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Safety Functions and Structural Design Requirements for Safety Significant Structures at the Savannah River Site

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Abstract

Structural design of DOE facilities for Natural Phenomena Hazards (NPH) is performed on the basis of their performance category (PC). The PC levels are traditionally related to the functional classification (FC) of systems, structures and components (SSC). For General Services and Production Support structures, requirements are driven to national building codes whereas for Safety Class structures the requirements are driven to national consensus nuclear codes. For Safety Significant SSC, however, the relationship between FC and PC of the structures can go either way. Current methodology often leads to adaptation of more conservative PC-level for some SS structures: PC-3 designs, which can be expensive and time consuming.

The objective of this work is to provide a rational framework to determine NPH structural requirements for DOE facilities and to make them consistent with the required Safety Functions of structures, and of SSC housed in the structure, and not just their FC. The Safety Functions, which must be determined in the course of safety analysis, for structures are Life Safety, Structural Interaction (seismic II/I), and Passive (building alone) or Active (building plus ventilation) Confinement, whereas those for systems and components are Position Retention, Pressure Boundary and Active Function.

Current Practice and Statement of Structural Problem

Typically for buildings and structures at DOE facilities, the natural phenomena hazards (NPH) design requirements[1,2] are derived directly from the Functional Classification (FC)[3], safety function (SF) and Performance Category (PC)[4] of the structure. Similarly the design requirements for structures may also be governed by the FC, SF or PC of structures, systems, and components (SSCs) that are housed or supported within the structure.

At SRS Functional Classifications are General Services (GS) and Production Support (PS) for facilities with minimal or no radiological hazard. Safety Significant (SS) and Safety Class (SC) facilities pose radiological hazard to the site population or the public.

The safety functions for the structure are life safety, seismic/structural interaction, and confinement. Confinement can be passive (the building structure alone) or the building structure with an active ventilation system (referenced to, hereafter, as “active confinement”). The SF for the systems and components are position retention, pressure boundary or active (operability) function.

For FC of General Services (GS) and Production Support (PS), which translate in PC levels of PC-1 and PC-2, respectively, NPH requirements are clearly and unambiguously governed by the national building code, IBC[5], to material codes such as ACI 318[6] for concrete and AISC 360[7] or equal for steel. Whereas for Safety Class (SC) structures, the requirements are governed by national consensus nuclear codes such as ACI 349[8] for concrete and AISC N690[9] or equal for steel.

When the radiological hazard impacts only the site population, the FC is safety significant. However, for SS the relationship between FC and the PC level is ill defined in the standards and design has specific choices to make that may not be clear to the structural engineer. For Safety Significant SSC, the standards identify meeting PC-2 requirements without any further guidance on meeting the function and therefore are frequently designed to building code requirements (IBC, etc.) and as such receive minimal seismic design emphasis. If more stringent functional requirements are placed on SS SSCs, current practice often leads to adaptation of more conservative PC-level for some SS structures: namely to PC-3 analysis and designs, which can be expensive and time consuming.

The issue here is that little or no guidance has been provided to link definitions of PC-2 and PC-3 to the safety functions that they are required to support. For example, for SS, the radiological or chemical consequence to the collocated worker, which is Worker Group 3 in accordance with SRS E7 Manual[3], could be significant and could exceed the high hazard threshold mentioned in DOE G 420.1-2[10]. Thus a category of building structures may be recognized which may have a Safety Significant (SS) function of supporting SS or Safety Class (SC) systems and components with pressure boundary integrity, or of housing or supporting systems and components with an SS or SC active safety function. For such structures, especially when there is a potential of challenging or exceeding "high hazard" consequence for the worker[10], it is intended that the structure be analyzed and qualified for earthquake requirements higher than PC-2 level, approaching the PC-3 level, but not mandatorily implementing the rigor of a full blown PC-3 seismic analysis.

There are four primary differences between PC-2 and PC-3 seismic analyses:

- Seismic Forces – Seismic demand forces are greatly reduced, PC-2 versus PC-3
- Soil Structure Interaction (SSI) – SSI is not mandated in PC-2
- Dynamic Settlement – Seismically induced settlement is not required for PC-2
- Instructure Response Spectra (IRS) – Building codes used in PC-2 provide for simple static coefficient method which can be grossly conservative or unconservative

Objective and Methodology

The objective of this work is to make the determination of NPH structural requirements for SS DOE facilities more rational and to make it consistent with the required Safety Functions (SF) of structures, and of systems and components housed in the structure, and not just their FC.

Where radiological or chemical consequence to collocated workers, is significant, the SS structure is deemed to be able to resist PC-3 loads without failure. In order to achieve that objective, cost effective methodologies referred to as “Enhanced PC-2” and “Simplified PC-3”, are developed taking into account the experience data at Savannah River Site.

The development of these methods is based on identifying what is significant. Thus, for seismic design, the important considerations are seismic forces, soil-structure interaction (SSI), instructure response spectra (IRS), and post-seismic differential settlement. Each of these is addressed and resolved in a cost effective manner without compromising safety.

Enhanced PC-2

The enhanced PC-2 method consists of upgrading the PC-2 IBC seismic analysis to limit the Response Modification Coefficient, R, value for structures to F• values (as defined in Reference 2). It also consists of providing bounding values for the peak Instructure Response Spectra (IRS) spectral acceleration, as a function of the height above base, based on prior SSI analyses of selected building structures at SRS, as discussed before.

This has the benefit of reduced work (shorter schedule) at the cost of somewhat more conservative results.

Seismic Forces

Adequacy of PC-2 seismic forces is based on the fact that 1.5 times PC-1 SRS site specific input spectra envelop the SRS site specific PC-3 input spectra. Response Modification Coefficient, R, as allowed by IBC, is limited, not to exceed the F. (as defined in Reference 2) values of PC-3 structures.

Soil Structure Interaction (SSI) and Instructure Response Spectra (IRS)

An engineering calculation[11] was performed to obtain bounding peak spectral accelerations for the IRS for typical PC-3 concrete building structures at SRS that have been analyzed in the past using soil structure interaction (SSI) methodology with time history analyses, and to make recommendations for the IRS peak accelerations for 5 percent damping level, identifying the limitations clearly.

The calculation[11] provides bounding peak accelerations for the analysis, design and evaluation of systems and components, short of going through the SSI analysis of the individual facility. The methodology enables structural analyst to provide a conservative PC-3 input for the design of systems and components without going through the cost of PC-3 seismic analysis of SS building structures.

IRS Results[11]

The ratio of IRS peak spectral acceleration for 5 percent damping level at various elevations to the peak of the input spectra are plotted for heights up to about 65 feet. The height factor is a normalized height parameter varying from 0 to 1.0, and is taken as the ratio of the height at a given elevation to the height of the building or structure or 65 feet, whichever is lower. That is, for building structures in excess of 65 feet height, IRS only up to about 65 feet height is considered. It is recognized that in this methodology, building structures shorter than 65 feet are penalized with a higher recommended peak IRS spectral acceleration.

Peak spectral accelerations for 5 percent damping level are provided as a factor times the peak input acceleration because the selected structures were analyzed for different input spectra, as applicable. The factor of 1.2 required for PC-3 seismic design of new structures given in Revision 7 of SRS Engineering Standard 01060[8] shall be included in determining the peak input acceleration, if applicable.

Based on the results of the past SSI time history analyses of selected PC-3 concrete building structures at SRS, it is recommended that the peak Instructure Response Spectra (IRS) spectral accelerations for 5 percent damping level, for elevations up to 65 feet height from the base of the structure, may be taken as (2.0 x S_{DS}) at the base linearly increasing to (5.5 x S_{DS}) at the top of the structure or at 65 feet height, whichever is lower, where S_{DS} is the peak input acceleration, as shown in Figure 1. The recommendation is applicable to concrete buildings at SRS that are partially or fully underground, or completely above ground.

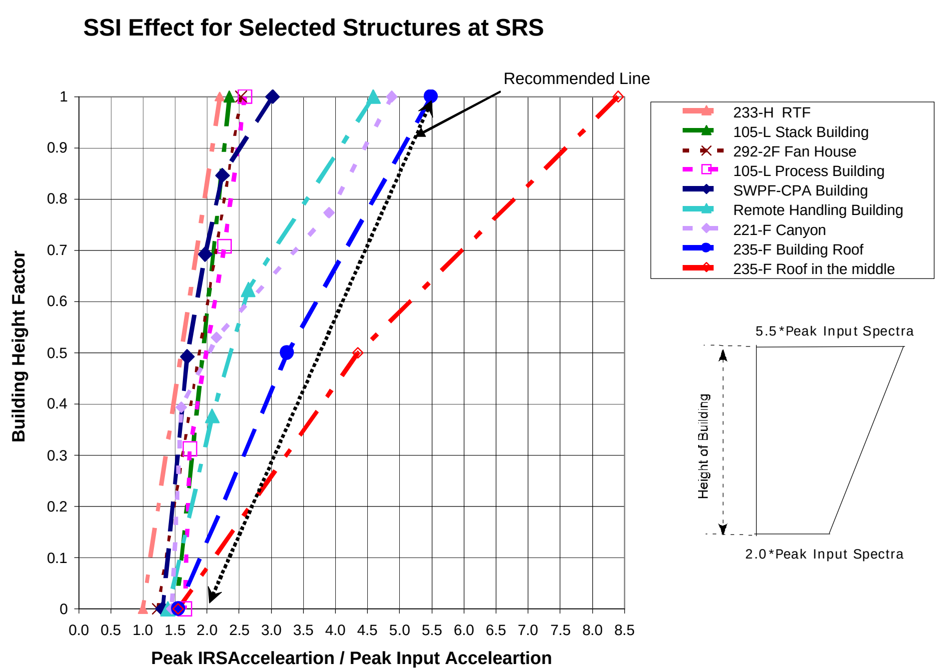

Figure 1 (Peak IRS Acceleration/Peak Input Acceleration) through Building Height for Selected SRS Building Structures.

Based on results of the same analyses, ratios of peak IRS spectral accelerations at 2 and 10 percent damping levels to the peak IRS spectral acceleration at 5 percent damping level of 2.0 and 0.80, respectively, are recommended[11].

Post-Seismic Differential Settlements

Based on the experience data, it is observed that cast-in-place concrete and structural steel building structures designed to PC-3 seismic loads and detailed to current codes can accommodate post seismic differential settlements at SRS. Hence facility specific foundation settlements required for PC-3 structures in SRS Engineering Standard 01060 are not required even though systems and components may be PC-3 with FC of SC, or FC of SS safety function of pressure boundary or active function.

Simplified PC-3

This approach is less time consuming than "full blown" PC-3 analysis and results in less conservative design than "Enhanced PC-2" approach but more conservative design than a full blown PC-3 approach. The Simplified PC-3 approach provides the assurance that the safety function can be performed.

The simplified PC-3 seismic analysis methodology is used with the clarification and simplification as follows:

Seismic Forces

Seismic forces are consistent with SC/PC-3 analysis. F. values (as defined in Reference 2) are used.

Soil Structure Interaction (SSI) and Instructure Response Spectra (IRS)

The SSI analysis is permitted to be based on a single stick or multistick model with spring and dashpot values obtained from the building geometry and Best Estimate (BE) soil properties, obtained from one of the existing Geotechnical Reports for the area of interest, if available. Alternatively Geotechnical Engineering may provide average/BE soil properties for the area without field testing. Hence project or facility specific soil profile and properties normally required for PC-3 structures in accordance with SRS Engineering Standard 01060 are not required for this alternate.

IRS are obtained consistent with SC/PC-3 analysis.

Post-Seismic Differential Settlements

For the same logic as provided in "Enhanced PC-2", dynamic settlement need not be considered.

Safety Input to Structural Requirements Matrix

An input matrix identifying possible Safety Functions (SF) of structures, and of structures, systems and components (SSCs) housed in the structure is developed. As noted earlier NPH safety functions must address the role of the building structure (and its confinement function) as well as the safety function of the SSCs within the facility. These two drivers provide the key inputs to the specific structural requirements and the required analyses. Therefore, they are the key drivers for the Structural Requirements Matrix developed for the engineering standard. A structured process of arriving at the NPH structural requirements for the structure for possible combinations of SF is summarized in a Structural Requirements Design Matrix incorporated into SRS Engineering Standard on Structural Design Criteria[12].

A portion of the Structural Requirements Matrix[12] is provided in Table 1. It provides building/structure design requirements considering both the FC and safety function (SF) of the building/structure, and the FC and SF of the SSC within the structure, as well as the unmitigated exposure consequences for the collocated worker (Worker Group 3, in accordance with SRS Manual E-7, Procedure 2.25[3]).

Information in row numbers 1 through 4 and 10 in the Structural Requirements Matrix is the input to the determination of design requirements for structures. The input is obtained from design criteria documents including but not limited to the Functional Classification Report and the Consolidated Hazard Analysis Process (CHAP) Report. The remaining rows, 5 through 9, provide the acceptable alternatives for the NPH design of structures. Decisions on which alternative to utilize for a specific application are made during the course of analysis and design of the structure.

The process can also be explained through flow charts (as provided in Appendix A).

Table 1 Structural Requirements Matrix.

<u>Input: Functional Classification and Safety Function of SSCs</u>

			1	2	3	4	5	6	7	8	9
1	**Worker Group 3 Exposure •**		**Worker Group 3 exposure not significant (A)**			**Worker Group 3 exposure is significant (B)**			**(B or C)**	**Safety Class SSC or Worker Group 3 exposure • "High Hazard" Criteria (C)**	
2	FC of Structure for NPH (UNO) •		GS or PS	GS or PS	SS or SC (not for NPH)	SS	SS	SS	GS, PS or SS	SS or SC	SS or SC
3	Building/ Structure Safety Function, •		Life Safety or Structural Interaction, no confinement, and •	Life Safety or Structural Interaction, no confinement, and •	Life Safety or Structural Interaction, no confinement, and •	Life Safety or Structural Interaction, no confinement, and •	Building confinement with active ventilation system, and •	Building Passive Confinement, and •	Life Safety or Structural Interaction, No confinement, and •	Building confinement with active ventilation system, and •	Building Passive Confinement, and •
4	Highest FC for NPH (UNO) of systems and components inside building that could be damaged by building failure, and safety function•		GS or PS	SS (for Worker Groups 1&2), Safety functions of Position Retention, Pressure Boundary or Active Function (operability)	All FC (but N/R for NPH events)	SS, Safety function of Position Retention	SS or SC, Safety functions of Position Retention, Pressure Boundary or Active Function (SS Ventilation & Power system)	SS or SC, Safety functions of Position Retention, Pressure Boundary or Active Function	SS or SC, Safety function of Position Retention, Pressure Boundary or Active Function (systems and components provide confinement)	SS or SC, Safety functions of Position Retention, Pressure Boundary or Active Function (Ventilation & Power Systems)	SS or SC, Safety functions of Position Retention, Pressure Boundary or Active Function

<u>Notes:</u>

(A) When unmitigated exposure consequence resulting from NPH event is not significant for Worker Group 3, i.e., the collocated worker, defined in E7, Procedure 2.25.
(B) When unmitigated exposure consequence resulting from NPH event is significant for Worker Group 3, i.e., the collocated worker, defined in E7, Procedure 2.25.
(C) When unmitigated exposure consequence resulting from NPH event exceeds a "High Hazard" criteria for Worker Group 3, i.e., the collocated worker, defined in E7, Procedure 2.25.

			1	2	3	4	5	6	7	8	9
	Worker Group 3 Exposure•		**Worker Group 3 exposure not significant (A)**			**Worker Group 3 exposure is significant (B)**			**(B or C)**	**Safety Class SSC or Worker Group 3 exposure • "High Hazard" Criteria (C)**	
5	Seismic Forces		IBC @ PC of highest SSC, GS: I = 1 PS: I = 1.0 or = 1.5	IBC, PC-2 I = 1.5	IBC, I = 1	IBC, PC-2 I = 1.5	enhanced PC-2: IBC, I = 1.5; Or PC-2 with R per IBC and calculated Leak Path Factor; Or simplified PC-3	enhanced PC-2: IBC, I = 1.5; Or PC-2 with R per IBC and LPF; Or simplified PC-3	enhanced PC-2: IBC, I = 1.5; Or Simplified PC-3	PC-3 and ventilation w/calculated Leak Path Factor	PC-3, Confinement through PC-3 requirements with additional leak tightness detailing
6	Soil Structure Interaction		Not Required (NR)	NR	NR	NR	enhanced PC-2; Or simplified PC-3	enhanced PC-2; Or simplified PC-3	enhanced PC-2; Or simplified PC-3	PC-3	PC-3
7	Instructure Response Spectra (IRS)		NR	NR	NR	NR	enhanced PC-2; Or simplified PC-3; Or NR if SSC GS/PS	Enhanced PC-2; Or Simplified PC-3; Or NR if SSC GS/PS	Enhanced PC-2, Or simplified PC-3; Or NR if SSC GS/PS	PC-3	PC-3
8	Post-Seismic Differential Settlement		NR	NR	NR	NR	NR	NR	NR	PC-3	PC-3
9	Wind		IBC @ PC of highest SSC	IBC: 100 mph with I = 1.15	IBC: 100 mph with I = 1	IBC: 100 mph with I = 1.15	IBC @ highest FC of SSC: SS = 100 mph with I = 1.15, SC = 133 mph			PC-3	PC-3
10	Tornado		NR	NR	NR	HA	For SC or Per Hazard Analysis (HA)		HA	HA	HA

Benefit to Others

The SRS experience suggests that a more structured process of arriving at NPH structural design requirements for DOE facilities, especially for Safety Significant (SS) structures, based on the required Safety Functions (SF) of structures and of SSCs housed in the structure can be developed and implemented. The site specific approach could make structural designs more cost effective, especially for SS structures, without compromising safety. Structures should be designed only for what is required for their Safety Functions.

The suggested process identifies the level of detail the safety analyses need to go into, namely the Safety Functions of the structure and of SSCs housed in the structure, so that NPH structural requirements can be determined.

References

1. DOE Order, O 420.1B, "Facility Safety," (2005).
2. DOE-STD-1020-2002, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities," (2002).
3. SRS E7 Manual, Procedure 2.25, "Functional Classifications," Revision 15 (TBD).
4. DOE-STD-1021-93, "NPH Performance Categorization Guidelines for Structures, Systems, and Components," Change Notice 1, (1996), (Reaffirmed 2002).
5. International Code Council (ICC), "International Building Code (IBC)," (2003).
6. American Concrete Institute, ACI 318-05, "Building Code Requirements for Structural Concrete," (2005).
7. American Institute of Steel Construction, ANSI/AISC 360-05, "Specification for Structural Steel Buildings," (2005).
8. American Concrete Institute, ACI 349-01, "Code Requirements for Nuclear Safety Related Concrete Structures," (2001).
9. American Institute of Steel Construction, ANSI/AISC N690-1994, "Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities," Supplement No. 2 (2004).
10. DOE Guide, G 420.1-2, "Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities," (2000).
11. SRS Engineering Calculation, T-CLC-G-00257, "Recommended Peak IRS Spectral Accelerations for PC-3 Concrete Structures at SRS," (2005).
12. SRS Engineering Standard, 01060, "Structural Design Criteria," Revision 8 (2006).

Appendix A
Logic Flow Diagram

On Figure 2

The new approach being taken at Savannah River Site for design requirements of SSCs consists of:

- Determine if consequence to collocated worker is “significant”.

If the consequence to collocated worker is not significant then the functional classification of all SSC is GS or PS, and the SSCs may be designed with the International Building Code (IBC) requirements for PC-1 or PC-2.

- Determine if consequence to collocated worker is greater than significant or has “high hazard”.

If the consequence to collocated worker is high hazard, then the following line of thought process is essential:

- Is confinement provided through Systems and Components or through Building structure?

If confinement is provided through Systems or Components then two alternatives are available for evaluation and qualification of SSC: Enhanced PC-2 or Simplified PC-3.

Is confinement is provided through the Building structure then the question is:

- Does the Building safety function require passive confinement system?

If the Building safety function requires passive confinement system, then the building not only needs to be designed for PC-3 requirements but also needs to be detailed for leak tightness given in 5.3.6 of SRS Engineering Standard 01060 and/or of ACI 350.

If the Building confinement safety function requires active ventilation system, then the building not only needs to be designed for PC-3 requirements but leak path factor (LPF) determination shall be based on explicit quantitative evaluation of potential openings in the external structural envelope from penetrations, doors, and through cracks, if any, in concrete, to allow design ventilation system to maintain the desired negative pressure.

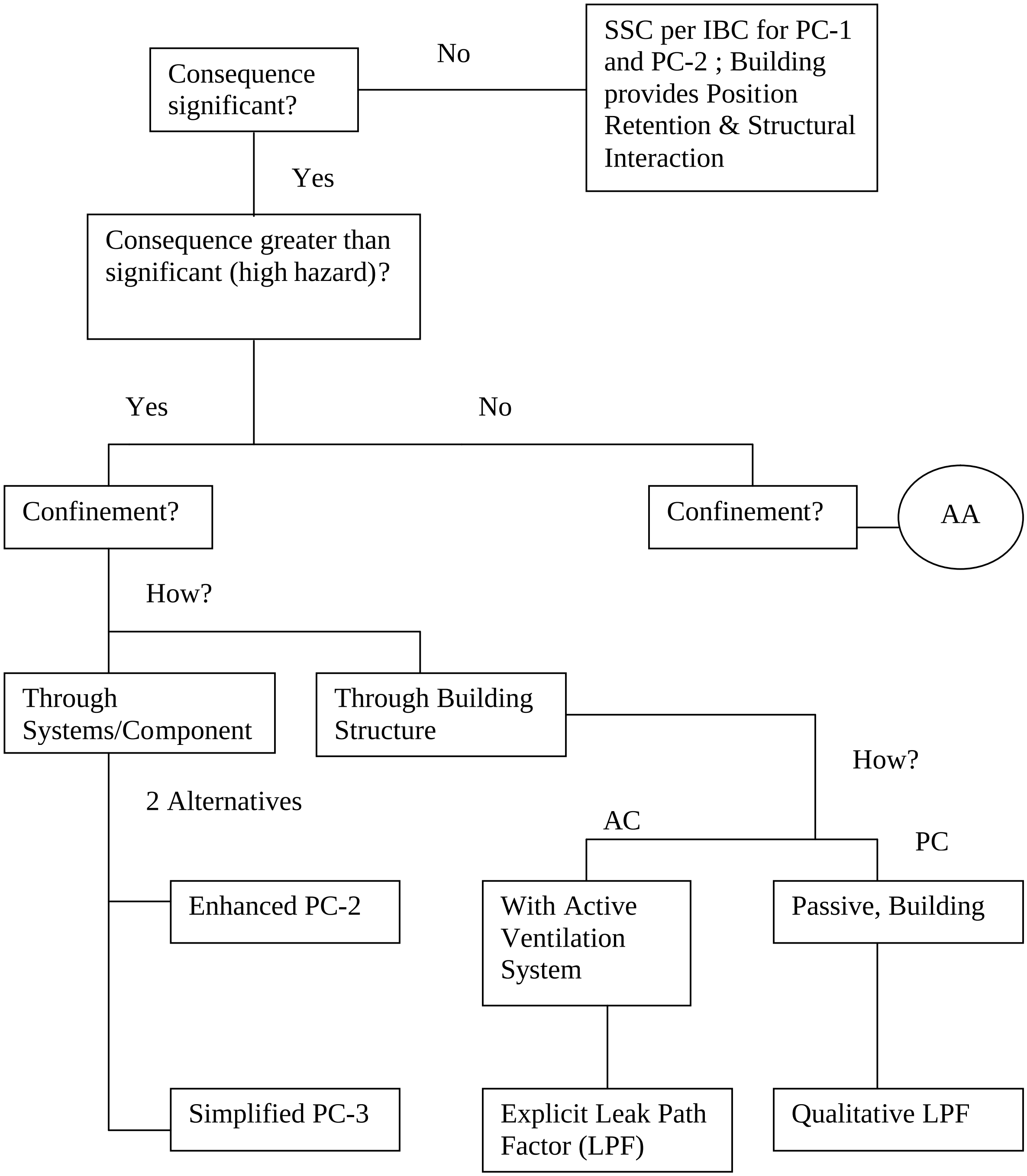

Figure 2 Flow Diagram for Methodology for SSC Evaluation and Qualification.

On Figure 3

When the consequence is significant but not high hazard:

- Determine if confinement is required.

If confinement is not required as a safety function then the functional classification of all SSC is GS or PS, and the SSCs may be designed with the International Building Code (IBC) requirements for PC-1 or PC-2. The structure provides only for Position Retention and Structural Interaction.

- Does the Building safety function require passive confinement system?

If confinement is provided through passive Building structure then three alternatives are available for evaluation and qualification of SSC: IBC PC-2 with qualitative LPF, Enhanced PC-2 or Simplified PC-3.

If confinement is provided through active ventilation system then three alternatives are available for evaluation and qualification of SSC: IBC PC-2 with explicit LPF, Enhanced PC-2 or Simplified PC-3.

Consequence greater than significant but not high hazard:

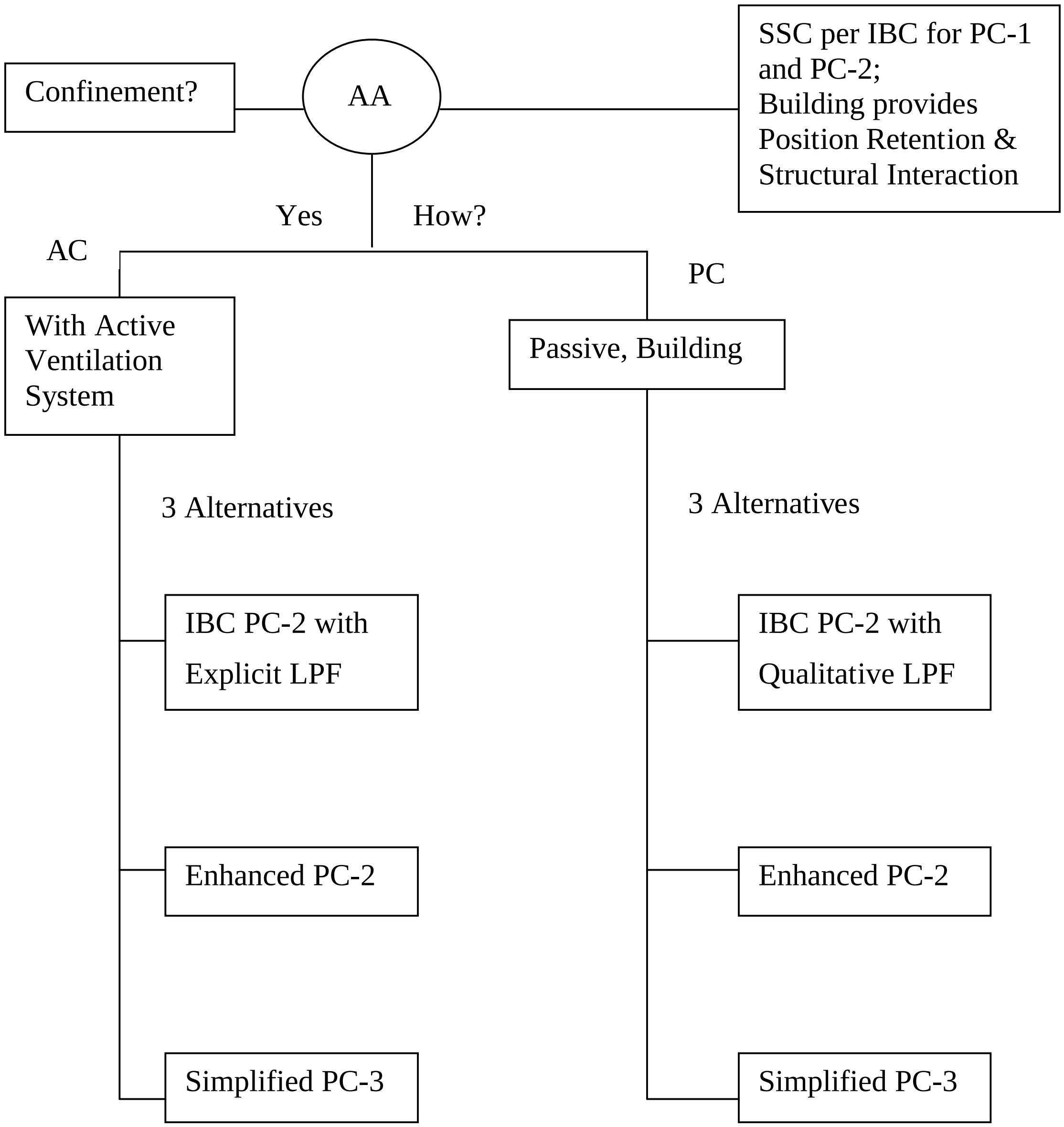

Figure 3 Flow Diagram for Methodology for SSC Evaluation and Qualification, contd.