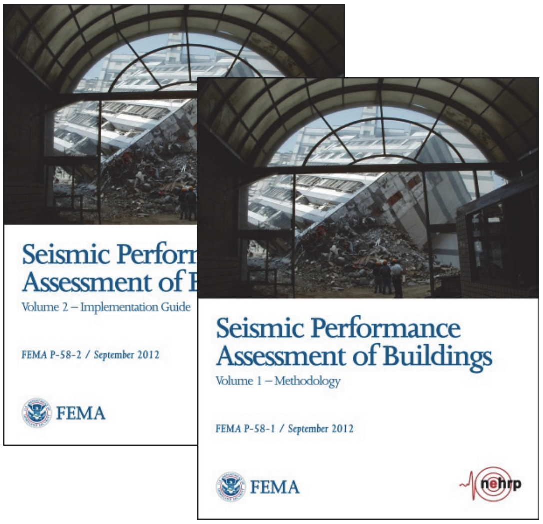

Background Document

FEMA P-58/BD-3.7.18

Nonstructural and Non-Modeled Structural Stiffness

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Background Documentation

FEMA P-58 Background Documents are a series of reports documenting the technical background and source information for key aspects of the FEMA P-58 methodology and its implementation. This report was developed over the course of the 5-year ATC-58-2 Project funded under FEMA Contract HSFE60-12-C-0243.

Background Documents were developed by consultants, serving at various levels within the project hierarchy, reporting the results of: (1) decisions on technical development protocols; (2) focused studies on the development of key aspects of the methodology; (3) documentation of recommended procedures; and (4) collection of available data for the development of structural and nonstructural fragilities. They were initially intended to serve as a record of the technical state-of-knowledge at the time they were produced, and as resources for the development of the eventual project reports. As such, they represent a snapshot in time, and may, or may not, match the technical content, recommended procedures, or data incorporated into the final methodology and its implementation.

This Background Document is intended for the purpose of providing supplemental knowledge to users of the FEMA P-58 methodology. Information contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology. Specifically in the case of certain nonstructural component fragilities, the NISTIR fragility classification numbering scheme was modified over the course of the project, and the fragility classification number assigned in this document might be different from numbers assigned in the final fragility database. Users of information in this document assume all liability arising from such use.

Notice

Cover photograph – Collapsed building viewed through the archway of an adjacent building, 1999 Chi-Chi, Taiwan earthquake (courtesy of Farzad Naeim, Farzad Naeim, Inc).

NONSTRUCTURAL AND NON-MODELED STRUCTURAL STIFFNESS

Introduction

In structural analysis and design, it is a common practice among engineers to make a "bare-frame" model of a building to estimate the response and behavior of that building to seismic events. Using the bare frame model, the structural stiffness and strength of the building will only depend on elements of the lateral force resisting system. The lateral stiffness coming from components of the gravity system and nonstructural components are ignored in these bare frame models. This is considered acceptable in the engineering community because the structural responses will be slightly over predicted and therefor the designs will have embedded conservatism. But the goals of building specific seismic risk assessment differ from those of traditional design; to more accurately understand and predict risk, conservatisms must be removed. This study aims to observe the effect that modeling structural components, the gravity system, and nonstructural components has on seismic loss predictions using the FEMA P-58 Methodology.

1. Methodology

A complete loss analysis was performed on several reinforced concrete and steel special moment frame buildings using the Seismic Performance Prediction Program (SP3) which implements a FEMA P-58 analysis through a web based interface. An outline of the models that were analyzed can be seen in Table 1. A variable amount of additional components were included for each baseline model analyzed. These additional components that were modeled include; additional structural elements, gravity system, and nonstructural components that contribute to building stiffness.

Table 1 - Overview of models assessed in study

Building ID	Building Type	SDC	Occupancy Type	Number of Stories	Additional Stiffness Modeling	Fundamental Period (s)
C401	RC SMF	D_{max}	Office	4	Bare Frame	1.7
C402					+Str[1]	1.12
C403					+Str,+Grav[2]	0.96
C404					+Str,+Grav,+NS[3]	0.92
C801				8	Bare Frame	2.23
C802					+Str	1.71
C803					+Str,+Grav	1.51
C804					+Str,+Grav,+NS	1.43
C1201				12	Bare Frame	2.65
C1202					+Str	2.01
C1203					+Str,+Grav	1.78
C1204					+Str,+Grav,+NS	1.7

Table 1 - Overview of models assessed in study (continued)

Building ID	Building Type	SDC	Occupancy Type	Number of Stories	Additional Stiffness Modeling	Fundamental Period (s)
S402	Steel SMF	D_{max}	Office	4	+Str	1.62
S403					+Str,+Grav	1.3
S404					+Str,+Grav,+NS	1.04
S802				8	+Str	2.29
S803					+Str,+Grav	1.92
S804					+Str,+Grav,+NS	1.62
S1202				12	+Str	3.12
S1203					+Str,+Grav	2.71
S1204					+Str,+Grav,+NS	2.3

[1] *+Str includes non-modeled structural stiffness from elements like finite joints and beam-slabs.*
[2] *+ Grav includes gravity system effects on overall structural stiffness*
[3] *+ NS includes nonstructural component stiffness effects of on overall structural stiffness*

For each variation of the models, stiffness matrices were created that accounted for each contributing component modeled. Using an eigenvalue analysis, the fundamental building period was then calculated for each model. That period was used to estimate structural response of each model using the FEMA P-58 Simplified Method. Using the estimated structural responses along with normative component quantities, loss assessment models were created and analyzed using FEMA P-58.

1.1 Modeling of Additional Structural Elements

When creating a model of a structural system, many engineers will create a “bare-frame” model of the lateral force resisting system of the structure. However that bare frame model will sometimes fail to account for details that effect the overall stiffness, response, and behavior of the lateral frame. This study investigates the effect of modeling finite joint sizes (rather than a centerline model) and the stiffening effects that the slab has on the lateral beams. These were only investigated for the reinforced concrete models since the “bare-frame” models of the steel buildings already considered the effects of finite joint and beam slab elements.

1.2 Modeling of the Gravity System

For the concrete moment frame models, an 8 inch reinforced concrete flat slab was used as the gravity system. The stiffness contribution from the gravity system was calculated at each story and then combined with the structural stiffness matrix that was used to estimate the fundamental building period.

For the steel moment frame models, a modification factor that accounted for the assumed stiffness of the gravity system was applied to the bare frame fundamental period. This period modification factor was calibrated based on the steel models analyzed in the ATC 63-2/3 study.

1.3 Modeling Contributions of Nonstructural Components

To investigate the effects that the nonstructural components within the building have on the overall stiffness and response behavior of the building, stiffness models were developed for each component within the structure. The stiffness model for each component was calibrated based on hysteretic data from fragility testing available in the FEMA P-58 documentation. Figure 1 shows the estimated stiffness model for each component assumed to contribute to the overall building stiffness in this study.

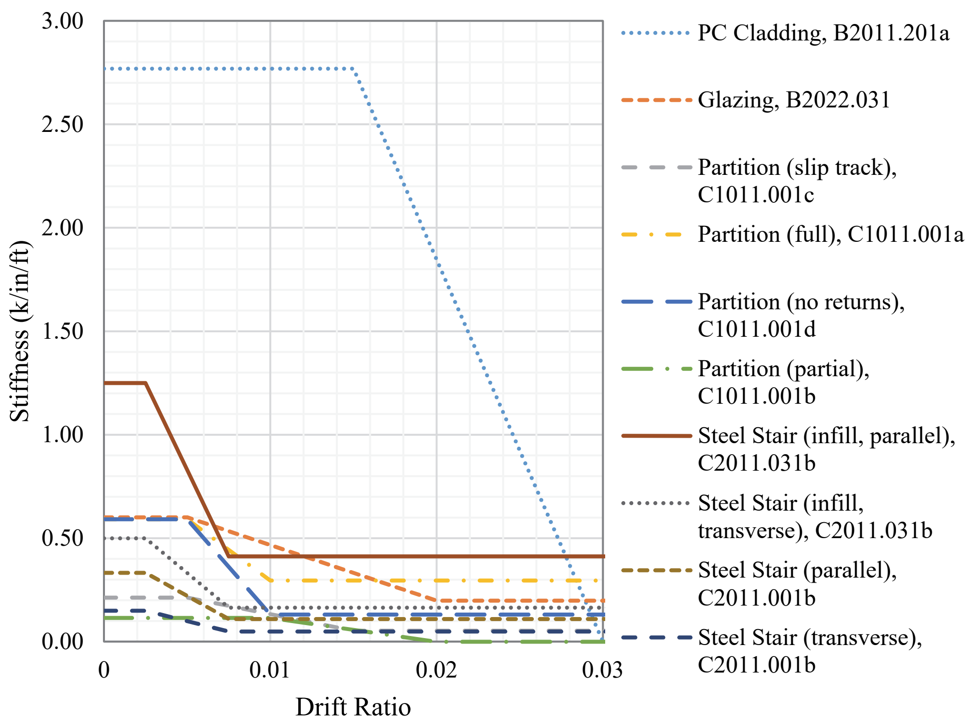

Figure 1 - Stiffness models for each component contributing to stiffness. Models are normalized by each foot of component length within the story.

Each component stiffness model is a function of the drift ratio to which the component is subjected to account for the stiffness degradation of the component as it is damaged. In turn this effect will cause an elongation of the fundamental building period of the model as the ground motion intensity increases and the structure is damaged.

To account for the stiffness contributions from nonstructural components the global stiffness matrix, including nonstructural components, was calculated individually for each ground motion intensity that was assessed in the FEMA P-58 analysis. The effect on damping from nonstructural components was not considered in this study.

2. Comparison of Results

To compare the effects of additional stiffness modeling on overall seismic risk, the average monetary loss (as a ratio to the total building value) was compared for each variation of the baseline models. Figure 2 and Table 2 shows how the probable loss is affected by the building stiffness across many levels of ground motion intensity.

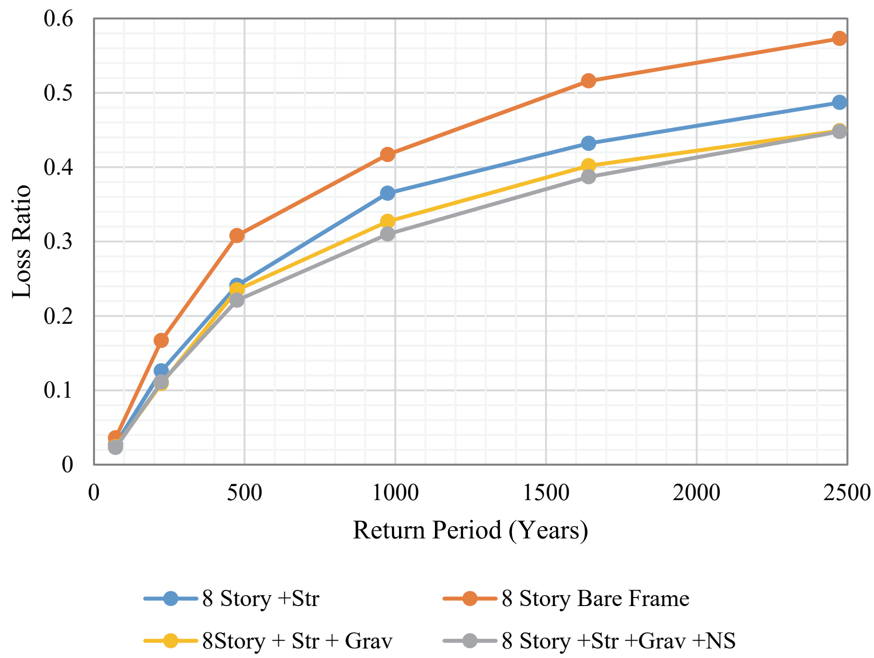

Figure 2 - FEMA P-58 Loss Results for 8 Story RC SMF variations

Table 2 – FEMA P-58 Loss results for all models analyzed

Building ID	Number of Stories	Fundamental Period (s)	50 in 50 Loss Ratio	10 in 50 Loss Ratio	2 in 50 Loss Ratio
C401	4	1.7	0.09	0.43	0.63
C402		1.12	0.04	0.27	0.51
C403		0.96	0.02	0.21	0.45
C404		0.92	0.02	0.21	0.45
C801	8	2.23	0.04	0.31	0.57
C802		1.71	0.03	0.24	0.49
C803		1.51	0.02	0.24	0.45
C804		1.43	0.02	0.22	0.45
C1201	12	2.65	0.02	0.15	0.33
C1202		2.01	0.02	0.11	0.28
C1203		1.78	0.01	0.10	0.26
C1204		1.7	0.02	0.11	0.26

Table 2 – FEMA P-58 Loss results for all models analyzed (continued)

Building ID	Number of Stories	Fundamental Period (s)	50 in 50 Loss Ratio	10 in 50 Loss Ratio	2 in 50 Loss Ratio
S402	4	1.62	0.05	0.34	0.69
S403		1.3	0.03	0.26	0.56
S404		1.04	0.02	0.23	0.55
S802	8	2.29	0.02	0.20	0.41
S803		1.92	0.02	0.15	0.33
S804		1.62	0.02	0.13	0.32
S1202	12	3.12	0.01	0.08	0.21
S1203		2.71	0.01	0.09	0.20
S1204		2.3	0.01	0.08	0.19

Without exception, the models that include stiffness from the additional structural components and the modeling of the gravity system perform significantly better at the higher intensity seismic events than there counterpart “bare frame” models. However the addition of the stiffness contribution from nonstructural elements does little to increase the seismic performance of the models compared to the additional structural and gravity contributions.

3. Summary of Findings

The results of this study indicate that both modeling details and assumptions of the structural system and the stiffness contributions of the gravity system have a significant effect on the predicted loss for a moment frame building based on seismic risk assessment. However no significant change in predicted loss was measured upon the inclusion of nonstructural components in the models. Based upon this study it is recommended that when performing a FEMA P-58 seismic risk assessment one of two methods be used to more completely represent a building including structural details and non-LRFD components:

1. The structural model should account for beam slab effects and finite joint sizes in the lateral frame as well as the gravity system.
2. The fundamental building period of a bare frame model should be modified by the appropriate factor outlined in Table 3.

The modification factors are a simplified estimation of the additional stiffness within the structural model itself contributed by the gravity frame and structural modeling details. The factors were calibrated based on the results of the findings presented in this study as well as the calculated fundamental period from models of other studies. (Elkady 2015, ATC-63-2/3, Chopra 2000, Tremblay 2005)

Table 3 - Modification factor to the bare frame fundamental period to account for non-modeled factors that affect the lateral stiffness.

Building Type	Just Gravity Frame	Gravity Frame and Other Modeling Parameters
RC Frame	0.9	0.55-0.75
Steel Frame	0.9	0.85
Braced Frame	0.9	0.85
Shear Wall	0.9	0.9

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