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SRG IMPLEMENTATION FOR RETROFITS

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ABSTRACT:

The Seismic Retrofit Guidelines (SRG) have been developed by the Engineers and Geoscientists British Columbia (EGBC) on behalf of the British Columbia Ministry of Education. SRG has been developed over a 15-year span that features five SRG editions. SRG has established best current practice for the seismic risk assessment and retrofit of all low-rise school buildings in British Columbia. EGBC recognizes SRG as best current seismic engineering practice for all low-rise buildings in the province.

SRG incorporates a library of fourteen (14) manuals that detail different aspects of the SRG performance-based methodology. *The Guidelines and Commentary* is the title of SRG Manual No. 2 and is the main document engineers' reference when implementing the guidelines for both assessment and retrofit projects. Manual 7 *Library of Retrofit Details* and Manual 8 *Example Retrofit Strategies* are intended to be references that assist engineers in producing viable retrofit solutions.

An example project is used to demonstrate the successful use of the SRG, utilizing Manuals 2, 7 and 8. The example takes the project from assessment, project approval, design, and construction over a more than ten-year period, incorporating changes to local codes and updates to the SRG itself.

Keywords: SRG, Seismic Performance Analyzer Tool, Performance Based Design, Evaluation, Implementation

INTRODUCTION

As noted in the Abstract, the SRG [1] have been developed by EGBC, the provincial engineering and geoscientist association. The SRG Guidelines have been prepared to allow Structural Engineers to use Performance-Based Design methodologies for both the evaluation of existing buildings and the implementation of seismic retrofits.

This paper is intended to demonstrate the implementation of the guidelines for practitioners, from the evaluation, seismic retrofitting, and post earthquake performance of low-rise buildings.

The complex non-linear dynamic analysis needed for Performance Based Design is provided as part of the Seismic Retrofit Guidelines in the form of a web based Seismic Performance Analyzer Tool developed by EGBC and the University of British Columbia (UBC).

This allows practitioners access to pre-performed performance-based analysis of a variety of Lateral Design Resisting System (LDRS) prototypes in an easy to use and intuitive tool.

NEED

The development of these guidelines has been primarily funded by the BC Ministry of Education for the evaluation and seismic retrofitting of high-risk school buildings. EGBC considers the SRG [1] best current practice for the evaluation and retrofitting of all low-rise buildings in the province. This has recently been supported by the British Columbia, Building and Safety Standards Branch. As the performance-based design approach reflected in the SRG and supported by the Provincial Government and EGBC, is considered best practice, examples of its implementation are critical in educating the Engineering community in their use. Table 1 illustrates their development since 2000.

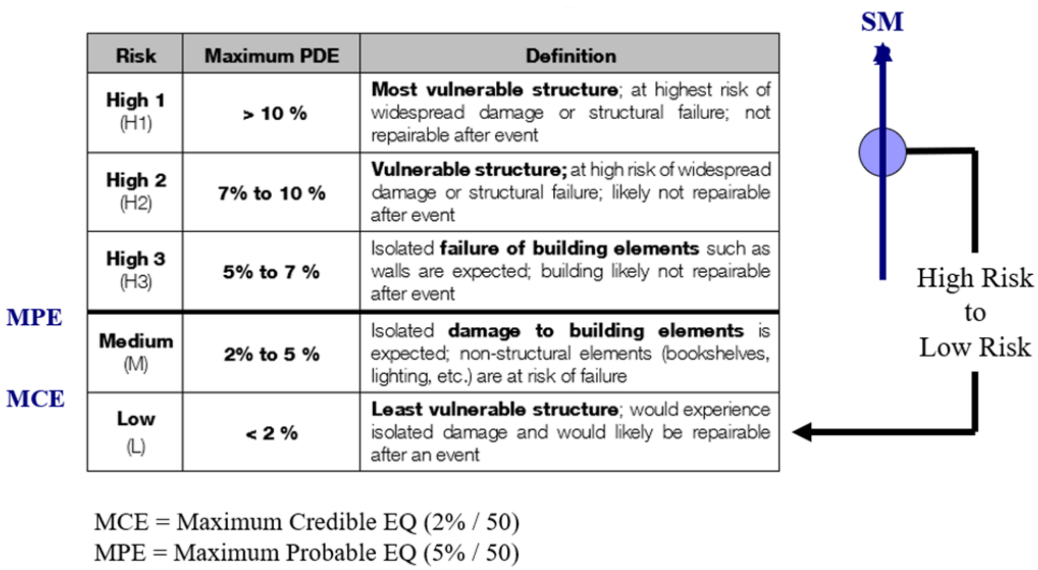
SRG HISTORY

Table 1: SRG Chronology

2000	The Seismic Mitigation Branch of the Ministry of Finance and Corporate Relations program for evaluating the performance of non-structural elements in schools. This initiated a variety of non-structural upgrading in various districts. Examples in include retrofitting ceilings, lighting etc. Various smaller seismic initiatives were implemented through out the 1990's.
2004	The BC Ministry of Education develops excel templates for the seismic evaluation and costing of school retrofits in the high seismic zones of BC. These were completed by the engineering community that same year. Risk ratings for the schools are produced. Prior to this ATC21 and percentage of seismic capacity relative to the building code was being used.
2005	The BC Ministry of Education announced the $1.5B Seismic Mitigation Program (SMP) for schools.
2006	The Bridging Guidelines Second Edition were published where performance based deign Principals were introduced to the wider engineering community. These Guidelines were titled Seismic Assessment and Retrofit Design Concepts using a Performance Based Approach. Seismicity taken from 2005 National Building Code (NBC).
2008	EGBC (then APEGBC) were engaged to further develop the technical guidelines.
2009	Screening assessment template created, and Seismic Risk Assessments (SRA's) performed in 2010.
2011	Seismic Retrofit Guidelines 1st Edition were released. Seismic Performance Analyzer Tool Introduced. Correlates to seismicity in NBC 2010. No significant increase in seismicity from 2005
2013	Seismic Retrofit Guidelines 2nd Edition. Correlates to seismicity in National Building Code 2010.
2017	Seismic Retrofit Guidelines 3rd Edition. Correlates to seismicity in National Building Code 2015. Significant increases in seismicity occurred for Vancouver Island. Guidelines moved from Design Based Drift Limits to Collapse Prevention Drift Limits.
2018	Seismicity expected to increase again with incoming NBC 2020. Introduction of SRA web-based tool. High risk schools on Vancouver Island evaluated. Created to determine impact of increased seismicity for Vancouver Island.
2020	Resiliency based High Risk Prioritization Procedure and applied to High-Risk Blocks.
2023	Seismic Retrofit Guidelines 4th Edition. Correlates to seismicity in National Building Code 2020 – Significant increase in seismicity on Vancouver Island for weak soils introduced.

RETROFIT PRIORITY RANKING

Since 2006 seismic risk has been categorized in terms of Retrofit Priority Ranking (RPR). This is illustrated in figure 1. The ranking is given in terms of Probability of Drift Exceedance PDE for a given LDRS prototype which is generated by the Seismic Performance Analyzer Tool.



Risk	Maximum PDE	Definition
High 1 (H1)	**> 10 %**	**Most vulnerable structure**; at highest risk of widespread damage or structural failure; not repairable after event
High 2 (H2)	**7% to 10 %**	**Vulnerable structure;** at high risk of widespread damage or structural failure; likely not repairable after event
High 3 (H3)	**5% to 7 %**	Isolated **failure of building elements** such as walls are expected; building likely not repairable after event
Medium (M)	**2% to 5 %**	Isolated **damage to building elements** is expected; non-structural elements (bookshelves, lighting, etc.) are at risk of failure
Low (L)	**< 2 %**	**Least vulnerable structure**; would experience isolated damage and would likely be repairable after an event

Figure 1: Illustration of Retrofit Priority Ranking based on probability of drift Exceedance for a given earthquake.

EXAMPLE PROJECT

We have chosen Cilaire Elementary School of the Nanaimo and Ladysmith School District recently completed in 2022. The school comprised three seismically high-risk blocks. A block is considered a seismically distinct area of the school building. Table 1 summarises the pre-retrofit conditions of the blocks in relation to the above ratings in figure 1. For the purposes of brevity, we have focused on Block 1, the Classroom Block to illustrate the SRG process and implementation over the past two decades. See figures 2 and 3.

Table 2. Block Summary

Block	Name	Area	Year	Floors	Construction Type	RPR
1	Classrooms	1739m^2	1966	3	Horizontal boards on walls and plywood diaphragms (unblocked) on suspended concrete slab with retrofit steel cross bracing. Third floor added in 1971.	H1
2	Gymnasium	416m^2	1971	2	Diagonal boards on walls and unblocked plywood diaphragm. Unreinforced masonry partition walls at one end. Gym built behind a retaining wall.	H1
3	Concrete changing rooms.	348m^2	1971	2	Reinforced concrete changing rooms comprising suspended roof slab. Slab partially supports administration space at second floor comprising horizontal boards on walls and plywood diaphragms (unblocked).	H3

Figure 2. Block 1 photo

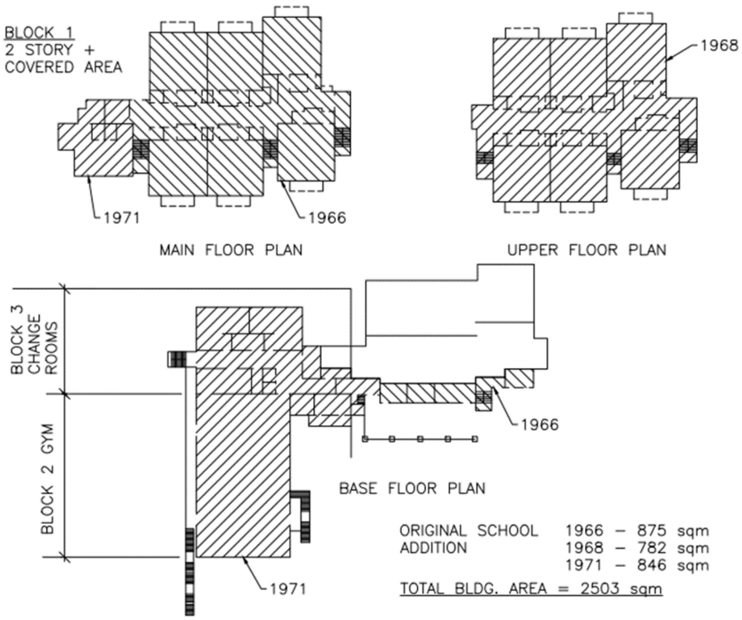


Figure 3 showing relationship between blocks. Taken from 2004 initial assessment.

EVALUATION HISTORY AND DEFICIENCIES

The Classroom Block has had a series of reviews since the 2004 initial assessment indicated in table 3 gives a brief history of the ratings of the block as seismicity and knowledge of the building expected performance improved.

Table 3. Evaluation History

Date	Comments	Rating
2004	Block rated based on force-based approach relative to the building code.	Medium/ High
2010	SRA completed to reflect SRG 1 and performance-based analysis.	Medium
2015	SRA updated to reflect SRG 2 and increased local seismicity.	H2
2016	Seismic Project Identification Report (SPIR) completed and reviewed including retrofit solution and costing.	H2
2018	Due to increases in seismicity on Vancouver Island because of work on the incoming NBC 2020, the school was reviewed again to confirm risk.	H1
2019	SPIR updated and project approved as part of the Seismic Mitigation Program.	H1

Risk Assessment Results (Box #5-1)

Principal Element	Prototype No.	Prototype Description	PDE	RPR(2)
LDRS	W4	Shiplap	19%	H1
LDRS	S3	Steel bracing	1.8%	Low
Roof Diaphragm	D2	19 mm plywood	2.5%	Medium
Floor diaphragm	D2	19 mm plywood	0.4%	Low
Out-of-Plane	OP3	Unreinforced masonry	1.3%	Low
		Maximum PDE / RPR	19%	H1
			Liquefaction Risk	Low
			Existing Block Retrofit Priority Ranking	H1

Note:

(1) RPR – Retrofit Priority Ranking

(2) Liquefaction is not assigned a PDE value. The RPR value is assigned for liquefaction on the following basis:

(a) H (High): significant risk of structural failure due to liquefaction movement

(b) L (Low): no significant risk of structural failure due to liquefaction movement

(3) Maximum assigned RPR for an out-of-plane element is H3 for non load-bearing walls and is not restricted for load-bearing walls.

(4) Diaphragms do not have an assigned RPR value (refer to Guidelines and Commentary).

Figure 4. Governing RPR ratings taken from 2019 SPIR.

SEISMIC RETROFITTING APPROVAL PROCESS

As the SRA designated the school as the highest rating H1, the Ministry of Education approved the development of a Seismic Project Identification Report (SPIR). The SPIR is a template-based document [2] for recording seismic risk and providing a schematic retrofit design suitable for a Class C cost estimate. It includes input from Architectural, Mechanical, Electrical and Geotechnical consultants and any Hazardous materials information the school district may have.

This SPIR forms a base seismic upgrade option for consideration in a Project Definition Report (PDR). The PDR [2] is a business case developed by the school district to determine the most appropriate capital planning solution for that school area. Options considered include seismic retrofitting but may also include school replacement, partial replacement, or relocation. At this stage the structural engineer addresses any additional risks that may not have been considered at the SPIR stage.

PROCUREMENT

In this case the PDR recommended that Cilaire Elementary School have a Seismic Retrofit and Mechanical Upgrade. These were combined into one project. Procurement was done under the Construction Management model to allow flexibility during construction. This was at the time of COVID 19, and so subcontractor procurement risk was assigned to the Construction Manager (CM) under the appropriate contract.

In this case school swing space was created in another school facility and so the school remained unoccupied during construction. Pre-construction services began in April 2021 and construction onsite commenced July 1st, 2021, and was completed August 31st, 2022. The project was completed on time and below budget.

SEISMIC RETROFITTING DESIGN DEVELOPMENT

The first SPIR for this Block was created in 2016 however an increase in seismicity (expected due to the incoming NBC2020 Code) led to the SPIR being updated in 2019. The scope of the seismic retrofit concept did not change however the risk rating for the school increased from a H2 to an H1. Figures 5 and 6 indicates the level of retrofit drawings required at the SPIR stage. The level of retrofit information at this stage is intended to be sufficient for a Class C Cost estimation. Figure 7 indicates the capacity demand ratio to be used in the retrofit design taken from the Seismic Performance Analyzer Tool.

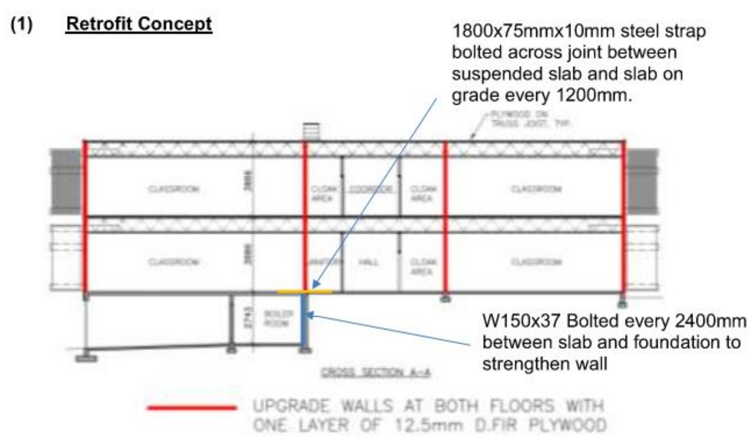


Figure 7.1: Foundation Layout

Figure 5, Section though Block 1

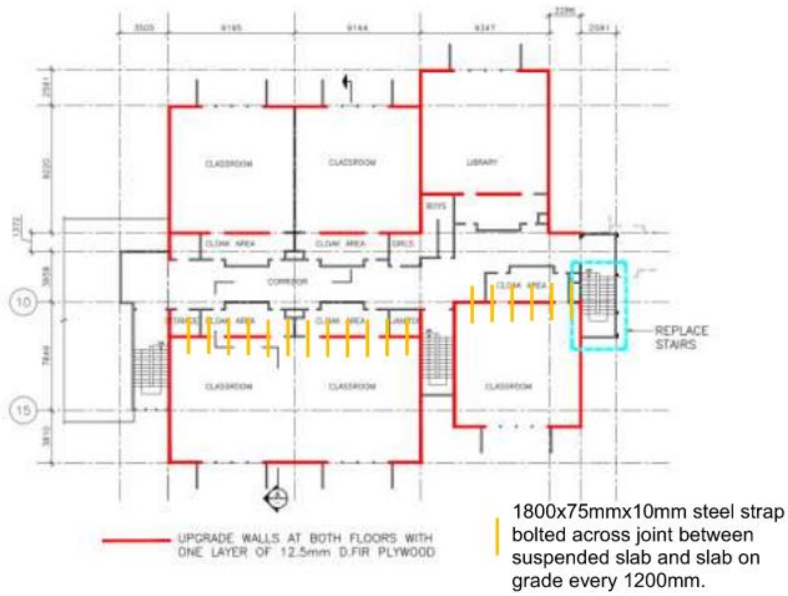


Figure 7.2: Floor Plan

Figure 6. Main level floor plan showing upgrade concept.

(2) Retrofit LDRSs

Number of Retrofit LDRS Prototypes (Box #7-2)

1

Retrofit LDRS Prototype Details (Box #7-3)

Shaking Direction	Prototype No.	LDRS Prototype Description	Max PDE	Max CDL	R_m
N/S/E/W	W2	Unblocked plywood	2%	2.0%	32.4%

Comments on Retrofit LDRS Prototypes (Box #7-4)

Perimeter strapping is required to improve chord performance of diaphragms. Upgrading the chords will reduce the RPR of the roof diaphragm to Low.

Apply 12.5mm plywood to all walls acting as shear walls and install straps between floors and anchor bolts and hold downs to foundations and suspended slab.

Figure 7 showing typical capacity demand ratio for retrofit solution taken from SPIR.

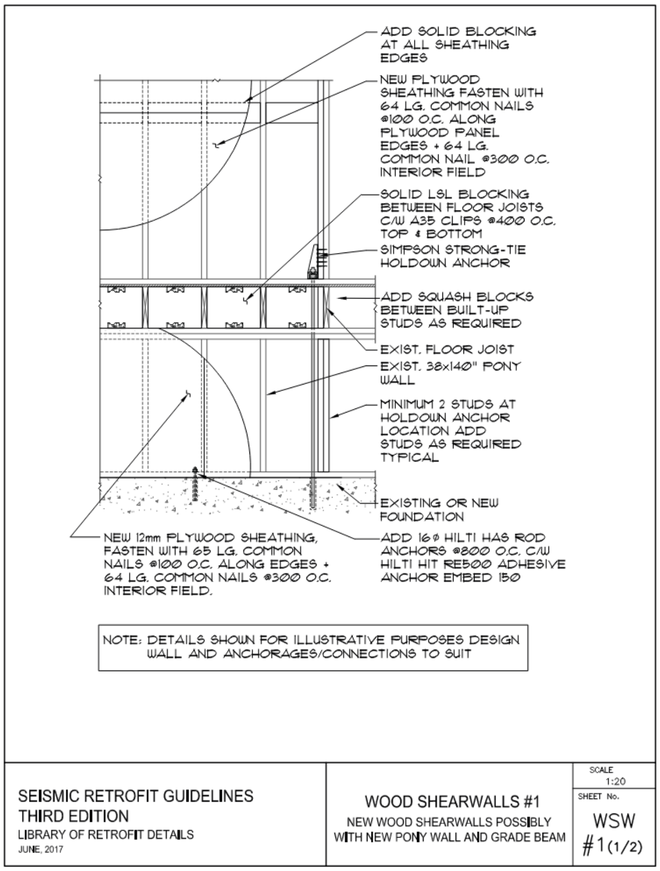


Figure 8 showing typical detail included in SPIR and taken from SRG Guidelines.

CHANGES FOR PDR AND DETAILED DESIGN

There were three main changes to the overall upgrading approach to this Block.

1. During the PDR process the decision was made to do the upgrade work from the interior of the school. This was done to avoid costly building envelope work. Blocked plywood prototype W1 were also selected not the original W2 unblocked prototypes.
2. The other significant change was to utilize the seismicity of the incoming NBC2020 Code. At this stage in 2020 the Analyzer Tool was not ready for general use and so the Engineer of Record had to work directly with UBC to get the necessary Capacity Demand Ratios. This required a Vs30 value for the local soils and so the geotechnical engineer needed to give a Vs30 for the soil previously noted as Site Class C. In this case the recommended value was 560m/s. This was given to UBC along with the prototype description and drift requirements. A capacity demand ratio was then provided to use in the retrofit design*.
3. The final change was to replace the steel bracing installed in 1999. The risk rating increased during the PDR process to medium and so the decision was made to replace the steel bracing with concrete shear walls rather than upgrade them.

*****(The Seismic Performance Analyzer Tool is now released and Vs30 values are required for all projects).

FINAL DESIGN AND IMPLEMENTATION EXAMPLES

Below are design details and project photos of their implementation. Figures 9 to 11.

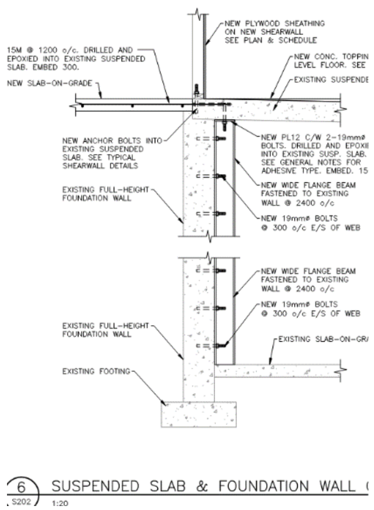


Figure 9, basement wall upgrade

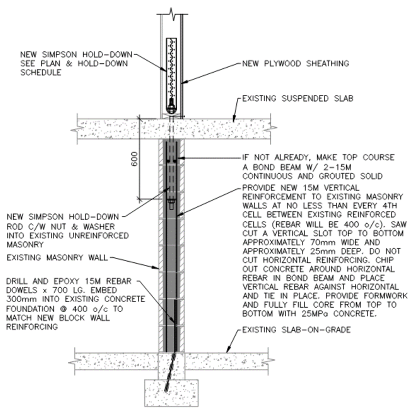


Figure 10, masonry wall upgrade for out of plane loading.

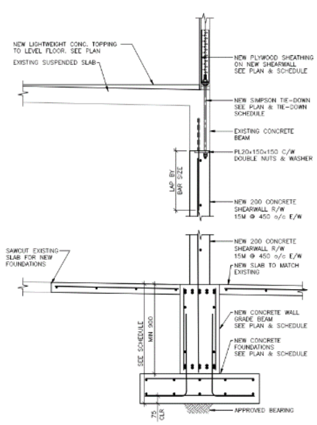


Figure 11, Concrete shear walls replacing steel braces.

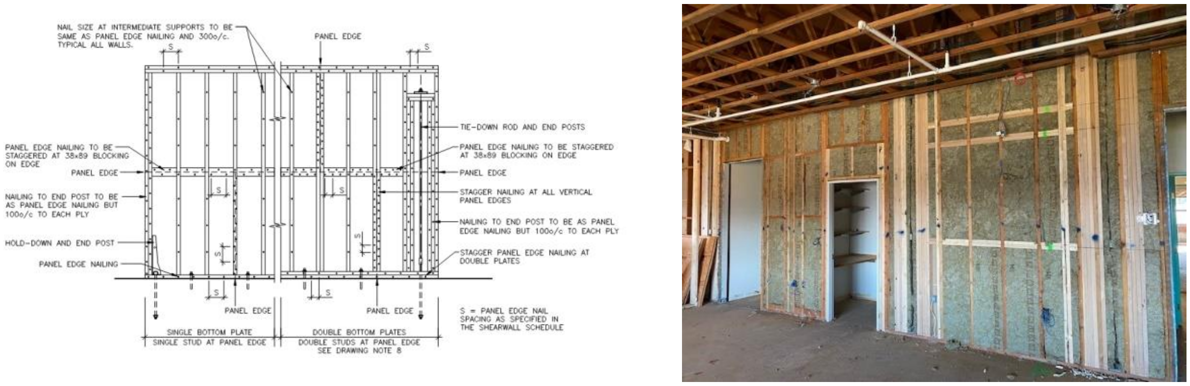


Figure 12, Shear wall details

OPERATIONAL AND FUNCTIONAL COMPONENTS (OFC's)

As part of the retrofit project the OFCs of the all the blocks were addressed and most of the hazardous materials removed. This is important, not only for life safety reasons but also for post earthquake occupancy to ensure hazardous materials have not been released. See next section.

POST EARTHQUAKE CONSIDERATION

The school district is one of the first organizations in Canada to have a PPR network. This network is based on a series of ground motion sensors installed in several school sites around the district. This network was created by Dr. Graham Taylor of TGB Seismic.

The sensors create a map of ground motions in the district. The expected performance of the building is compared to those ground motions and expected damage levels can be estimated. Thereby shortening the time taken to return to the building if the event shaking is below the thresholds given below.

The PPR threshold data for the three retrofitted Cilaire blocks is as follows:

(1) Block #1 – 1966 2 Storey Classrooms: 44%g/60%g

(2) Block #2 – Gym: 40%g/65%g

(3) Block #3 – Concrete Changerooms: 50%g/70%g

The listed thresholds are the Resilience Threshold (Sa(1.0)) and the Total Damage Threshold (Sa(1.0)) respectively. The maximum damage states for the thresholds are DS2/DS4 respectively. gives details of the expected damage states. See table 4.

The improved PPR thresholds for the retrofitted blocks are based on:

(1) Block #1: No hazmat in first storey and improved LDRS.

(2) Block #2: Improved roof diaphragm

(3) Block #3: Masonry wall reinforced; roof diaphragm upgraded.

Table 7.1: Damage States		
No.	**Damage State**	**Damage State Description**
1	DS1	• Minor damage • Repairs – lower cost, non-disruptive • Life Safe • PPR Green
2	DS2	• Moderate damage • Repairs – moderate cost, minor disruptions during operations • Life safe • PPR Green
3	DS3	• Heavy damage • Repairs – expensive, building closure for repairs • Potentially unsafe • PPR Yellow
4	DS4	• Total damage • Repairs – close to replacement cost (demolition possible) • Unsafe • PPR Red

Table 3, Damage States

CONCLUSIONS

SRG has a consistent core of performance-based analysis and design using the Seismic Performance Analyzer. The benefits and risks associated with this are significant. As seismicity changes, updating guidelines around risk assessment, retrofitting, and post earthquake are simplified and consistent. However, the risks associated with a single document and tool mean extensive peer reviewing is needed and performed. Figure 13 illustrates the SRG range of scope.

The project example clearly shows how the SRG was updated over the past 19 years and how resilient the process of evaluation and retrofitting were to those changes.

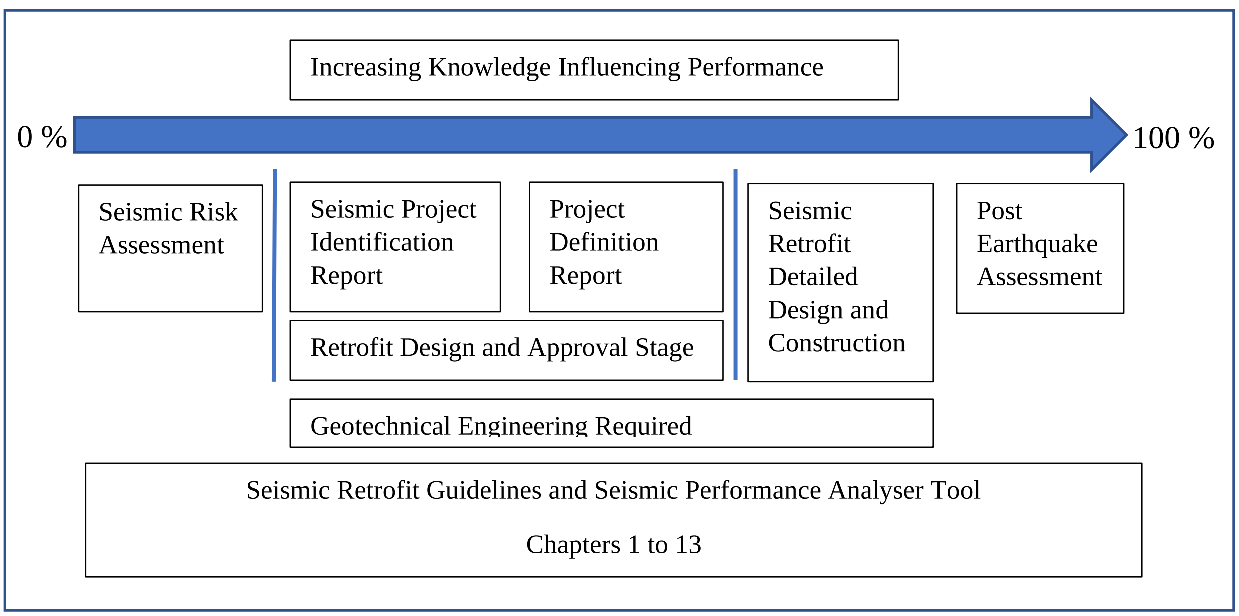


Figure 13, Chart showing relationship with SRG and project initiation through to post earthquake assessment.

ACKNOWLEDGEMENTS

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REFERENCES

[1] EGBC Seismic Retrofit Guidelines

[2] EGBC Seismic Project Identification Report Guidelines