Integrated BIM-analysis Framework for Plan-irregular Structures

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Abstract

Plan-irregular structures are generally more vulnerable to earthquake damage due to torsional response, and they usually need more iterative assessments and adjustments in their structural design. However, in the traditional design process, consistency between design and analysis is not always assured; rather, manual efforts are required to keep them continually in sync. This makes it difficult to achieve a reliable and efficient design especially for plan-irregular structures. To overcome this challenge, this study proposes an integrated framework, where a seamless interaction can be guaranteed between the structural design and analysis processes. Under this framework, Revit Structure Building Information Modeling (BIM) software is connected to the advanced structural analysis software ZEUS-NL through the robust link interface that can transfer data from the design software into the structural analysis software and vice versa. The feasibility of the proposed framework is demonstrated via a pilot implementation.

Keywords
Building Information Modeling (BIM), Plan-irregular structures, Integrated framework, Inelastic seismic response

1. Introduction

Structural design is an iterative process of architectural design and structural analysis. In the traditional design process, structural engineers are required to keep interpreting updated architectural designs and to generate its representative analytical models for structural analysis. This results in multiple architectural and structural models during the design process; thus, it is extremely important to keep them constantly in sync throughout the process (Autodesk, Inc., 2007). If these models are not consistent at any given time, the overall structural design would be invalid and could be potentially very dangerous. Therefore, maintaining the thorough consistency is the key in the traditional structural design process.

In order to deal with the consistency issue in the traditional design process, this study presents an integrated framework that ensures seamless interaction between structural design and analysis processes. To develop an integrated seismic assessment and design environment, Revit Structure (Autodesk, Inc., 2008), a well-known Building Information Modeling (BIM) software package, is connected to ZEUS-NL (Elnashai *et al*., 2010) from Mid-America Earthquake (MAE) Center, an advanced dynamic analysis software package, by using newly developed link interface. The proposed framework enables the pursuit of more reliable designs, especially for plan-irregular structures, which usually involves more iterative design and analysis processes.

2. Proposed Framework

To achieve more reliable and fine-tuned designs, an integrated approach is proposed, combining design and analysis software packages. In this study, one of the innovative BIM software packages, Revit Structure, was employed as the design tool, while one of the most advanced structure analysis packages, ZEUS-NL, was utilized as the structural analysis tool. Then, a bi-directional link interface, named *ZeusNLRevitLink*, was developed, which can transfer data in both directions without any loss of information (Moon, 2012). This link interface is developed by using ExternalCommand in Revit API (Autodesk, Inc., 2009), and Figure 1 briefly shows how it communicates between two software packages. The proposed framework for integration of structural design and analysis is shown in Figure 2.

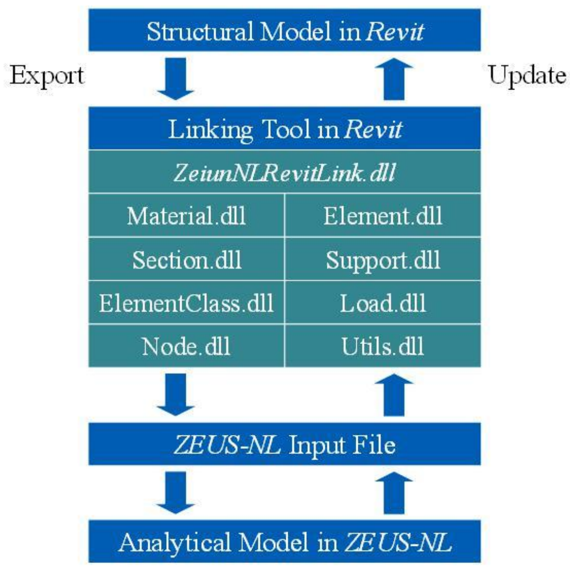

Figure 1: Flow Chart of Link Interface

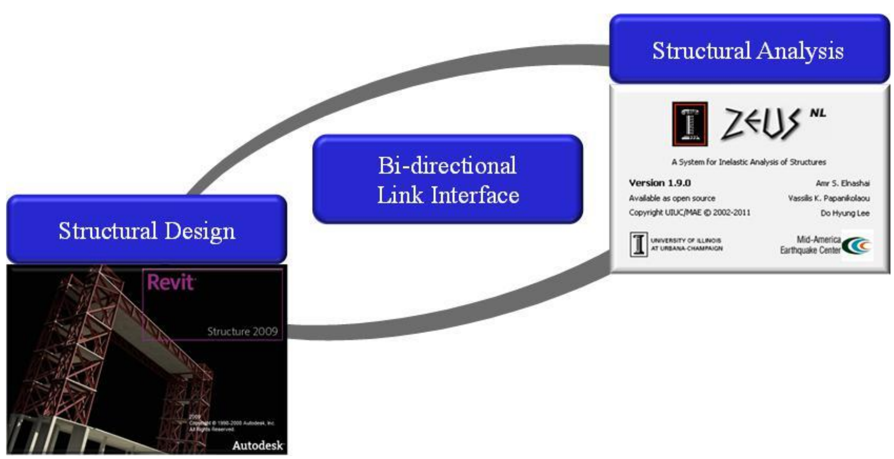

Figure 2: Proposed Framework for Integration of Structural Design and Analysis

A seamless integration of seismic assessment and design processes require the development of robust communication interface between structural design and analysis software. Especially for plan-irregular structures, the link interface needs to provide the functionality of exporting/updating the non-structural components, which often contribute substantially to the mass and stiffness of a structure, as well as the structural components. The newly developed link interface, *ZeusNLRevitLink*, supports various exporting/updating options for both structural and non-structural components, unlike other exiting linking tools. It has additional functionality useful for plan-irregular structures, such as displaying eccentricity variation and suggested seismic design guidelines.

The general steps in the structural design process with the proposed framework are as follows:

- Import sets of components from the design software and generate a structural model;
- Run an inelastic dynamic analysis and assess the inelastic seismic response;
- Export the results to the design software with instructions for which components need adjustment and how;
- Find suitable components from its library to add in the design software;
- Import into an inelastic dynamic analysis again;
- Iterate the above procedure until the pre-defined criteria are satisfied.

The development of the integrated framework offers a number of advantages, including the following: the elimination of inconsistencies in the structural design process; easy access to various analytical models; the visualization capability to check structural analysis results in a 3-D based software which could give better understanding of the behavior of the structures to designers/engineers and owners/decision-makers.

3. Verification Example

3.1 Analytical model

A three-story, mass-eccentric, reinforced concrete frame structure is utilized to verify the proposed framework. It has two bays in longitudinal direction and one bay in transverse direction, and the length of each bay is 4 m and the height of the frame is 3 m. It is designed to have five percent eccentricity in each story; it has a symmetric stiffness distribution, while mass is distributed asymmetrically. This structure is first created in Revit Structure, and then, using the link interface, an analytical model is generated in ZEUS-NL, as shown in Figure 3.

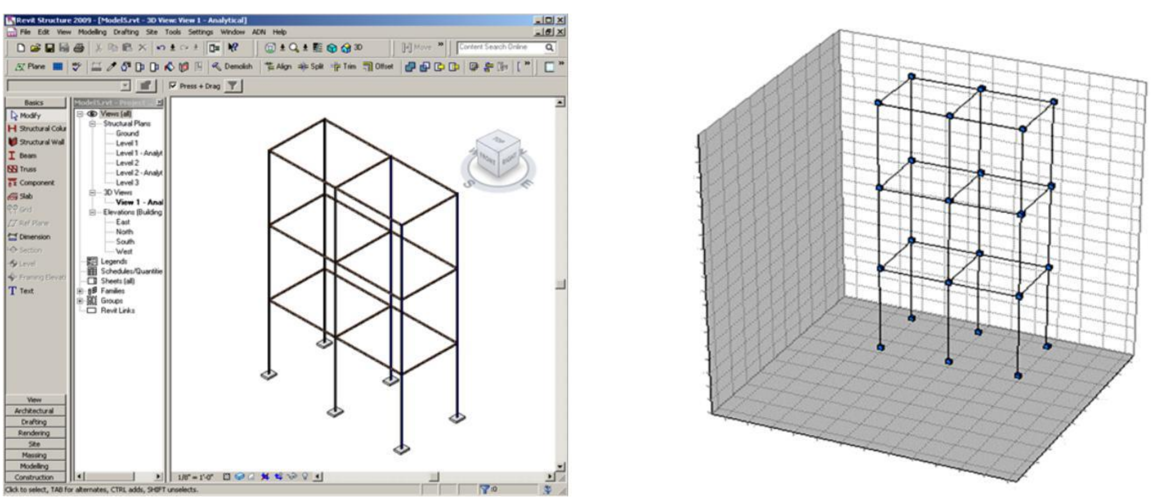

Figure 3: Structural Model in Revit Structure and Generated Analytical Model in ZEUS-NL

3.2 Input Ground Motion

It is important to include a sufficient number of ground motions which can represent a hazard well when evaluating the performance of interested structures. A previous study by Wen and Wu (2001) showed that median response spectra from 10 sets of ground motions closely matched the uniform hazard spectra in the elastic and inelastic ranges with coefficient of variation of less than 10%. Thus, total ten ground motion records are used in this study. The selected motions are synthetic uniform hazard (10% in 50 years) ground motions for Memphis, Tennessee, based on the “representative” soil profile. Detailed descriptions of them are given in MAE Center Report by Wu and Wen (2003). Figure 4 shows the simulated ground motion records.

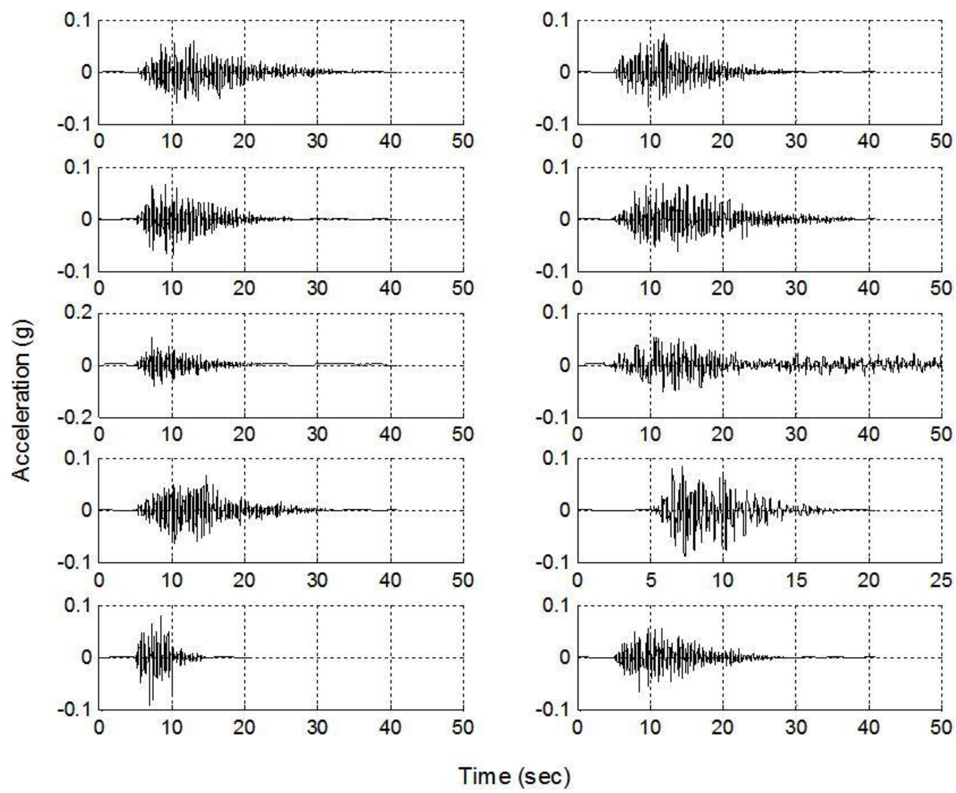

Figure 4: Simulated Input Ground Motions

3.3 Seismic Response Analysis

First, inelastic dynamic response-history analysis (RHA) with the analytical model generated in ZEUS-NL is carried out with ten earthquake records, having peak ground accelerations of 0.1g, 0.3g and 0.5g. Then, equivalent lateral force (ELF) analysis, the code-allowed static analysis procedure, is conducted with the design eccentricities adopted in International Building Code (ICC, 2009) and ASCE/SEI 7-05 (American Society of Civil Engineers, 2005). The average values of maximum ductility demands from dynamic RHA and static ELF analysis are compared in Table 1. As the earthquake intensity increases, the code-defined static analysis increasingly underestimates the ductility demand for both flexible- and stiff-side members. It means that the structure, which is designed by considering the misjudged ductility demand from the code-allowed static analysis, would not perform well during a severe earthquake event.

Table 1: Comparison of Average Maximum Ductility Demand

	Flexible-side Members in the First Story			Stiff-side Members in the First Story		
PGA	ELF	RHA	Difference	ELF	RHA	Difference
0.1g	1.92	1.78	+0.14	1.51	1.34	+0.17
0.3g	2.73	3.35	-0.62	1.73	2.07	-0.34
0.5g	3.17	4.51	-1.34	2.31	3.85	-1.54

The given structure has non-coincident centers of mass and stiffness, and it experiences additional torsional response due to the eccentricity between the centers. To improve its seismic performance, the center of stiffness is suggested to move toward the center of mass. This can be done by increasing the stiffness of the lateral load-resisting members on the flexible side. Their cross-sectional dimensions are accordingly changed in the analytical model. Then, this change is immediately reflected to the structural model in Revit Structure with the help of the developed link interface which automatically finds suitable components from its own library and updates the corresponding structural members. This change in the structural model is highlighted in Figure 5

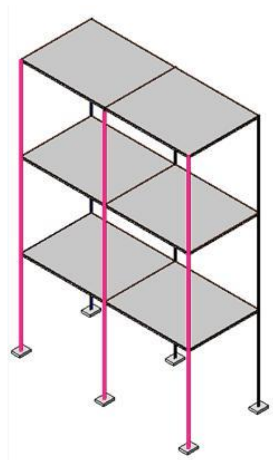

Figure 5: Updated structural members in Revit Structure

The updated structural model in Revit Structure is exported again to ZEUS-NL to evaluate the seismic performance of the new design. The analysis results are shown in Table 2. A comparison of the results from the new and original designs demonstrates that a better design is achieved with the proposed framework.

Table 2: Comparison of Average Maximum Ductility Demand of a New Design

	Flexible-side Members in the First Story			Stiff-side Members in the First Story		
PGA	ELF	RHA	Difference	ELF	RHA	Difference
0.1g	1.63	1.44	+0.19	1.52	1.38	+0.14
0.3g	2.26	2.36	-0.10	2.01	2.18	-0.17
0.5g	2.81	3.45	-0.64	2.89	3.29	-0.40

4. Summary

This study introduces an integrated seismic assessment and design framework for plan-irregular structures. The traditional structural design requires manual efforts to keep the design and analysis processes in sync. In order to better deal with the consistency issue in the traditional design, this study develops an integrated design-analysis framework. As the structural design and analysis tools, Revit Structure from Autodesk and ZEUS-NL from MAE Center are utilized. To communicate between these software packages, a bi-directional link interface is newly created. The link interface can export both structural and non-structural members and provide additional useful tools for torsional response prediction. The proposed framework and developed link interface are successfully verified through a pilot application example. With the proposed framework, it is proved that better seismic designs for plan-irregular structures can be achieved.

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