USRC Tiltup Seismic Retrofit Study

Achieving a USRC Gold Rating is both economical and a good investment

Contributors

Evan Reis, US Resiliency Council	Project manager
Dustin Cook, HB-Risk	SP3 risk modeling of tilt-up designs
Ali Sahabi, Optimum Seismic	Construction cost estimating
Jeff Ellis, Simpson Strongtie	Construction cost estimating
Damon Ho, Simpson Strong tie	Construction cost estimating
John Lawson, Cal Poly SLO	History of tilt-up code evolution
David McCormick, SE, SGH	Structural engineering
Confidential, retailer	Building layout, replacement cost and description

Objectives

- Consider a typical single story, big-box retail store, built to four building codes (1973 UBC, 1976 UBC, 1991 UBC, ASCE 7-10).
- 1976UBC representative of 1976-1988UBC designs. 1991UBC representative of 1991 and 1994UBC designs.
- Determine the expected USRC performance rating for each of the four designs along the dimensions of SAFETY, DAMAGE and RECOVERY.
- Estimate the cost to seismically retrofit each of the buildings to achieve a USRC GOLD rating (minimum of 4 stars in each of the three dimensions)

Assumptions

Based on information provided by confidential retailer

Code:	Conforms to 1973, 1976, 1991UBC or ASCE 7-10
Dimensions:	~135,000sf, ~500'x270' floor plan, height estimates – 24' for 1973UBC, 27' for 1976, and 1991UBC, 30' for ASCE 7-10
Location:	Los Angeles, CA (34.05, -118.25, Class D soil)
Construction:	Concrete tilt-up with panelized plywood roof and interior steel post columns. Rectangular with no significant re-entrant corners or other irregularities.
Replacement cost:	~$142/sf = $19.2 million
Retrofit:	Occurs simultaneously with major renovation/refresh schedule that includes replacing ceiling. Access to underside of roof is available. Roofing is not replaced.

Limitations

Irregularities

Many tilt-up buildings contain irregularities such as large re-entrant corners lacking collector elements. This study does not consider buildings with these features or mezzanines

Deterioration

Concrete, steel and wood deterioration within a building can impact seismic performance. This project assumes that the building has been well maintained.

Rooftop equipment

Assumed properly anchored to roof.

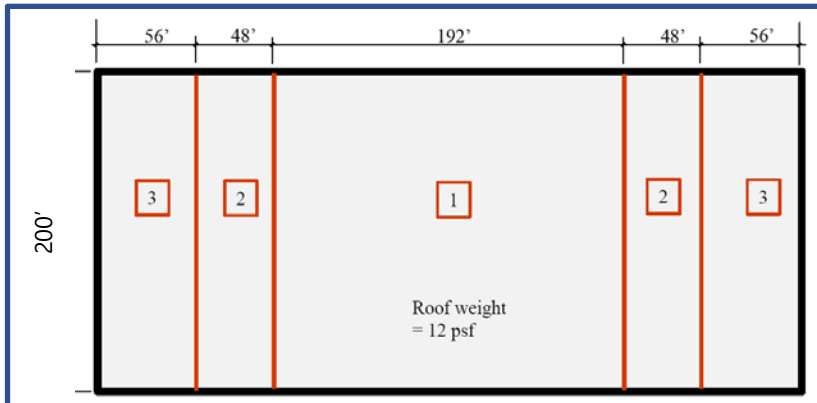
Age

Tilt-up buildings constructed in the 1950's, 1960's and early 1970's may have very significant deficiencies in the anchorage of walls to foundations, panel interconnections, and wall reinforcing. This study considers only buildings designed to the 1973UBC or later when many of these design deficiencies were addressed in codes.

Soil conditions

Tilt-ups with warehouse occupancies may be located in industrial areas, near the water or other areas with poor soil conditions that can increase damage or be expensive to retrofit, in particular under wall footings and interior slabs. This study assumes a retail style building located in a suburban or urban environment without significant soil deficiencies.

Typical Roof Diaphragm Details



1973 UBC

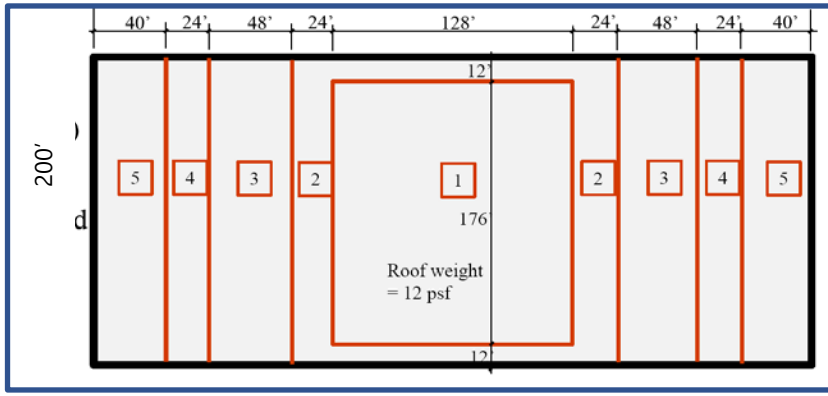
24-ft roof + 3-ft parapet, 6½" panels

Wall Anchorage: 0.20Wp(ASD)

Wall Force (out-of-plane): 0.20Wp(ASD)

Base Shear:V=0.133W (ASD)

Diaphragm: Fp=0.133Wp(ASD)



1976-1994 UBC

27-ft roof + 3-ft parapet, 7½" panels

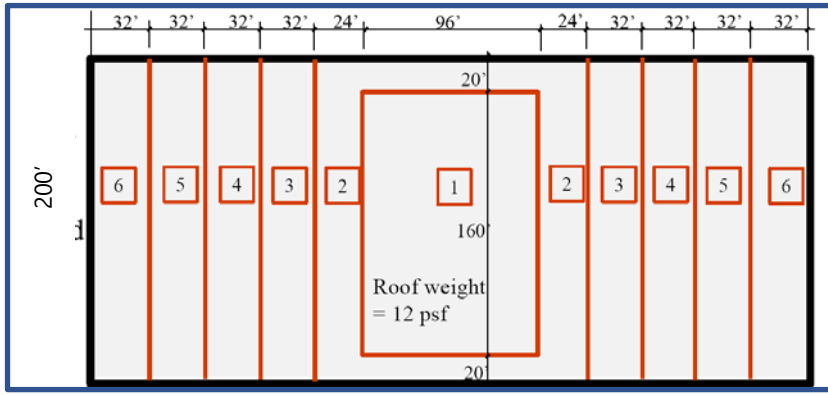
Wall Anchorage: 0.30Wp(ASD)

Wall Force (out-of-plane): 0.30Wp(ASD)

50% increase in middle of diaphragm forces in 1991-1994UBC

Base Shear:V=0.183W (ASD)

Diaphragm: Fp=0.183Wp(ASD)



1997 UBC and 2000+ IBC

30-ft roof + 3-ft parapet, 9¼ " panels

Wall Anchorage: 0.80Wp(LRFD)

Wall Force (out-of-plane): 0.40Wp(LRFD)

Base Shear:V=0.244W (LRFD)

Diaphragm: Fp=0.25Wp(LRFD)

Assume 2:1 aspect ratio similar to subject building (500x270)

Diaphragm Nailing

Zone 1	10d@ 6, 6, 12 (Boundary, panel edges, field)
Zone 2	10d@ 4, 6, 12
Zone 3	10d@ 2-½, 4, 12
Zone 4	10d@ 2, 3, 12 with 3x framing at panel edges
Zone 5	2 lines of 10d@ 2-½, 4, 12 with 4x framing at panel edges
Zone 6	2 lines of 10d@ 2-½, 3 12 with 4x framing at panel edges

Diaphragm Framing

15/32" Struct I ply, panel edges align with purlins and subpurlins

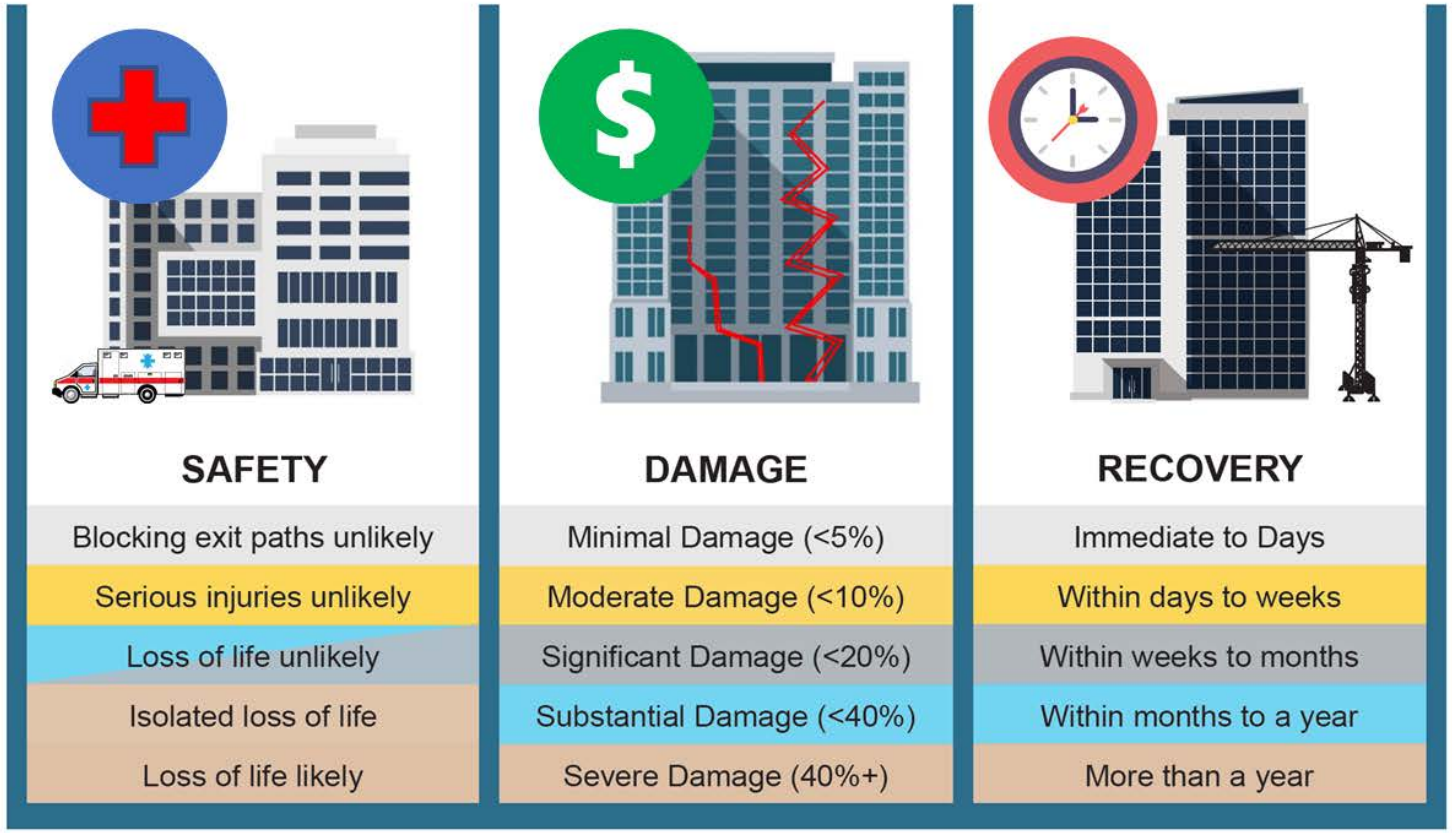
2x4x8' subpurlins @ 2'oc

4x purlins 20' spans @ 8'oc

Glulam girders 40' spans @ 20'oc

Credit: John Lawson, Cal Poly SLO

US Resiliency Council Rating System



SAFETY	DAMAGE	RECOVERY
Blocking exit paths unlikely	Minimal Damage (<5%)	Immediate to Days
Serious injuries unlikely	Moderate Damage (<10%)	Within days to weeks
Loss of life unlikely	Significant Damage (<20%)	Within weeks to months
Isolated loss of life	Substantial Damage (<40%)	Within months to a year
Loss of life likely	Severe Damage (40%+)	More than a year

Resilience Based Design PLATINUM GOLD SILVER **Code Based Design** CERTIFIED

Approximate USRC Safety Performance

- Based on SEAONC EPRS and ASCE 41-13 (NC = Nonconforming, C=Conforming)
- Based on discussions with Dr. John Lawson and David McCormick, SE

PC1 (Precast/Tilt-Up Concrete Shearwalls - Flexible Diaphragms)		EPRS Rating	1973 UBC	1976 UBC	1991 UBC	ASCE 7-10
16.12LS	WALL ANCHORAGE	2 Stars	NC	NC	NC	Conforming by ASCE 41 benchmark status
16.12LS	REDUNDANCY	3 Stars	C	C	C	
16.12LS	WALL SHEAR STRESS CHECK	2 Stars	C	C	C	
16.12LS	REINFORCING STEEL	3 Stars	Close	C	C	
16.12LS	WALL THICKNESS	3 Stars	NC	C	C	
16.12LS	WOOD LEDGERS	2 Stars	Possibly NC	C	C	
16.12LS	TRANSFER TO SHEAR WALLS	2 Stars	NC	NC	NC	
16.12LS	GIRDER-COLUMN CONNECTION	2 Stars	NC	NC	NC	
16.12LS	WALL OPENINGS	2 Stars	C	C	C	
16.12LS	CROSS TIES IN FLEXIBLE DIAPHRAGMS	2 Stars	NC	NC	NC	
16.12LS	STRAIGHT SHEATHING	2 Stars	C	C	C	
16.12LS	SPANS	2 Stars	C	C	C	
16.12LS	DIAGONALLY SHEATHED AND UNBLOCKED DIAPHRAGMS	2 Stars	C	C	C	
16.12LS	OTHER DIAPHRAGMS	2 Stars	C	C	C	
16.12LS	MINIMUM NUMBER OF WALL ANCHORS PER PANEL	2 Stars	C	C	C	
16.12LS	PRECAST WALL PANELS	2 Stars	C	C	C	
16.12LS	UPLIFT AT PILE CAPS	3 Stars	?	C	C	
Approximate USRC SAFETY Rating			1 star	1 star	1 to 2 stars	4 to 5 stars*

* Assumes seismic bracing of ceilings and light fixtures + racks > 6′ tall, required as part of standard remodel

Credit: SEAONC, ASCE

Expected Seismic Performance

- Based on information provided by HB-Risk, ASCE 41-13 and SEAONC EPRS
- 500’ x 270’ floor plate
- Based on Design Level event with return period in Los Angeles ~711 years

	USRC RATING		
CODE LEVEL	SAFETY*	DAMAGE	RECOVERY**
1973 UBC	1 star	28% (2 star)	99 days (3 star)†
1976 UBC	1 star	26% (2 star)	95 days (3 star)†
1991 UBC	1 to 2 stars	21% (2 star)	86 days (3 star)†
ASCE 7-10	4 to 5 stars	8% (4 star)	15 days (4 star) ††

* Based on ASCE 41-13 and SEAONC EPRS

** Assumes retailer has a BORP program and financing in place

†Assumes at least some structural damage that may produce a Yellow Tag, where city closes building until structural repairs are completed following issuance of a permit (8wk permitting delay as per REDi)

†† Minimal structural damage and Green Tag expected, allowing for occupancy while repairs are ongoing, so no permitting delay. Recovery time based on time required to restore basic functionality

Retrofit

- Based on results from HB-Risk study, **1997UBC and later designed buildings, can achieve a USRC GOLD rating** so long as rapid response measures are put in place: post event inspection, retainers with contractors, and adequate financing. For national big-box retailers all three are well within their capabilities. This eliminates REDi impeding factors that can substantially extend repair times.

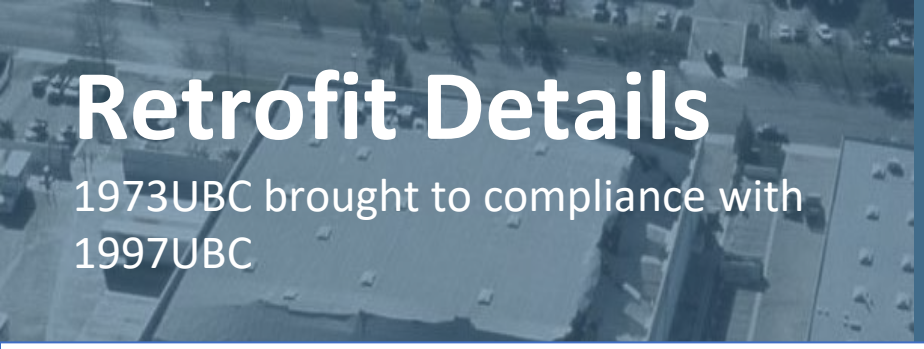
- Therefore, the retrofit expectation will be that pre 1997UBC buildings will be brought into conformance with the 1997UBC/2000IBC.

- The HB-Risk study indicates that little damage occurs in the tilt-up walls themselves, either in- or out-of-plane, at the design level event, so that retrofit will be limited to the roof diaphragm and its connections to the walls.

- Assumption is also that in a major renovation/refresh for retailer, the existing ceiling is dropped and replaced with a current code compliant ceiling, including grid and light fixture bracing.

Retrofit Assumptions

- Per the study by John Lawson, requirements for concentric wall and crosstie anchors appeared in the 1997UBC.
- 1973UBC – Assume old style wall-roof, subdiaphragm and crosstie connections will be completely replaced because of eccentric connections and low design forces.
- 1976-1994UBC – Assume wall-roof and crosstie connections will be doubled up in order to become concentric. The increase in wall anchorage forces from 0.30Wp (ASD) to 0.80Wp (LFRD) would be achieved by the additional anchors.
- 1976-1994UBC – Assume subdiaphragm details are all replaced in direction parallel to 4x purlins, and use newer style detail with block between subpurlins.
- All nailing augmentation done from below roof.
- Plywood is oriented with panel edges aligned with 2x4 subpurlins and 4x purlins so that supplementary blocking is not needed.
- (E) 2x4 subpurlins need to be doubled where panel edge nailing requires 3x or 4x elements.



Retrofit Details

1973UBC brought to compliance with 1997UBC

Wall anchors

Parallel to girders: Use (e) 4x14 purlins (DETAIL D) @ 8'oc — Double Simpson HDU4-SDS2.5 with 5/8" rod

Perp to girders: Space at 8' oc use block between purlins 16' back (DETAIL B) 4x block with Simpson 2-HUC hanger, 5/8"x16' rod and 3" pl

Crossties

On girders at 20'OC: Ties at 40' girder span (DETAIL F) — Double Simpson HCSTR4 with 3/4" bolts

On purlins at 40'OC: Ties at 20' purlin span (DETAIL G) — Double Simpson HHDQ11 with 1" rod

Girder to wall ties

At 20'OC parallel to long direction (DETAIL E) — Double Simpson HHDQ11 with 1" rod

Sub diaphragms

Parallel to girders: use (e) 4x14 purlins with std wall anchors (DETAIL D) — Wall anchors achieve this

Perp to girders: space at 8' oc use block between purlins 16' back (DETAIL B) — wall anchors achieve this

Diaphragm nailing augmentation

Calculate average boundary nailing for 1973 and 1997 UBC designs and augment nailing with clips to achieve equivalent average spacing (DETAIL H).

- Simpson A35 clips with #6x1/2" screws to underside of plywood deck or as a preferred alternative, renail from above when roofing is replaced. The nailing will be lower cost when done from above.
- Assume (e) ledgers at wall edges are 3x or 4x Where 1997 UBC panel edge requirements require 3x or 4x at subpurlins, double up (e) 2x4.

Note: Based on cost estimates provided by Simpson Strongtie variation as a function of the precise size of the hold down anchors is relatively small compared with the average material and installation cost. Therefore, the selection of specific anchor was based on simplified calculations.

Retrofit Details

1976 and 1991UBC brought to compliance with 1997UBC

Wall anchors

Parallel to girders: Use (e) 4x14 purlins (DETAIL D), assuming 1-sided connection already existsSingle Simpson HDU4-SDS2.5 with 5/8" rod
Perp to girders: Space at 8' oc use block between purlins 16' back (DETAIL B) 4x block with Simpson 2-HUC hanger, 5/8"x16' rod and 3" plate

Diaphragm crossties

On girders at 20'OC: Ties at 40' girder span (DETAIL F), assuming 1-sided connection already exists Single Simpson HCSTR4 with 3/4" bolts
On purlins at 40'OC: Ties at 20' purlin span (DETAIL G) , assuming 1-sided connection already exists Single Simpson HHDQ11 with 1" rod

Girder to wall ties

At 20'OC parallel to long direction (DETAIL E), assuming 1-sided connection already exists Single Simpson HHDQ11 with 1" rod

Sub diaphragms

Parallel to girders: use (e) 4x14 purlins with std wall anchors (DETAIL D) Wall anchors achieve this
Perp to girders: space at 8' oc use block between purlins 16' back (DETAIL B) wall anchors achieve this

Diaphragm nailing augmentation

Calculate average boundary nailing for 1976 and 1997 UBC designs and augment nailing with clips to achieve equivalent average spacing (DETAIL H). Augmentation would be slightly less for 1991 UBC where higher forces in middle half of diaphragm were assumed.

- Simpson A35 clips with #6x1/2" screws to underside of plywood deck or as a preferred alternative, renail from above when roofing is replaced. The nailing will be lower cost when done from above.
- Assume (e) ledgers at wall edges are 3 or 4x Where panel edge requirements require 3 or 4x at subpurlins, double up (e) 2x4 .

Retrofit Quantities

1973UBC brought to compliance with 1997UBC

Connection	Piece*	Rod	Other	Detail
Purlin to tiltup wall anchors (epoxied into 6” wall)	(246) HDU4-SDS2.5	(246) 5/8" rod x 18"		D
Subpurlin to tiltup wall anchors (epoxied into 6” wall)	(132) HUC hangers	(66) 5/8"dia x 16'	(66) 3" bearing pl.	B
Girder crossties	(288) HCSTR4 w/ ¾” bolts			F
Purlin crossties	(576) HHDQ11	(288) 1" rods x 24"		G
Girder to wall connection	(50) HHDQ11	(50) 1" rods x 18"		E
Diaphragm strengthening	(25,000) A35		PH6-121 screws to plywood deck	H
Subpurlin augmentation	(1,000) 2x4x8’			

* (x) Refers to the total number of pieces, not the total number of detail locations

Retrofit Quantities

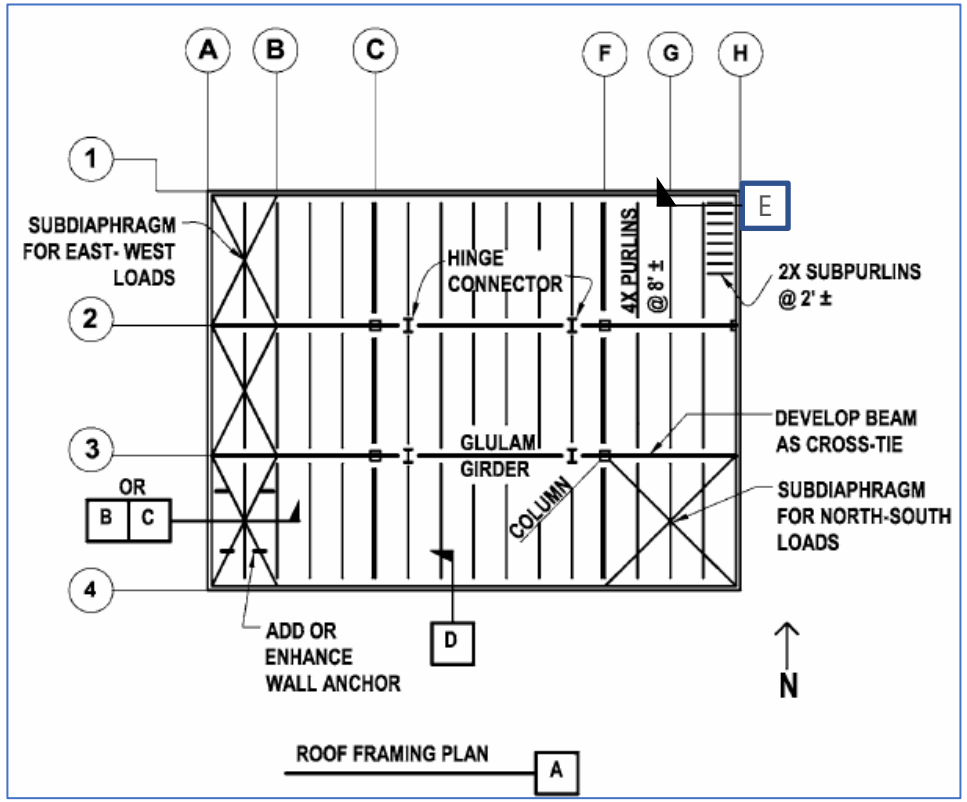
1973 and 1991UBC brought to compliance with 1997UBC

Connection	Piece*	Rod	Other	Detail
Purlin to tiltup wall anchors (epoxied into 6″ wall)	(123) HDU4-SDS2.5	(123) 5/8" rod x 18"		D
Subpurlin to tiltup wall anchors (epoxied into 6” wall)	(132) HUC hangers	(66) 5/8"dia x 16'	(66) 3" bearing pl.	B
Girder crossties	(144) HCSTR4			F
Purlin crossties	(288) HHDQ11	(144) 1" rods x 24"		G
Girder to wall connection	(25) HHDQ11	(25) 1" rods x 18"		E
Diaphragm strengthening	(6,000) A35		PH6-121 screws to plywood deck	H
Subpurlin augmentation	(325) 2x4x8’			

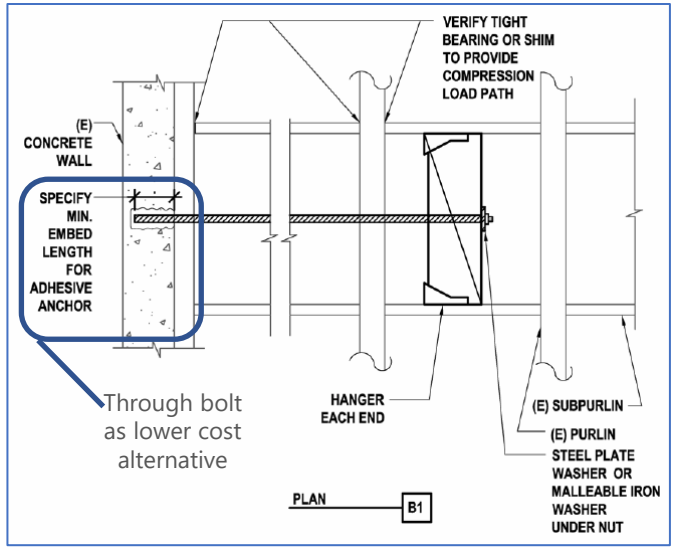
* (x) Refers to the total number of pieces, not the total number of detail locations
** 1991 and 1994UBC increased OOP forces at middle half of diaphragm so this retrofit would be a bit conservative

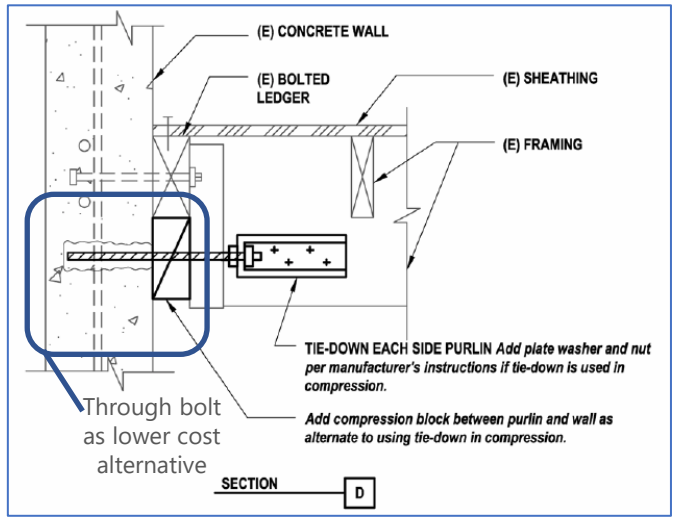
Retrofit Details

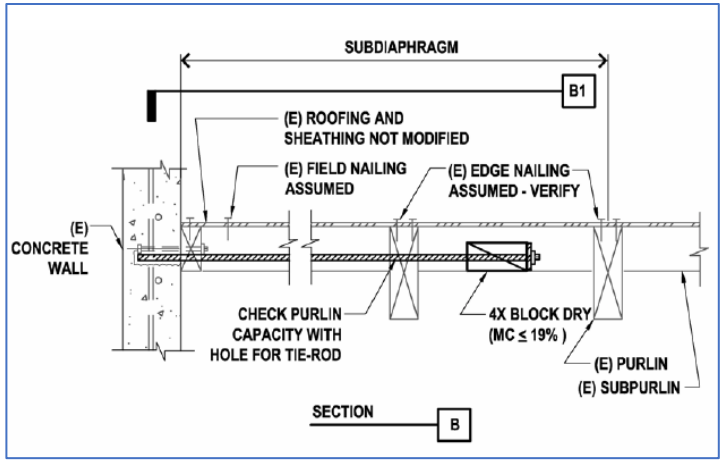
From FEMA 547



Credit: FEMA







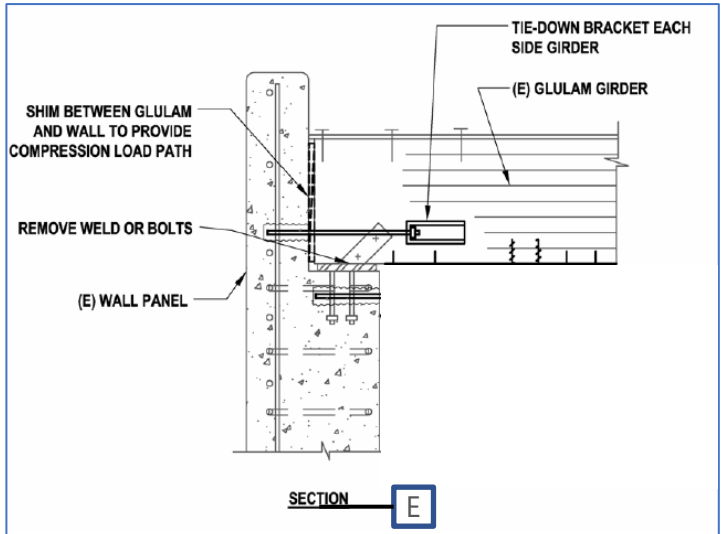


Figure 16.4.2-3: Enhanced Girder Connection at Pilaster

Retrofit Details

From FEMA 547 and Simpson Strongtie

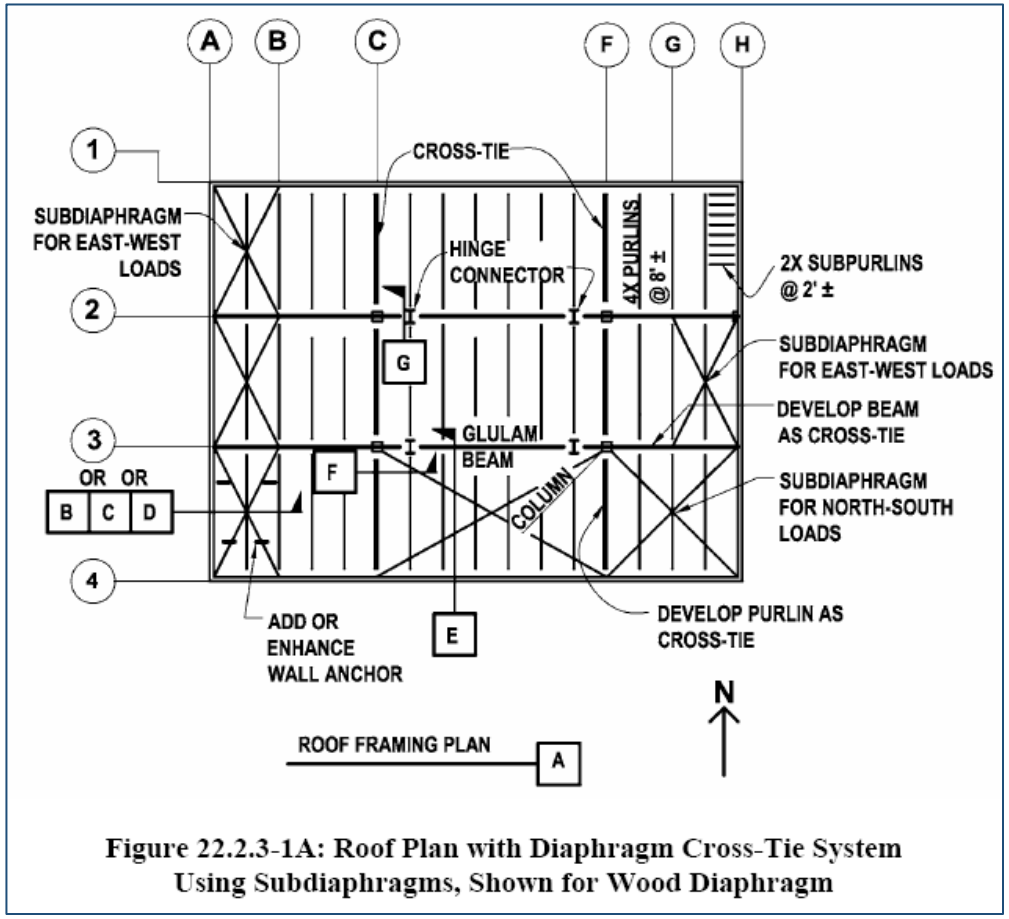
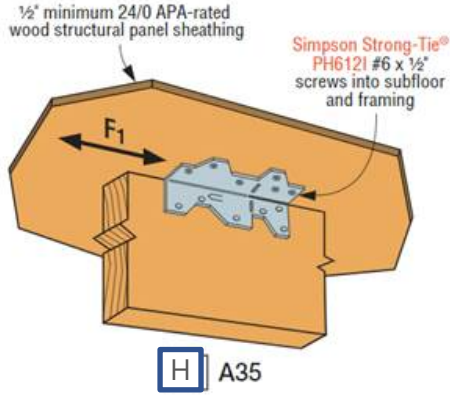


Figure 22.2.3-1A: Roof Plan with Diaphragm Cross-Tie System Using Subdiaphragms, Shown for Wood Diaphragm

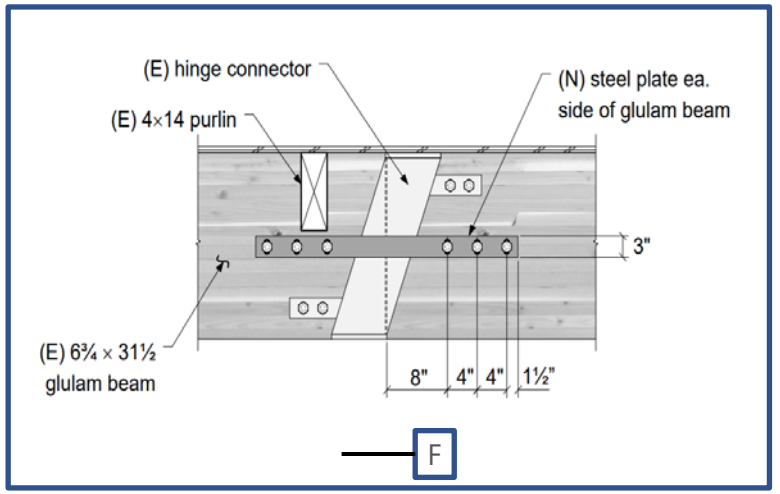
Credit: FEMA

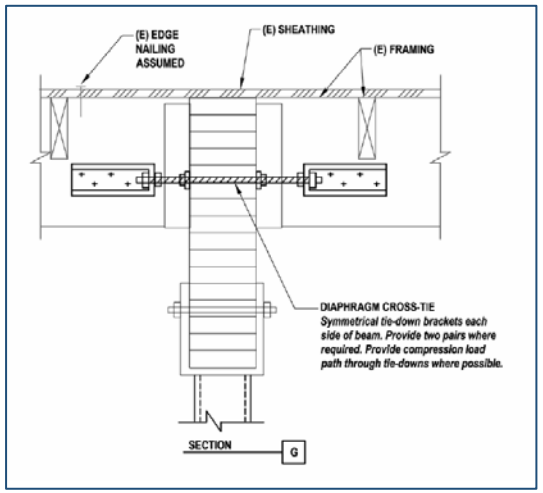


Diaphragm nailing augmentation

Replacement or patching of roofing and nailing from above as preferred alternative

Credit: Simpson





Retrofit Pricing

- Price includes materials, installation and inspections
- General conditions, profit and overhead included.
- Mobilization and demolition of ceilings not included because during renovation and refresh process, contractor will already incur these costs.
- Costs are averaged from estimates provided by Simpson Strongtie, Optimum Seismic and Concrete West.

Connection	Material	Unit list price	Cost 1973UBC		Cost 1976 through 1994 UBC	
Sub-purlin wall anchors	HUC hangers	$29.86	132	$15,028	$132	$14,805
Purlin wall anchors	HDU4-SDS2.5	$32.10	246	$27,316	$123	$14,686
Girder crossties	HCSTR4 w/¾"bolts	$57.87	288	$52,487	$144	$28,787
Purlin crossties	HHDQ11	$109.55	576	$174,398	$288	$88,929
Girder to wall connection	HHDQ11	$113.30	50	$16,634	$25	$8,723
Diaphragm strengthening	A35	$1.25	25,000	$131,344	$6,000	$31,085
Sub-purlin augmentation	2x4x8'	$2.50	1,000	$30,678	$325	$9,738
Total				$447,887		$196,752
$/sf				$3.32		$1.46
% of Replacement Cost				2.3%		1.0%
* All markups distributed to line items: Installation, Permits, Rentals, Inspections, GC, OH, Profit						

Pricing Provided by Confidential Retailer

- Pricing provided from retailer for two recent Southern California project and which includes all markups.
- Location impacts costs significantly. Urban and coastal areas are typically more expensive.
- The specific retrofit implemented was provided for Location 2. It is similar to that proposed in this study.

Location 1

- **Range of cost is $4 to $5 per square foot**
- **$540,000 to $675,000**
- **2.8% to 3.5% of replacement cost**

Location 2

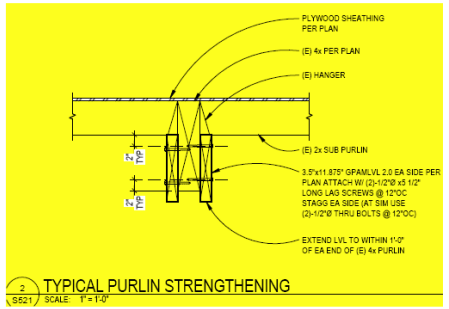
- **$2 per square foot**
- **$222,000**
- **1.4% of replacement cost**

Retrofit Details

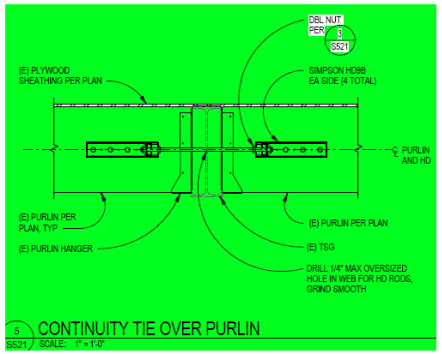
From Confidential Retailer

Cost Data

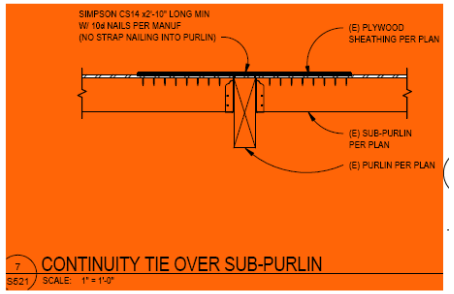
Hardware:	$54,701
Lumber:	$25,350
Labor:	$142,072



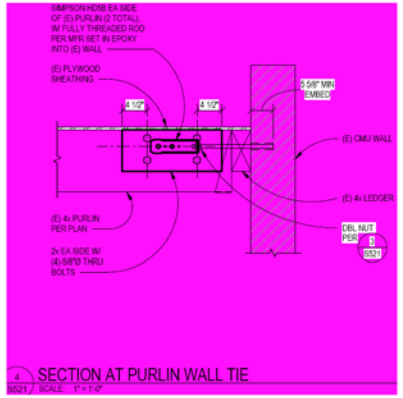
(28) LOCATIONS @ 17FT EA
REQUIRES:
(1) 3.5" x 11.875" LVL
(2) 1/2" x 5-1/2" LAG SCREWS @ 12" OC



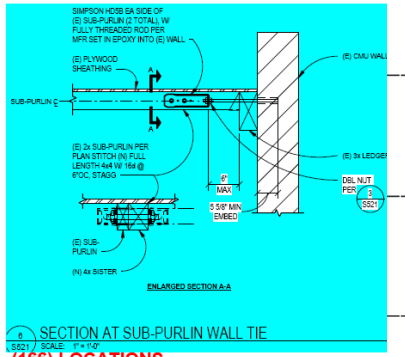
(90) LOCATIONS
REQUIRES:
(2) 1/4" CORE THRU (E) I-BEAM WEB
(2) HD RODS
(4) SIMPSON HD9B



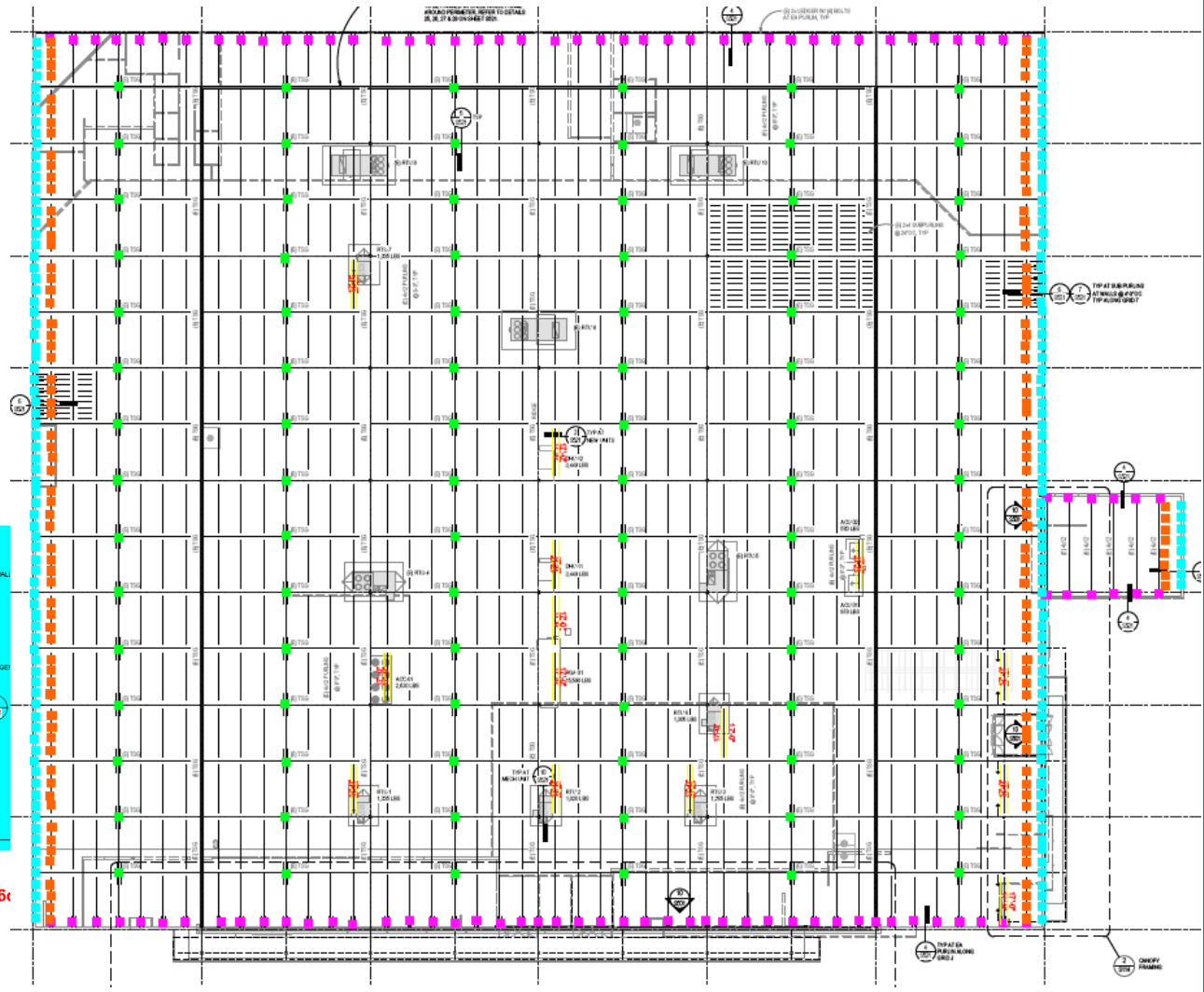
(136) LOCATIONS
REQUIRES:
(1) SIMPSON CS14 x 2'-10" LONG STRAP



(99) LOCATIONS
REQUIRES:
(2) 2x W/ (4)-5/8" THRU BOLTS
(2) ALL THREAD RODS SET IN EPOXY
(2) SIMPSON HD5B



(166) LOCATIONS
REQUIRES:
(1) 4x SISTER (APPROX. 6ft LENGTH) W/ 16d
(2) ALL THREAD RODS SET IN EPOXY
(2) SIMPSON HD5B



Summary

To achieve a ***USRC GOLD*** rating, assuming post earthquake engineering inspection and contractor mobilization retainers are in place, and retailer has adequate financing in place so that REDi impeding factors are not triggered.

Building parameters: 135,000sf, 500'x270' floorplan, no irregularities, $19,200,000 replacement cost, located in Los Angeles

Cost to retrofit a 1973UBC compliant building:	$448,000 $3.32 / sq.ft. 2.3% of replacement cost
Cost to retrofit a 1976UBC through 1994UBC compliant building:	$197,000 $1.46 / sq.ft. 1.0% of replacement cost
Cost to achieve USRC GOLD for a 1997UBC or later building: (With inspection, mobilization and financing in place)	$0

Return on Improved Performance

- Older buildings retrofitted to be USRC Gold compliant
- Building replacement cost value (RCV): $19,200,000
- Average CA store revenue based on public information ~ $134,000 per day

DAMAGE IN A DESIGN LEVEL EVENT *									
	Damage			Recovery (days)			Total Return	Retrofit Cost	BCR
CODE LEVEL	Existing	Retrofitted	Savings at RCV	Existing	Retrofitted	Revenue savings			
1973 UBC	28.3%	7.6%	$3,970,000	99	15	$11,210,000	$15,180,000	$448,000	34
1976 UBC	25.9%	7.6%	$3,510,000	95	15	$10,680,000	$14,190,000	$197,000	72
1991 UBC	21.3%	7.6%	$2,630,000	86	15	$9,480,000	$12,110,000	$197,000	61

* From SP3 evaluation Design Event has 711 year return period at Los Angeles site.

Return on Improved Performance to Achieve USRC Gold Rating

- **Annualize ROI when older buildings retrofitted to be USRC Gold compliant**
- **Building replacement cost value (RCV): $19,200,000**
- **Average CA store revenue based on public information ~ $134,000 per day**

ANNUAL DAMAGE AND RETURNS *											
	Average Annual Loss*			Average Annual Recovery (days)			Total Annual Savings (Return)	Retrofit Cost	Annual ROI	PV Return over 10 years**	BCR over 10 years
CODE LEVEL	Existing	Retrofitted	Savings at RCV	Existing	Retrofitted	Revenue savings					
1973 UBC	0.42%	0.06%	$69,696	2.37	0.27	$281,264	$350,960	$447,887	78%	$2,846,597	6.4
1976 UBC	0.38%	0.06%	$62,016	1.98	0.27	$228,268	$290,284	$196,752	148%	$2,354,461	12.0
1991 UBC	0.28%	0.06%	$42,048	1.50	0.27	$164,974	$207,022	$196,752	105%	$1,679,136	8.5

* From SP3 evaluation, average annual values include overall earthquake risk from multiple events on an annualized basis.
** 10 years is recommended by retailer

Design Performance Goal for New Buildings

- Buildings built to current code are likely to receive a USRC Gold Rating with no additional construction costs
- Owner needs to have in place:
  - Business Recovery program that includes engineering inspection and contractor mobilization
  - Adequate financing to complete repairs

	USRC RATING		
CODE LEVEL	SAFETY	DAMAGE	RECOVERY
ASCE 7-10	4 to 5 stars	8% (4 star)	15 days (4 star)