column reinforcement

KPFF analyzed the building using a computer model and FEMA 356 methods using reasonable assumptions for a 1966 structure based on the available as-built drawings. In accordance with the FEMA 356 method, KPFF conducted a limited number of destructive tests to determine the state of important components of the existing structure. To confirm assumptions made in the computer modeling of the strength of the existing structure, KPFF requested a destructive test of an existing coupler where the #18 rebar was spliced. Their model assumed a strong mechanical connection between the vertically spiced bars. The concrete columns were chipped open enough to expose the coupler, which was removed and sent to a testing lab for tensile testing.

Testing revealed that the coupler used had essentially no tensile strength and was in effect a construction alignment device rather than a structural element. This problem exists at locations where the #18 rebar are vertically spliced — the first, third, and fifth floors, primarily at the interior and perimeter columns. Above the fifth floor, the rebar are smaller and use a lap splice, which was deemed sufficiently strong.

Given the unexpected rebar coupler test results, KPFF redesigned and reconfigured the model with the new data. They determined column-by-column and floor-by-floor the strength required at each column and therefore how many connections of rebar needed to be mitigated. Because the upper floors of the build-

Table 3. Ondine Hall project schedule and time line of major events.

Period	Event
1966	Original construction of Ondine building
1974	Oregon adopts first statewide building code
1976	Portland State University purchases Ondine building, which becomes Ondine residence hall
1994	State of Oregon mandates seismic design in statewide building code
2001	Oregon legislature mandates earthquake safety in public schools
2002	Voters approve general obligation bonds for earthquake safety in schools
2002-2003	Oregon Department of Geology and Mineral Industries (DOGAMI) and Oregon University System (OUS) partner to assess seismic risk of seven university campuses
2003	DOGAMI and OUS partner on Federal Emergency Management Agency (FEMA) Predisaster Mitigation (PDM) grant proposal
September 2003	DOGAMI submits FEMA PDM grant proposal for demonstration projects
April 2004	FEMA awards PDM grant for Ondine residence hall demonstration project
January 2005 - May 2005	Project planning, preconstruction design, contractor/subcontractor bids and awards
April 2005	FEMA 356 destructive testing reveals inadequate vertical rebar connections
April 2005	FEMA and other major stakeholders tour 1
April 2005 – June 2005	Permits and bidding for construction
June 2005 – September 2005	Construction of seismic strengthening
August 2005	VIP and other major stakeholders tour 2
September 2005 – November 2005	Finishing/architectural work
November 2005	Final on-site inspection by Oregon Emergency Management and others

ing remained occupied during column repair work, a detailed plan was developed with the sequencing requirements of the repair work. This was to ensure that overall stability of the building was maintained during the entire course of the repair work.

KPFF then designed a splice that put a heavy splice plate behind the rebar and was vertically welded to the rebar. This design necessitated the removal of a good portion of the column concrete. Also, this design added excessive heat to the rebar over such a large area that there was concern about damaging the remaining concrete above and below the repair.

To minimize the chipping required on the concrete column and to control the amount of heat introduced, three different techniques of a full penetration butt weld were examined and tested for the butt weld between the rebar, as shown in Figure 8.

Ultimately, the decision was made to use high-strength stick welding. Testing showed that this process could be accomplished in accordance with American Welding Society (AWS) standards. This stick weld would result in a splice that was stronger than the rebar itself, which is desirable. To conform to code, welding contractors are required to submit a written procedure for welding that must be approved prior to construction. By the time it was decided that high-strength stick welding would be used to solve this problem, there was only one contractor qualified and available to do the rebar welding. Figure 9 shows the construction process necessary for the rebar coupler improvements.

Figure 8. Testing rebar coupler weld.

Even with the process described above, heat from the welding damaged some concrete areas both above and below the bar splices. In order to repair these locations, all the unsound concrete was removed and the chipped areas were grouted back with concrete. Also, pressure epoxy injection was used around the bar splice repair area to further ensure that the columns remained sound.

The additional design and construction for mitigation 1 due to the rebar problem cost $600,000.

Mitigation 2: Add exterior concrete wall along the south elevation

Shear strength was improved on the exterior first and second stories of the south elevation of the building by adding a concrete shear wall to the existing shear wall. The additional concrete was tied in to the existing concrete by installing epoxy anchor bolts in the existing concrete. Temporary forms were placed to contain the new cast-in-place concrete thickness. Figure 10 shows construction of the new concrete on the south side of the building.

Lateral forces from this reinforced wall are transferred to steel plate reinforcing at the inside of the building at the lower levels. This transition resulted in a significant cost saving by avoiding expensive excavation work.

Mitigation 3: Add steel plates to the interior walls along north and south elevations

Steel plates were added to the interior of the subbasement, basement, and first floor along the north and south interior walls. The plates were then fabricated as described previously with predrilled holes to receive the threaded anchor bolts. Once the plate was in the proper location on the wall, it was secured to the wall by simply tightening a nut. None of the existing rebar was impacted during drilling and installation of the steel plates. Once installed, the plates were welded together and joined one floor to the next. Figure 11 shows the installation of steel plates.

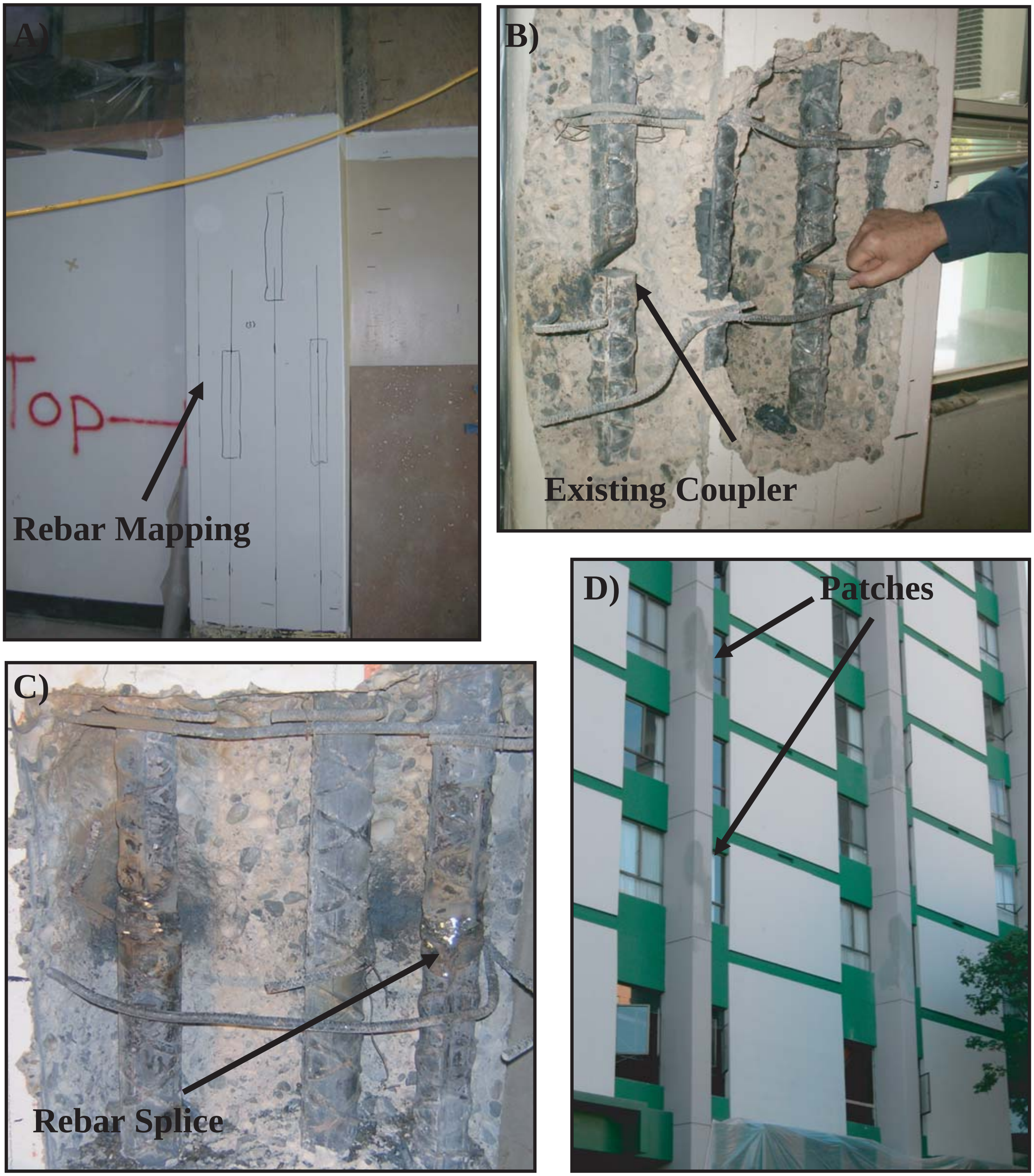


Figure 9. Construction process used to connect vertical rebar: (A) rebar mapping destructive tests expose inadequate rebar coupler, (B) existing coupler, (C) close-up of splice used for coupler repair, and (D) cement/concrete patches following coupler repair.

Figure 10. Construction of concrete shear wall along south side of Ondine Hall: (A) preparing new portion of concrete shear wall, and (B) completed shear wall.

Mitigation 4: Add cross-bracing along the west elevation

The major west elevation, with its soft stories on the first and second floors, was strengthened using a braced frame, the cross-bracing commonly seen in rehabilitated buildings. Horizontal steel members were bolted at the floor level, and vertical steel members were bolted to the existing shear wall. These steel members were used to tie in the new cross-bracing to the existing structure. Steel plates were used to weld the cross-bracing to the horizontal and vertical steel support members. In the building corners, the cross-bracing members were welded directly to the new steel plates. Construction of the braced frame is shown in Figure 12.

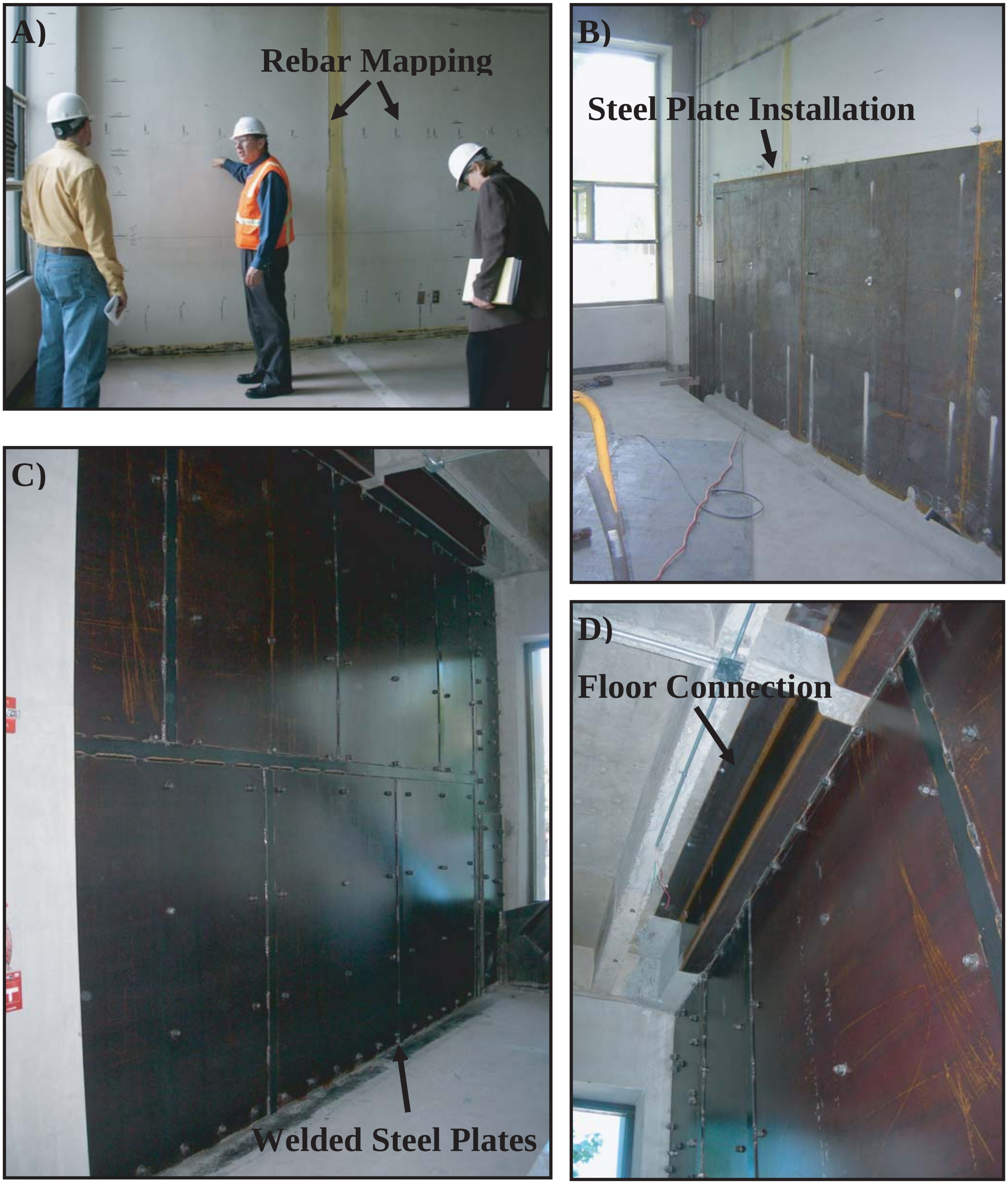


Figure 11. Construction process for steel plates: (A) rebar mapping, (B) installation in progress, (C) completed wall with sheets welded together, and (D) plate connected floor to floor.

Figure 12. Construction of cross-bracing on first and second stories along west elevation: (A) Installed cross-bracing, (B) cross-bracing installation in progress, (C) close up of welded plate at floor level, and (D) close-up of weld used to connect new cross-bracing to steel plates.

COST OVERRUNS

The entire cost of the seismic work totaled about $3.0 million — $700,000 over the original estimate of $2.3 million. The unplanned coupler repair comprised $600,000 of the overrun. The remaining $100,000 of the overrun is due to several factors. One possible factor is that the initial cost estimate was inaccurate. It is extremely difficult to estimate the cost of seismic repair to an existing building. Other factors include increases in the cost of materials (such as steel) and the cost of labor. To decrease cost overruns created by the coupler repair, it was decided to defer repairs on the interior faces of the third and fifth floors until later phases. (The exterior splices for these floors were performed in this phase.)

Ultimately, having more than one phase of splice repairs was not the best solution for PSU. It would have been more cost effective to perform all splice repairs during one phase; not only have some project team members who understand the issues and requirements now moved to other organizations, but contractor mobilization fees, construction space availability, and more will now have to be duplicated. Furthermore, the repair protocol has rigid restrictions on what columns can be worked at the same time. Working simultaneously on the same column on different floors is more efficient and cost effective.

In this case, a key lesson was the importance of performing special investigations and testing (such as testing for the coupler problem) as early in the project as possible, perhaps during preliminary seismic evaluations. The additional costs can then be estimated and included in the initial detailed cost analysis. It is better to have a good understanding of the extent of these issues early, so that more specific plans and estimates can be made to avoid cost overruns. Additionally, FEMA could allow for contingencies in construction cost estimates. This would provide for any additional funding needed for unforeseen costs that are almost inevitable during construction work on an existing building.

FUTURE UPGRADES MANDATED BY THE CITY OF PORTLAND

PSU facility managers and the mitigation project team have redesigned and gained approval for a seismic mitigation scheme to accommodate future seismic mitigation work on the upper floors, which has been mandated by city building officials to meet current code. This work will be conducted long after the FEMA PDM funded mitigation. It is expected that OUS and PSU will cover 100% of the cost for future mitigation.

Due to costs, it was decided to defer the seismic coupler repair on the interior face of the columns on the third and fifth floors until future phases of the planned 10-year building upgrade. The future upgrade will include repair to the rebar couplers where the #18 rebar is spliced on the interior columns of the third and fifth floors. The general contractor, Skanska USA Building, Inc., estimated that future seismic mitigation for the building up to the 15th floor will cost approximately $18 million. Their estimate factored in coupler repair costs of $600,000 for both the interior and exterior faces of the first floor and the exterior face only of the third and fifth floors.

DISCUSSION

Oregon is at risk for a major earthquake. In addition to the Cascadia Subduction Zone threat, many communities are situated near active crustal faults. Oregonians have expressed strong concerns about Oregon's earthquake risk and want to improve our state of readiness. One way to better prepare and protect Oregonians from earthquake losses is to increase awareness and preparedness through demonstration projects such as Ondine Hall.

The successful first-phase seismic rehabilitation of Ondine Hall created momentum in earthquake preparedness throughout the state. State agencies, the federal government, and the private sector worked together to accomplish the task. These same entities must work together to meet long-term mitigation goals. The Ondine Hall project also served as an impetus for individual owners and communities to become involved in similar seismic retrofit projects of their own.

Many valuable lessons were learned on the Ondine Hall project. In particular, the project serves as an example of the complicated nature of working on existing buildings that harbor structural uncertainties. Existing reinforced concrete buildings, such as Ondine Hall, can be complicated mitigation projects because the detailing of the reinforcement steel may not be apparent in available structural drawings. It may be necessary to conduct destructive or nondestructive tests to examine the reinforcement and connection detailing. This situation makes it difficult to estimate mitigation costs before the project starts. One possible solution to this situation is to perform any needed tests before submitting requests for funding. In the Ondine Hall case, the rebar coupler problem was discovered after the cost estimates in the grant proposal had been developed and FEMA had approved the grant amount. If the problem had been discovered earlier, it would have been possible to request additional funding in the initial grant proposal. In addition, FEMA could choose to allow for contingencies for any unanticipated problems. Alternatively, contingency funds from other sources could be factored in or pre-approved.

The Ondine Hall project also illustrates the difficult nature of working on an existing occupied high-rise building in an urban environment. A significant portion of the construction took place indoors, so it became necessary to move temporarily some occupants during construction. Access to the building was extremely difficult for equipment and crews during construction. The staging area and access from the east side of the building on a low-rise attachment was limited. On the south, north, and west sides of the building, only narrow corridors of open space were available to provide access for equipment, construction materials, and workers. In addition, because the building was occupied, it was necessary to maintain a safe means of egress at all times.

Beyond the rehabilitation itself and the technical lessons learned from this project is an increase in public awareness. Tours and news items gave the project and Oregon's need to prepare for earthquakes high visibility. A permanent plaque on the building's exterior and the new cross-bracing and steel walls in Ondine Hall cafeteria (Figure 13) are constant reminders that students and other building occupants are now better protected because of this mitigation action.

Figure 13. New structural cross-bracing and a wall of steel plates, burnished for aesthetic reasons, are permanently visible in Ondine Hall cafeteria.

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